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DEPARTMENT OF BIOLOGICAL AND ENVIRONMENTAL SCIENCES

AIR QUALITY IN URBAN AREAS OF LOW- AND MIDDLE-INCOME COUNTRIES.

A case study of Sub-Saharan Africa, Asia and Latin America.

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Abstract

The problem of air pollution is a major concern around the world most especially in low- and middle-income countries of the world mainly driven by increasing population growth, industrialization, use of solid fuels for cooking and dusts from unpaved roads etc. with consequent effect on human health.

This report assessed available data on air pollutants ($PM_{2.5}$, PM_{10}, O_3, NO_2 and SO_2) in urban areas of low-and middle income countries of Sub-Saharan Africa (SSA), Asia and Latin America (LA) respectively, through a literature review with a PRISMA flow synthesis method and compared the values with World Health Organization (WHO) guideline values and interim targets to understand the state of air quality. Particulate matter ($PM_{2.5}$ and PM_{10}) levels is a major problem in most Asian and SSA cities particularly in South-East Asia as compared to LA cities which has low concentrations. O_3 data obtained at country level showed lower concentrations in LA and SSA with the exception of Asia. NO_2 concentrations across the regions showed limits within and slightly above WHO recommendations while SO_2 showed a reduction trend around the regions.

The overall goal is to reduce emissions globally and air quality monitoring, as well as emission inventory has been identified as a major measure towards better air quality in urban areas of the world alongside other measures aimed towards clean air.

Keywords - Air pollution, Urban air quality, Particulate matter, Ozone, Nitrogen dioxide, Sulphur dioxide health and environment, Sub-Sahara Africa, Asia, Latin America.

Abbreviations

SSA - Sub-Saharan Africa

LA - Latin America

WHO - World Health Organization

GV - Guideline Value

IT - Interim Target

PM - Particulate Matter

LMIC - Low-and middle-income countries

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Introduction

Air pollution, a major risk on environmental and human health has for a very long time became a global menace with its effect mostly felt in the developing and poor countries of the world due to lack of studies and data to investigate its impacts. It was estimated by World Health Organization (WHO) that about 92% of the world population were living in places where air quality guidelines have been exceeded (Jorquera et, al., 2019).

Mainly propagated by urbanization and increasing population among other drivers, air pollution problem has been growing rapidly. Other drivers include the increasing number of vehicle ownership, industrialization, economic growth and consumption patterns, energy consumption, transportation etc. Sub-Saharan Africa has the fastest growing population in the world followed by Asia, and this has been projected to continue to increase with a growth rate of 3-5% (UN 2019). This rapid growth has a substantial effect in the rate of urbanization and changes in lifestyle which affects the quality of air. Fig.1 shows the percentage of people living in urban areas from 1950 to 2050 as projected by United Nations Population division (UN 2019).

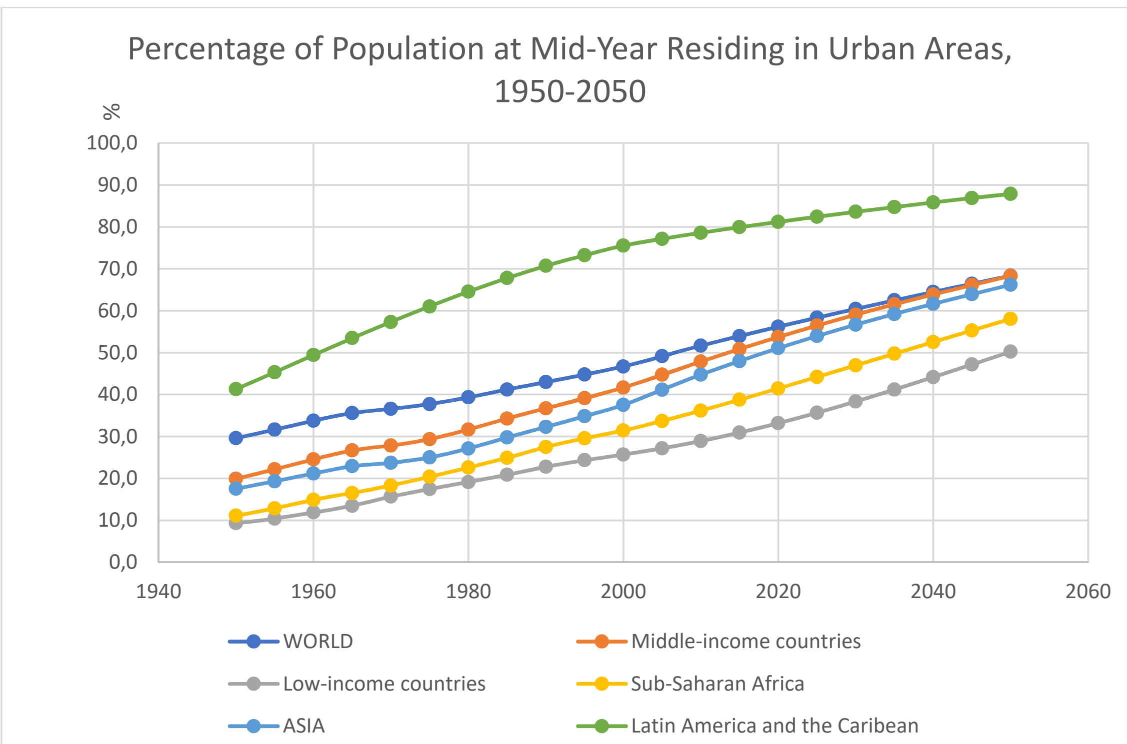


Figure 1. Percentage of population at the end of June residing in urban areas, 1950-2050

The continuous increase in the urbanization means there is a threat to air quality in urban areas and the projection (Fig 1) has it that by 2050, the percentage of people living in urban areas across Sub-Saharan Africa (SSA), Latin America (LA) and Asia will be above 50% which is a call to action for better air quality management.

Air pollution has continued to be a significant problem to health and environment as economic development and desire for improved lifestyle continues to persist. The process of economic development which is a major driver is diverse and cut across all sectors and Chen & Kan (2008) in their study used the concept of Environmental Kuznets Curve (EKC) fig. 2, to understand the relationship between air pollution and economic development.

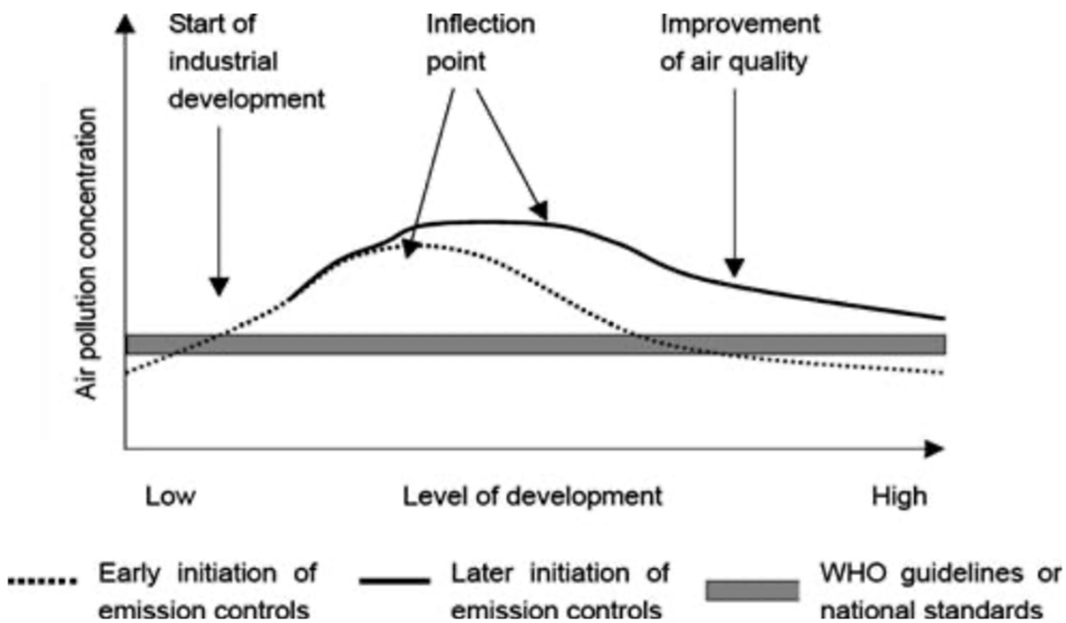


Figure 2. Environmental Kuznets Curve (Source: Chen and Kan 2008).

They (Chen and Kan 2008) reiterated that the rate of air pollution is often low in early stages of economic development but begins to increase rapidly towards the intermediate stage without effective mitigation measures, which at a higher development stage might reach an "inflexion point due to better environmental awareness and control measures".

Research Question?

Low- and middle-income level countries has been highlighted to suffer most from the problem of air pollution. This study therefore intends to investigate, to what extent has urban air quality been deteriorated?

Aims and Objectives

- To investigate the current state of air quality in urban areas of low- and middle-income countries in Sub Saharan Africa, Asia and Latin America.

- To investigate what the current levels of criteria pollutants are, most especially particulate matter, and its subsequent effect on human health.

Justification

With the continuous increase in the rate of urbanization, industrialization, economic growth and changes in lifestyle in these developing nations, the continuous deterioration of air quality cannot be overemphasized. Therefore, there is need to understand the current state of air quality, the drivers and potential health effect on human and environment so as to provide measures to curb and reduce its effects even as economies continues to grow and ensure an improved life quality with little or no effect on air quality.

2.0 Literature review

The problems associated with air quality especially in urban areas of the world have been a growing concern which has been highlighted through several studies.

Air pollution is characterized by a mixture of different components and pollutants emanating from both natural and anthropogenic sources ranging from particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2), and volatile organic compounds (VOCs). Of all these criteria pollutants, particulate matter has been widely used as an indicator for air quality since it is commonly measured, especially in LMIC.

2.1 Criteria pollutants/types of pollutants

The criteria pollutants included in this work was limited to Particulate matter ($PM_{2.5}$ and PM_{10}), O_3, NO_2 and SO_2 as they are considered to be classical and commonly used indicator pollutants mostly related to traffic and fuel combustion. (Chen & Kan 2008).

2.1.1. Particulate matter (PM): Varies in size and composition, is comprised of complex mixtures of compounds suspended in air in form of solid particles and liquid droplets. PM sizes ranged from ultrafine (0.1um), fine $PM_{2.5}$ (2.5 um) and coarse PM_{10} (2.5-10um) (Mandeep 2015). PM has also been attributed to be the most hazardous air pollutants (Hosseini & Shahbazi 2016;) which causes serious health problems when inhaled. PM is emitted from different number of sources such as vehicle emissions, dust from braking and tires, unpaved road dusts etc. and can also be formed in the atmosphere through more than one reaction of emissions from industries and power plants.

2.1.2. Ground-level ozone (O_3): A gas formed when nitrogen oxides react with volatile organic compounds in the presence of sunlight. These compounds that form ozone comes from a variety of sources ranging from vehicle emissions, aviation, industrial processes, oil and gas refineries etc. Like other gaseous air pollutants, its main route of exposure is through inhalation and which affects the respiratory tract.

2.1.3. Nitrogen dioxide (NO_2): A compound consisting of nitrogen and oxygen is a gaseous air pollutant formed from the burning of fossil fuels at high temperatures. With inhalation the major route of exposure, its high concentration causes adverse respiratory problems such as flu, coughing, wheezing etc. by inflaming the lining of the lungs.

2.1.4. Sulphur dioxide (SO_2): a gaseous pollutant formed from the combustion of sulphur containing fuels. Main sources of emission come from industrial activity and the burning of coal, oil and gas. Like NO_2, SO_2 is also emitted from motor vehicles. Its route of exposure is mainly through inhalation causing irritation to the air tract, nose and throat.

2.2 Air quality review

A conceptual framework of Driver, Pressure, State, Impact, and Response (DPSIR) by the United Nations Environment Program (UNEP 2016) as presented in figure 3 below, has been adopted to gain insight into the interaction between humans and air pollution and also to review air quality condition in the regions.

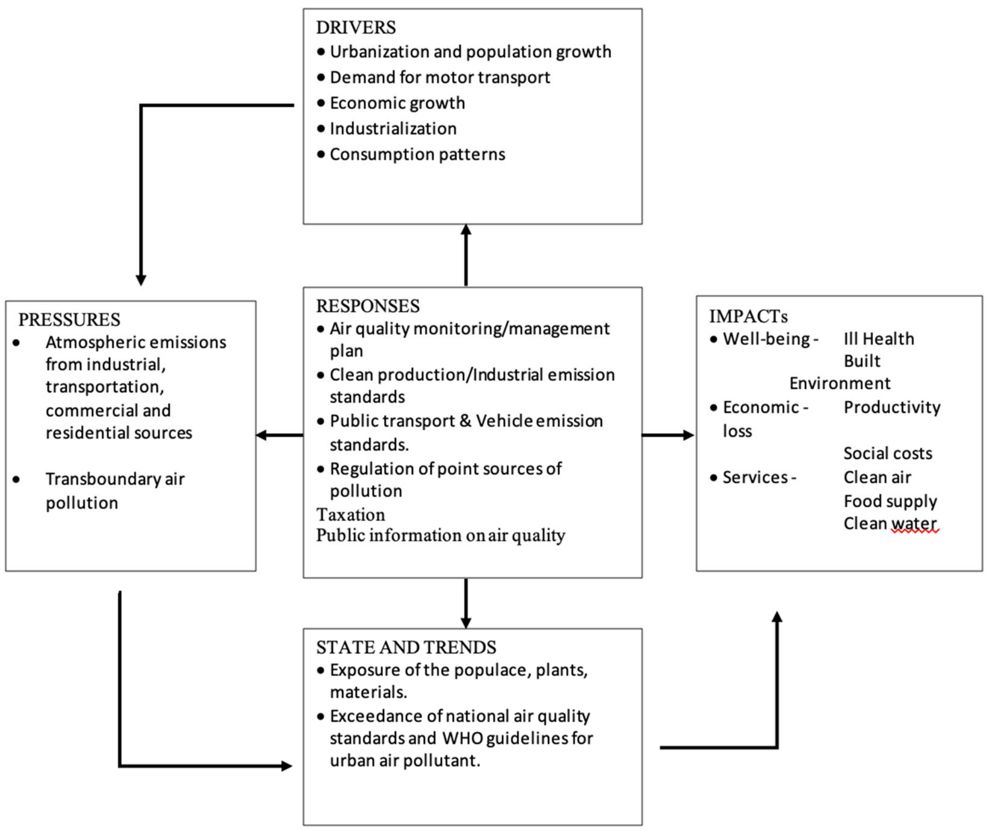


Figure 3. Driving-Pressure-State-Impact-Response (DPSIR) Framework. Modified from Schwela et al., 2012; Jorquera et al., 2019).

2.2.1 Sub-Saharan Africa

Driver and Pressures.

Major drivers of urban air pollution in SSA countries has been identified to be increasing population, urbanization, migration, vehicle ownership, and rising need for economic growth (Schwela et al, 2012). These drivers in turn causes pressures on the environment for example; increasing population and economic growth increases motor vehicles and fuel consumption that pollutes urban air either by transport, industrial, residential and/or commercial sources (Jorquera et al, 2019). This also includes the rapid increase and uncontrolled use of motorcycles as a fast and cheap method of transportation in SSA cities as well as the use of over-aged vehicles with poor maintenance. Re-suspended dust emissions owing to insufficient and poor infrastructure and unpaved roads including wears from tires and brakes further contributes to this menace.

Energy consumption and outdoor air pollution by industries and households through the use of uncontrolled old plants and obsolete technologies also plays a major role (Schwela et al 2012). Poor waste management is also a great contributor to air pollution in SSA cities as waste generation increases with population. The vast majority of people living in urban areas in SSA openly dump and burn their wastes. These emissions from burning of waste and biomass for both household and commercial purposes contribute greatly to air pollution. Decomposing waste releases gases such as methane, hydrogen sulfide, ammonia and other noxious gases (Amegah and Jaakola, 2014) which also adds to the deterioration of air quality.

State and Trends

Understanding the state and trends of urban air pollution in SSA is to a large extent difficult as the lack of monitoring (as evident in World's Air Pollution: Real-time Air Quality Index), emission inventories and generally low studies on air pollution in most part of the region has been established in the few available studies. Although air pollution modelling has been a substitute for this in most cases but assess to these studies is still a problem. Features such as topography, meteorology and land use, control the fate (state and trends) of air pollutants concentration, deposition of dusts and gases, acid rain etc. (Jorquera et al., 2019).

Air quality monitoring is very crucial in understanding and characterizing health risks, creating mitigation strategies, enforcing and setting air quality standards, and healthy urban planning (Petkova et al., 2013). Emission inventories also plays a vital role in helping to understand the trends (past and present) which is lacking in most SSA cities. In cases where data seemed to exist, they are not made publicly accessible and communicated, thereby limiting effective policy making and making the problem multifaceted (Petkova et al., 2013). Many of the countries in SSA have air quality standards/regulations but the lack of air monitoring data is a major constraint making enforcement difficult.

Impacts

Air pollution has been reported to cause the largest number of pollution related deaths and the global burden of disease indicates that low-income countries of SSA suffer the highest burden of disease and premature death (Landrigan et al., 2017). About 176,000 deaths in Africa were recorded from air pollution (WHO, 2012), and this figure is expected to have increased due to increasing pollution in the region. However, reviews on the effects of air pollution on human health are rarely assessed in SSA countries (Petkova et al., 2013; Schwela et al., 2012; Coker & Kizito, 2018) with endpoints generally linked to respiratory infections, lung cancer and cardiovascular diseases.

Responses

The overall goal of air pollution responses is to improve the wellbeing of the populace subject to natural, socioeconomic and technological constraint (Jorquera et al., 2019). National responses to the problem of air pollution should be in the form of creating environmental act and policies that is aimed towards clean air. Schwela et al. (2012) reports the non-existence of specific legislation in all SSA countries except for South Africa and suggest an integral approach to include emission inventories, assessing levels of health and environmental impacts, mitigation measures and cost-benefit estimates, which could be achieved through monitoring.

Urban air quality management plan has been proven to be an effective and efficient tool used in managing urban air quality with its key components including monitoring, air quality objectives, emission inventory mitigation strategies forecasting tools and public participation (Guila et al., 2015).

2.2.2 Asia

Drivers and pressures

Characterized by high and increasing population over the last decades, the Asian continent comprises the nations with the highest population in the world with the percentage of people living in the urban areas rapidly increasing. The region has often experienced continuous economic development which has led to poor urban planning (Hopke et al., 2008; Atkinson et al., 2012). Similarly, air pollution in Asia is mainly driven by increasing population, urbanization and economic growth and these altogether are putting pressures on the usage of motor vehicles, increase in energy use and urban planning.

Other sources of pollution in the region includes smoke and dust particles, burning of biomass such as firewood, agriculture and animal wastes. The cumulative effect of these effects has been felt in the populous countries like China and India (Schwela et al., 2006). Although, it appeared several cities in the region now has air quality monitoring stations (real time air quality index www.waqi.info), there is data scarcity on particle pollution which makes source apportionment difficult in the region (Hopke et al., 2008).

State and Trends

Air pollution levels have continued to increase with exceedances above the WHO GV (WHO 2005) in most of the Asian regions as industrialization and urbanization continues to grow

(Atkinson et al., 2012). Although several measures to curb the menace are being carried out, air quality falls below the standards in most cities in the region.

Impacts

The impact of air pollution on human health which affects mostly the poor people who live close to the sources has a range of direct and indirect effects. (Schwela et al., 2006). Air pollution in this region causes a large number of death and reduced healthy life annually (see air quality and health).

Responses

Legislations towards compliance with air quality standards, as well as consistent air quality monitoring has been established by various studies as effective towards reducing air pollution. Regional leaders have responded to this e.g. Chinese, Japanese and Korean governments by mandating lower emissions from motor vehicles and industries, the usage of clean energies as well as strict national air quality regulations (North et al., 2019).

2.2.3 Latin America

Drivers and pressures:

The rate of urbanization in LA is rapidly increasing with about 75% of its population living in cities (Cifuentes et al., 2005). Air quality in LA has been majorly hampered by transportation as the major source of emission. Air pollution in LA is also caused by dusts from paved and unpaved roads as well as the quality of fuel and high industrial activities. Aside the aforementioned drivers, air quality is still largely affected by the usage of wood fuel for heating and cooking in some certain areas (Cifuentes et, al., 2005).

State and trends

LA countries began monitoring of air quality in 1980s to tackle high levels of pollutions (Jorquera et al., 2019) and Cifuentes et, al. (2005), in his study highlighted the difficulties in finding air quality data and emission inventories in LA as existing data are inaccessible as well as the unknown quality of the available data. He also notes that in situations where record exists, there's need to contact a local official in order to obtain and verify its quality. However, this difficulty has been addressed to some extent as quite a number of cities in the region now have air quality monitoring stations with record data (which is visible in real time air quality index) and about 122 cities in 16 LA countries report particulate matter concentrations (Jorquera et al., 2019) to assess the state and trends of air pollution as well as exposure and health risk.

The improvement in the current state of air quality in LA is evident in the result presented later in the report.

Impacts

Ambient air pollution has been linked to several number of diseases from lung infections to cancer and other health effects and in some cases death. (see air quality and health).

Responses

Effective responses for better air quality and reducing the global burden of disease in LA should involve all sectors and focus towards better urban planning (Riojas-Rodriguez et al., 2016). This should involve implementation of sustainable strategies for transport sector, clean energy innovation and air quality management and control. Also, an effective response tool of Health Impact Assessment (HIA) to assess the cost-benefits of various types of policy interventions to tackle air pollution (Riojas-Rodriguez et al., 2016) should also be adopted.

2.3 Environmental Quality Indices

2.3.1 Air quality standards (AQS)

AQS are legally binding limits and guidelines often in concentrations for individual substances. There are several guidelines which has been adopted to define air quality levels such as Guideline Values (GV) by WHO, Limit Values for Air Quality (LVAQ) by EU, National Ambient Air Quality Standards (NAAQS) by the US Environmental Protection Agency etc. (Baldasano et al., 2003). For the purpose of this study, GV of WHO and other national standards for specific countries under the study area has been compiled in table 1.The Interim Targets (IT) for different pollutants proposed by the WHO aimed at progressive reduction in pollutants concentration was also included.

Table 1. International air quality regulations (µg/m3) for selected countries

Area	Pollutants	PM2.5		PM10		SO2		NO2		Ozone	
	Zone	Annual	24hr	Annual	24h	Annual	24h	Annual	24h	8h	1h
World	WHO	10	25	20	50	50	20	40	200	100	180
	IT-3	15	37.5	30	75						
	IT-2	25	50	50	100		50				
	IT-1	35	75	70	150		125			160	
Latin America	Brazil	-	-	50	150	80	365	100	320		160
	Colombia	50	100	50	25	80	250		100	80	120
	Mexico	12	45	40	75	66	288	100	395	70	95
	Ecuador	15	50	50	100	60	125	40		100	160
	Bolivia	10	25	50	150	80	365	100	400	100	236
	Argentina	15	65	50	150	80	365	100	-	157	235
Asia	China	35	75	70	150		150	40	200	160	200
	India	40	60	60	100		50	40	80	100	180
SSA	S/Africa	20	40							120	
	Botswana					80	300	100	400	157	235
	Burkina Faso					200-300	-	-	170		150-300
	Mauritius			-	100	50	150	40	200		100
	Zambia	-	-	-	70	-	350	-	150		

2.3.2 Air quality index (AQI)

AQI is mainly set-up and used by different nations to inform and forecast the current state of air pollution. The AQI rating differs between countries but it's a good tool in monitoring air quality. Stieb et al., (2005) reiterated the main objectives of AQI to be (i) informing the public of the state of air quality and exposure risk to pollution levels and (ii) to enable regulatory action for immediate control in cases where there are high pollution levels. AQI is calculated through comparisons with individual pollutants and standards (Stieb et al., 2005). "[…] AQI itself is simply a number that reflects some aspect(s) of air quality, in practice it is associated with color schemes, graphics, air quality category labels such as "good," "moderate," or "poor," and various messages" (Stieb et al., 2005). Presented in table 2 is the general AQI index obtained from real-time Air quality index (www.waqi.info).

Table 2. AQI index. Source (www.waqi.info)

AQI	Air pollution level	Health Implications	Cautionary statement (for PM2.5)
0 - 50	Good	Air quality is considered satisfactory, and air pollution poses little or no significant risk	None
51 – 100	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.
101 - 150	Unhealthy for Sensitive Groups	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.
151 - 200	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects	Active children and adults, and people with respiratory disease, such as asthma, should avoid prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion
201 – 300	Very Unhealthy	Health warnings of emergency conditions. The entire population is more likely to be affected.	Active children and adults, and people with respiratory disease, such as asthma, should avoid all outdoor exertion; everyone else, especially children, should limit outdoor exertion.
300+	Hazardous	Health alert: everyone may experience more serious health effects	Everyone should avoid all outdoor exertion

2.4 Air quality and health

Air pollution has been attributed to cause different kind of diseases to human health such as lung cancer, pulmonary and cardiovascular diseases. Bernstein et al, (2004) reiterated the advanced knowledge with respect to understanding the effects of air pollution in human health. This knowledge from various studies has helped in attributing health effects to various causal pollutants from CO, SO_2, NO_2, PM, O_3 and VOC's. These pollutants which emanates from different sources (both natural and anthropogenic) enters the human body system mainly through inhalation, ingestion and dermal contact with the later contributing to a few percentages. Exposure to these pollutants has been a growing concern and Bernstein et al., (2004) pointed out the complexities in attributing an exact mechanism to which air pollutants causes adverse effect on human health. Meanwhile, Kampa and Castanas (2008) attributed the causes of diverse health effect to the differences in composition, dose and time of exposure as well as the exposure to mixtures of pollutants rather than a single pollutant. Air pollution can have effect on the human health even when the level is below the limit of air quality guideline as individuals body system differ in response to air pollution exposure (Chen & Kan 2008).

The exposure assessment of the global burden of diseases attributable to outdoor air pollution estimates that fine particulate air pollution caused about 800,000 deaths and 6.4 million lost years of healthy lifestyle in 2000 with two-thirds of this estimates in South-East Asia (Brauer et al., 2012). This figure substantially increased as an estimated 2.9 million deaths were attributed to be caused by $PM_{2.5}$ in 2013 which was labelled as the "leading risk factor for global disease burden and 217,000 deaths was attributed to long-term ozone exposure (Brauer et al., 2015). Furthermore, the 2016 global burden of disease reported an estimated 6.1million deaths annually and 163 million adjusted healthy life years globally with most of the burden in the Asian region (North et al., 2019). It is therefore necessary for immediate actions for better air quality and subsequent reduction of health effects posed by air pollution.

3.0 Methodology

3.1. Study Area

The study area covers the region of Sub-Saharan African (SSA), Asia and Latin American countries, characterized by low- and middle-income countries and exclusive of the high-income levels as presented in fig. 4. SSA is the part of Africa that lies South of the Sahara consisting of 46 countries comprising of diverse climates, from the typical wet and dry seasons, the desert and semi-desert climate.

Latin America generally consists of 33 countries including the Caribbean states. Spanning a great distance from the equator, Latin America is bounded by the warm and cold currents from Atlantic and Pacific Ocean respectively. Latin America has a diverse climate ranging from extreme wet and dry conditions and from very hot temperatures to cold temperatures.

Asia, the world's most populous region, comprising of 48 countries is bounded by the Pacific Ocean, Indian Ocean and Arctic Ocean to the East, South and North respectively. Due to this, the region has many different climates.

This study has excluded the Caribbean and high-income countries to only focus on the low- and middle-income countries in these regions and presents data obtained on air pollution/pollutants to the extent possible.

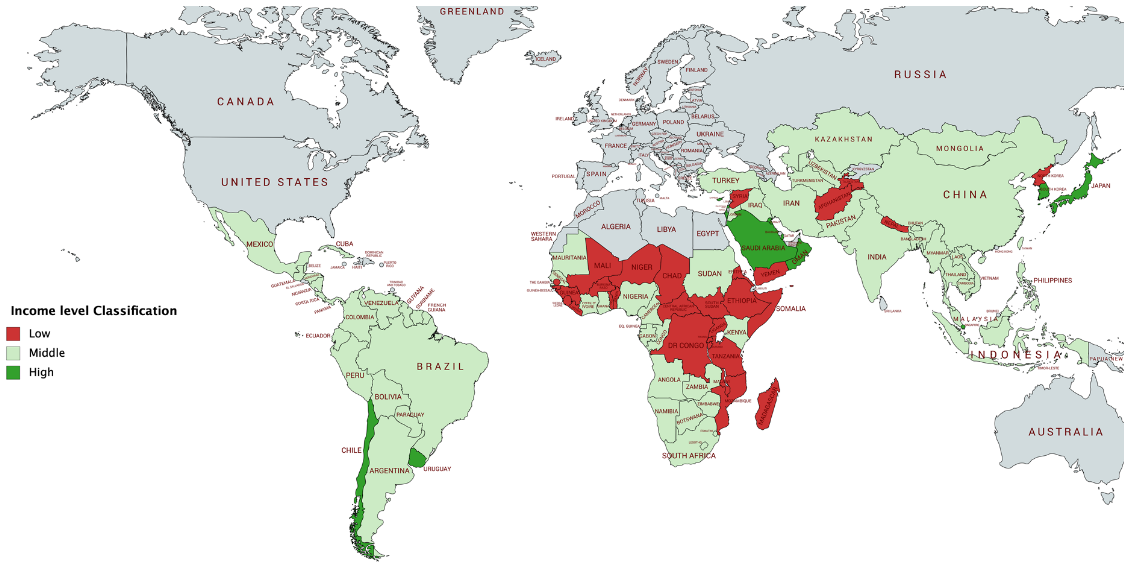


Figure 4. Map of study area highlighting income-levels.

3.2. Methods

The methods employed in this report involves a systematic review of various scientific literatures relating to urban air pollution in these regions as well as assessing databases with emission inventories to understand the current state and quality of urban air both in regional and income level where applicable. These data were compared and examined to analyze the trends and status of urban air pollution. A constant comparative method (CCM) was used where data collected were continuously compared with previous data in cases where data duplicate occurs both according to region and income level. A primary tool that was used is the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) flow diagram of qualitative and quantitative synthesis as shown in fig. 5 to help in selecting relevant studies and eliminating irrelevant ones and to some extent help in reducing the risk of bias which is an important step when using this tool for synthesis.

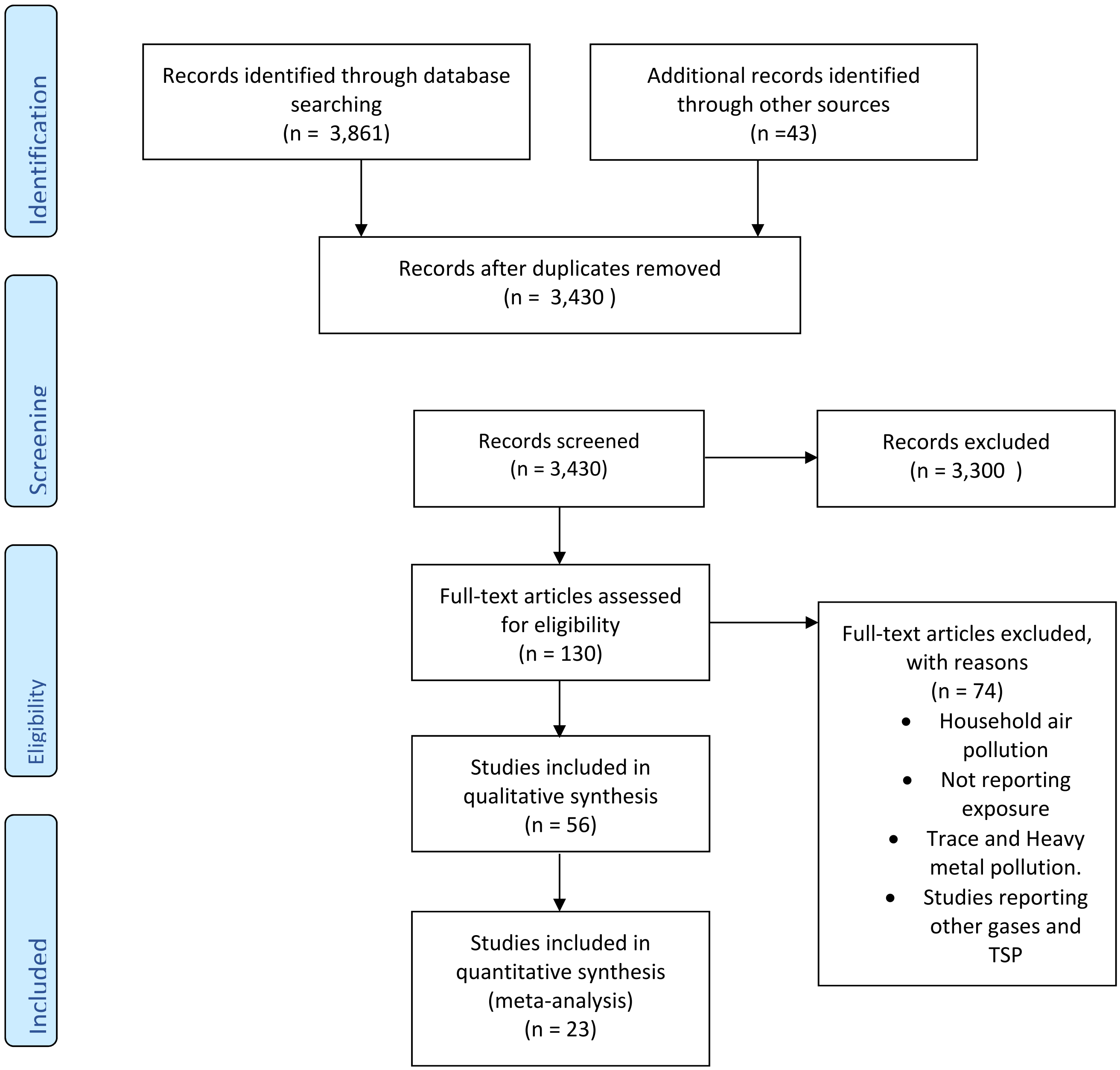


Figure 5. PRISMA flow diagram for selection of studies.

3.2.1. Search Strategy and selection criteria

Electronic databases such as Google Scholar, Scopus and Web of knowledge were searched in English. This was done by searching for the keyword "air pollution" as well as combination of words such as "ambient air pollution", "urban air pollution", "air pollution and health", "particulate matter", "Sub-Saharan Africa", "Asia", and "Latin America". Additional journals were obtained from references of selected publications that was not present in the general searches but were found to be relevant and useful for the study. Furthermore, sources such as the WHO database, State of global air, Statista, UNEP, were also used in obtaining data.

The time coverage for the data series ranged from 2000 – till date while relevant most cited articles were also included in cases where it falls out of the custom year range. This was made to span through two decades due to limited studies in some regions and also to give room for deep reviews.

Also, studies measuring the levels of pollutants as well as impact on health were included in the study to better understand the state and its subsequent effect on human health.

Criteria for selection of relevant studies used for this report included;
Study area: areas of low and middle income in the regions of SSA, Asia and Latin America
Subject of interest: Air pollution (urban, outdoor or ambient), particulate matter, criteria pollutants (PM, NO_2, O_3, SO_2).

Excluded in this study are studies that does not report concentrations on air pollution in the areas of study and those that reports on rural emission data. In cases where data presented was at country level for pollutants, only data from urban centers were included. Also excluded are studies focusing on specific health related issues such as mortality, lungs and cardiovascular diseases.

3.2.2. Data analysis

A narrative synthesis of all the data obtained was carried out and was reported using the PRISMA guidelines (Moher et al., 2009)

3.2.2.1. Data reliability:

The data obtained in various report where air quality data were found showed similar result in the levels of (non)-compliance to WHO air quality guideline values and interim targets which gives a narrative of the status of air quality in the area.

3.2.2.2. Data anomalies/uncertainties

The data compiled in this systematic review was generated from different literatures, publications and databases on urban air pollution taking across different levels and regions, which gives room for a "risk of bias" in data reporting which has been highlighted as an important element when using a PRISMA method (Moher et al., 2009) for reporting.
The data obtained varied from different method, locations, timing, seasons, year and composition of cities, nations and regions.
The shortcomings and question of the risk of bias in data in this report is that; to some extent it may not be the real-time situation in some of the region's most especially in regions and cities where air quality is being measured daily. Taking SSA as a case study, data and studies are very low and in cases where it is available, it is inaccessible and therefore the actual level of air quality deterioration can only be modelled based on the few available studies as there is no air quality monitoring been carried and likewise most nationals in these region have no air quality standards and regulations to checkmate this.

4.0 Results and Discussion

4.1 Particulate Matter 2.5 (PM $_{2.5}$)

High concentrations of $PM_{2.5}$ have been established from various studies most especially in low income countries and this has also been evident in the data acquired for this study which are further presented. The results showed great exceedances to the annual mean standard of 10µg/m^3 of the WHO (see table 1). The WHO guideline values (GV) were adopted for use in this study to adjudge air quality level on the same bases for all regions because; (i) it is a worldwide reference for air quality and (ii) since findings showed several countries lack air quality guidelines most especially in the African region. Also, the three interim targets (IT); IT3-15µg/m^3, IT2-25µg/m^3 and IT1-35µg/m^3 set by the WHO (WHO 2005) to check performances and gauging progress, was also adopted to check cities performance and emission levels.

The data reported is an aggregate of the annual mean concentrations of $PM_{2.5}$ of urban areas in a column graph Figs. 6a, 6b and 6c, which showed the compliance levels against the WHO GV and ITs for LMIC levels across the three (3) regions.

In SSA (Fig 6a), where there is lack of monitoring and emission inventory in its major parts, the data spanned across 2008-2017 for different cities as obtained and only the cities of Port Louis, Vacoas-Phoenix and Bramsthan (Mauritius) complied with GV of WHO with 6µg/m^3, 7µg/m^3 and 10µg/m^3 respectively. Other cities in the eastern part falls within the IT-2 limits with concentrations between 19µg/m^3 and 23µg/m^3 while Kampala (Uganda) recorded a very high concentration level of 104µg/m^3 can be attributed the low economic level and poor infrastructure and high rate of urbanization in the city.

$PM_{2.5}$ concentrations were higher in the western region consisting of nations of high populations, increasing economic growth rate and urbanization, with most of it above the IT-1 level in cities of Accra (Ghana), Yaoude, Bamenda & Bafoussam (Cameroon) with concentrations ranging between 49µg/m3 to 132µg/m^3 while the city of Dakar (Senegal) falls within the IT-2 with concentrations ranging between 17µg/m^3 and 34µg/m^3. $PM_{2.5}$ concentrations are generally low in south Africa due to the availability of monitoring stations in most of its areas having range of concentrations between 13µg/m^3 and 60µg/m^3.

Several studies have reported similar higher concentrations in level of $PM_{2.5}$ in different African cities above the regulatory standards attesting to the deterioration of urban air quality in the SSA. Sanbata et al, (2014) in his study in a sub-urban area in Addis Ababa (Ethiopia) found higher levels of $PM_{2.5}$ 818µg/m^3 mainly through biomass burning while Obioh et al, (2013) reported $PM_{2.5}$ levels of 14µg/m^3 and 102µg/m^3 in Abuja and Aba (Nigeria) respectively.

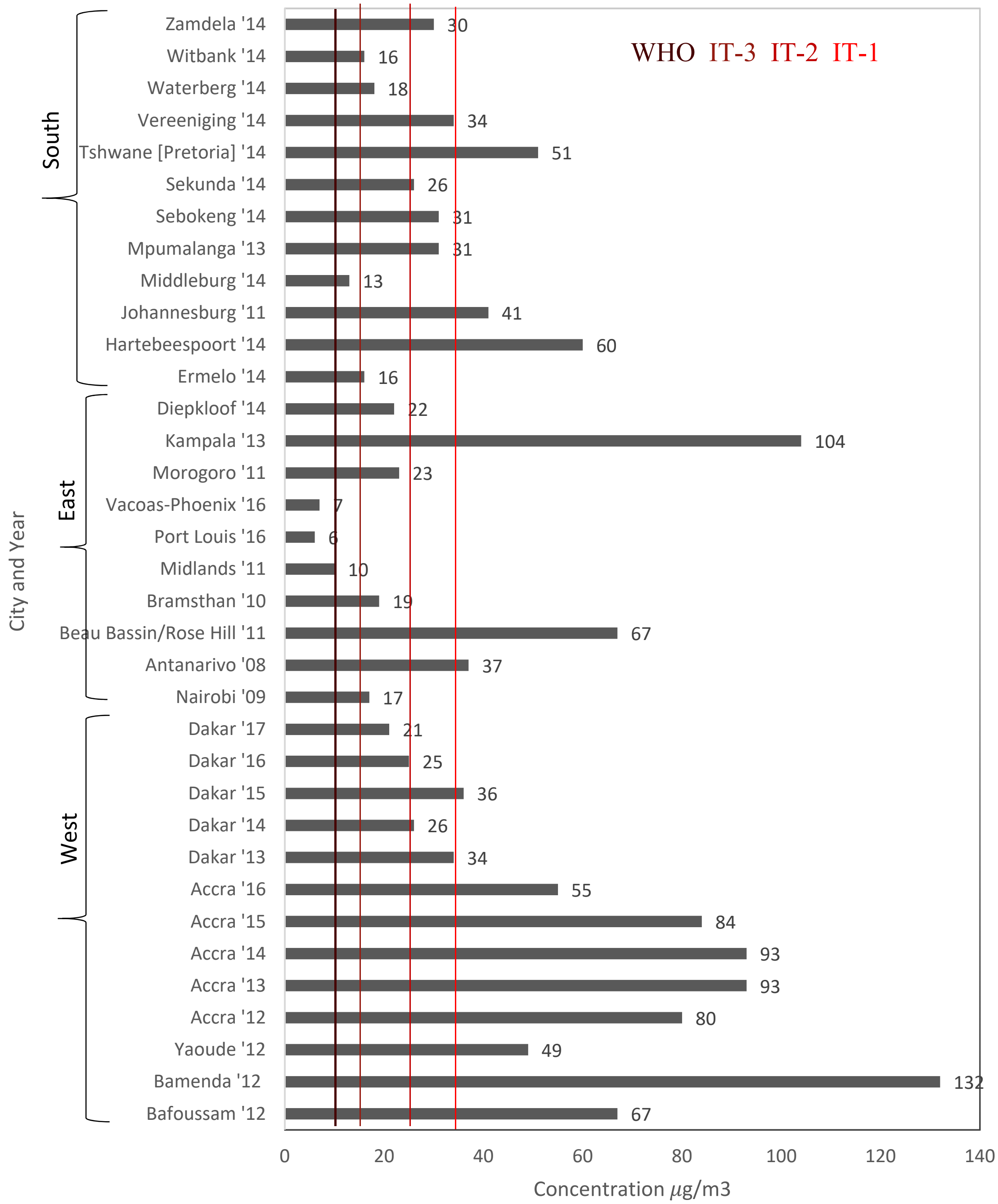


Figure 6a. SSA mean annual $PM_{2.5}$ concentration

For Asia (Fig. 6b), the mean annual concentrations of $PM_{2.5}$ was limited to South-East Asia due to; the high levels of ambient particulate air pollution and contributing to two-thirds of the total number of deaths and reduced healthy years in the global burden of disease estimates (Brauer et al., 2012) as well as much availability of data.

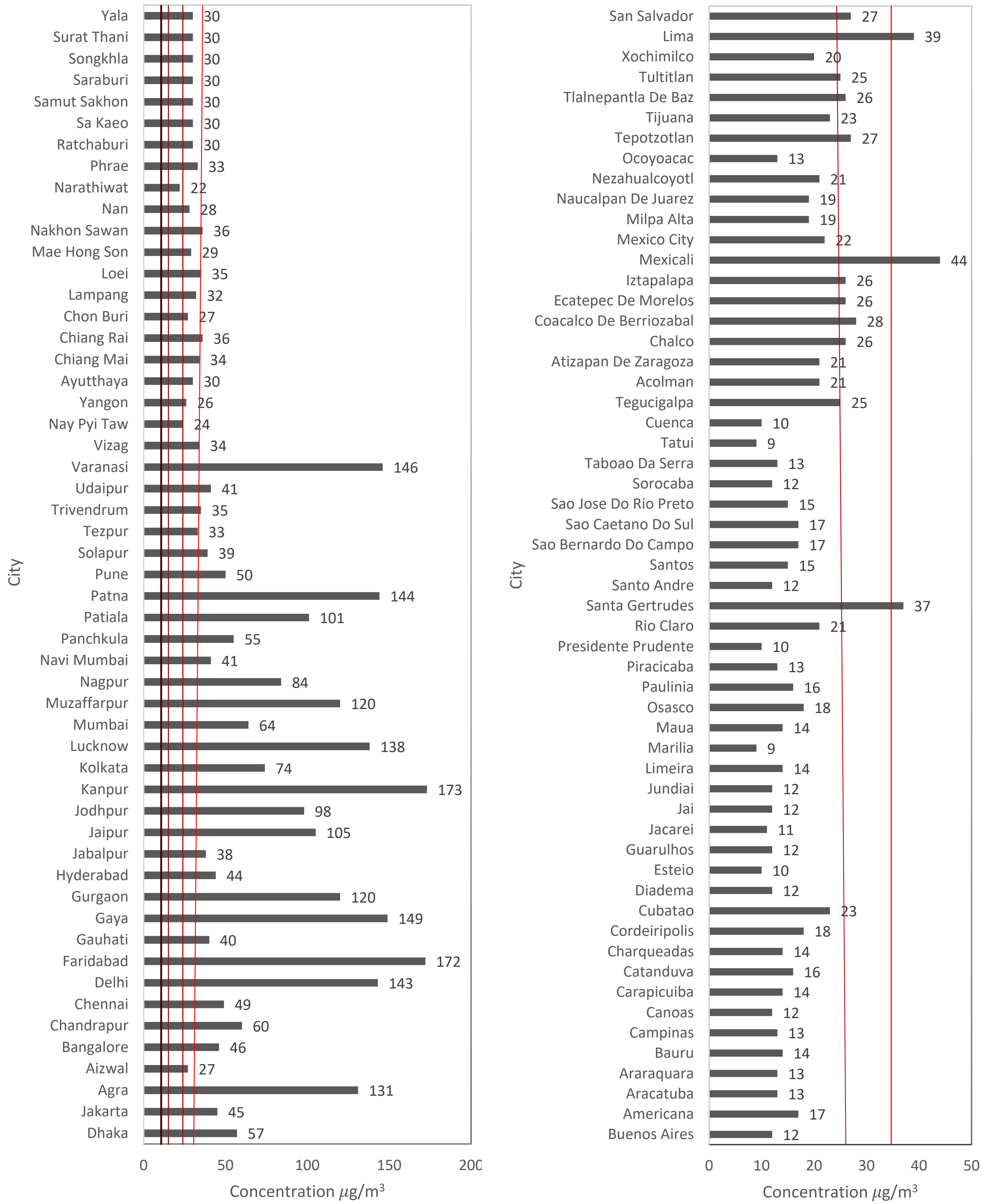


Figure 6b and 6c. Asia and LA mean annual $PM_{2.5}$ concentrations respectively.

WHO IT-3 IT-2 IT-1

In South-East Asia, $PM_{2.5}$ recorded across 53 cities showed that concentrations are generally high as no city conform to both WHO GV and IT-3 levels. Only two cities are within the IT-2 value with 22µg/m^3 and 24µg/m^3 while 22 cities are withing the IT-1 value with concentrations ranging from 26µg/m^3 to 35µg/m^3. Majority of the cities have high concentrations well above the IT-1 value of 35µg/m^3 ranging above 80µg/m^3.

In Asian cities, $PM_{2.5}$ average concentrations are much higher than WHO value of 10 µg/m^3 with concentrations between 23-304 µg/m^3. Cities such as Zhengzhou 175µg/m^3 (2010), Beijing 69µg/m^3 (2010), Seoul 42.6 µg/m^3 (2010), Jinan 169 µg/m^3 (2010), Chengdu 119 µg/m^3 (2011), New Delhi 168 µg/m^3 (2013), and Nagarkot 61 µg/m^3 (2003) (Guatam et al., 2016) all exceeding the WHO GV.

These results correlates to what North et al., (2019) and Guatam et al., (2016) found out in their study of air pollution in Asia-Pacific region (see fig. 10 in appendix) and also showed how bad $PM_{2.5}$ concentration level is in Asia.

In LA (Fig 6c), the result referenced to year 2016, was quite opposite to the situation of South-East Asia with a generally low concentration level. Of the 56 cities where data were obtained with a reference year to 2016, 5 cities complied to the WHO GV of 10µg/m^3, 22 cities complied with the IT-3 levels of 15µg/m^3, 19 cities complied with IT-2 levels of 25µg/m^3, 7 cities fall within IT-1 level of 25µg/m^3 while 3 cities fall well beyond. The low levels of $PM_{2.5}$ concentration in LA region is similar to what North et al., (2019) reported in his study as well as Jorquera et al., (2019) in his study of urban air pollution in LA. Similarly, it is also evident in the data obtained from statista (2019) for selected LA cities as shown in appendix. (Table 5).

These low concentrations of PM level in this region is attributed to improvement in air quality monitoring and urban planning as well as promoting the usage of cleaner fuels and improving public transport sector among other responses.

4.2 Particulate Matter 10 (PM_{10})

A fraction of particles with diameters of 10 micrometers and smaller is coarse in nature. Like $PM_{2.5}$, IT targets (see table 1) was also recommended by the WHO to protect against the effect of coarse PM (WHO, 2005).

PM10 concentration in SSA cities as obtained from WHO database (fig 7a) spanned across 2008-2017 due to scarcity data and low studies. Highest concentrations of PM_{10} were observed in the western part with concentrations as high as 190µg/m^3. All the cities in the western region were above IT-3 value with concentrations above 100µg/m^3 apart from one city that fell within the IT-2 value with 65µg/m^3 concentration. The high concentration is a result of rapid economic development and urbanization leading to poor urban planning while also putting pressures on transportation, fuel usage and energy demand. Dust from unpaved road, wears and tears of tyres are also a major factor for high air pollution levels. In the

Eastern part, concentrations are quite low in cities with low population and good urban planning. The Southern part consisting majorly of cities in South Africa also have concentrations well above the GV but not as high as compared to western region and this can be attributed to the availability of air quality monitoring system in most of its areas.

Furthermore, studies have reported similar higher concentrations in levels of PM_{10} in different SSA cities above the WHO regulatory standards attesting to the deterioration of urban air quality in the SSA. In Nigeria, Efe (2008) reported PM10 levels for Abuja and Maiduguri at 118.3µg/m^3 and 132.0µg/m^3 respectively while Obioh et al, (2013) reported PM_{10} levels of 38 µg/m^3 and 553µg/m^3 in Abuja and Aba (Nigeria) respectively.

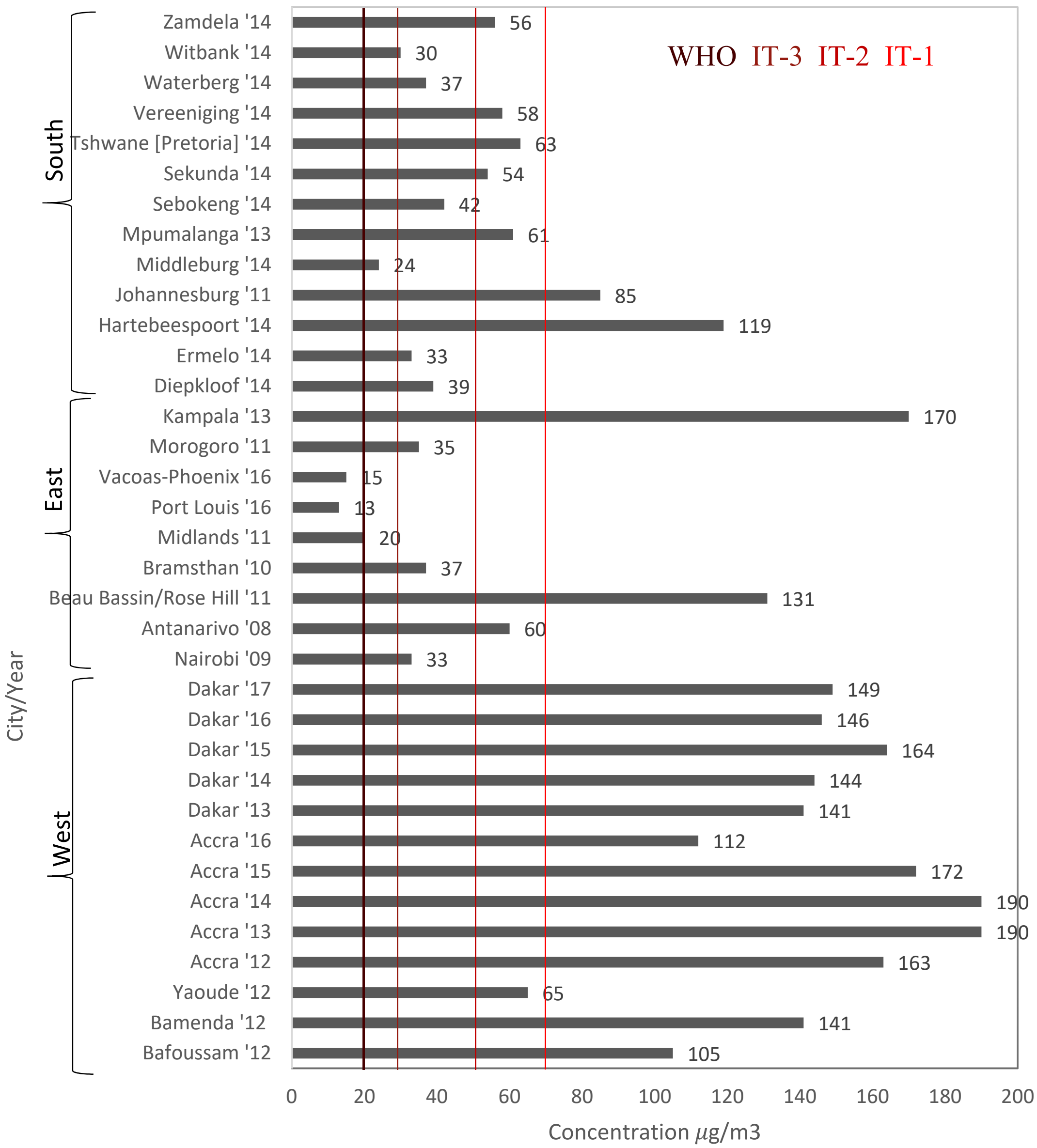
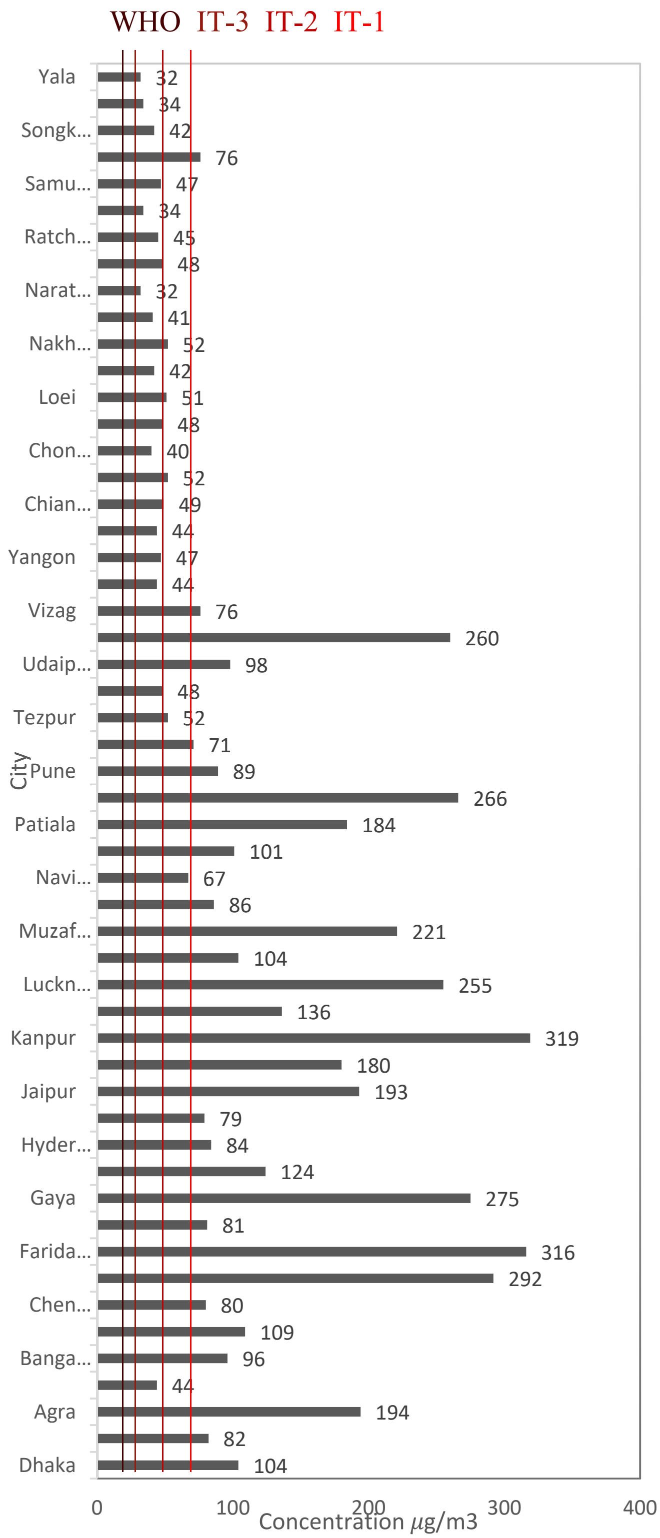


Figure 7a. SSA mean annual PM_{10} concentrations.

Figure 7b and 7c below indicates PM10 concentration levels for South-East Asia and LA according to the data obtained from WHO with reference year of 2016 respectively. Of the 53 cities with available data in Asia, PM10 concentration was high as no city was within the limit of the guideline and IT-3 values of 20µg/m^3 and 30µg/m^3 respectively. 18 cities fall within



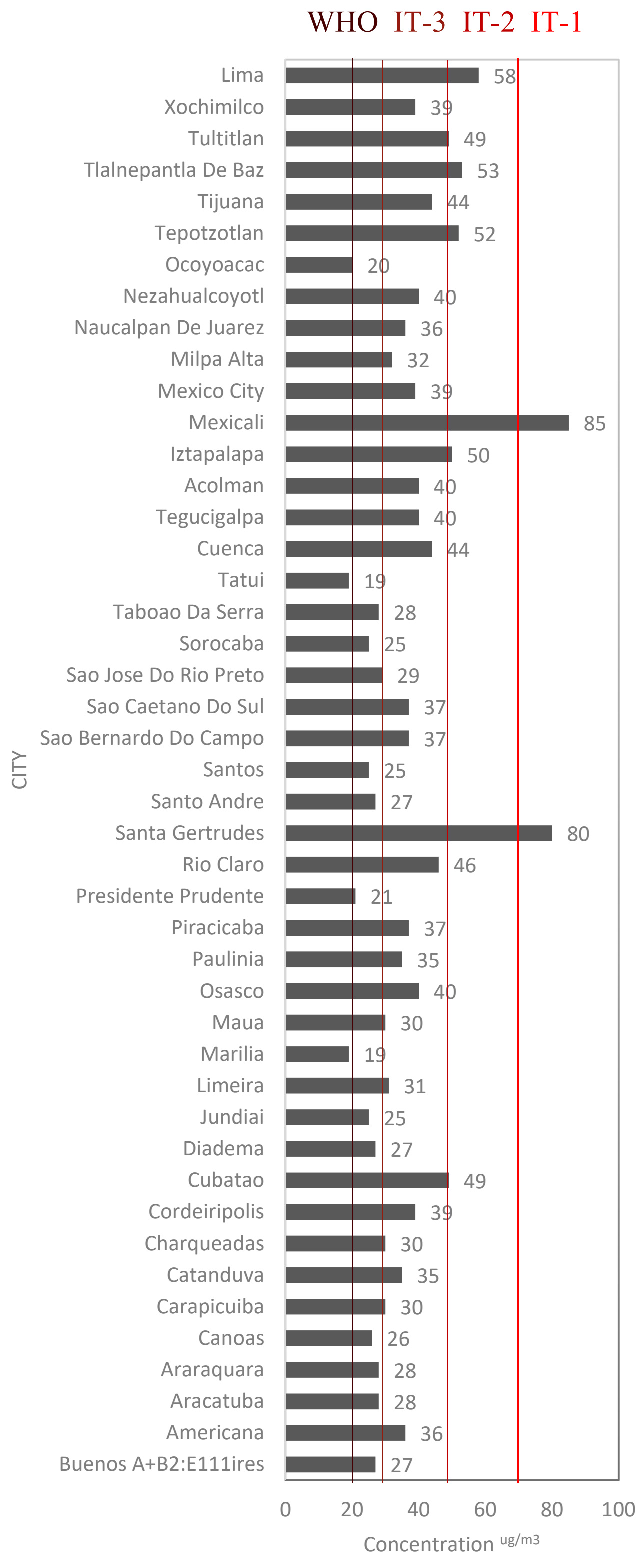
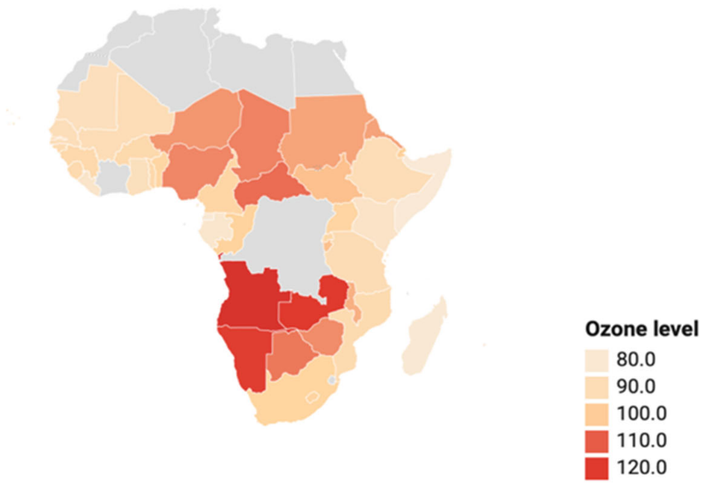


Figure 7b and 7c. Asia and LA PM10 mean annual concentrations respectively value with ranging concentrations from 32 to 49µg/m3 while a large majority of the cities (35) falls above the IT-1 value with concentrations well above the 70µg/m3 limit. This is an standards with relation to income level and economic drive in the region. respectively while 15 cities are within the IT-3 value with ranging concentrations from 21µg/m^3 and 30µg/m3. 22 cities fall within the IT-2 values with concentrations between 31µg/m^3 and 49µg/m3 while 2 other cities were well above the IT-1 value with concentrations of 80µg/m3 and 85µg/m3 respectively.

4.3 Ozone (O_3)

Ground level ozone is another major air pollutant measured across the world due to its probable effect on human health and environment. However, this has been mainly done in developed countries as data are scarce in developing countries. O_3 data are generally scarce in SSA and Asia and in few cases where studies have been carried out, they are mainly inaccessible or either focuses on biomes, forest or other aspects of the environment but not urban sprawls. In view of this, it was hard selecting a data that commonly demonstrates O_3 levels across urban areas within the study scope, therefore, a country level data was used as obtained from the state of global air report (2019) in a publication by the Boston-based Health Effects Institute (HEI). These data sets are national level ozone exposure levels for 2017 based on a population-weighted seasonal average of 8-hour mean in ppb. These values were converted to µg/m3 and compared to the WHO GV (WHO, 2005) of 100µg/m3 for 8-hour daily maximum. Figures 8a, 8b and 8c presents a map chart for SSA, Asia and Latin America national ozone levels respectively.

In SSA (Fig 8a), the concentrations of O_3 was higher than the WHO GV (WHO 2005) values in the Southern part, West and Central Africa with values ranging from 100µg/m^3 to 124µg/m^3. Countries such as Angola, Zambia, Namibia, Chad, Nigeria, Zimbabwe, Niger and Eritrea have high values of 124µg/m^3, 118µg/m^3, 113µg/m^3, 106µg/m^3, 106µg/m^3, 105µg/m^3, 104µg/m^3 and 104µg/m^3 respectively (see table 4 in appendix). These countries are characterized by old and poor vehicle maintenance leading to emission from exhaust, smoke wildfires, oil and gas extractions, power plants etc. which are the major sources nitrogen oxides and VOC's.



In

Figure 8a. SSA country level annual average ozone concentration

addition to these, high and hot temperatures in SSA also triggers the concentration of ozone levels by speeding up the reactions between these compounds to form ozone. Although it appeared that many SSA nations are relatively doing well below the maximum daily average, the quality of the result can be questioned.

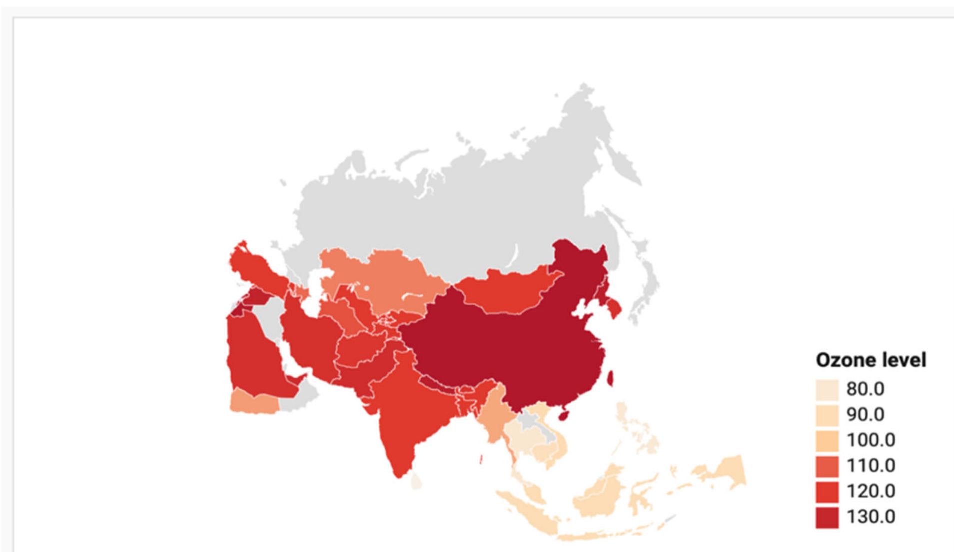


Figure 8b. Asia country level annual average ozone concentration

In the case of Asia (Fig 8b), where data are available, most of the countries are beyond the 8-hour daily maximum which indicates that ozone pollution in generally high. The hotspots of high ozone daily concentration levels are Iraq, China, North Korea, Nepal, Palestine, Syria Lebanon, Pakistan, Iran, Afghanistan, Tajikistan and India, with their daily concentrations ranging from 120μg/m^3 and 140μg/m^3 (see full table in Appendix). These countries have a common characteristic on the source and cause of ozone pollution similar to that of polluted countries in SSA. Similar to that of SSA, the major drivers of increased ozone concentration level in Asia can be attributed to increasing urbanization and industrialization, use of inefficient energy fuels, emissions from plants and vehicles.

Contrary to the cases of SSA and Asia, ozone concentration levels in Latin America (Fig 8c) are below the WHO GV of 100μg/m^3 except for Mexico with 123μg/m^3 which can be attributed to high inhabitants and industrialization in Mexican urban areas.

Figure 8c. LA country level annual average ozone concentration

However, these concentrations have been decreasing as a result of the integration of air quality monitoring and management with measures such as strengthening the capacity of environmental institutions, imposing emission standards in the region for industries and vehicles as well as improving fuel quality (Cifuentes et. Al, 2005).

4.4 Nitrogen dioxide (NO_2) and Sulphur dioxide (SO_2)

For SO_2 and NO_2, table 3 shows the mean annual concentrations for urban areas measured at different period, source type and different sampling method, thereby giving uncertainty in results. The reference level (WHO GV) for both SO_2 and NO_2 are 50µg/m^3 and 40µg/m^3 respectively. Concentration data of these pollutants are scarce in developing countries and in some cases where available, are too old making it difficult to predict the current levels of pollution.

NO_2 emissions in urban areas emanate mainly from high number of vehicles. NO_2 studies (mainly focus on traffic emission) were scarce and widely dispersed and in cases where available, satellite images /modelling were carried out on a larger scale covering country and regional perspective. The data reported that NO_2 concentrations were within 40µg/m^3 annual mean of WHO with a few cases slightly above the limits.

The leading cause of SO_2 pollution comes from the industrial sector due to the use of coal for energy purposes. The few studies examining SO_2 emissions (Table 3) showed that emissions were within range of WHO GV and the reduction in the level of sulphur is attributed to the removal of sulphur from coal combustion by combustion scrubbers (Smith et al., 2011). Fig. 9 illustrates the decline in SO_2 emission which Smith et al., (2011) further attributed to shifts to lower sulphur coal and desulphurization of flue gas.

Table 3. NO_2 and SO_2 mean/average annual concentration.

Region	City	Type	Period	Annual mean/average annual mean concentrations		Sources
				NO_2 µg/m^3	SO_2µg/m^3	
SSA	Dakar, Senegal	Traffic	Jan. 2008-Dec 2009	59.6	41.6	Adon et al., 2016
	Bamako, Mali	Traffic	Jun 2008 – Dec 2009	30.5	9.4	Adon et al., 2016
	Kampala, Uganda	Urban	July 2014	9.12-51.7	0.75-8.19	Kirenga et al., 2015
	Accra, Ghana	Urban	July 2006	21.1-66.76	2.9-3.2	Arku et al., 2008
	Abidjan, Cote' Ivoire	Traffic	Mid-term 2015-2017	25	3.66	Bahino 2017
	Ouagadougou, B/Faso	Urban	Feb-June 2007	22-27	0.5-10.5	Nanaa 2t al., 2012
Asia	Lahore, Pakistan	Urban	Dec 2005 – Feb 2006	-	19.36	Biswas et al., 2008
	Kolkata, India	Urban	Nov 2003 – Nov 2004	32.53	12.30	Gupta et al., 2008
Latin America	Salvador, Brazil	Urban	Two weeks	3.6-12	1.8-3.9	Campos et al., 2010
	Curitiba, Brazil	Urban	Two weeks	6.7-11	1.2-1.9	Campos et al., 2010

While it seemed that mainly the developed nations experienced decline in SO_2 emissions compared to developing regions, Smith et al., (2011) noted that the aggregate emission factor greatly reduced across all regions.

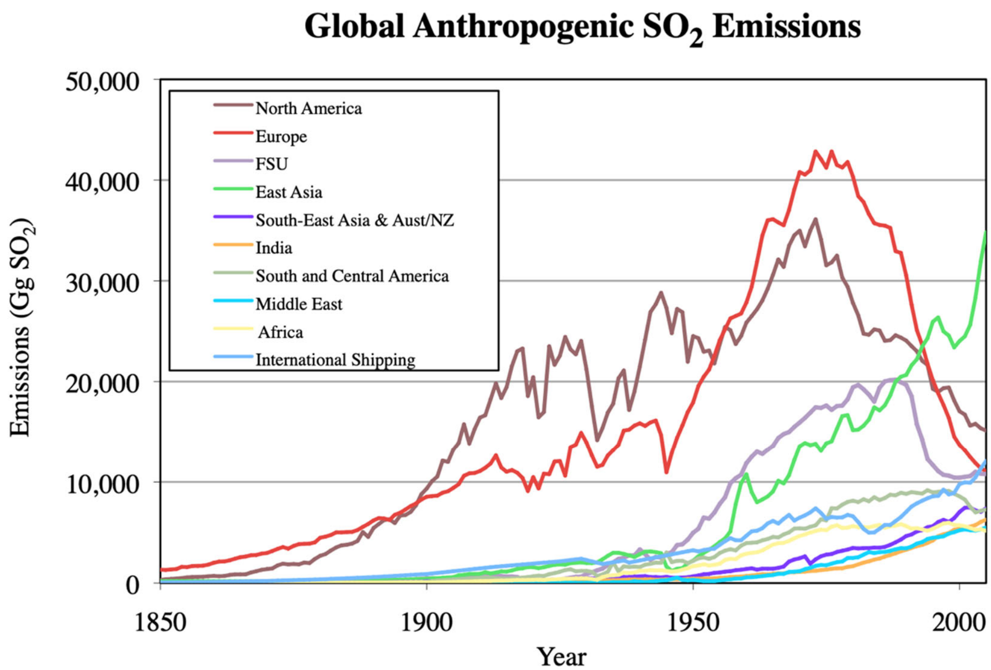


Figure 9. Global Sulphur dioxide emissions by region (North America =USA + Canada; East Asia = Japan, China +, and South Korea). Source: Smith et al., (2011)

5.0 Conclusion

This study used air quality data and information's collected from various studies. The above evidences showed how economy affects air quality, the effect of which is felt mostly by LMIC countries as abatement of its problems and health effects are often costly.

Evidences have shown the poor quality of air in LMIC with concentrations twice the WHO limits in most of the urban areas covered in this report especially in the Asia region.

The current state showed that air quality with respect to $PM_{2.5}$ and PM_{10} concentrations were moderate in LA and high in regions of SSA and Asia. Air quality in most urban areas is greatly influenced by topography, local climate and other socio-economic conditions. Evidences showed high concentration of ground level ozone over the Asian region and parts of SSA indicating that often times, it is not a sole problem associated with income levels but air quality management, from the results in LA. NO_2 average concentrations in the few studies showed levels within and close to WHO values while SO_2 concentrations fall below the WHO GV and continues to decline.

In general, these high concentration levels of air pollutants most especially in the SSA and South-East Asia is a growing concern and health risk and there's need for countries to address, as a matter of urgency, the state of air quality. For better performance towards air quality, there's need for continued monitoring and modelling in areas where monitoring is still difficult in order to understand the trend, state and its consequent impact on human health. Efforts are required both at national and societal levels to formulate policies, regulations and standards aimed at improving air quality and achieving clean air.

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Annex

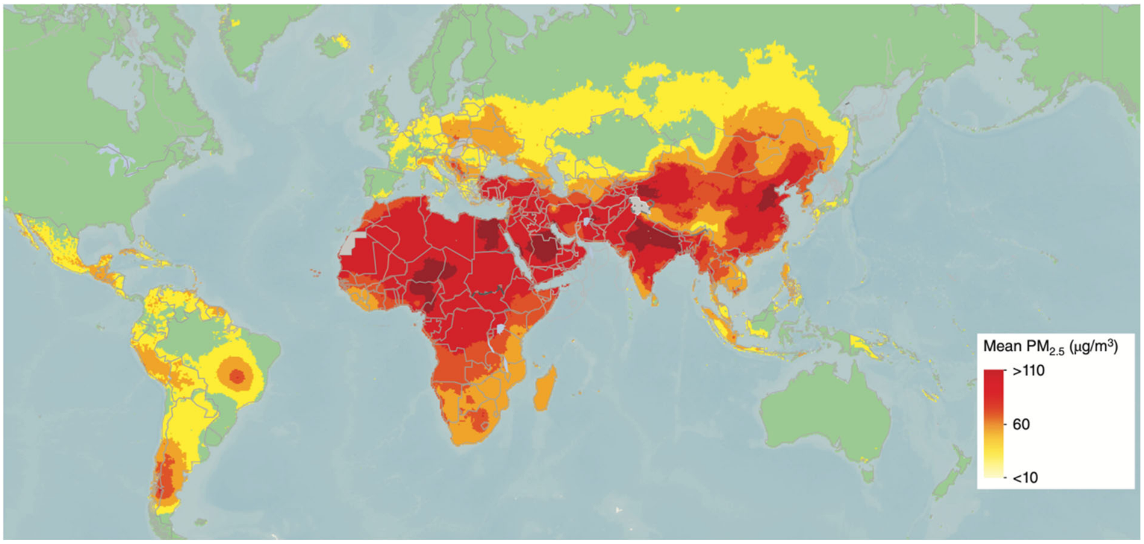

Figure 10. Global PM2.5 concentration. Source: North et al., 2019

Table 4. National level ozone exposures 2017 (Population-weighted seasonal average 8-hour maximum ozone exposure). Source: state of global air (2019).

Region	Country	O3 (µg/m3)	Region	Country	O3 (µg/m3)	Region	O3 (µg/m3)	O3 (µg/m3)
Asia	Iraq	139	SSA	Angola	124	Latin America	Mexico	123
	China	136		DR Congo	118		Venezuela	91
	Jordan	135		Zambia	117		Vietnam	90
	Taiwan	135		Namibia	112		Paraguay	89
	North Korea	133		Central African Republic	108		Brazil	89
	Nepal	133		Botswana	107		Argentina	86
	Palestine	132		Nigeria	106		Uruguay	83
	Syria	131		Chad	106		Trinidad and Tobago	83
	Lebanon	130		Zimbabwe	105		Peru	82
	Pakistan	126		Niger	104		Panama	81
	Iran	124		Swaziland	104		Colombia	81
	Afghanistan	123		Sudan	103		Costa Rica	81
	Tajikistan	121		Eritrea	103		Ecuador	77
	India	121		Malawi	102			
	Kyrgyzstan	116		South Sudan	100			
	Uzbekistan	116		Burundi	100			
	Bangladesh	116		Djibouti	99			
	Armenia	113		Congo	98			
	Turkmenistan	110		Lesotho	98			
	Azerbaijan	108		South Africa	97			
	Kazakhstan	106		Uganda	96			
	Myanmar	103		Benin	96			
	Indonesia	89		Cameroon	95			
	Guatemala	87		Rwanda	93			
	Thailand	80		Guinea	93			
	Philippines	79		Togo	93			
				Burkina Faso	92			
				Sierra Leone	92			
				Mozambique	91			
				The Gambia	91			
				Guinea-Bissau	90			
				Tanzania	90			
				Mali	89			
				Ethiopia	89			
				Senegal	88			
				Ghana	87			
				Kenya	83			
				Liberia	82			
				Gabon	81			
				Cote d'Ivoire	80			
				Equatorial Guinea	79			
				Somalia	78			
				Mauritius	78			

Table 5. Particulate Matter concentrations in Latin America cities in 2019. source: statista (2020)

City (Country)	**$PM_{2.5}$**
Toluca (Mexico)	29.4
Lima (Peru)	23.7
Saba Neta (Colombia)	22.4
Leon (Mexico	20.9
Mexico City (Mexico)	20.5
San Benito (Guatemala)	20.2
Campinas (Brazil)	20
Medellin (Colombia)	19.9
Monterrey (Mexico)	19.3
Guadalajara (Mexico)	18.9
Trujillo (Peru)	18.1
Santos (brazil)	15.4
Sao Paulo (Brazil	15.3
Bogota (Colombia)	13.1
Buenos Aires (Argentina)	12.4
Quito (Ecuador)	8.6