



Appraisal of Emissions from Ocean-going Vessels Coming to Kolkata Port, India

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Abstract Rapid economic growth has escalated India's share in international trade. The pressure on these ports, which handle a substantial portion of the trade, has increased to perform with optimal efficiency, and decrease turnaround time so as to increase the number of ships visiting the port area. The caveat is that increased shipping activity is accompanied by enhanced emissions of harmful pollutants and green house gases. This study has revealed increased turnaround time for ships resulting in substantial emissions from auxiliary engines. There should be an optimum balance between operational control and environmental control of pollutants. Kolkata is a megacity with active riverine ports that can generate high levels of air quality emissions, especially NO_x, SO_x and particulate matter. An exhaustive annual emissions inventory based on ocean going vessels activity has been developed for 2013–2014 for Kolkata port, using recent EPA approved methodology. This includes greenhouse gas emissions from marine engines as well. The study indicates that amongst the different categories of ocean going ships, containers contribute the most (49%) of air and greenhouse gas emissions in 75th percentile class and above followed by general cargo (14%) and oil tankers (13%). The study depicts existing status of marine emissions in Kolkata port from ocean going vessels, which would serve in development of integrated air quality and climate change

management plans and serve as a prototype for other major ports of India.

Keywords Air quality · Climate change · Conditional probability distribution · Green house gas emissions · Marine emissions · Shipping activity

Introduction

Ports serve as nucleus of international trade with 90% of the international cargo being transported through ships [1]. The major drivers of port development are developing countries such as China and India due to their high economic growth rates. Operational performance indicators of major Indian ports indicate that most of them lag behind standard benchmarks [2]. Therefore there is an urgent need to improve port performance by augmenting the number of ocean going vessels (OGVs), which means substantial increase in air pollutant and greenhouse gas emissions [3], since they are significant non-road mobile sources [4] and amongst least regulated sources of air pollution. The relative contribution of emissions from OGVs to global air pollution is around 15% of global anthropogenic nitrogen oxides (NO_x) emissions and (5–8) % of sulfur oxides (SO_x) emissions [5]. Nearly 70% of ship emissions are estimated to occur within 400 km of land [6] leading to deterioration of air quality along the coast or river bank. Long-term exposure to NO_x, SO_x and particulate matter emissions in ports has been linked to respiratory, cardiovascular diseases and even premature births.

In addition, emissions are also generated from auxiliary equipments such as generators, while vessels are at berth. Moreover, the main engines are not always switched off

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during berthing time. Recent studies have attributed contributions from shipping to ambient NO_2 levels range between 7 and 24% [7] and to approximately 13% of aerosols up to $10 \mu\text{m}$ (PM_{10}) levels and around 17% of fine particulate matter ($\text{PM}_{2.5}$) [8]. Emissions from maritime transport account for 3% of global greenhouse gas emissions [9].

Ships arriving in India ports use bunker fuel or residual oil (RO). The exhaust from these engines consists of enhanced primary emissions of PM_{10} and $\text{PM}_{2.5}$, NO_x , and SO_x linked with adverse health effects [10]. Secondary sulfates and nitrates contribute to acid rain and primary NO_x emissions from diesel engines along with hydrocarbons (HC) form regional ozone that further threaten human health and ecology. The port regions in India located in megacities such as Mumbai and Kolkata have high population densities that increase health risks due to emissions from OGVs much more than their analogous global counterparts.

The International Maritime Organization (IMO) has added the clause Annexure VI for prevention of air pollution from ships since May 19, 2005 in the International Convention for the Prevention of Pollution from Ships (Marine Pollution, MARPOL) that impose restrictions on sulphur oxides and nitrogen oxides emissions from ship exhausts and a chapter inducted in 2011 necessitates technical and operational energy efficiency measures for reducing greenhouse gas emissions from ships [11]. Advanced ports have taken measures to regulate ship emissions and provide incentives to encourage the use of clean fuel. The exigency of circumstances such as sustenance in global trade and business would enforce ports in India to follow similar maritime protocols in the near future.

In previous study [2] based on a 10-year exhaustive analysis (2004–2013) of key indicators of port performance it was found that Kolkata port system lagged behind most other major ports of India. Kolkata port serves a vast hinterland comprising the entire eastern India including West Bengal, Bihar, Uttar Pradesh, Assam, other North Eastern states and two land-locked neighboring countries Nepal and Bhutan. The industrial development, trade and commerce of this vast region is inextricably intertwined with the development of Kolkata port and vice versa. The enhancement in the port performance would be naturally accompanied with increase in emissions. However in the current scenario, excess turnaround time is also associated with intemperance of hoteling time for ships, which can cause excessive emissions from auxiliary engines. The first task of the port is to assess the relative contributions of emissions from different air pollutants and green house gases from OGVs in different modes of operation. This paper appraises detailed emissions from OGVs for the most

recent year (2013–2014) and is one of the first of its kind to evaluate and quantify these emissions from one of the major ports in India. This case study would serve as a model for other major ports in India to develop marine emissions inventory that would help build effectual emission control strategies.

Shipping Activity and Data Collection

The jurisdiction of the riverine Kolkata Dock System (KDS) situated on the left bank of the Hooghly river at $22^\circ 32' 53''\text{N}$ $88^\circ 18' 05''\text{E}$ starts about 232 km upstream from Sandheads (Fig. 1), with one of the largest pilotage distances in the world. It consists of several docks from Sandheads to Garden Reach (Fig. 1),

The docks are situated at Sagar, Diamond Harbour, Budge Budge, Kidderpore, Garden Reach (Netaji Subhas dock). Once the marine vessels come within the port limits, it needs to follow the maritime guidelines of the port. An OGV's activities are based on its speed within the segments classified as reduced speed zone, maneuvering and hoteling. The distance travelled by the vessels as well as activity varies as per the location of the docks within the KDS. The shipping channel is divided into two parts. The first segment is from Sandheads to lockgate of the

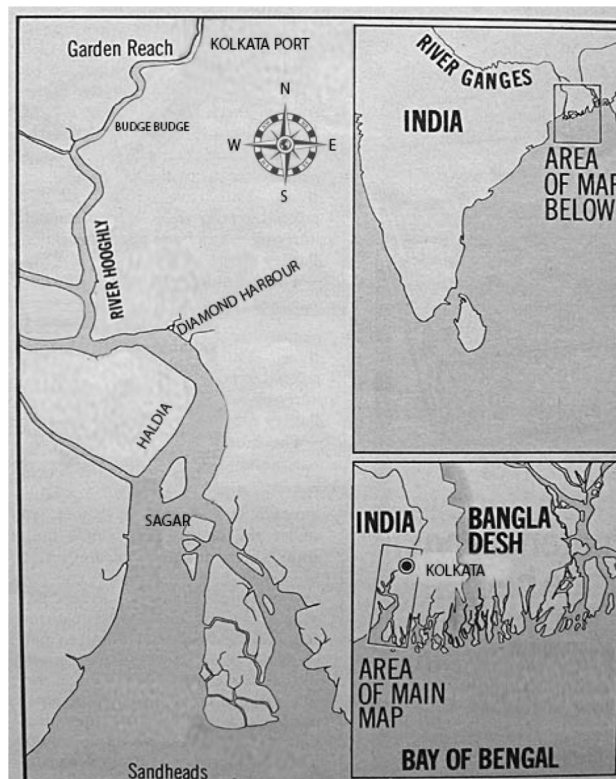
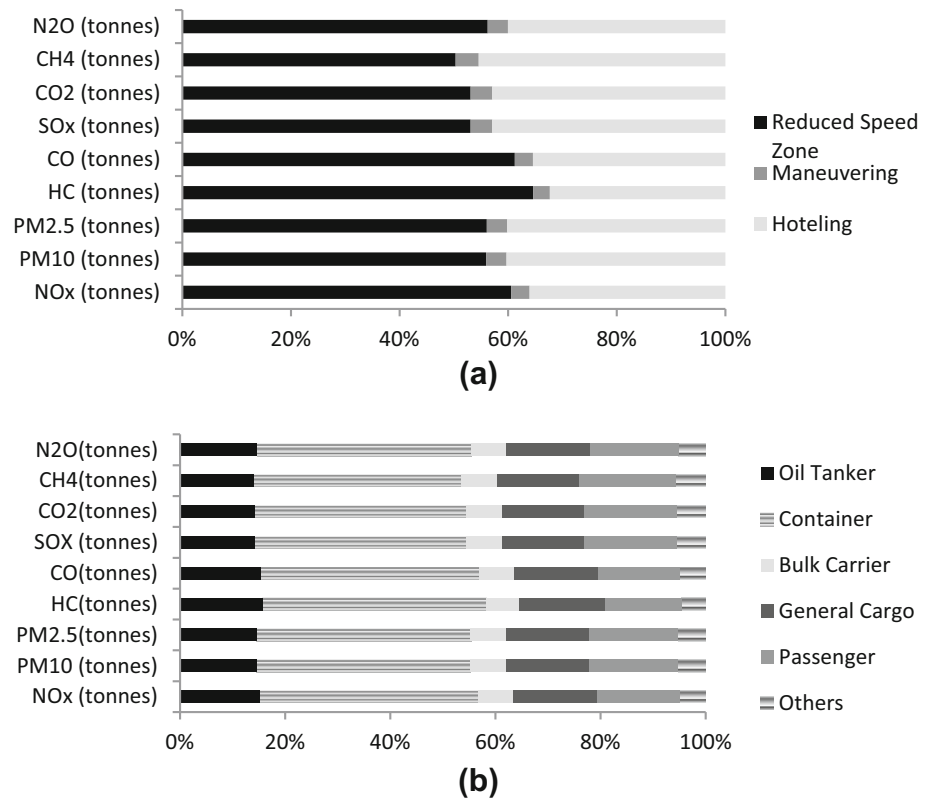


Fig. 1 Shipping channel map

Fig. 2 **a** Emissions in different activity zones. **b** Emissions from different ship categories



particular dock and the second segment is from the lock-gate to the allocated berth. The ships are traveling at reduced speed (11 knots) within segment 1. The average speed associated within maneuvering zone (segment 2) is 2 knots while the ships are assisted by tugboats to their berthing docks. The duration of a ship berthing at docks for loading and unloading operations is hoteling. The internal movement of ships within the docks is known as shifting.

Emissions are associated with activities of ships in all these operational modes. A comprehensive database consisting of more than five hundred ships (1334 vessel calls) visiting Kolkata port system during 2013–2014 and their activity times spent within the different sectors was obtained from the marine department of Kolkata Port Trust.

Each ship in the database was identified by a unique International Maritime Number (IMO). The details of main engine and auxiliary engine of each ship were obtained from Lloyd’s database [12]. The International Maritime Organization (IMO) and vessel classification societies do not mandate reporting of vessel auxiliary power characteristics. The missing values of auxiliary engine power of ships were estimated using average vessel ratio of auxiliary engines to main engines by ship type as specified in [13, 14].

To estimate the impact of shipping emissions air pollution monitoring sites close to Kolkata Port area was considered (within 5 km) at Mominpore and Hyde Road

maintained by West Bengal Pollution Control Board. The air pollutants considered in this study are NO_x and PM₁₀ concentrations. The observational sites are downwind of Kolkata dock area.

Methodology

Emissions from marine diesel engines are primary contributors to air pollution in the study area. Diesel engines on OGVs are of two types, viz., main propulsion engines and auxiliary engines. The emission calculations were based on the vessel activities, ship details and United States Environmental Protection Agency (USEPA) recommended methodology. Following the methodology prescribed by USEPA [13] and detailed in [4], the emissions from main engines and auxiliary engines of ships based on OGV details, shipping activity modes (Fig. 2) are calculated as follows:

$$E_i = EF_i \times P \times LF \times t, \tag{1}$$

where E_i : emission of pollutant i in transit segment (tonnes), EF_i : emission factor for pollutant i (g/kW-h), P : rated power of propulsion engine by vessel and engine type (kW), LF : load factor (fraction of rated power) by mode, t : average time for each mode by vessel and engine type per call (h).

Table 1 Engine emission factors (g/kW-h) [13]

Engine type	Fuel type	NO _x	PM ₁₀	PM _{2.5}	HC	CO	SO _x	CO ₂	CH ₄	N ₂ O
SSD	RO	18.10	1.42	1.31	0.60	1.40	10.29	620.62	0.006	0.031
	MDO	17.00	0.45	0.42	0.60	1.40	3.62	588.79	0.006	0.031
MSD	RO	14.00	1.43	1.32	0.50	1.10	11.24	677.91	0.004	0.031
	MDO	13.20	0.47	0.43	0.50	1.10	3.97	646.08	0.004	0.031
Auxiliary	RO	14.70	1.44	1.32	0.40	1.10	11.98	722.54	0.008	0.031
	MDO	13.90	0.49	0.45	0.40	1.10	4.24	690.71	0.008	0.031

Load factors are expressed as a percentage of the vessel's total propulsion or auxiliary power. At service or cruise speed, the propulsion load factor is 83%. At the lower speeds, the propeller law should be used to estimate ship propulsion loads, based on the fact that propulsion power varies by the cube of speed.

The load factor calculation for the main engine is shown in Eq. (2), while the formula of load factor, LF , for the auxiliary engines has been adopted from the study USEPA, 2009 [7] as follows:

$$LF = \alpha^3 \beta^{-3}, \quad (2)$$

where α denotes the actual speed (knots) and β , maximum speed (knots).

The transit time of each of the vessels (t) in (1) for each activity zone was computed from the extensive shipping database by tracing movements of ships from the time of entry of each ship within boundary of port jurisdiction (Fig. 1) till its departure.

The emissions consist of different air pollutants, NO_x, SO_x, PM₁₀, PM_{2.5}, hydrocarbon (HC) and carbon monoxide (CO), and greenhouse gas emissions (carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O)). The emission factors used in this study for calculations of emissions from marine fuel residual oil (RO) and marine diesel oil (MDO) for slow-speed diesel (SSD), medium-speed diesel (MSD), are specified in Table 1 for main and auxiliary engines. These emission factors generated by Entec [15] are based on emissions data of 142 propulsion engines of ships and from two research programs: Lloyd's Register Engineering Services in 1993 [16] and from Cooper and Gustaffson [17] and are generally accepted as the most current set available.

The auxiliary to main engine power ratio is assumed to be 0.25 for container, 0.23 for general cargo, 0.30 for both oil tanker and bulk carrier, 0.16 for passenger and 0.35 for other ships. The main and auxiliary engine emission factors adopted in this study were reported in US EPA [13]. Irrespective of ship engine type Slow Speed Diesel (SSD) and Medium Speed Diesel (MSD) the sulfur content in Residual Oil (RO) is 2.70% and in alternative cleaner fuel such as Marine Diesel Oil (MDO) is 1.00% [11].

Different statistical methods involving probability distribution function, conditional joint probability distribution are used to find the relative contribution of particular categories of ships and engine powers towards emissions.

Emissions in different activity zones of shipping channel (reduced speed zone, maneuvering and hoteling) and ship category wise total emissions in Kolkata port are compared using component bar charts. Observing the ratio of emissions from main engine and auxiliary engine is important for the purpose of determining their relative importance in emission distribution. Month wise emission and number of ship calls are compared through multiple axes line charts to gauge the impact of number of ship calls on magnitude of emission.

The distributions of emissions of different pollutants and green house gases are obtained to assess their characteristics including their central values, different percentiles, relative dispersion measures (such as coefficient of variation expressed as a ratio of standard deviation to mean, in percentage) and degree and direction of skewness.

The presence of outliers is determined for each category of ships by identifying the values beyond boundary values obtained by deducting 1.5 times 25th percentile value from 2.5 times 75th percentile value to detect suspect outliers and deducting three times 25th percentile value from four times 75th percentile values to detect extreme outliers, so that we can identify the ships that contribute to a huge quantum of emissions, and investigate the reason behind it.

We fit a theoretical distribution to the data with a purpose of evaluating probabilities of any range of emission values, the random variable of our interest, from the fitted curve. From different areas under the density curve corresponding to different ranges of values we can get an idea about the possible relative frequencies of different value-ranges, which can help us understand to what extent each range of values may contribute to the total quantum of emissions, an assessment of which is necessary prior to making any policy decisions regarding emissions control from OGVs.

To know the relative contribution of different engine power ranges and cargo types to very high emission levels (75th percentile or above), their conditional joint

probability distribution and hence their marginal probability distributions are obtained. Here emission values are considered per unit of time to make the total quantum of emissions from different ships comparable, irrespective of time spent within the shipping channel.

Results and Discussion

Total Annual Emissions

A summary of total annual emissions from all shipping activities are represented in Table 2. It is seen that amongst air pollutants NO_x emissions are the highest with total of around 1835 tonnes (approximately 51% of total emissions), followed by SO_x (around 1256 tonnes and 35% of total emissions), PM₁₀ (160 tonnes, 4.5% of total emissions), PM_{2.5} (148 tonnes, 4% of total emissions), CO (139 tonnes, 4% of total emissions) and HC (56 tonnes, 1.5% of total emissions). Amongst greenhouse gases CO₂ emissions are significantly high (over 75,000 tonnes). The primary reason for these high emissions is the substantial length of the shipping channel in for reduced speed zone that includes shifting of ships between docks, which causes considerable emissions from main engines of OGVs, followed by significant emissions during hoteling due to large turnaround time for ships. This signifies that effectiveness of emission reductions depends substantially not only on using cleaner fuel and reduction of shifting time by better management of loading–unloading operations at docks, but also on diminution of turnaround time of ships.

Relative Contribution Towards Total Emissions

Different Modes of Operation

Relative contributions from different activity modes of ships can be calculated from Table 2 and are illustrated as

Table 2 Activity zone wise OGV emission (in tonnes)

Activity zones of shipping channels	NO _x	PM ₁₀	PM _{2.5}	HC	CO	SO _x	CO ₂	CH ₄	N ₂ O
Reduced speed zone	1110.8	89.9	82.9	36.0	85.6	666.9	40,223.1	0.4	2.0
Maneuvering	62.2	6.1	5.6	1.7	4.7	50.3	3034.7	0.0	0.1
Hoteling	661.6	64.8	59.4	18.0	49.5	539.2	32,518.5	0.4	1.4
Total	1834.57	160.82	147.86	55.67	139.72	1256.39	75,776.29	0.79	3.49

Table 3 Emission ratio between main and auxiliary engines

	NO _x	PM ₁₀	PM _{2.5}	HC	CO	SO _x	CO ₂	CH ₄	N ₂ O
Main engine	52.80	47.25	47.41	57.67	53.62	43.83	43.83	40.52	47.60
Auxiliary engine	47.20	52.75	52.59	42.33	46.38	56.17	56.17	59.48	52.40

percentages in a component bar chart in Fig. 2a. It is seen that emissions from reduced time zone vary between (50 and 65)%, whereas for hoteling the emissions range a significant (30–45)% for all emission categories. Emissions from ship maneuvering are much lower than other two segments, which is approximately (3–4)% from all ship categories.

Table 3 depicts the relative percentage of emissions from main and auxiliary engines. CO₂ emissions from main engines of OGVs (44%) are notably lower than from auxiliary engines (56%) due to large turnaround time for ships. The emissions of SO_x, PM₁₀ and PM_{2.5} are also higher from auxiliary engines than main engines despite lower emission factors due to their long running times during hoteling period.

Passenger ships contributed most (32% of total emissions during hoteling) due to very high average hoteling time (312 h) followed by containers (27% of total hoteling emissions). Although average hoteling times of containers are lower (71 h). The largest number of ships in this category ensures highest contributors (28%) of total hoteling time and thus more emissions. General cargo comprises of 14% of total emissions and bulk carriers 9%. The average hoteling time of bulk carriers is quite high (213 h) signifying that should more number of bulk carriers visit port due to change in cargo type, there would be considerable rise in hoteling emissions. For oil tanker hoteling time is lowest (56 h) and hence they are the lowest contributors (8% of total emissions during hoteling). The above sets of analyses re-emphasize that Kolkata port needs to implement measures to reduce turnaround time of ships to diminish emissions from auxiliary engines.

Different Categories of Ships

The OGVs calling the port can be broadly divided into six categories: container ships, which is the predominant ship type (41% of total ship calls) visiting the port followed by

general cargo (25%), oil tankers (19%), bulk carriers (8%), passengers (3%) and ships which do not fall under any specific category listed as others (4%). Figure 2b displays a component bar chart summarizing the relative contribution of each category of ships towards emissions. Container ships have the highest percentage of overall emissions for the vessels (approximately 43 to 45%), followed by passengers, oil tankers and general cargo (approximately 15 to 17%). Bulk carriers and others (includes RoRos and ocean-going tugboats) supply approximately 4 to 5% in all emissions ranges. The above analysis indicates that passenger ships are amongst the highest polluting ships.

A detailed perspective of emissions contributions from different ship categories is presented in Table 4. NO_x emissions is used as a prototype since NO_x emissions are highest amongst emissions of air pollutants and all emissions have same patterns being activity-based data. Containers have highest total emissions followed by passenger ships, general cargo, oil tanker bulk carrier and other vessels. Passengers have lowest count but contribute appreciably due to higher engine power and elevated hoteling times. Bulk Carriers contribute lower emissions due to lower average transit time and less no of ship calls in comparison to other ship categories.

Emission Distribution from Main Engines

Table 5 reinforces the analysis in Fig. 2. Passenger ships have highest mean values of NO_x emissions (1.5 tonnes) followed by containers and oil tankers. Passenger ships have highest values in all ranges of emission distributions (25th to 95th percentile) as well. Considering variability in emission contribution, it is seen that oil tankers have the highest variability (coefficient of variation 76%) and skewness (4.01) followed by bulk carriers, general cargo, containers and passengers ships. In case of oil tankers, because of high variabilities, emission control strategies need to be based on their efficacy to decrease the maximum emissions averaged over all ship calls. Although containers have highest number of ship calls the range of emission distribution and variability is lower than other categories that can lead to more effective emission reductions in this category. All emissions distributions are positively skewed.

Table 6 further explores the joint conditional probability distribution of main engine power and ship category towards elevated emissions distribution. It is seen that engine power within the range (7000–9000) kW contribute the most, above 50% of total emissions amongst all ship categories. Although the containers as a single group supply 49% of total emissions amongst all ship categories, the distribution of its emissions is distributed amongst all engine powers. Oil tankers and general cargo that visit the port have main engines limited to 9000 kW and contribute

(13–14)% of higher emissions. Passenger ships and ships in others category are skewed towards higher engine powers. This examination depicts that Kolkata port needs to exert most emission control over ships with engine power in the (7000–9000) kW category. Amongst the different ship types foremost considerations on emissions reduction has to be given to container ships (because of their high number of ship calls) followed by passenger ships and others which are amongst highest emitters though small in numbers. Other important contributors of high emissions include general cargo with 5000 to 7000 kW main engine power that generate 11% of total emissions.

Emissions Due to Shifting

Shifting between different docks causes outliers in emissions (container 2.23%, general cargo 4.49%, bulk carrier 1.75%, oil tanker 5.06%) within different ship categories. Bulk carriers have highest rate of shifting to other docks (61% of total bulk carriers) but with an average shifting hours (5.81 h.), which is minimum shifting time among all types of cargo. Container is the 2nd highest in shifting of ships (24%) with maximum average shifting time of 20 h. General cargo contributes to 18% shifting of ships with an average 14 h time and oil tanker only 14% shifting with an average of 18 h. Therefore emissions from shifting are significant and the ports should reduce shifting times with better cargo handling facilities and improved traffic management.

Probability Distribution of Total Emissions

Figure 3 exhibits the probability distribution of archetype NO_x emissions. The best-fit distribution has been found to be a lognormal distribution with probability density function $f(x)$ as given below:

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\log_e x - \mu)^2}{2\sigma^2}}, \quad 0 < x < \infty, \quad -\infty < \mu < \infty, \\ 0 < \sigma < \infty,$$

with an expected value of 0.73 tonnes and a standard deviation of 0.54 tonnes.

The distribution curve reveals high frequencies between 25th percentile (at 0.36 tonnes of emissions) and 50th percentile (at 0.60 tonnes of emissions). Area under the curve corroborates that in lower percentiles, although amount of NO_x emissions is low but quantum of ships in this category is very high. Total NO_x emission below 25th percentile is around 82 tonnes, 158 tonnes between 25th to 50th percentile, 245 tonnes between 50th to 75th percentile and 332 tonnes between 75th to 95th percentile. Though there are only 65 ships above 95th percentile but total NO_x emission in this range is 152 tonnes which is very high.

Table 4 Emissions from different ship categories (in tonnes)

	Container	Bulk carrier	Oil tanker	General cargo	Other	Passenger
NO _x	763.80	119.38	278.91	295.65	90.41	286.42
PM ₁₀	65.41	10.79	23.51	25.58	8.44	27.09
PM _{2.5}	60.18	9.91	21.64	23.53	7.74	24.86
HC	23.65	3.52	8.75	9.07	2.59	8.09
CO	58.37	9.05	21.36	22.56	6.82	21.56
SO _x	503.61	85.82	179.14	198.24	68.39	221.19
CO ₂	30,373.93	5176.03	10,804.42	11,956.63	4124.67	13,340.61
CH ₄	0.31	0.06	0.11	0.12	0.04	0.15
N ₂ O	1.42	0.23	0.51	0.55	0.18	0.58

Table 5 NO_x emissions characteristics by ship category

	Oil tanker	Container	Bulk carrier	General cargo	Passenger	Others	Total
Minimum ^a	0.16	0.05	0.01	0.03	0.58	0.0001	0.001
Maximum ^a	5.53	5.16	1.52	1.89	2.98	1.25	5.53
Mean ^a	0.77	0.9	0.42	0.52	1.5	0.39	0.73
25th percentile ^a	0.47	0.58	0.19	0.28	1.14	0.21	0.36
Median ^a	0.56	0.74	0.33	0.39	1.42	0.35	0.6
75th percentile ^a	0.89	1.12	0.58	0.64	1.96	0.49	0.93
95th percentile ^a	1.58	1.78	0.99	1.29	2.37	1.02	1.7
Skewness	4.01	2.12	1.12	1.69	0.65	1.03	2.46
Coefficient of variation (%)	76.05	62.37	71.04	68.61	36.21	74.82	74.16

^ain tonnes

Table 6 Conditional joint probability distribution of engine power type and type of cargo for a very high level of PM_{2.5} (75th percentile or above)

Engine power, kW	Container	Oil tanker	General cargo	Bulk carrier	Passenger	Others	Marginal probability
1000–3000	0	0	0	0	0	0	0
3000–5000	0.012	0.006	0	0.018	0	0	0.036
5000–7000	0.063	0.012	0.114	0.009	0.055	0.015	0.268
7000–9000	0.343	0.113	0.024	0.030	0.003	0	0.512
9000–11,000	0.045	0	0.006	0.051	0.040	0	0.142
> 11,000	0.030	0	0	0.009	0.003	0	0.042
Marginal probability	0.493	0.130	0.144	0.117	0.101	0.015	1

This investigation signifies that emission control strategies need to account for ships emitting in (25–75)th percentile range in addition to the higher emitters above 75th percentile range to counter significant emissions.

Monthly Distribution of Total Emissions

Figure 4 below illustrates monthly ship calls versus monthly NO_x emission through a multiple axes chart.

Ship calls show a flat line depicting homogeneous number of ship calls, whereas emissions reveal high peaks during July and December. Study found more emissions in July due to average high hoteling time which created more emissions from auxiliary engines of vessels. In December, most of the visiting container ships were equipped with heavy main propulsion power that resulted in amplification of emissions in comparison to other months. There is no effect of seasonality on emissions.

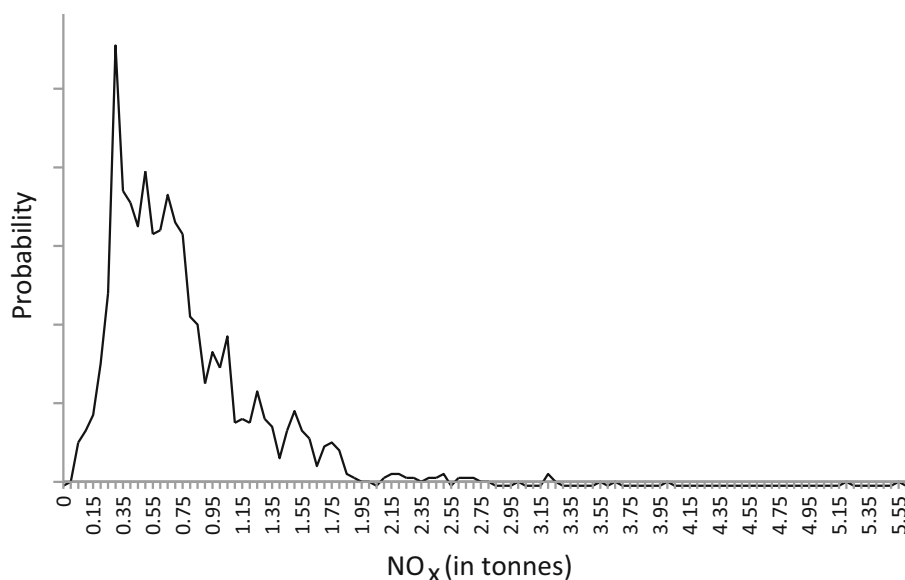


Fig. 3 Probability distribution of NO_x emissions

Emissions and Pollutant Concentrations

Although a large portion shipping emissions occur while ship is in transit, the most noticeable influence of emissions takes place within port areas from emissions during hoteling when ships reside at docks. Hence in this study, impact of shipping emissions from hoteling has been considered only and their effect on nearby monitoring sites has been considered. The average air pollutant concentrations at monitoring sites for NO_x and PM_{10} concentrations at Hyde Road and Mominpore are 47.5 and 161.78 $\mu\text{g}/\text{m}^3$, 36.2 and 105 $\mu\text{g}/\text{m}^3$ respectively and varies significantly with season with highest averaged concentrations (72.42 and 287 $\mu\text{g}/\text{m}^3$, 64 and 236 $\mu\text{g}/\text{m}^3$ respectively) occurring in winter and lowest concentrations during monsoon season (34.1 and 91.72 $\mu\text{g}/\text{m}^3$, 24 and 50 $\mu\text{g}/\text{m}^3$ respectively). PM_{10} averaged concentration values are above National Ambient Air Quality Standards ($> 100 \mu\text{g}/\text{m}^3$) in winter for both sites. Air quality concentrations are strongly seasonal revealing influence of meteorology whereas shipping emissions computed directly from auxiliary engines of ships are not affected by meteorology. The emissions are borne downwind towards monitoring sites and during this period of travel NO_x emissions can be converted to nitrates (secondary aerosols) or acid rain (nitrous acid) or even surface ozone by reacting with hydrocarbons in the atmosphere. Different constituents of particulate matter (PM_{10}) are related to direct emissions and transformation of gaseous species such as SO_2 , NO_x through physico-chemical processes in the atmosphere. Thus formation of ambient air pollutants is a very complex and nonlinear phenomenon. Hence non-linear regression method is a better representative of the association between ship emissions and air

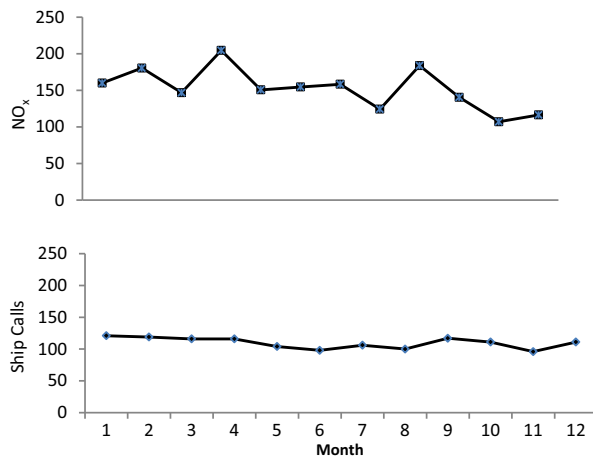
pollution concentrations downwind at receptor sites. The R^2 value between marine emissions and concentrations at the monitoring sites is around 0.3 for both pollutants, indicating that approximately 30% of variability in air pollutant concentrations at the observational sites may be explained by variations in shipping emissions.

Preliminary Control Strategy

The study examined the consequences of replacing bunker fuel RO with cleaner fuel MDO with lower emission factors (Table 1). Significant diminutions are observed with NO_x emission decreased by 5.78%, PM_{10} by 67.08%, $\text{PM}_{2.5}$ by 66.87%, SO_x by 64.70%, CO_2 by 4.72% and others unchanged.

Conclusion

The results reveal significant emissions from OGVs, which are an unregulated emissions source in Kolkata port for recent year 2013–2014. This is because shipping emissions in this region are created by international and national ships that are not yet observing stringent emission standards of SO_x and NO_x as stated in Annex-VI and its amendments mandated by International Maritime Organization's Prevention of Air Pollution from ships. Ships visiting Kolkata port are still using bunker fuel or dirty diesel, which have higher NO_x and SO_x emission factors. Considering magnitude of emissions, NO_x has highest emission concentrations (approximately 51% of total emissions), followed by SO_x (around 35% of total emissions). Emissions can be almost equally apportioned between reduced



*Month '1' indicates April, 2013

Fig. 4 Monthly NO_x emissions and ship calls

time zones and hoteling activity. Therefore ports have to reduce operational turnaround times to lessen substantial proportion of hoteling emissions. Containers have the largest number of ship calls and should definitely be prioritized in implementation of emission control strategies. However other high emitters such as passenger ships have also to be considered due to very high emissions despite lower ship calls. Oil tankers have high variability in emissions that can cause uncertainty in efficacy of emission control strategies. Thus this study should be extended to other years to cover longer averaging times that would increase relevancy in emissions-management decisions by reducing uncertainties.

The ambient air quality concentrations at observational sites downwind of Kolkata port are quite high with average NO_x and PM₁₀ concentrations (45.81 and 149.35 µg/m³). There is an association (30%) between shipping emissions and ambient air quality concentrations within 5 km of shipping dock areas.

Preliminary study of a measure of emission control strategy such as replacement of low grade fuel RO with higher grade fuel MDO causes significant decline of emissions. Overall, this study is a necessary first step for Kolkata port to be appraised of emissions from OGVS and will help in formulation of clean port plans that would diminish air pollution and greenhouse gas emissions from shipping activities at port. As stated in this paper the first step in that direction would be for Kolkata port to enforce stricter fuel standards such as (0.5–0.1%) sulphur emission cap on ships. This would become a necessity in near future if Indian ports have to remain globally competitive and ensure sustainable growth under stricter regulations imposed by International Convention for the Prevention of Pollution from Ships.

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