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Air Pollution in Bangalore, India: A Six-Year Trend and Health Implication Analysis

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***Abstract:* Air pollution is increasingly becoming a global concern and is believed to be amongst the leading causes of death in the world today. Developing countries, with rapidly growing economies, are struggling between the focus on economic development and curbing air pollution emissions. Bangalore is one of India's fastest growing metropolises and, although benefiting economically due to its rapid development, has a rapidly deteriorating environment. This paper provides a critical analysis of the air pollution trend in the city over the period 2005-2011 at 6 specific locations where measurements have been consistently recorded. It also discusses the potential health implications pertaining to exceeding levels of pollutants where these are applicable.**

Keywords: *Environment; Environmental Health; Air Quality Monitoring*

I. Introduction

Air pollution is a significant environmental health concern for both the developing and the developed world. The World Health Organization (WHO) estimates that 2 million people die prematurely due to air pollution [1]. The WHO ranks air pollution as the 13th leading cause of world-wide mortality, with 527,000 people annually dying prematurely in India due to air pollution [2].

Several epidemiological studies [3] and clinical evidence have linked the effects of both the short- and long-term exposures of air pollution on various health effects such as chronic respiratory disease, lung cancer, heart disease and even damage to the brain and nerves [4].

Bangalore has the largest concentration of number of IT, electronic and bio-tech industries and is popularly known as the 'Silicon Valley of India'[5]. The advance of economic development in the city has led to a rise in population (approx. 8.4 million inhabitants [6]) and number of vehicles (approx. 4 million vehicles [7]). This has exerted a tremendous pressure on the infrastructure of the city which is now witnessing a significant increase in air pollutants and a deterioration of environmental quality and health [8]. This paper lists the sources of the pollutant analysed, provides the general effects of that pollutant on health and also assesses the possible impacts of the air pollution situation on the health of citizens in Bangalore.

In addition to vehicular emissions, the main sources of pollution in Bangalore are small scale industries, increased use of diesel generator (DG) sets, domestic sources, non point sources, such as waste burning, and construction activities.

II. Air Pollution Data Collection In Bangalore

Under the National Ambient Air Quality Monitoring Programme, the Karnataka State Pollution Control Board (KSPCB) monitors ambient air quality in the following locations in Bangalore City [9] : Graphite India Limited, KHB and Peenya (classified as 'industrial areas'), AMCO Batteries and Yeshwanthpur Police Station (YPR) (classified as 'residential areas') and Victoria hospital (the only 'sensitive area' location).

III. Six-Year Data Analysis

Annual average levels of SO_2, NO_x and $RSPM/PM_{10}$ collected at the 6 monitoring locations for six years (2005-2011) are given in Tables 1-3, respectively. The bar charts in Figs. 1-3 also give a representation of the data collected by KSPCB during those years for each of the pollutants under consideration.

Concentration ranges for the different pollutants, based on the Notification Standards and area classes described by the Central Pollution Control Board (CPCB), can be calculated through an Exceedence Factor (EF) as follows [10]:

$$EF = \frac{\text{Observed annual mean concentration of a criterion pollutant}}{\text{Annual standard for the respective pollutant and area class}}$$

Using the above expression for EF, air quality during the years 2005 to 2011 with respect to each pollutant measured is also given in Tables 1-3. Such air quality can be expressed in terms of low, moderate, high or critical according to the following criteria, based on the EF of the various sites monitored:

- Critical pollution **(C):** EF > 1.5
- High pollution **(H):** EF 1.0 - 1.5
- Moderate pollution **(M)**: EF 0.5 - 1.0
- Low pollution **(L):** EF < 0.5

Table 1. SO_2 Levels, EF and Air Quality Classification, 2005-2011

	YPR [RESIDENTIAL]			AMCO [RESIDENTIAL]			PEENYA [INDUSTRIAL]		
	LEVELS (µg/m^3)	EF	AIR QUALITY	LEVELS (µg/m^3)	EF	AIR QUALITY	LEVELS (µg/m^3)	EF	AIR QUALITY
2005-06	21.7	0.434	L	21.2	0.424	L	18.3	0.366	L
2006-07	17.2	0.344	L	15.3	0.306	L	15.5	0.31	L
2007-08	16.2	0.324	L	15.9	0.318	L	16.3	0.326	L
2008-09	15.1	0.302	L	14.9	0.298	L	15	0.3	L
2009-10	16.3	0.326	L	14.2	0.284	L	15.4	0.308	L
2010-11	16.5	0.33	L	13.9	0.278	L	15.4	0.308	L
STANDARDS	50µg/m^3			50µg/m^3					
	KHB [INDUSTRIAL]			GRAPHITE [INDUSTRIAL]			VICTORIA [SENSITIVE]		
	LEVELS (µg/m^3)	EF	AIR QUALITY	LEVELS (µg/m^3)	EF	AIR QUALITY	LEVELS (µg/m^3)	EF	AIR QUALITY
2005-06	20.3	0.406	L	20.6	0.412	L	18.3	0.915	M
2006-07	16.7	0.334	L	18.9	0.378	L	15.5	0.775	M
2007-08	15.5	0.31	L	16.3	0.326	L	16.1	0.805	M
2008-09	14.8	0.296	L	16.1	0.322	L	14.9	0.745	M
2009-10	14.6	0.292	L	16.5	0.33	L	13.3	0.665	M
2010-11	14.8	0.296	L	16.1	0.322	L	12.7	0.635	M
STANDARDS	50µg/m^3			50µg/m^3			20µg/m^3		

Table 2. NO_x Levels, EF and Air Quality Classification, 2005-2011

	YPR [RESIDENTIAL]			AMCO [RESIDENTIAL]			PEENYA [INDUSTRIAL]		
	LEVELS (µg/m^3)	EF	AIR QUALITY	LEVELS (µg/m^3)	EF	AIR QUALITY	LEVELS (µg/m^3)	EF	AIR QUALITY
2005-06	32.1	0.802	M	39.1	0.977	M	29.6	0.74	M
2006-07	31.4	0.785	M	27.8	0.695	M	27.7	0.692	M
2007-08	39.8	0.995	M	38.5	0.962	M	39	0.975	M
2008-09	41	1.025	H	40.7	1.01	H	40.8	1.02	H
2009-10	37.2	0.93	M	34.5	0.862	M	36.4	0.91	M
2010-11	30.4	0.76	M	29	0.725	M	30	0.75	M
STANDARDS	40µg/m^3			40µg/m^3			40µg/m^3		
	KHB [INDUSTRIAL]			GRAPHITE [INDUSTRIAL]			VICTORIA [SENSITIVE]		
	LEVELS (µg/m^3)	EF	AIR QUALITY	LEVELS (µg/m^3)	EF	AIR QUALITY	LEVELS (µg/m^3)	EF	AIR QUALITY
2005-06	37.3	0.932	M	50.7	1.267	H	35.7	1.19	H
2006-07	29.2	0.73	M	32.5	0.812	M	29.3	0.976	M
2007-08	39	0.975	M	40	1.0	M	38.7	1.29	H
2008-09	40.1	1.002	H	43	1.075	H	40.5	1.35	H
2009-10	35.6	0.89	M	37.9	0.947	M	33.4	1.11	H
2010-11	29.8	0.745	M	30.4	0.76	M	27.2	0.906	M
STANDARDS	40µg/m^3			40µg/m^3			30µg/m^3		

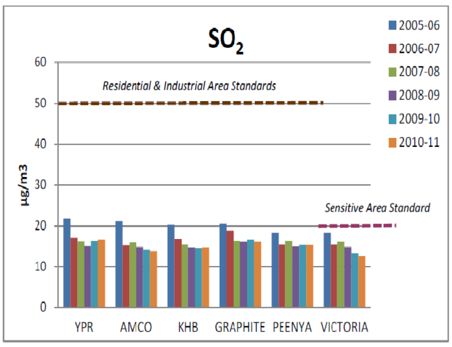

Fig. 1. SO_2 Levels at 6 sites in Bangalore, 2005-2011

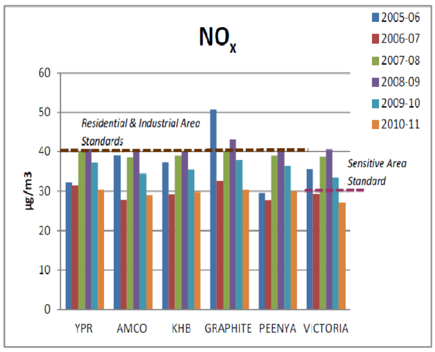

Fig. 2. NO_x Levels at 6 sites in Bangalore, 2005-2011

Table 3. RSPM/PM_{10} Levels, EF and Air Quality Classification, 2005-2011

	YPR [RESIDENTIAL]			AMCO [RESIDENTIAL]			PEENYA [INDUSTRIAL]		
	LEVELS (µg/m^3)	EF	AIR QUALITY	LEVELS (µg/m^3)	EF	AIR QUALITY	LEVELS (µg/m^3)	EF	AIR QUALITY
2005-06	71	1.183	**H**	64.7	1.078	**H**	103	1.716	**C**
2006-07	61	1.016	**H**	49	0.816	**M**	78	1.3	**H**
2007-08	67	1.116	**H**	71	1.183	**H**	101	1.683	**C**
2008-09	125	2.083	**C**	71	1.183	**H**	120	2	**C**
2009-10	221	3.683	**C**	65	1.083	**H**	74	1.23	**H**
2010-11	100	1.666	**C**	80	1.333	**H**	92	1.53	**C**
STANDARDS	**60µg/m^3**			**60µg/m^3**			**60µg/m^3**		
	KHB [INDUSTRIAL]			**GRAPHITE [INDUSTRIAL]**			**VICTORIA [SENSITIVE]**		
	LEVELS (µg/m^3)	EF	AIR QUALITY	LEVELS (µg/m^3)	EF	AIR QUALITY	LEVELS (µg/m^3)	EF	AIR QUALITY
2005-06	57.6	0.96	**M**	91.8	1.53	**C**	69.3	1.155	**H**
2006-07	63	1.05	**H**	194	3.233	**C**	80	1.333	**H**
2007-08	78	1.3	**H**	129	2.15	**C**	66	1.1	**H**
2008-09	69	1.15	**H**	184	3.06	**C**	63	1.05	**H**
2009-10	56	0.933	**M**	122	2.033	**C**	59	0.983	**M**
2010-11	72	1.2	**H**	122	2.033	**C**	64	1.066	**H**
STANDARDS	**60µg/m^3**			**60µg/m^3**			**60µg/m^3**		

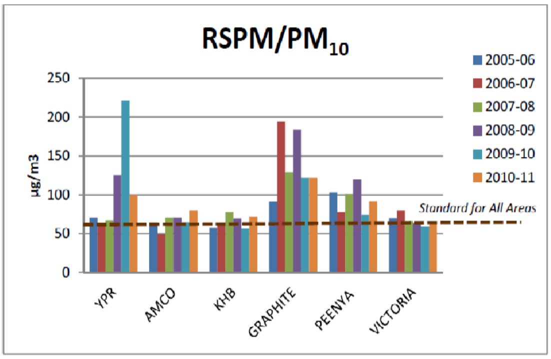

Fig. 3. RSPM/PM_{10} Levels at 6 sites in Bangalore, 2005-2011

A. Analysis of SO_2 Levels

The sources of SO_2 applicable to Bangalore are mainly due to the burning of fossil fuels and diesel exhaust, and the salient health effects attributable to it are known to be inflammation of the respiratory tract, dysfunction of lungs and irritation of the eyes. SO_2 also causes health illnesses such as coughing, aggravation of asthma, chronic bronchitis and respiratory tract infections [1].

As can be seen from Table 1, in the Yeshwanthpur Police Station (YPR) residential area, the SO_2 level in 2005-2006 was 21.7µg/m^3. Over the subsequent 3 years it sustained a gradual decrease by 30.4% to 15.1µg/m^3. On the other hand, during the 2 most recent years 2009-2011, there has been an increase of 9.3% to 16.5µg/m^3. Despite this increase, there is a noticeable overall reduction of 24% from 2005 to 2011, and the levels have remained well below the standard 50µg/m^3. Indeed in 2010-11, the level of SO_2 in YPR was a third of that of the standard set by the CPCB. The other residential area, AMCO batteries, sustained a consistent reduction in SO_2 levels from 2005 to 2011, witnessing an overall decrease of 34.4%.

In the case of industrial areas, Peenya, although having decreasing levels of SO_2 from 18.3µg/m^3 in 2005-06 to 15.4µg/m^3 in 2010-11 (an overall reduction of 15.8%), has nevertheless seen a slight (2.7%) increase in SO_2 levels over the period 2009-11, compared with the previous year. The second industrial area, KHB, saw an overall reduction in SO_2 levels of 27.1% during the 6 years under consideration, but again with a very slight (1.4%) increase in 2010-11 over the previous year. In the Graphite industrial area, the overall reduction over the 6-year period was 21.8%. However, it appears that the levels during the last 3 years (2008-11) have remained generally stagnant around the 16.1µg/m^3 level, although in 2009-10, it slightly peaked to 16.5µg/m^3.

The SO_2 levels in Victoria, the only sensitive area, were 18.3µg/m^3 in 2005-06 and decreased by 15.3% in 2006-07. There was a slight increase to 16.1µg/m^3 in 2007-08, but the levels have since demonstrated a general decreasing trend with values at 12.7µg/m^3 in 2010-11. Therefore the overall percentage decrease during the years 2005-11 was 30.6%. Victoria, being a sensitive area, has SO_2 standards set at 20µg/m^3 and thus has an EF that puts it in the Moderate category for air pollution. Surprisingly, amongst all 6 areas under consideration, this is the only area that has consistently shown a moderate air pollution exceedance factor over the 6-year period.

Generally, the levels of SO_2 tend to be decreasing in all areas and throughout the 6 years under analysis. As fuel type and quality are one of the major contributors to SO_2, the reduction may be attributed to various measures taken, such as the reduction of sulphur in diesel fuel and the wider use of liquefied petroleum gas (LPG) instead of coal as domestic fuel.

According to the WHO, a study conducted in Hong Kong in 2002 suggested a two-week intervention to reduce sulphur content in fuels and witnessed a substantial reduction in childhood respiratory diseases, all age mortalities and related health effects over an increasingly extended period of time [11]. It is expected that, given the downward trend of SO_2 levels in Bangalore, in general, this will also be the case. Our team is indeed currently engaged in carrying out a comprehensive study assessing the health impacts of air pollution in the city in order to corroborate those findings.

B. Analysis of NO_X Levels

Fig. 2 and Table 2 represent the levels of NO_x at the 6 sites under consideration in Bangalore over the years 2005-2011. NO_x emissions result from all types of combustion sources and motor vehicle exhausts (petrol, diesel, liquid petroleum gas (LPG) and compressed natural gas (CNG)) [3]. NO_x exposure is linked to adverse respiratory effects and airway inflammation in healthy people and increased respiratory symptoms in people with asthma. NO_x reacts with other compounds such as ammonia and moisture to form small particles that penetrate deeply into sensitive parts of the lungs. This can either induce or worsen respiratory diseases, aggravate existing heart disease leading to increased hospital admissions or even premature death [1].

As can be seen from Fig. 2 and Table 2, in the YPR and AMCO residential areas in Bangalore, the NO_x levels over the year 2006-07 dropped by 2.2% and 28.9%, respectively, from 2005-06, maintaining an air quality classification of moderate pollution. However, over the following two years i.e. 2007-09, NO_x levels increased by 30.6% and 46.4%, changing the air quality category in 2008-09 to high in both residential locations.

Interestingly, the three industrial areas KHB, Graphite and Peenya saw a similar trend of reduction in NO_x levels in 2006-07 before peaking up over the following two years (2007-09) by 37.3%, 32.3% and 47.3%, respectively. The air quality toggled to high levels of NO_x over the same duration in all three areas, indicating levels in excess of the standard values. Likewise, the sensitive area of Victoria experienced a similar trend to the residential and industrial areas of having moderate levels of 29.3µg/m^3 in 2006-07, increasing by 38.2% in 2007-09 and also changing the air quality classification to high.

In the residential and industrial areas, the levels in 2009-10 decreased, changing the air quality category back to moderate level. In Victoria, although the levels decreased, as the recommended standards of NO_x are 30µg/m^3 (Victoria being a sensitive area), the air quality category remained high until 2010-11 when the levels dropped by 18.6% making the air quality classification in Victoria moderate as well.

A possible explanation for the increase in trend over the two years 2007-09 may be attributed to vehicular number. Although the number of vehicles has been increasing in Bangalore, the number of registered vehicles, particularly over 2007-09, saw an exponential increase of over half a million more vehicles. In 2007 the estimated number of vehicles was 3.1 million and in 2009 it was 3.65 million [7]. As motor vehicle exhausts are one of the major contributors to NO_x emissions, this noticeable increase in vehicular traffic could have contributed to the increase in levels in all areas.

The values in all areas decreased again to achieve an air quality classification of moderate pollution. As the same combustion processes are involved, the same arguments that applied to SO_2, i.e. reduction of sulphur in diesel and wider use of liquefied petroleum gas (LPG) as fuel, would also apply to NO_x.

C. Analysis of RSPM/PM_{10} Levels

Respirable Suspended Particulate Matter (RSPM) generally refers to most coarse particles of diameter size <10µm (also more commonly referred to as PM_{10}). The main sources of RSPM/PM_{10} are identified to be automobile exhausts (especially diesel) and road dust. Fig. 3 and Table 3 show the levels of RSPM in Bangalore over the years 2005-2011 at the 6 sites under consideration. From Fig. 3 and Table 3, it is clear that the residential area of YPR has seen alarmingly increasing levels of RSPM over the last 3 years (2008-11), with an air quality classification of critical. The levels of RSPM were never below the recommended standard for the area over all the six years. The EF over the years 2005-08 remained at about 1.0-1.1, suggesting the air quality category to be high. However 2008-11 saw the EF increase, with values even being as high as 221µg/m^3 in 2009-10, suggesting the values being 3.68 times above the prescribed limit.

On the other hand, the residential area of AMCO generally had an air quality classification of high for RSPM pollution, except in 2006-07, when the levels decreased by 24.3% from the previous year to 49µg/m^3 and the air quality category was moderate. The following year saw an increase of 44.9% to 71µg/m^3, thus changing the air quality category to high. In 2010-11 the values were recorded at 80µg/m^3 or 33% above the prescribed limit.

The 3 industrial areas varied in air quality classification from moderate to critical, with the KHB industrial area generally having fluctuating levels of pollution. In 2010-11, the level of RSPM in KHB reached its second highest value (72 µg/m^3) across the 6 years under consideration. The Graphite industrial area is alarming with critical levels of pollution throughout the entire 6-year period. The RSPM values of 194µg/m^3 in 2006-07 and 184µg/m^3 in 2008-09 were over 3 times above the recommended standard. The current level stands at twice the recommended standard, making the area critical in respect of RSPM pollution. In the Peenya industrial, the EF fluctuated between high and critical and currently stands at the critical level.

Victoria consistently maintained a high level of RSPM pollution the 6 year period, except in 2009-10 when the level fell by 6.8% from the previous year to 59µg/m^3, making it 1µg/m^3 below the recommended standard and classifying the air quality category as moderate for that year. In 2010-11, however, the concentration of RSPM increased again to reach a high classification level.

In general, all 6 sites under consideration have exceeded the recommended RSPM level of 60 µg/m^3 with YPR, being a residential area, falling in the critical category and Graphite being critical, having levels over twice the recommended standard.

A study conducted by The Energy Research Institute (TERI) concluded that 50% of Bangalore's RSPM/PM_{10} is caused by dust [8]. A multitransit rail system (MTRS) proposed for Bangalore to improve the public transport system began its first construction phase of the project in 2007. The city witnessed more widening of roads and increased construction activities, inevitably increasing the dust level in the city. This may have largely contributed to the elevated levels of RSPM at various locations.

Particulate matter has been identified to have direct adverse effects on morbidity and mortality rates. According to the WHO [1], multi-city studies demonstrated that increases in PM_{10} by 10µg/m^3, 50µg/m^3 and 100µg/m^3 resulted in increased mortality rates of 1%, 3-6% and 10-17%, respectively. If this mortality reflection is translated to Bangalore's levels of RSPM, then projected increases in mortality rates in Graphite and YPR would be 10-17%, 8% in the AMCO residential area and 6-9% in Peenya and Victoria.

IV. Further PM Analysis

Findings from the TERI study [8] in Bangalore city showed that dust is the major source of PM_{10}; vehicle emissions, on the other hand, are major contributors of $PM_{2.5}$. Contributions of PM_{10} from industrial and domestic sources are relatively small at only 4.5% and 4.2%, respectively. DG sets contribute significantly to PM levels – 13% for PM_{10} and nearly 25% for $PM_{2.5}$.

With the increasing attention to PM as a major factor for air quality concern, the KSPCB carried out measurements of ambient air at breathing level (2 meters above the ground level) in 2008 using mobile laboratories at 4 major traffic intersections. These were City Railway Station, Central Silk Board, Badami House and 11th Cross, Malleswaram, and these areas are mixed urban with maximum traffic. While the pollutants measured were PM_{10}, $PM_{2.5}$, NO_x and SO_2, this analysis mainly focuses on PM, and Table 4 gives the PM_{10} and $PM_{2.5}$ values measured at those 4 locations.

At Central Rail Station, Central Silk Board and Badami House, the values over 24 hours were 4.8, 3.5 and 1.5 times the recommended India standard of 100µg/m^3 for PM_{10}, respectively, making all three areas having critical levels of PM_{10} pollution. Meanwhile, values at Malleswaram were 1.17 times the standard value making the PM_{10} in this area high.

For $PM_{2.5}$, again, the levels recorded at Central Rail Station, Central Silk Board and Badami House were 6.6, 5 and 2 times the 24-hour standard value of 60µg/m^3, respectively. The levels at all 3 sites were thus critical. Malleswaram had levels just below the recommended level at 59µg/m^3 with a moderate $PM_{2.5}$ pollution classification.

PM, due to their small size, are not filtered and penetrate deeply into the cardiovascular system where they can cause damage [12]. The link between PM and health has only begun to attract research attention in recent years, especially attempting to convincingly link ambient air pollution to CVD, as witnessed by one of the first texts in the subject which has only just been published [2].

Sri Jayadeva Institute of Cardiovascular Sciences and Research, a leading cardiovascular hospital in

Table 4. PM levels at 4 Select Locations in Bangalore City, 2008

		CENTRAL RAILWAY STATION			CENTRAL SILK BOARD		
	Standard ($\mu g/m^3$)	LEVEL ($\mu g/m^3$)	EF	CLASSIFICATION	LEVEL ($\mu g/m^3$)	EF	CLASSIFICATION
PM_{10}	100	477.8	4.78	**C**	349.8	3.49	**C**
$PM_{2.5}$	60	396.7	6.61	**C**	298.6	4.98	**C**
		BADAMI HOUSE			**MALLESWARAM**		
	Standard ($\mu g/m^3$)	LEVEL ($\mu g/m^3$)	EF	CLASSIFICATION	LEVEL ($\mu g/m^3$)	EF	CLASSIFICATION
PM_{10}	100	152	1.52	**C**	117	1.17	**H**
$PM_{2.5}$	60	118	1.97	**C**	59	0.98	**M**

Bangalore recently reported that, based on their statistics, there has been a consistent substantial increase in the number of outpatients, number of inpatients and number of procedures (such as ECG, echocardiography, CAG, coronary angioplasties, balloon valvuloplasties, open heart surgeries, valve replacements, bypass surgeries, etc.,) since 2006 as compared to statistics from previous years [13].

Although no link has yet been established in Bangalore between polluted air exposure and CVD, hospital admissions, patient symptoms and CVD morbidity and mortality rates would be important indicators that can assist in determining such a potential link.

V. Conclusions

Bangalore is experiencing varying levels of pollution with certain areas having either high or critical levels of the pollutants analysed in this study. The KSPCB has taken many initiatives to improve the quality of air, such as improving fuel quality, introducing alternate fuels for autorickshaws, improved traffic management, implementation of emission norms, promoting use of green fuel by industries for DG sets, etc., Reduction in SO_2 and NO_x levels in the city may be a consequence of a combination of various interventions such as implementing stringent emission norms for vehicles and improvement in the quality of fuel, as an increasing number of vehicles are switching to LPG as automotive fuel. However the levels of PM remain high or critical in many areas.

Exposure to elevated concentrations of fine PM can trigger health risks and can reduce life expectancy by several months to few years. The critical levels of PM are likely to have a damaging effect on the health of the citizens in Bangalore that may result in a tremendous burden on the public health system. Also if this were to affect the skilled young human resource, it would pose a threat to the city's economy that is growing exponentially. It is vital that the government addresses the issue of health impact due to air pollution by adhering to stringent measures of pollution control.

There is a need for wider research and publications in the area of air pollution and its effects on health. In particular, the development of a relevant and comprehensive evidence base would equip Bangalore and India with the capability to take informed actions.

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