Introduction
Air pollution is a major public health hazard, particularly in developing countries [1]. Air pollution is defined as the presence of foreign substances in the air that affect the health and well-being of living beings [2]. As the world progresses, air pollution has become a major problem that has to be faced. This problem is likely to have adverse effects on health, even when pollutant levels are within the standards required by legislation.

There has been considerable interest in recent years in the health effects of exposure to both short-term fluctuations and long-term levels of air pollution, in particular common environmental pollutants including particulate matter (PM), ozone (O\textsubscript{3}), carbon monoxide (CO), nitrogen dioxide (NO\textsubscript{2}), and sulphur dioxide (SO\textsubscript{2}) [3]. The potentially deleterious effect of episodes of high air pollution on health has been suspected for more than 50 years [4].

Since the 1990s, many epidemiological studies have demonstrated associations between air pollution levels and human health in terms of hospital admissions [5, 6]. Air pollution are positively associated with hospital admission for cardiovascular disease [3], respiratory disease [7], and gastrointestinal disease [8].

Method

Database and sources
We searched five large databases covering health and medical literature which are Sage, Ovid Medline, Science Direct, Wiley, and ProQuest from 2010 to 2016 using keywords “hospital admission and air pollution”. Studies of any relevant design were included if they presented original data, included at least one analysis where hospital admission was the specific outcome, and one or more of the following exposures were investigated: PM, O\textsubscript{3}, CO, NO\textsubscript{2}, and SO\textsubscript{2}.
that were published from 2010 to 2016. Reference lists of all relevant studies were scanned to identify any further studies, and if these revealed that search terms had been missed, extra terms were added to the main database searches. Conference abstracts and unpublished studies were not included in this review.

**Search keywords and terms**
Our search of database used the following keywords “hospital admission and air pollution”. All sub-terms were also included and we limited the search to studies of humans, published in English.

**Inclusion and exclusion criteria**
To examine the hypothesis that ambient air pollutant exposure would be associated with risk of hospitalization, studies of any relevant design were included if they presented original data, and included at least one analysis where hospital admission was the specific outcome, and one or more of the following exposures were investigated: PM, O$_3$, CO, NO$_2$, and SO$_2$. We excluded studies in which the authors did not control for (or stratify by) any potential confounding factors or did not report measures of precision or $p$ values for the analysis of interest.

**Procedure**
Titles and abstracts were screened for relevance, and full-text versions obtained where appropriate for assessment with reference to the inclusion and exclusion criteria; we were able to obtain full-text papers in all cases where required and it was not necessary to contact specific authors. For each study included, the following information was recorded based on prior beliefs about key aspects of study methodology and in order to summarise study quality: study design, study population, event of interest, number included, location and setting, time period, exposure variables, adjustment for weather variables, and other potential confounders, lags considered. The main results of each study were also recorded – in particular, the effects of each pollutant of interest on risk of hospitalization, including effect sizes and confidence intervals where possible.

Flow diagram of the search study are shown in Figure 1 below.

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**Figure 1**: Search results and selection of studies for systematic review.
Results
From the 22 articles, nine were time-series (TS) study design, five cohort, five case-crossover (CCO), two retrospective cross-sectional (RCS), and one combination of time series and case-crossover study. Some of the studies focus on the hospital admission of certain group of disease such as cardiovascular and respiratory, while some of them more directly focus on the certain diseases. Table 1 below showed the studies that were involved in this systemic review.

The trend of hospitalization
The air pollution has cause the increasing trend of hospitalization. Air pollution was noted to have an excessive risk of 3.46 (95% CI, 1.67, 5.27) of total hospital admissions [28]. Most other studies shown the increasing trend of hospitalization by the disease group such as cardiovascular admission and respiratory admission.

Cardiovascular admission was noted to have an increased risk of hospitalization between 1.5 to 2.0 for

Table 1: Studies that were involved in this systemic review.

| No | Study                                | Study period | Location | Study design                  | Health effect                              |
|----|--------------------------------------|--------------|----------|-------------------------------|--------------------------------------------|
| 1  | Montresor-López et al. 2015 [9]      | 2002–2006    | US       | Case-crossover                | Stroke admission                           |
| 2  | Cheng et al. 2015 [10]               | 2006–2010    | Taiwan   | Case-crossover                | COPD admission                             |
|    |                                      |              |          |                               | Asthma admission, Pneumonia admission       |
| 3  | Milojevic et al. 2014 [11]           | 2003–2009    | England  | Case-crossover                | CVS admission, Atrial fibrillation, Heart failure |
| 4  | Iskandar et al. 2011 [12]            | 2001–2008    | Denmark  | Case-crossover                | Asthma admission                           |
| 5  | Ghozikali et al. 2015 [13]           | 2008–2009    | Iran     | Case-crossover                | COPD admission                             |
| 6  | Wong et al. 2016 [8]                 | 1998–2001    | Hong Kong| Cohort                        | Peptic ulcer admission, Gastric ulcer       |
|    |                                      |              |          |                               | Duodenal ulcer                             |
| 7  | Tonne et al. 2016 [14]               | 2003–2007    | London   | Cohort                        | Readmission of Myocardial infarction        |
| 8  | Atkinson et al. 2014 [15]            | 2003–2007    | London   | Cohort                        | COPD admission                             |
| 9  | Andersen et al. 2011 [16]            | 1993–2006    | Denmark  | Cohort                        | COPD admission                             |
| 10 | Andersen et al. 2012 [17]            | 1993–2007    | Denmark  | Cohort                        | Asthma admission                           |
| 11 | Alimohammadi et al. 2016 [18]        | 2012–2013    | Iran     | Retrospective cross sectional | Ischaemic stroke admission                  |
| 12 | Mansourian et al. 2010 [19]          | 2005–2006    | Iran     | Retrospective cross sectional | Respiratory admission                      |
| 13 | Ferreira et al. 2016 [20]            | 2010–2011    | Brazil   | Times-series                  | Respiratory admission, CVS Admission        |
| 14 | Phung et al. 2016 [21]               | 2004–2007    | Vietnam  | Times-series                  | Respiratory admission, CVS Admission        |
| 15 | Vidotto et al. 2012 [22]             | 2000–2007    | Brazil   | Times-series                  | Paediatric rheumatic diseases admission     |
| 16 | Kollanus et al. 2016 [23]            | 2001–2010    | Finland  | Times-series                  | CVS admission, Respiratory admission        |
| 17 | Oudin et al. 2010 [24]               | 2001–2005    | Sweden   | Times-series                  | Ischaemic stroke admission                  |
| 18 | Vidal et al. 2010 [25]               | 2000–2003    | Italy    | Times-series                  | Ischaemic stroke admission                  |
| 19 | Jevtić et al. 2014 [26]              | 2007–2009    | Serbia   | Times-series                  | CVS admission                               |
| 20 | Xie et al. 2014 [27]                 | 2010–2012    | China    | Times-series                  | IHD admission                               |
| 21 | Zhang et al. 2014 [28]               | 2008–2011    | China    | Times-series                  | Hospital admission, Respiratory admission, Stroke admission |
| 22 | Chen et al. 2016 [29]                | 2003–2013    | Adelaide | Times-series & case-crossover | Asthma admission                            |

Note: CVS: Cardiovascular; IHD: Ischaemic Heart Disease; COPD: Chronic Obstructive Pulmonary Disease.
For respiratory admission, PM$_{2.5}$ can cause an increased risk of hospitalization by 1.1 to 1.8 [20, 23]; (1.007 to 1.3) for PM$_{10}$ [20, 21]; (1.08 to 1.94) for NO$_2$ [21, 28] and 1.02 for SO$_2$ [21].

The rest of the studies showed the effect of the air pollutant to certain disease such as asthma, pneumonia, stroke, and others are shown in Table 2.

Type of AP that cause the hospitalization
In this review, five air pollutant were identified that cause their own health effect. They are particulate matter less than 2.5 μm (PM$_{2.5}$), particulate matter less than 10 μm (PM$_{10}$), nitrogen dioxide (NO$_2$), sulphur dioxide (SO$_2$), and ozone. Each pollutant has their own effect to certain disease as shown by the relative risk (RR), odds ratio (OR), and hazard ratio (HR) depending on the type of the study design.

For example, PM$_{2.5}$ has effect on asthma, pneumonia, COPD, stroke, Ischaemic heart Disease (IHD), myocardial infarct (MI), gastric ulcer, and other admission. Table 2 summarizes the effect of these pollutants.

Diseases that were affected by air pollution
From this review, several diseases were identified that has association with the air pollutants. For certain disease, such as asthma, PM$_{2.5}$, PM$_{10}$, and NO$_2$ contribute to the

Table 2: Effect of the pollutant to hospitalization.

| Pollutant | Health effect | RR/OR/HR (95% CI) | Study design | Study                  |
|-----------|---------------|--------------------|--------------|------------------------|
| PM$_{2.5}$ | Respiratory admission | RR 8.5% (−6.8, 26.3) | TS | Ferreira et al. 2016 |
|           |               | RR 10.5% (−2.2, 24.8) | TS | Kollanus et al. 2016 |
|           | Asthma admission | RR 30.2% (13.4, 49.6) | TS & CCO | Chen et al. 2016 |
|           |               | OR 1.229 (1.139, 1.327) | CCO | Iskandar et al. 2011 |
|           |               | OR 1.09 (1.04, 1.13) | CCO | Cheng et al. 2015 |
| COPD Admission | OR 1.11 (1.09, 1.13) | CCO | Cheng et al. 2015 |
| Pneumonia admission | OR 1.12 (1.11, 1.13) | CCO | Cheng et al. 2015 |
| CVS Admission | OR 1.96% (6.4, 34.6) | TS | Ferreira et al. 2016 |
|               | RR 1.5% (−6.9, 10.6) | TS | Kollanus et al. 2016 |
| Ischaemic stroke | OR 1.09 (1.03, 1.15) | RCS | Alimohammadi et al. 2016 |
| IHD admission | RR 0.27% (0.21, 0.33) | TS | Xie et al. 2014 |
| MI admission | HR 1.02 (0.98, 1.06) | Cohort | Atkinson et al. 2014 |
| PUD admission | HR 1.18 (1.02, 1.36) | Cohort | Wong et al. 2016 |
| Gastric ulcer | HR 1.29 (1.09, 1.53) | TS | Ferreira et al. 2016 |
| Duodenal ulcer | HR 0.98 (0.78, 1.22) | RCS | Mansourian et al. 2010 |
| PM$_{10}$ | Respiratory admission | RR 12.8% (6.0, 20.0) | TS | Ferreira et al. 2016 |
|           |               | (β coefficient = 0.63; p < 0.001) | RCS | Tonne et al. 2016 |
|           | Asthma admission | RR 8.3% (2.5, 14.4) | TS & CCO | Chen et al. 2016 |
|           |               | OR 1.035 (1.007, 1.064) | CCO | Cheng et al. 2015 |
|           |               | OR 1.04 (1.03–1.06) | CCO | Iskandar et al. 2011 |
| COPD Admission | OR 1.05 (1.03–1.06) | CCO | Cheng et al. 2015 |
| Pneumonia admission | OR 1.05 (1.04–1.05) | CCO | Cheng et al. 2015 |
| CVS Admission | RR 2.7% (−2.2, 7.9) | TS | Ferreira et al. 2016 |
|               | RR 1.005 (1.009) | TS | Phung et al. 2016 |
| Ischaemic stroke | RR 1.14 (1.06, 1.22) | RCS | Alimohammadi et al. 2016 |
|               | RR 13% (4, 22) | TS | Oudin et al. 2010 |
| MI admission | HR 1.05 (1.00, 1.10) | Cohort | Tonne et al. 2016 |

(Contd.)
hospitalization with certain effect size as shown by the RR, OR, or HR depending the type of the study design. The rest of the diseases with the certain type of pollutants that effect the admission are shown in Table 3 below.

**Discussion**

*Main results and comparisons with existing literature*

Our systematic review of literature of 22 studies on the effect of air pollution and hospital admission showed that there are increasing risk of hospital admission for cardiovascular and respiratory group of diseases. Air pollution was believed to have influence only the respiratory disease such as asthma and COPD in the old studies in the 1990. However, in the early 2000, more studies were done to establish the connection of the air pollution with the cardiovascular disease as we have more understanding of the components in the air pollutant and the physiology that they can cause to the human body. Therefore, our study concurrent with the other study that state that air pollution cause higher risk of cardiovascular and respiratory disease hospitalization [30–34].

This paper also showed that the PM either the fine particulate (PM$_{2.5}$) or coarse particulate (PM$_{10}$) has a higher influence of hospital admission either in cardiovascular or respiratory disease than the other air pollutants. This was due to the fact that physiology of the PM that can penetrate deep into the lungs and heart and alters the autonomic control of the heart which lead to cardiovascular problem [35]. It also act as an irritant and induce defensive responses in the airways, such as increased mucus secretion and increased bronchial hyperactivity and lead to respiratory problem [36]. This finding is congruent with other studies as well stated that increased concentration of PM associated with hospitalization [30–32].

**Weaknesses of our methodology**

Despite carrying out a comprehensive search some studies may have been missed to be included for this systematic review. However, by searching a number of different databases, with different indexing systems, and, furthermore, checking reference lists and the websites of major organisations, we believe that all major studies with hospital admission as the primary outcome have been picked up. In addition, there might have been publication bias: studies finding effects may have been more likely to be published. The extent of publication bias is difficult to assess in studies with such varied methodology and reporting. Though such concerns should always be borne in mind, our goal was not to produce a definitive numerical estimate of the effects of air pollution on hospital admission

| Pollutant | Health effect                  | RR/OR/HR (95% CI) | Study design | Study          |
|-----------|--------------------------------|-------------------|--------------|----------------|
| NO$_2$    | Respiratory admission          | RR 1.08 (1.06, 1.011) | TS           | Phung et al. 2016 |
|           |                                | RR 1.94 (0.50, 3.40) | TS           | Zhang et al. 2014 |
| Asthma    | admission                      | RR 12.5% (6.6, 18.7), OR 1.077 (1.046, 1.109) | TS & CCO     | Chen et al. 2016 |
|           |                                | HR 1.12 (1.04, 1.22) | Cohort       | Andersen et al. 2012 |
|           |                                | OR 1.10 (1.04, 1.16) | CCO          | Iskandar et al. 2011 |
| COPD      | Admission                      | HR 1.06 (0.98, 1.15) | Cohort       | Atkinson et al. 2014 |
|           |                                | HR 1.08 (1.02, 1.14) | Cohort       | Andersen et al. 2011 |
|           |                                | OR 1.0038 (1.0004, 1.0094) | CCO | Ghozikali et al. 2015 |
| CVS       | Admission                      | RR 1.04 (1, 1.06) | TS           | Phung et al. 2016 |
|           |                                | OR 1.049 (1.009, 1.091) | TS           | Jevtić et al. 2014 |
|           |                                | OR 1.7% (95% CI 0.9 to 2.6) | CCO | Milojevic et al. 2014 |
| Ischaemic stroke | RR 1.07 (1.04, 1.1) | RCS               | Alimohammadi et al. 2016 |
|           |                                | RR 1.039 (1.066, 1.013) | TS           | Vidale et al. 2010 |
| MI        | admission                      | HR 1.05 (0.99, 1.10) | Cohort       | Tonne et al. 2016 |
| SO$_2$    | Respiratory admission          | RR 1.02 (1.01, 1.03) | TS           | Phung et al. 2016 |
|           |                                | β coefficient = 0.59; p < 0.001 | RCS | Mansourian et al. 2010 |
| COPD      | admission                      | OR 1.0044 (1, 1.011) | CCO          | Ghozikali et al. 2015 |
| CVS       | Admission                      | RR 1.007 (1, 1.01) | TS           | Phung et al. 2016 |
| Ischaemic stroke | RR 1.08 (1.06, 1.1) | RCS               | Alimohammadi et al. 2016 |
| Paediatric rheumatic diseases | RR 1.98% (0.25, 3.69) | TS           | Vidotto et al. 2012 |
| Ozone     | COPD admission                  | RR 1.0058 (1.0022, 1.0094) | CCO | Ghozikali et al. 2015 |
| Ischaemic stroke | RR 1.07 (1.03, 1.11) | RCS               | Alimohammadi et al. 2016 |
| Stroke    | admission                      | OR 0.98 (0.96, 1.00) | CCO          | Montresor-López et al. 2015 |

*Note: CVS: Cardiovascular; IHD: Ischaemic Heart Disease; COPD: Chronic Obstructive Pulmonary Disease; MI: Myocardial infarction; PUD: Peptic Ulcer Disease.*
Impact of our results
The result of this paper strongly supports the fact that the effect of air pollution is associated with the higher risk of hospital admission for cardiovascular and respiratory diseases. This is supported by several systemic reviews done previously [3, 32, 37]. It is plausible that morbidity and mortality from non-communicable diseases such as stroke and ischaemic heart disease, the impact of air pollution is also an important and act as modifiable risk factor [30, 31]. Understanding this, it should give enough evidence to the policy makers to make same action and plan to reduce this effect.

Future research
The exact role of individual pollutants is still unclear, and perhaps only further experimental studies under controlled conditions can deal with this issue. There is also a need for biomarkers of exposure that can be used in epidemiological studies to give more reliable estimates of individual exposure to air pollutants. There is also a need for more studies that take into account the potential effect modifiers; though a few studies have presented stratified or age-restricted data, there is little direct evidence on how age, and other individual-level factors such as previous disease, affect a person’s vulnerability.

Table 3: The disease and the pollutant that effect the admission.

| Diseases     | Pollutant | Study                          | Study design | Effect                  |
|--------------|-----------|--------------------------------|--------------|-------------------------|
| Asthma       | PM\textsubscript{2.5} | Chen et al. 2016              | TS & CCO     | RR 30.2% (13.4, 49.6)  |
|              |           | Cheng et al. 2015             | CCO          | OR 1.10 (1.06, 1.13)   |
|              |           | Iskandar et al. 2011          | CCO          | OR 1.09 (1.04, 1.13)   |
|              | PM\textsubscript{10} | Chen et al. 2016              | TS & CCO     | RR 8.3% (2.5, 14.4)    |
|              |           | Cheng et al. 2015             | CCO          | OR 1.04 (1.03–1.06)    |
|              |           | Iskandar et al. 2011          | CCO          | OR 1.07 (1.03, 1.12)   |
|              | NO\textsubscript{2} | Chen et al. 2016              | TS & CCO     | RR 12.5% (6.6, 18.7), OR 1.077 (1.046, 1.109) |
|              |           | Iskandar et al. 2011          | CCO          | OR 1.10 (1.04, 1.16)   |
|              |           | Andersen et al. 2012          | Cohort       | HR 1.12 (1.04, 1.22)   |
| COPD         | PM\textsubscript{2.5} | Cheng et al. 2015             | CCO          | OR 1.11 (1.09, 1.13)   |
|              |           | Atkinson et al. 2014          | Cohort       | HR 1.05 (0.98, 1.13)   |
|              | PM\textsubscript{10} | Cheng et al. 2015             | CCO          | OR 1.05 (1.03–1.06)    |
|              | NO\textsubscript{2} | Atkinson et al. 2014          | Cohort       | HR 1.06 (0.98, 1.15)   |
|              |           | Andersen et al. 2011          | Cohort       | HR 1.08 (1.02, 1.14)   |
|              | SO\textsubscript{2} | Ghozikali et al. 2015         | CCO          | RR 1.0038 (1.0004, 1.0094) |
|              |           | Ghozikali et al. 2015         | CCO          | RR 1.0044 (1, 1.011)   |
|              | Ozone     | Ghozikali et al. 2015         | CCO          | RR 1.0058 (1.0022, 1.0094) |
| Pneumonia    | PM\textsubscript{2.5} | Cheng et al. 2015             | CCO          | OR 1.12 (1.11, 1.13)   |
|              |           | Cheng et al. 2015             | CCO          | OR 1.05 (1.03–1.06)    |
|              | PM\textsubscript{10} | Alimohammadi et al. 2016     | RCS          | RR 1.14 (1.06, 1.22)   |
|              | NO\textsubscript{2} | Alimohammadi et al. 2016     | RCS          | RR 1.07 (1.04, 1.1)    |
|              | SO\textsubscript{2} | Alimohammadi et al. 2016     | RCS          | RR 1.08 (1.06, 1.1)    |
|              | Ozone     | Alimohammadi et al. 2016     | RCS          | RR 1.07 (1.03, 1.11)   |
|              |           | Montresor-López et al. 2015  | CCO          | OR 0.98 (0.96, 1.00)   |
Finally, future studies are needed to ascertain factors contributing to why some people or indeed populations are more susceptible than others to the detrimental effects of air pollution.

**Conclusion**

The exposure to air pollutants confers to an increased risk of hospital admission for several diseases. Our findings call for greater awareness of environmental protection and the implementation of effective measures to improve the quality of air, which may reduce the risks of adverse effects on the population’s health. Public and environmental health policies that aim to reduce air pollution levels might reduce the burden of multiple diseases such as stroke, asthma, and ischaemic heart diseases that are influenced by the air pollutants.

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**Competing Interests**

The authors have no competing interests to declare.

**Author Contribution**

All authors had access to the data and participate in writing the manuscript.

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