International Journal of Engineering, Management and Humanities (IJEMH)
Volume 1, Issue 1, pp: 48-67 www.ijemh.com

Spatio-Temporal Analysis of Improvement in Air Quality Following Corona Virus Pandemic Induced Lockdown and Suspension of Vehicular Movement: A Case Study in Kolkata Metropolitan Core and Its Adjacent Area

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Date of Submission: 28-01-2021 Date of Acceptance: 08-02-2021

ABSTRACT:
Along with rest of the world, the Government of India mandated a nationwide lockdown on March 23, 2020 to avert the possibility of community transmission of Corona virus Disease 2019 (COVID-19) which is still persistent in the form of unlock phase. It has been experienced that suspension of functions in all sectors of economy due to lockdown helped in preventing air pollution, as unplanned urbanization and industrial development has deteriorated air quality in most of the urban centres of India. The study monitors ambient concentration of pollutants namely PM_{10}, $PM_{2.5}$, CO, NO_2 and SO_2 at different monitoring stations of Kolkata Municipal Corporation (KMC) and adjacent area during pre-lockdown (March 1, 2020 - March 22, 2020) and lockdown (March 23, 2020 - April 30, 2020), temporal variation of pollutants observed at various places between March 1, 2020 and April 30, 2020, predominance of different pollutants and status of air quality at different million-plus cities of India during pre-lockdown and lockdown period (March 23, 2020 - May 31, 2020). Results show that percentage decline in the concentration of different pollutants between pre-lockdown and lockdown period vary in the range of 10%-90%, and observations are normalized by computation of composite Z-score. It is also learnt that transport sector takes determinant position in urban energy footprint and consequent pollution load. Therefore, relation between daily average vehicular volume and concentration of pollutants at different traffic intersection points of Kolkata has been analyzed. Sopher index idealizes differences in service provided by different types of vehicles between pre-lockdown and unlock period. Non-hierarchical (K-means) cluster analysis and T-test validates the significance of emission generated by vehicular weight. The study recommends lockdown has given respite to alleviate the apathy of staggering air pollution and necessitates implementation of alternative strategy in public transport in this direction.

KEYWORDS: Lockdown, Suspension, Concentration of Pollutants, Transport

I. INTRODUCTION

Cities are generally regarded as epicenters of economic growth, infrastructural development, land-use planning, promotion of civic amenities and housing. Like all over the world, metro cities in India experience tremendous vertical and horizontal expansion which leaves downturn in resource base and a negative impact is realized on overall quality of life across the urban entity.

The eastern economic pivot of India, i.e., Kolkata has seen an unprecedented growth of vehicular population of 12.04 lakhs within its limited territorial extent of 185 sq Km (Roy Chowdhury, 2014). This vehicular composition of road transport together with vehicular mass of other million-plus cities of India contributes 3.3% of India's Gross Value Addition (GVA) (Government of India [GoI], 2018). But rapid growth of urbanization, industrialization and motorization has set up direct correlation with emission of Green House Gases (GHGs) and other toxic particles in the atmosphere of city space, which amounts to 56.32 million tonnes in 2011, soaring up from 6.6 million tonnes in 1981 (Institute of Urban Transport [IUT], 2013).

The pollution level of Kolkata is immediately preceded by Delhi, the national capital of India which has been ranked among top 25 polluted cities over the globe (World Health Organization [WHO], 2018). Maximum percentage of concentration of suspended particulate matter has been observed in Kolkata. During the month of December, the air quality index goes up as high as 414 and pollution becomes critical due to temperature inversion (Basu, 2016). Huge quantities of aerosols and gases are released from chimneys of factories and incomplete combustion of fossil fuel in the engine of vehicles which constitute dust domes over the cities and accelerate complexity of air pollution. It has been identified that in Kolkata metropolitan core and its associated area industries contribute 46.3% (600 tonnes) followed by transportation (27.2%, 360 tonnes), thermal power plants (14.7%, 195 tonnes) and domestic emissions (11.8%, 150 tonnes) (Observer Research Foundation [ORF], 2019). Unless air pollution could be averted, average Indian life expectancy to be curtailed by more than eight years (Mukherjee, 2020). An in-depth analysis of spatial and temporal variation of air quality is therefore quite important to tackle the menace faced by biosphere and climatic condition in particular.

Considering the severity of community transmission of Corona Virus Disease 2019 (COVID-19), the Government of India issued a nationwide lockdown from March 23, 2020 for 21 days initially and later extended into phases. As a consequence, activities in industrial, transport, power and manufacturing sector came to a halt and the environment became relaxed from the burden of undesirable externalities. It is quite paradoxical that while transport sector goes hand-in-hand with upliftment of economic prospects and regional development, restriction of vehicular movement has come to the aid of environmental purification (Samaddar, 2020).

The air quality index is evaluated by adopting simulation model, with the help of database of atleast three pollutants including particulate matter for a minimum period of 16 hours along with health breakpoint concentration range for a particular location (Central Pollution Control Board [CPCB], 2016). Most specifically, five of the million-plus cities in India namely Delhi, Mumbai, Kolkata, Bengaluru and Hyderabad have seen 50-80% drop in concentration of different air pollutants. Therefore, the present lockdown situation has offered immense opportunity for potential control systems and regulations for improved urban air quality.

The study primarily focuses on detection of changes in concentration of different air pollutants between pre-lockdown and lockdown session, and consequent changes in vehicular movement and its relation with air pollutant concentration in Kolkata with respect to other million-plus cities in India during lockdown period.

II. METHODOLOGY

Analytical part of the study has been organized mainly with the help of secondary database collected from official website of West Bengal Pollution Control Board (WBPCB) and Central Pollution Control Board (CPCB), and reports prepared by Census of India, Ministry of Road Transport and Highways (MoRTH), Government of India (GoI) and Bureau of Applied Economics and Statistics (BAES), Government of West Bengal (GoWB). Mean daily and monthly concentration of five air pollutants such as Particulate Matter of radius less than 10μm (PM_{10}), Particulate Matter of radius less than 2.5μm ($PM_{2.5}$), Carbon Monoxide (CO), Nitrogen di-Oxide (NO_2) and Sulphur di-Oxide (SO_2) respectively for 11 monitoring stations located in different parts of Kolkata metropolitan core and its adjacent area, namely Rabindrabharati, Moulali, Fort William, Victoria Memorial, Topsia, Birla Industrial and Technological Museum (BITM), Rabindra Sarobar, Chakmir, Indian Association for the Cultivation of Science (IACS), Jadavpur, Behala Chowrasta and Baishnabghata where presence of all or selected number of pollutants mentioned above has been computed for the month of March 2020 to identify deviation in concentration of pollutants in the atmosphere of Kolkata between pre-lockdown and lockdown period.

Isopleth maps have been constructed for all of the pollutants based on locational concentration value of the target pollutant for pre-lockdown period and lockdown period for the month of March 2020 to determine spatial variation of those pollutants. Since lockdown period started on March 23, 2020 by imposition of Janta Curfew, data for the period from March 1, 2020 to March 22, 2020 have been considered for pre-lockdown period and data for the period between March 23, 2020 and March 31, 2020 have been considered for lockdown period.

Z-score (Eq. 1) has been evaluated to figure out normalization of percentage deviation in concentration of particular pollutant between pre-lockdown and lockdown period in the month of March 2020 and on the basis of z-scores for individual pollutants composite z-score has been determined for particular monitoring station as under.

Z-Score= (y-ȳ)÷σ (1)

where, y= percentage deviation of particular pollutant between pre-lockdown and lockdown period for particular station, ȳ= mean of percentage deviation of particular pollutant for all stations available, σ= standard deviation.

Relation between frequency of dominance of a particular pollutant by days and mean air quality index for those days has been determined for five monitoring stations across different million-plus cities of India namely Anand Vihar of Delhi, Chhatrapati Shivaji International Airport of Mumbai, Alandur Bus Depot of Chennai, Victoria Memorial of Kolkata and Marhatal of Jabalpur to idealize status of air quality of Kolkata with respect to other metro cities of India during pre-lockdown and lockdown period.

Bi-variate analysis between daily average volume of vehicles at seven selected traffic intersection points of Kolkata during peak (9:00 A.M.-1:00 P.M.) and lean (5:00 P.M.-9:00 P.M.) and concentration of different pollutants in their nearest monitoring stations during the corresponding time period in a usual day has been executed. Primary surveys have been conducted at different regional transport offices and traffic junctions and on the basis of survey gross traffic volume in Kolkata and adjacent area has been estimated.

Sopher index of disparity (Eq. 2) (Sopher, 1974) has been calculated to determine degree of disparity between different categories of vehicles on road between pre-lockdown and lockdown period as under.

Disparity Index by Sopher (**DI**$_S$) = [log $(x_2 \div x_1)$+log$(100-x_1)$]÷$(100-x_2)$ (2)

where, x_1, x_2= percentage share of particular category of vehicles during pre-lockdown and lockdown period respectively

Volume of estimated registered motor vehicles as on March 31, 2020 has been evaluated for metro cities of Delhi, Jabalpur, Kolkata, Greater Mumbai and Chennai and it has been correlated with mean hourly air quality index for the respective cities for that day (table 10). Estimated registered motor vehicles for the year 2020 have been found out as under.

Growth rate of registered motor vehicles (**r**)= [$^4\sqrt{}${(Registered motor vehicles in 2016÷Registered motor vehicles in 2012)-1}*100] (3)

Estimated registered motor vehicles for the year 2020= Registered motor vehicles in 2016*$(1+r\div100)^4$ (4)

K-means cluster analysis and one sample T-test has been executed on the basis of data for estimated registered motor vehicles and concentration level of different air pollutants in metro cities mentioned above using SPSS software version 25.0. These analyses are carried out to examine homogeneity in concentration pattern in different cities and significance of vehicular exhaust in concentration pattern.

III. STUDY AREA

The district of Kolkata (Kolkata metropolitan core) is located in the eastern part of river Hooghly, with latitudinal extent between 22°26´33´´N. and 22°38´04´´N., and longitudinal extension between 88°14´22´´E. and 88°27´43´´E. (Google Earth, 2020). It is the only completely urbanized district of West Bengal, consisting of 141 wards under 15 boroughs with a population size of 4486679 under an area of only 185 sq Km (Census of India, 2011). The Kolkata metropolitan core or Kolkata Municipal Corporation (KMC) is surrounded by a number of urban bodies with the objective of accommodating overspilling population and consequent demand for civic amenities under single territorial domain of Kolkata Metropolitan Area (KMA), which comprises an area of 1875 sq Km with population density of 7978 persons/sq Km and includes three municipal corporations, 38 municipalities and 22 panchayat samities (IDFCL and SGICPL, 2008). The district belongs to fluvio-marine delta crisscrossed by river Hooghly and its numerous tributaries. The average relief of the surface is not more than ten metres, (WBPCB, 2017) with greater possibility of southward extension. Mean annual range of temperature varies between 15°C. and 36°C., whereas mean annual precipitation stands about 140.78 mm (Department of Planning, Statistics and Programme Implementation, 2016).

Figure 1 and table 1 demonstrate spatial configuration and status of transport and communication system of Kolkata Municipal Corporation and its adjacent area.

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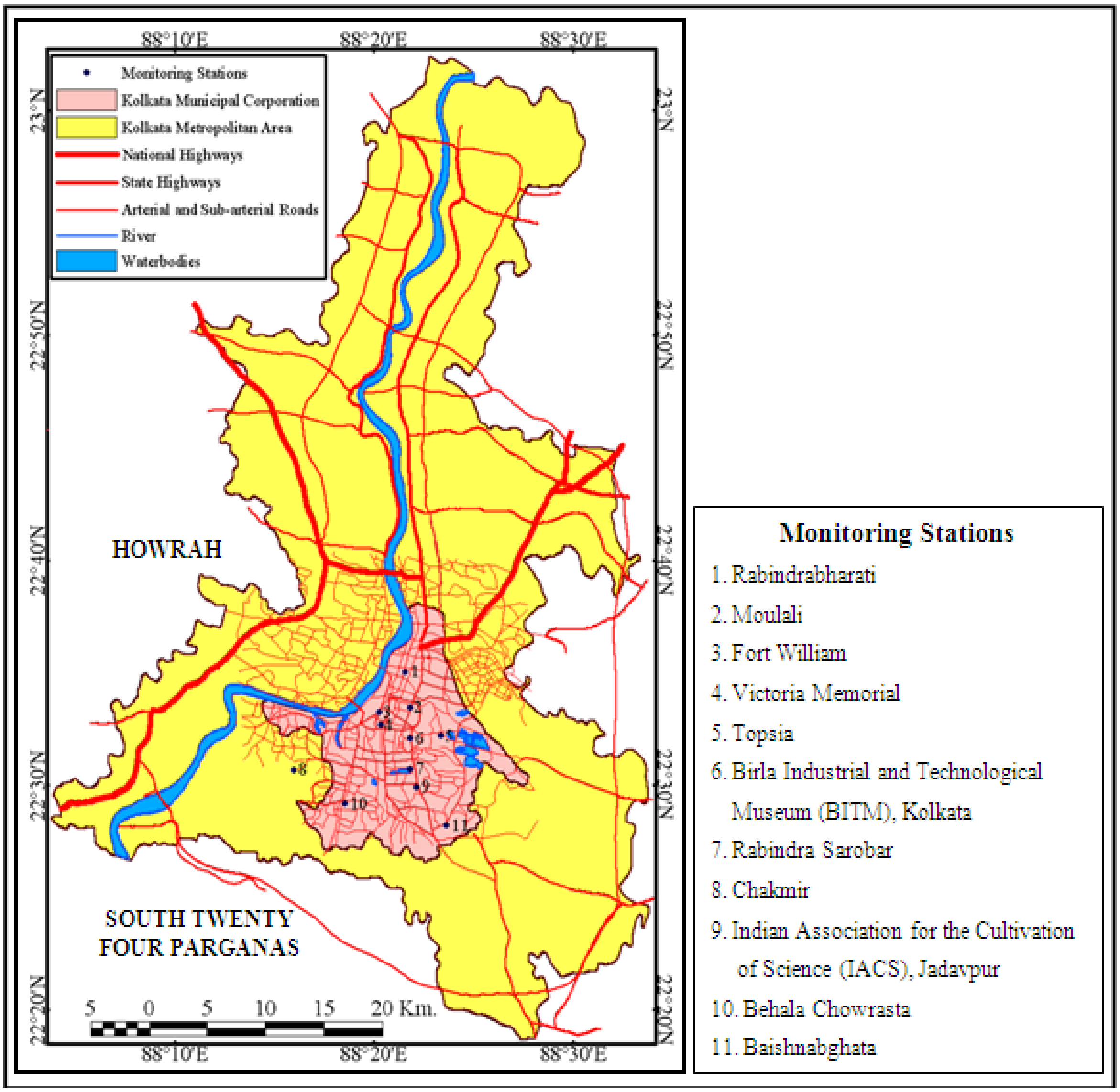


Source: NATMO, WBPCB and Google Earth (accessed on 22.4.2020)

Figure 1: Spatial distribution of selected air pollution monitoring stations in different parts of Kolkata Municipal Corporation (metropolitan core) and its adjacent area

Table 1: Estimates of Net Domestic Product in Transport, Storage and Communication Industry in Kolkata District for the Year 2014-15 (Rs. in Lakh)

Sector	Value
Railways	39553
Transport by Other Means	255099
Storage	3803
Communications	209075

Source: Department of Planning, Statistics and Programme Implementation (2017)

Transport infrastructure consisting of various types of surface and water transport play crucial role in shaping the morphology of city Kolkata. The district has a total route network length of 1947 Km with gross registered vehicular volume of 740879 under transport and non-transport category (Ministry of Surface Transport GoI, 2016). This tremendous growth of road transport system is responsible for emission of various types of pollutants in the air which needs to be mitigated by technological measures.

IV. RESULTS AND DISCUSSION

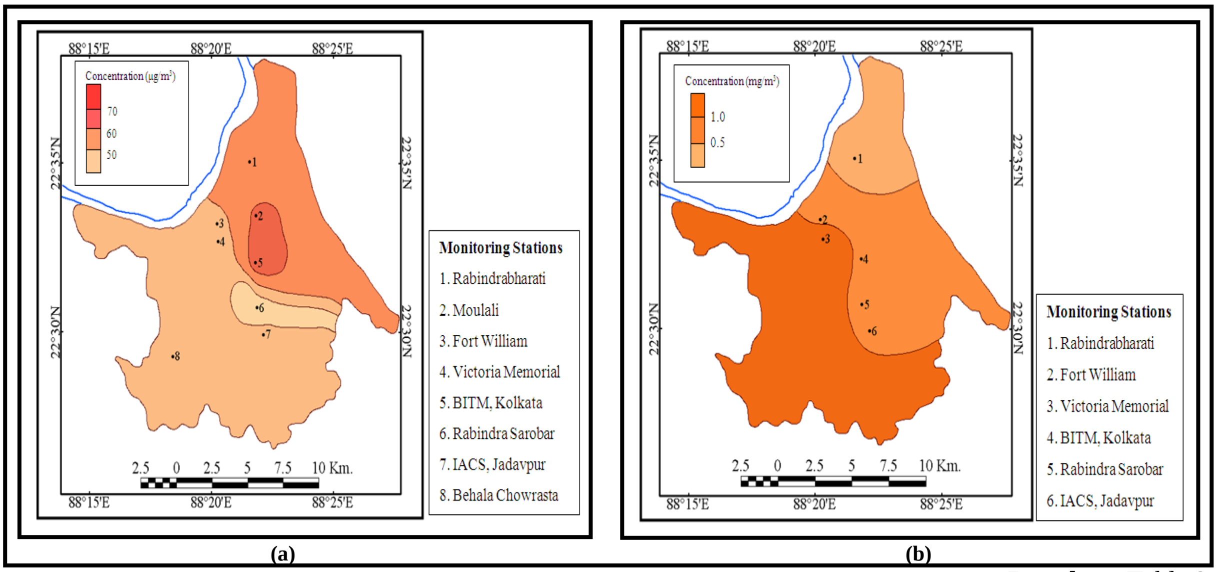
SPATIAL VARIATION OF AIR POLLUTANTS IN DIFFERENT PARTS OF KOLKATA METROPOLITAN CORE DURING PRE-LOCKDOWN PERIOD:

Table 2, figure 2 and figure 3 provide a brief analysis of concentration of major air pollutants in Kolkata during pre-lockdown period.

Table 2: Concentration Level of Different Air Pollutants in Different Monitoring Stations during Pre-lockdown Period (1st March 2020-22nd March 2020)

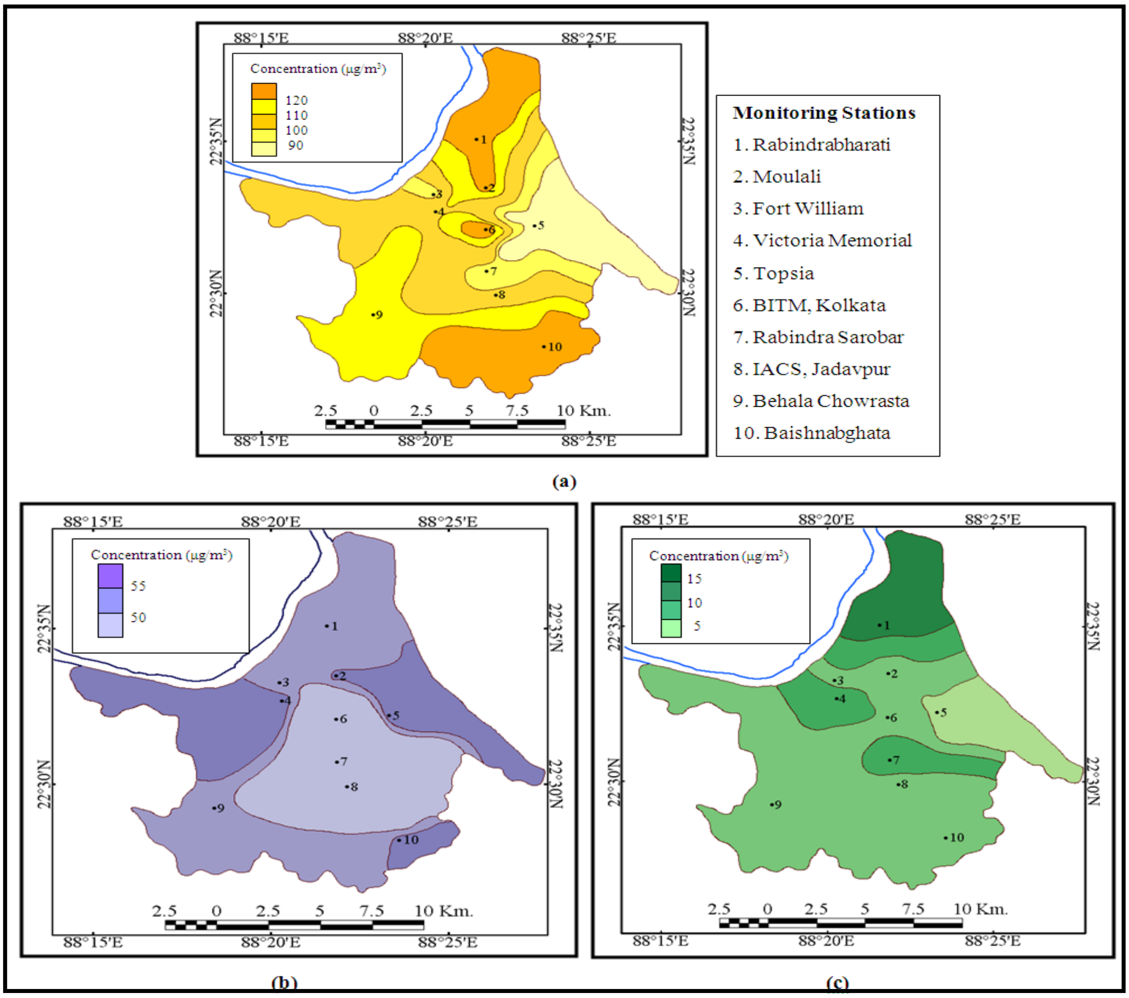
Monitoring Stations	Concentration of Air Pollutants With Measuring Units				
	µg/m³				mg/m³
	PM_{10}	$PM_{2.5}$	NO_2	SO_2	CO
Rabindrabharati	124.78	67.06	51.63	17.97	0.486
Moulali	128.44	70.38	55.76	5.86	
Fort William	99.54	57.08	51.85	8.72	0.67
Victoria Memorial	108.26	52.2	58.08	13.03	1.65
Topsia	80.66		58.39	4.59	
BITM, Kolkata	136.78	75.04	26.19	8.19	0.64
Rabindra Sarobar	93.68	46.83	17.18	12.73	0.542
IACS, Jadavpur	100.75	51.04	28.91	8.03	0.81
Behala Chowrasta	114.9	59.05	54.5	5.07	
Baishnabghata	135.32		55.46	6.58	

Based on: www.wbpcb.gov.in (accessed during April-July 2020)



Based on: Table 2

Figure 2: Spatial variation of pollutants in different parts of Kolkata metropolitan core area during pre-lockdown period (1st March 2020-22nd March 2020)- (a) $PM_{2.5}$ (b) CO



Based on: Table 2

Figure 3: Spatial variation of pollutants in different parts of Kolkata metropolitan core area during pre-lockdown period (1st March 2020-22nd March 2020)- (a) PM_{10} (b) NO_2 (c) SO_2

Table 2 and figure 3(a) interpret during pre-lockdown period (1st March 2020-22nd March 2020), concentration of PM_{10} remains above 110 µg/m^3 in northern, central and southern part of city Kolkata which records movement of above 3000 vehicles per minute (Bandyopadhyay, 2019) during office hours (8:00 A.M.-11:00 A.M. and 6:00 P.M.- 9:00 P.M.) at the traffic intersection points like Shyambazar five point crossing, Moulali, Ballygunge Phanri, Jadavpur and elseother, whereas concentration of $PM_{2.5}$ varies between 50-70 µg/m^3 and above 70 µg/m^3 in these areas which exceeds annual standard by 25% to 75%. Concentration of CO is found only in six stations out of 11 stations [figure 2(b)] where concentration is much less than eight-hourly recommended standard of 8.0 mg/m^3 and maximum concentration is estimated in southern and south-western segment of KMC which are characterized by industrial units and shipping activities near Kolkata port. Figure 3(b) illustrates that concentration of NO_2 lies 30%-60% below in the south-eastern and south-central part because emission from engines of trucks and buses has been controlled to a great extent followed by adoption of Bharat Stage IV (BS-IV) norms, whereas this is upto 45% above annual standard in eastern and western part of Kolkata because trucks plying in these areas mostly use adulterated fuel. Concentration of SO_2 is quite high in northern fringe of KMC because of frequent movement of diesel driven vehicles, petroleum refining centres, emission from power generator sets etc. but this is also much less than annual standard.

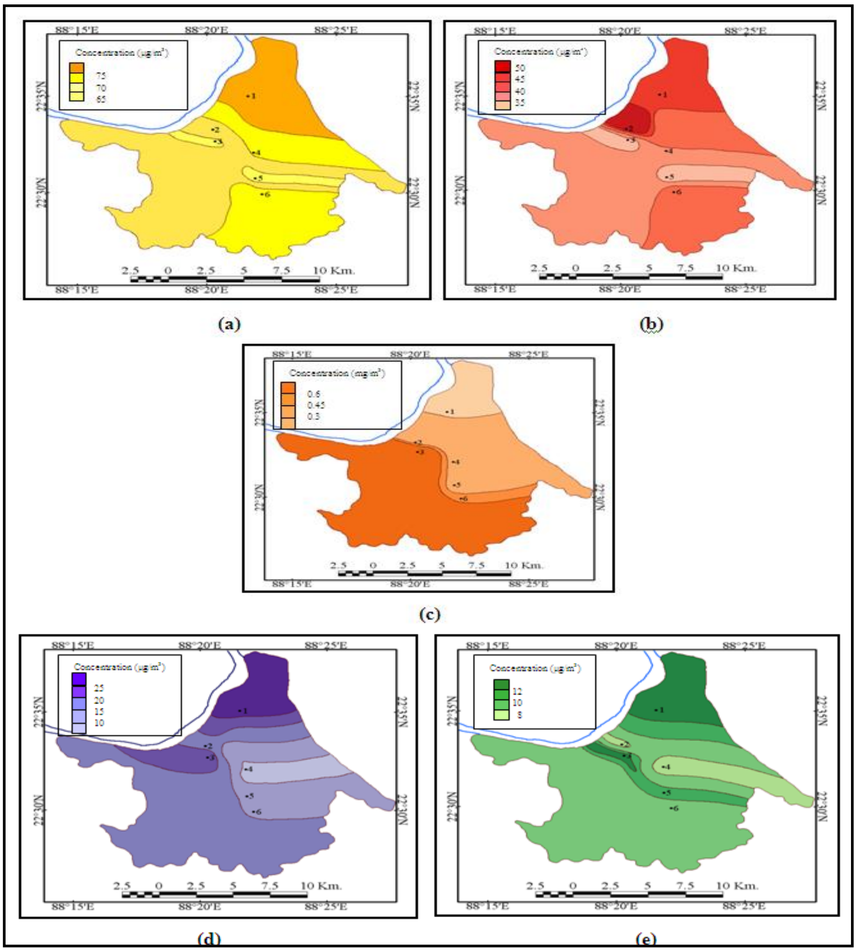
SPATIAL VARIATION OF AIR POLLUTANTS IN DIFFERENT PARTS OF KOLKATA METROPOLITAN CORE DURING LOCKDOWN PERIOD:

Table 3 and figure 4 have explained changes observed in concentration level of different air pollutants after announcement of Janta curfew and consequent lockdown on March 23, 2020,.

Table 3: Concentration Level of Different Air Pollutants in Different Monitoring Stations during Lockdown Period (23rd March 2020-31st March 2020)

Sl. No.	Monitoring Stations	Concentration of Air Pollutants With Measuring Units				
		µg/m³				mg/m³
		PM_{10}	$PM_{2.5}$	NO_2	SO_2	CO
1	Rabindrabharati	81.32	47.38	26.6	13.86	0.294
2	Fort William	66.6	52.13	18.99	7.89	0.43
3	Victoria Memorial	64.3	33.39	21.72	12.97	1.35
4	BITM, Kolkata	70.16	39.84	8.84	6.44	0.34
5	Rabindra Sarobar	63.67	30.26	10.93	11.06	0.319
6	IACS, Jadavpur	73.35	44.99	14.15	8.79	0.55

Based on: www.wbpcb.gov.in (accessed during April-July 2020)



Note: Figures inside are according to serial no. of table 3

Based on: Table 3

Figure 4: Spatial variation of pollutants in different parts of Kolkata metropolitan core area during lockdown period (23rd March 2020-31st March 2020- (a) PM_{10} (b) $PM_{2.5}$ (c) CO (d) NO_2 (e) SO_2

Table 3 and figure 4 show in northern, central and southern part of KMC where concentration of PM_{10} and $PM_{2.5}$ hovered around 110 $\mu g/m^3$ and between 50 and 70 $\mu g/m^3$ respectively during pre-lockdown session, concentration level of both the pollutants brought down to 70-75 $\mu g/m^3$ respectively within nine days of lockdown period in March 2020. This is attributed to the closure of industries, construction activities, and re-suspension of road dust. Percentage decline in concentration of CO between pre-lockdown and lockdown session is recorded as low as 18% at BITM to as high as 47% at Rabindra Sarobar probably due to restriction in combustion practice from road traffic operation, manufacturing industry and power plants.

CHANGES IN THE CONCENTRATION OF AIR POLLUTANTS BETWEEN PRE-LOCKDOWN AND LOCKDOWN PERIOD IN DIFFERENT PARTS OF KOLKATA METROPOLITAN CORE (KMC) AND ITS ADJACENT AREA:

Table 4 comprises normalization of changes in the concentration of different air pollutants between pre-lockdown and lockdown period in different places of Kolkata metropolitan core and its adjacent area as follows.

Table 4: Z-Score Showing Normalization of Percentage Deviation in Concentration of Different Air Pollutants at Different Monitoring Stations between Pre-lockdown and Lockdown Period (March 2020)

Monitoring Stations	Z-Scores For Percentage Deviation of Different Pollutants					Composite Z-Score
	PM_{10}	$PM_{2.5}$	CO	NO_2	SO_2	
Rabindrabharati	0.04	0.11	0.61	0.07	1.3	2.13
Fort William	-0.19	-1.54	0.34	0.77	0.08	-0.54
Victoria Memorial	0.82	0.64	-0.93	0.74	-0.75	0.52
BITM, Kolkata	1.91	1.5	1.14	0.91	1.16	6.62
Rabindra Sarobar	-0.34	0.58	0.73	-0.5	0.41	0.88
IACS, Jadavpur	-0.99	-1.28	0.07	0.19	-1.65	-3.66
Chakmir	-1.25	-0.01	-1.96	-2.18	-2.07	-7.47

Note: Values of negative sign imply change rate in concentration level is either less than standard rate of change or concentration level has gone up during lockdown phase compared to pre-lockdown phase

Based on: Table 2 and Table 3

Table 4 describes maximum reduction in concentration of all pollutants with respect to standard deviation between pre-lockdown and lockdown phase is observed at BITM, whereas this is minimum at Chakmir except for $PM_{2.5}$ which is minimum at Fort William. Chakmir is located outside KMC where condition of road transport infrastructure is not as good as any other place within KMC, in addition to relative inability of quick response to suspension of industrial activities.

DIURNAL VARIATION IN CONCENTRATION OF AIR POLLUTANTS AT DIFFERENT MONITORING STATIONS OF KMC AND ADJACENT AREA DURING PRE-LOCKDOWN AND LOCKDOWN PERIOD:

Table 5 observes diurnal variation in concentration of various pollutants as follows.

Table 5: Temporal Variation in Concentration of Different Air Pollutants in Various Places of Kolkata Metropolitan Core and Its Adjacent Area during Pre-lockdown and Lockdown Period

Monitoring Stations	Pollutants														
	PM_{10}			$PM_{2.5}$			CO			NO_2			SO_2		
	March 1	March 23	April 30	March 1	March 23	April 30	March 1	March 23	April 30	March 1	March 23	April 30	March 1	March 23	April 30
Rabindrabharati	207.63	61.6	23.3	121	34.84	14.32	0.819	0.265	0.157	60.35	30.56	16.6	16.45	13.51	7.97
Fort William	148.42	52.21	36.59	78.97	38.92	16.46	1.04	0.4	0.29	73.24	23.99	10.8	10.07	8.35	7.83
Victoria Memorial	189.36	51.92	32.11	92.66	23.61	15.18	2..26	1.31	0.61	79.39	28.16	12.37	10.58	12.31	11.7
BITM, Kolkata	197.3	45.6	33.35	126.25	25.51	12.29	1.01	0.4	0.21	43.93	13.23	4.11	10.16	7.35	4.19
Rabindra Sarobar	156	50.12	26.73	70.72	30.9	11.96	0.894	0.333	0.205	65.84	12.18	6.41	18.33	11.5	5.83
Chakmir	183.73	65.93	26.61	59.7	18.95	37.5	0.77	0.58		14.23	14.08		4.11	4.44	
IACS, Jadavpur	169.09	59.34	27.49	87.72	31.43	12.27	1.58	0.53	0.39	52.98	16.38	8.26	8.38	7.15	7.04

Based on: www.wbpcb.gov.in (accessed during April-July 2020)

Outdoor urban air pollution is of serious concern because it not only affects physical environment but also bears great economic cost. Apart from indigenous vehicular emission, factors which accelerate vehicular emission such as traffic congestion, limited road space, interference by pedestrians and vehicular population, industrial activities etc. play significant role in encouraging urban air pollution. Table 5 describes on March 1, 2020, all other places except Fort William had recorded concentration of PM_{10} as high as above 150 μg/m^3 with Rabindrabharati having maximum concentration of 207.63 μg/m^3, i.e., almost 3.5 times above annual standard. At the advent of lockdown on March 23, 2020 concentration level varied only between 45 and 65 μg/m^3, with minimum concentration of 45.6 μg/m^3 recorded at BITM. Concentration at April 30, 2020 reveals that it has dropped as low as 30% to as high as 70% in all places and concentration at Rabindrabharati dipped as minimum as 23.3 μg/m^3.

BITM has observed maximum concentration of $PM_{2.5}$ (126.25 μg/m^3) followed immediately by Rabindrabharati and Victoria Memorial (121 μg/m^3 and 92.66 μg/m^3 respectively). On March 23, concentration was minimum at Chakmir but exceptionally concentration increased during lockdown period due to stable mulching or greater usage of domestic fuels. Concentration dropped about 50% less than recommended annual standard of 40 μg/m^3 on April 30.

Concentration of CO at Fort William, Victoria Memorial, BITM and IACS, Jadavpur on March 1 reached above 1.0 mg/m^3 but it never exceeded 8-hourly standard of 8.0 mg/m^3. Nominal presence of CO in the air is infact, fatal for undesirable attenuation of surface temperature and cardiovascular disorder in human health. Data for CO, NO_2 and SO_2 at Chakmir on April 30 is unavailable and therefore it cannot measure percentage deviation in concentration after one month from the advent of lockdown.

Concentration of NO_2 during pre-lockdown period (March 1) was about 4-40 μg/m^3 high compared to annual standard in all the stations except Chakmir. Two of the stations namely Fort William and Victoria Memorial, located in the western part of KMC and close to river Hooghly record concentration above 70 μg/m^3 and facilitate emission from large cargo ships and ferries. Concentration reduced by the level of one-half to one-fourth during lockdown followed by suspension of transport, industrial production and other emission sources.

Concentration of SO_2 dipped by 15%-30% in all places between March 1 and March 23 except Victoria Memorial and Chakmir. Infact, at some stations percentage deviation in concentration of some pollutants is less between March 1 and March 23 compared to the period from March 23 to April 30, while at other stations the reversal is found. Little concentration of SO_2 implies that quality of fuel used in different sectors has reduced sulphur content.

RELATION BETWEEN FREQUENCY OF DAYS PARTICULAR POLLUTANT CONSIDERED DOMINANT AND MEAN AIR QUALITY INDEX (AQI) ON THOSE DAYS IN DIFFERENT MONITORING STATIONS ACROSS SELECTED MILLION-PLUS CITIES IN INDIA DURING PRE-LOCKDOWN PERIOD (1ST MARCH 2020-22ND MARCH 2020):

CPCB launched National Air Monitoring Programme (NAMP) in 1985 involving 342 operating stations under 127 cities/towns in 26 states and four union territories in India (Greenhouse Gas and Air Pollution Interactions and Synergies [GAINS], 1998) with a view to constantly monitor air quality and control air pollution. NAMP also proposed six-fold classification of air quality category namely Good (1-50), Satisfactory (51-100), Moderate (101-200), Poor (201-300), Very Poor (301-400) and Severe (401-500) based on ambient concentration of air pollutants and health breakpoints (CPCB, 2011).

Table 6 identifies condition of air quality with respect to dominance of different pollutants in different places of different cities of India respectively to determine relative position of Kolkata during pre-lockdown period.

Table 6: Relation between Frequency of Days Particular Pollutant Considered Dominant and Mean Air Quality Index (AQI) on Those Days in Different Monitoring Stations across Selected Million-plus Cities in India during Pre-lockdown Period (1st March 2020-22nd March 2020)

Monitoring Stations	Frequency of Days Considered Dominant Pollutant and Mean AQI									
	PM_{10}		$PM_{2.5}$		CO		NO_2		O_3	
	Days	AQI	Days	AQI	Days	AQI	Days	AQI	Days	AQI
Anand Vihar, Delhi	10	164.47	4	181.52	7	109.26				
Chhatrapati Shivaji International Airport, Mumbai	21	141.96	1	145.2						
Alandur Bus Depot, Chennai			19	58.6	2	73.78			1	44.08
Victoria Memorial, Kolkata	4	109.95	6	170.98	4	91.99			8	131.46
Marhatal, Jabalpur	22	103.58								

Based on: https://app.cpcbccr.com (accessed on 21.06.2020)

Table 6 shows during pre-lockdown period, maximum dominance of PM_{10} was observed for 22 days at Marhatal, Jabalpur followed immediately by Chhatrapati Shivaji International Airport, Mumbai of 21 days. This particulate matter mainly comes from residue of jet engine propulsion of fuel boarding and de-boarding the airport. Mean air quality in all places of dominance of PM_{10} remained moderate. Dust, ash, soot or secondary particulates as by-products of chemical reactions constitute bulk share of respirable suspended particulate matter [RSPM] (PM_{10} and $PM_{2.5}$). It is seen that maximum RSPM concentration reaches as high as 1400 $\mu g/m^3$ at industrial sites in Delhi compared to residential and background locations (CPCB, 2016).

Maximum dominance of $PM_{2.5}$ is found at Alandur Bus Depot, Chennai but mean air quality during this predominance belongs to satisfactory level. Infact, Chennai records good and satisfactory air quality during predominance of Ozone (O_3) and CO respectively, as represented by observations of Alandur Bus Depot. Concentration of $PM_{2.5}$ exceeds standard by over 100% in Delhi, Mumbai and Kolkata at kerb stations, industrial and residential belt.

Delhi also experiences building up of concentration of CO due to unfavourable meteorological conditions and substantial vehicular movement till late night, as indicated by greater dominance period and higher mean air quality during predominance in comparison to other places of Kolkata and Chennai. Higher dominance of O_3 is seen at Kolkata but strong wind movement during night hours diminishes its concentration.

RELATION BETWEEN FREQUENCY OF DAYS PARTICULAR POLLUTANT CONSIDERED DOMINANT AND MEAN AIR QUALITY INDEX (AQI) ON THOSE DAYS IN DIFFERENT MONITORING STATIONS ACROSS SELECTED MILLION-PLUS CITIES IN INDIA DURING LOCKDOWN PERIOD (23RD MARCH 2020-31ST MAY 2020):

Table 7 characterizes condition of air quality with respect to dominance of different pollutants in different places of different cities of India respectively to determine relative position of Kolkata during lockdown period as follows.

Table 7: Relation between Frequency of Days Particular Pollutant Considered Dominant and Mean Air Quality Index (AQI) on Those Days in Different Monitoring Stations across Selected Million-plus Cities in India during Lockdown Period (23rd March 2020-31st May 2020)

Monitoring Stations	Frequency of Days Considered Dominant Pollutant and Mean AQI									
	PM_{10}		$PM_{2.5}$		CO		NO_2		O_3	
	Days	AQI	Days	AQI	Days	AQI	Days	AQI	Days	AQI
Anand Vihar, Delhi	10	68.9	13	163.61	11	61.57			13	120.86
Chhatrapati Shivaji International Airport, Mumbai	57	55.18	4	29.91			3	27.15	1	0
Alandur Bus Depot, Chennai			30	42.66	24	24.96	6	27.3	8	35.78
Victoria Memorial, Kolkata	9	42.46	4	47.98	9	36.08			29	71.83
Marhatal, Jabalpur	39	96.29	4	60.82					24	72.37

Based on: https://app.cpcbccr.com (accessed on 21.06.2020)

Table 7 demonstrates mean air quality during predominance of PM_{10} in lockdown period improves from moderate to satisfactory category at monitoring stations of Delhi, Mumbai and Jabalpur, and in Kolkata mean air quality is elevated to good category. Maximum predominance of $PM_{2.5}$ is observed again at Alandur Bus Depot, Chennai coupled with improvement in mean air quality from satisfactory to good level. Exception to this trend is also seen Marhatal, Jabalpur wherein predominance of $PM_{2.5}$ is absent during pre-lockdown session but it remains predominant for four days during lockdown session with a mean air quality of 60.82. Delhi also does not respond to upgradation in air quality between pre-lockdown and lockdown session because mild dust storms encouraged pollutants to become concentrated close to surface. Maximum predominance of CO is identified at Alandur Bus Depot with consequent progress in mean air quality from satisfactory to good category, followed immediately by Anand Vihar, Delhi which also realized improvement in air quality from moderate to satisfactory class. It is also interesting to note that during pre-lockdown period NO_2 was found predominant nowhere but during lockdown it is predominant at Chhatrapati Shivaji International Airport, Mumbai and Alandur Bus Depot, Chennai. Monthly comparison of air quality reveals that Mumbai has surfaced 69% reduction in NO_2 concentration (Chatterjee, 2020). Marginal utilization of O_3 followed by dwindling concentration of Nitrogen Oxides (NO_X) (Mahato, Pal and Ghosh, 2020) and natural increase of insolation in northern hemisphere as a consequence of northward migration of sun between March and August has encouraged considerable increase in concentration of O_3 during lockdown period.

RELATION BETWEEN DAILY AVERAGE VOLUME OF TRAFFIC AT SELECTED TRAFFIC INTERSECTION POINTS OF KOLKATA AND ADJACENT AREA DURING PEAK AND LEAN HOURS AND CONCENTRATION OF DIFFERENT POLLUTANTS:

KMC under the jurisdiction of KMA is characterized by very extensive public transport system comprising suburban rail service, metro, trams, buses etc. and private cars and two-wheelers. Total volume of registered motor vehicles in Kolkata has soared up from 444718 in 2011 to 740879 in 2016, an increase of 66.6% as against decennial population growth rate of -1.88% between years of 2001 and 2011 (Government of West Bengal, 2016). KMC experiences maximum vehicular density of 1421 vehicles/sq Km (Kolkata Metropolitan Development Authority [KMDA], 2011). Master Plan of Traffic and Transportation in KMA states that the region will facilitate an increase of daily transit passenger volume from 187 million to 322 million and goods vehicles amounting to 71000 from 41000, an increment of 73% by 2025. It also forecasts although land allotted for transportation would be only eight percent, 75% of city transport relies on road based transport system (KMDA, 2000).

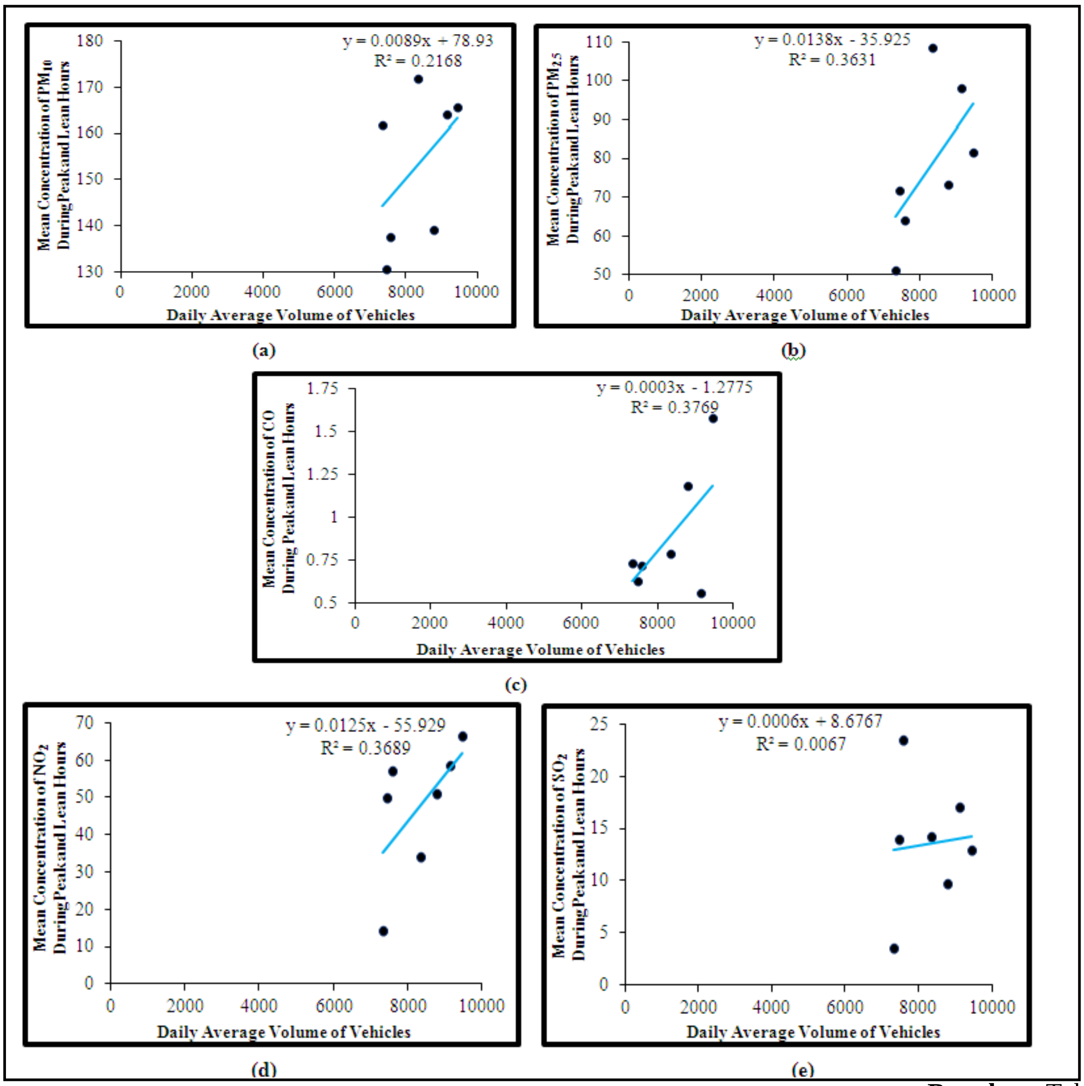
Table 8 and figure 5 represent relation between daily average volume of traffic at TIPs during peak and lean hours and mean concentration of air pollutants during corresponding time as follows.

International Journal of Engineering, Management and Humanities (IJEMH)
Volume 1, Issue 1, pp: 48-67 www.ijemh.com

Table 8: Daily Average Volume of Vehicles at Selected Traffic Intersection Points (TIPs) during Peak and Lean Hours and Mean Concentration of Different Air Pollutants at Nearest Monitoring Station during Corresponding Hours in Pre-lockdown Period

Traffic Intersection Points	Daily Average Traffic Volume	Nearest Monitoring Station	Mean Concentration during Peak and Lean Hours				
			PM_{10}	$PM_{2.5}$	CO	NO_2	SO_2
Girish Park	9126	Rabindrabharati	164.14	98.06	0.56	58.5	17
Kidderpore	7447	Fort William	130.69	71.66	0.63	49.74	13.9
Minto Park Exide Crossing	9448	Victoria Memorial	165.63	81.41	1.58	66.54	12.9
Ballygunge Phanri	8336	BITM, Kolkata	171.8	108.49	0.79	34.09	14.14
Tollygunge Phanri	7566	Rabindra Sarobar	137.61	63.83	0.716	57.13	23.42
Zinzira Bazar	7324	Chakmir	161.59	51.21	0.73	14.36	3.46
Jadavpur Police Station Crossing	8778	IACS, Jadavpur	139.2	73.23	1.18	50.82	9.71

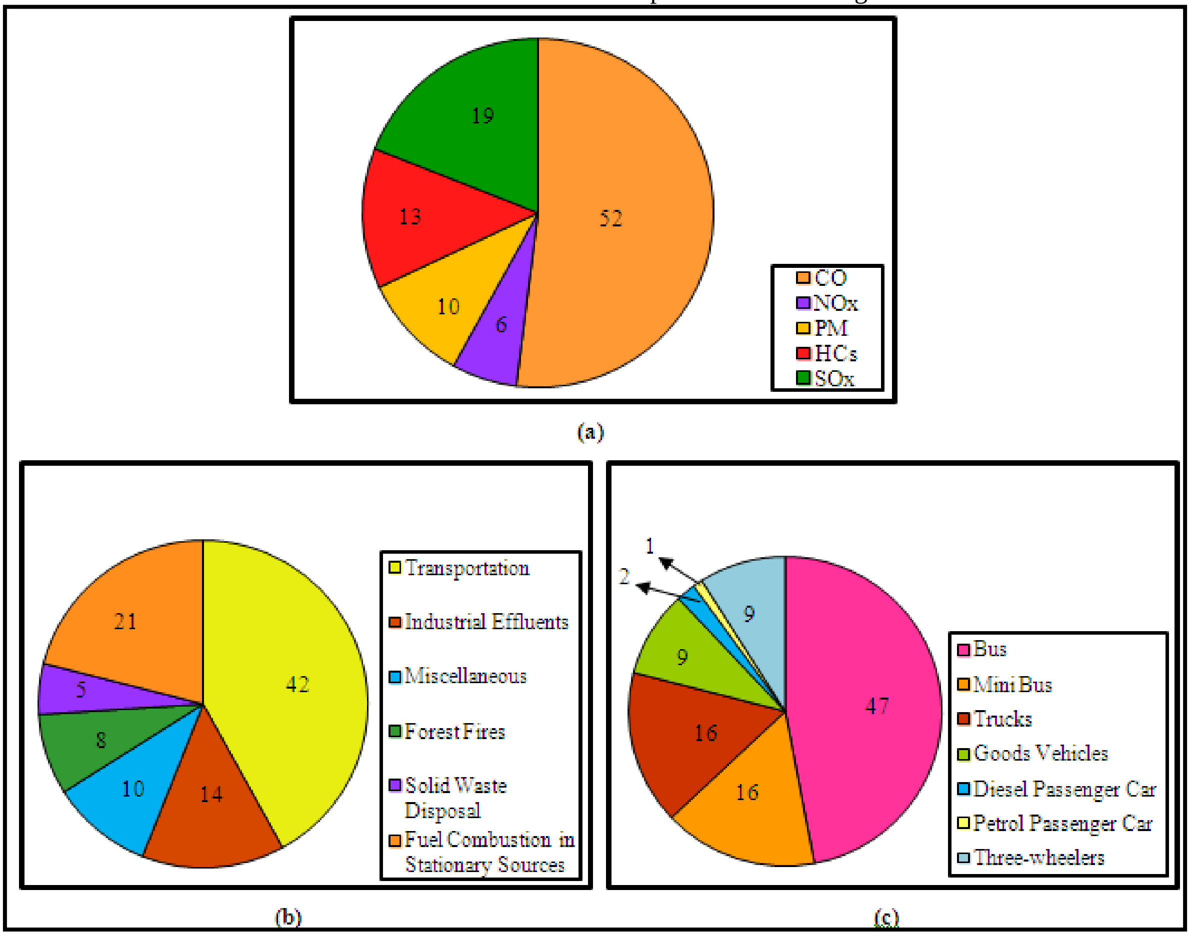
Based on: Primary survey (2020) and www.wbpcb.gov.in (accessed during April-July 2020)



Based on: Table 8

Figure 5: Bi-variate analysis between daily average volume of vehicles at selected traffic intersection points during peak and lean hours and concentration of different pollutants at nearest monitoring stations during corresponding hours in pre-lockdown period- (a) PM_{10} (b) $PM_{2.5}$ (c) CO (d) NO_2 (e) SO_2

Table 8 and figure 5 explain for all pollutants daily average vehicular volume bears a direct relationship. Maximum r^2 value is determined in case of CO which shows a strong positive relationship (figure 5[c]) and minimum r^2 value is found for SO_2 because this pollutant at present mainly comes from thermal power stations rather than vehicular emission. The share of motor cars/jeeps in Kolkata has increased from 43.66% in 2011 to 46.98% in 2016, followed by surge of two-wheelers from 40.94% in 2011 to 42.32% in 2016 (Ministry of Urban Development [MoUD], 2017). Despite insufficient public transport system has popularized growth of private vehicles in most of the cities of India, growing travel demands in Kolkata represent a hike of registered buses and mini buses



Based on: Asian Development Bank [ADB] (2005)

Figure 6: Generalized emission inventory in Kolkata- (a) percentage share of pollutants emitted in atmosphere (b) percentage share of sources of pollution (c) percentage share of different types of vehicles contributing pollution

by the degree of 51.18% between 2015 and 2016, and 106.46% between 2014 and 2015 respectively (Nasim and Chattopadhyay, 2018).

Diesel engines are identified as principal source of emission of four major pollutants namely CO, Hydrocarbons (HC_s), PM and NO_X. Road transport sector in Kolkata produces 4.6 tonnes PM daily in addition to 44 tonnes of NO_X, 60 tonnes of CO and 0.15 tonnes of SO_2 (CPCB, 2014). PM emissions are also encouraged by brake and tyre wear and road abrasion. Figure 6 (c) explains that high temperature combustion in the engines of heavy-duty trucks (16%) and buses including mini buses (63%) and their exhaust emissions produce maximum NO_2 concentrations. Petrol driven two-wheelers release 21% of CO emissions (Royal Automobile Club Foundation, 2014). It has been projected that a car after combustion of 1000 litres of fuel emits 350 Kg. of CO, 0.6 Kg. of SO_X, 0.1 Kg Lead (Pb) and 1.5 Kg. particulate matters (White, 2006).

DISCREPANCY IN VEHICULAR MOVEMENT IN KOLKATA AND WEST BENGAL BETWEEN PRE-LOCKDOWN AND LOCKDOWN PERIOD:

After ending of nationwide lockdown and beginning of unlock period on June 1, 2020 vehicular movement was drastically retarded. Therefore, all categories of registered vehicles were not on road. Table 9 demonstrates a comparative scenario of vehicular movement for those types of vehicles for which data is available during unlock period.

Table 9: Disparity in Daily Movement of Different Types of Transport Vehicles in Kolkata between Pre-lockdown and Lockdown Period

Category	Frequency		Percentage Share of Particular Vehicle		Sopher Index
	Pre-lockdown	Unlock	Pre-lockdown (x_1)	Unlock (x_2)	
Bus	6020	1529	0.81	4.57	0.03
Taxi	49098	4700	6.63	14.04	0.03
Auto	20628	7900	2.78	23.6	0.04

Based on: Field Survey (2020) and MoRTH, Government of India (2018)

Table 9 shows after lockdown period, significant portions of public and private buses, taxis as stage carriage and autos as intermediate carriage were found in the streets of Kolkata. It is also to be considered that only 4%-5% of daily average gross vehicular load of pre-lockdown period was in service per day at the end of lockdown phase. Sopher index of disparity observes anomaly in the availability of bus and taxi service between pre-lockdown and unlock phase is equivalent while this anomaly is quite higher for autos because per unit distance service charge in auto is higher compared to bus or taxi.

RELATION BETWEEN VEHICULAR VOLUME, AIR QUALITY AND EMISSION STATUS OF DIFFERENT POLLUTANTS IN SELECTED MILLION-PLUS CITIES OF INDIA DURING LOCKDOWN PERIOD:

There is rare possibility of introducing radical change in the urban public transport scenario of India as it is highly dominated by fuel-driven vehicular fleet. But imposition of nationwide lockdown has affected production and sale of automobile industry a lot. Society of Indian Automobile Manufacturers (SIAM) has demanded domestic sale is only about 1491216 all over India in June 2020 as compared to 6084478 vehicles between April and June 2020. New retail registration of private vehicles, three-wheelers and other segments has declined by 70%-90% in different states (“Vehicle Registrations”, 2020). The following section deals with relation between registered vehicular volume and air quality status experienced in different million-plus cities of India. Table 10 explains relation between estimated registered motor vehicles and mean AQI in different million-plus cities across India as follows:

Table 10: Relation between Estimated Registered Motor Vehicles and Mean AQI in Different Million-plus Cities across India on 31st March 2020 (Lockdown Period)

Million-plus City	Estimated Registered Motor Vehicles (‘000)	Mean AQI
Delhi	10660	76.99
Jabalpur	727	66.25
Kolkata	1107	96.36
Greater Mumbai	3920	91.09
Chennai	6473	55.21

Based on: www.cpcb.nic.in (accessed on 24.07.2020) and www.morth,nic.in (accessed on 25.06.2020)

Table 10 interprets emission from greater number of vehicles is not only responsible for deterioration of air quality. Delhi has nine times greater vehicular load compared to Kolkata, yet mean air quality index (AQI) of both cities differ by 20 units approximately. Jabalpur is identified with second minimum AQI because apart from lesser vehicular weight, this city is also characterized by relative absence of emission from heavy industrial units.

Table 11 shows status of registered motor vehicles and emission level of different pollutants as follows.

Table 11: Status of Estimated Registered Motor Vehicles and Emission Level of Different Pollutants in Different Million-plus Cities across India on 31st March 2020 (Lockdown Period)

Million-plus City	Estimated Registered Motor Vehicles ('000)	PM_{10}	$PM_{2.5}$	CO	NO_2	SO_2
Delhi	10660	73.21	61.46	0.495	24.25	11.58
Jabalpur	727	53.79	39.79	0.17	25.21	8.54
Kolkata	1107	72.69	34.4	1.31	27.96	11.7
Greater Mumbai	3920	68	54.63	1.04	16.79	17.67
Chennai	6473		39.46	0.24	9.42	4.42

Based on: Office of State Transport Administration and www.cpcb.nic.in (accessed on 28.07.2020)

Results obtained from executing K-means cluster analysis and one-way T-test of table 11 are provided as under.

Table 12: Final Cluster Centres

Parameters	Cluster	
	1	2
PM_{10}	70.6	63.24
$PM_{2.5}$	58.05	37.1
CO	0.768	0.74
NO_2	20.52	26.59
SO_2	14.63	10.12

Based on: Table 11

Execution of K-means cluster analysis shows convergence achieved due to no or small change in cluster centres. The minimum distance between initial centres is 29.274.

Table 13: One-Sample T-Test

Parameters	T-test Value	Degree of Freedom (df)	Significance (2-tailed)
PM_{10}	14.768	3	0.001
$PM_{2.5}$	8.931	4	0.001
CO	2.897	4	0.044
NO_2	6.136	4	0.004
SO_2	4.962	4	0.008

Based on: Table 11

Comparing the observations from table 12 and table 13, it can be inferred that concentration pattern of CO (Carbon Monoxide) and SO_2 (Sulphur Di-Oxide) are identified homogeneous in different million-plus cities in India and T-test results for CO and SO_2 are determined at significance level above 0.005 (ρ= 0.044 and ρ= 0.008 respectively) which comprises test results are not significant at ρ= 0.005 and concentration level of CO and SO_2 are not considerably affected by volume of registered motor vehicles.

V. CRITICAL REVIEWS

Major findings observed in the study are provided as under.

- Table 2, table 3, figure 2, figure 3 and figure 4 show between pre-lockdown and lockdown period, minimum and maximum percentage deviation in concentration is observed at Victoria Memorial and BITM, Kolkata for concentration of SO_2 and NO_2 respectively. Considerable decrease of NO_2 has helped piling up of O_3 in the atmosphere.

- Table 6 and table 7 explain between pre-lockdown and lockdown period, most of the million plus cities of India selected in the study have improved mean air quality index during predominance of different pollutants, from moderate to satisfactory level and satisfactory to good category respectively. Figure 5 (c), figure 6 (a) and figure 6 (b) describe transportation contributes maximum emission load, CO occupies maximum share of evaporative and exhaust emission and daily average vehicular volume in selected traffic intersection points bear strong positive relation with emission of CO but this tendency is contradicted in the results of table 13 when compared with vehicular volume of other million-plus cities of India.
- Public transport system of Kolkata is heavily reliant on bus, taxi, auto etc. but their movement is considerably affected due to lockdown. New-normal situation demands avoid crowding and maintain social distance, and in this context travel by two-wheeler is going to be order of the near future.

VI. CONCLUSION

Cities possess only two percent of the earth's land surface but consume more than 75% of global resource pool. Urban energy consumption and energy related problems have thwarted ecosystem of cityspace, and this is particularly critical in the metropolitan cities of developing countries. Population projections 2026 assumes rate of urbanization in India will notch the mark of 47.8% in 2051 rising from 31.1% in 2011, vehicular penetration rate has increased from eight per thousand persons in 1981 to 167 per thousand persons in 2015 while the availability of road space for vehicles has diminished from 0.18 Km/vehicle to only 0.004 Km/vehicle between 2001 and 2020. Therefore, lockdown measures have given us scope for neutralizing human impact on the environment and recovering environmental resilience.

Air pollution scenario of Kolkata is particularly worrying for excessive concentration of particulate matters and nitrogen oxides. Table 2 and figure 3 (a) identifies during pre-lockdown period in March 2020, concentrations of PM_{10} at Rabindrabharati, Moulali, BITM and Baishnabghata were more than double the recommended annual standard of 60 μg/m^3 and concentrations of $PM_{2.5}$ in these areas were more than 50% of annual standard of 40 μg/m^3. But after imposition of lockdown, concentration of these pollutants was reduced by 10%-40%. Between March 1, 2020 and April 30, 2020, one month after lockdown, curtail in the concentration of different pollutants in different parts of KMC and adjacent area is far more effective. Comparative assessment of Kolkata with respect to other million-plus cities of India describes air quality has significantly improved, probably as an outcome of restriction in industrial activities, vehicular impedence, manufacturing units and other emission inventories. Bi-variate analysis between concentration of pollutants and daily average vehicular volume at different traffic intersection points of Kolkata (figure 5) explains emission of CO is more directly related than all other pollutants. Different categories of registered vehicles in Kolkata have experienced growth by 40%-100% but their on-road frequency is highly affected during lockdown period.

COVID-19 lockdown has realized city planners to rethink and reshape saturated urban public transport profile. There is a need to introduce avoid, shift and improve spectrum in the action plan for curbing urban vehicular emissions, where avoid strategy leads to separation of slow-moving and fast-moving vehicles using the same corridor, shift involves increasing reliance for cleaner and efficient modes of transport and non-transport mediums like walking, cycling etc. among people and improve considers progressive advancement of emission norms implemented by commissioning of effective inspection and maintenance, retrofitting with diesel particulate filters and prohibiting movement of outdated commercial vehicles. In 2019, the Government of India announced it is going to adopt National Clean Air programme which sets the target to reduce particulate matter concentration by 20%-30% in 2024 with respect to 2017 benchmark, and the present lockdown is expected to achieve the feat in a great way.

ACKNOWLEDGEMENT

The first author would like to acknowledge University Grants Commission, New Delhi, India for the financial support as Senior Research Fellowship [Award Letter No.: F.15-9(JULY2016)/2016(NET), UGC-Ref. No.: 3276/(NET-JULY2016)] to carry out the research work presented in this paper. The authors thank the editor-in-chief for acceptance of the paper. We are also greatly thankful to the DST-PURSE II programme, University of Kalyani, Kalyani, Nadia-741235 for also some financial assistance in the processing of the research paper.

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