Study on emission characteristics of non-road mobile source pollutants in Tianjin

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Abstract. According to the collected activity level data for 2018, the emission inventory of non-road mobile sources in Tianjin was updated with the method recommended by the ministry of environmental protection. In 2018, the emissions of CO, HC, NOx, PM, and SO₂ from the non-road mobile source in Tianjin were 6.72×10³ t, 2.85×10³ t, 3.59×10⁴ t, 1.63×10³ t, and 1.69×10⁴ t, respectively. Among all kinds of non-road mobile sources, emissions of ship were the largest, followed by non-road mobile machinery; civil aviation aircraft and railway locomotive were relatively small. In general, emissions from non-road mobile source rose from March through November, and were relatively low at the end of each year and the beginning of the following year. The discharge of pollutants was concentrated in rural areas and counties with developed agriculture, urban center with dense population and municipal construction, port area, railway lines and airports.

1. Introduction

The non-road mobile source usually includes non-road mobile machinery, ship, railway locomotive, and aircraft, which has the characteristics of low emission technical level, long service life, poor maintenance, high fuel consumption, and large single-machine emission of air pollutants [1,2]. Due to the weakness of basic research, the lag of standard formulation, and the large number of departments involved, the pollution control of non-road mobile source is relatively backward in China for a long time [3]. Moreover, the emission characteristics (i.e. emission inventory and its distribution characteristics) are the basis of environmental air quality management, but the research on non-road mobile source inventory is still in its infancy [4].

Based on the demand of non-road mobile source pollution control in Tianjin, and according to the collected data of activity level in 2018, the non-road mobile source emission inventory for Tianjin was well updated in this paper with the recommended method of the Compilation Guide for Non-road Mobile Source Emission Inventory (trial edition) (hereinafter referred to as "the GUIDE") released by Ministry of Environmental Protection [5]. Through the establishment of the non-road mobile source emission inventory, this paper further analyzed the spatial and temporal distribution of pollutants, focusing on solving the persistent problem that the amount of pollutants was not clear, in order to
provide reference and support for the relevant atmospheric environmental science research and air quality improvement decision-making.

2. Materials and methods

2.1. Research objects
This study calculated the emission inventory of non-road mobile source in Tianjin in 2018, including non-road mobile machinery (i.e. construction machinery and agricultural machinery), ship (i.e. the offshore vessel, oceangoing vessel, fishing vessel in Bohai Sea, and the inland river vessel on the Haihe River), railway locomotive (referring to trains powered by internal combustion engines), and civil aviation aircraft (mainly referring to the incoming and outgoing flights in Tianjin Binhai International Airport). The pollutants included CO, HC, NOx, PM, and SO2. Location of Tianjin on the map of China is shown as Figure 1.

![Tianjin](image)

**Figure 1.** Location of Tianjin on the map of China.

2.2. Accounting method
Based on the method of the GUIDE, a mathematical calculation model was established to calculate the emission inventory of various non-road mobile sources.

For non-road mobile machinery, ship, and railway locomotive, the emission of CO, HC, NOx, and PM was calculated based on fuel consumption, from:

\[ E = (Y \times EF) \times 10^{-6} \]

where \( E \) was the emission amount of CO, HC, NOx, and PM from non-road mobile machinery, ship, and railway locomotive (t); \( Y \) was the fuel consumption (kg); \( EF \) was the emission factor (g/kg fuel).

For civil aviation aircraft, the emission of CO, HC, NOx, and PM was calculated based on the land and taking-off cycle (LTO cycle). The LTO cycle was a closed process — an aircraft landed from the air to the airport and then took off again to the high altitude. The ideal LTO cycle included 4 typical conditions, i.e. taking-off, climb, land, and taxiing. The emission of CO, HC, NOx, and PM from civil aviation aircraft was calculated by:

\[ E = (C_{LTO} \times EF) \times 10^{-3} \]

where \( E \) was the emission amount of CO, HC, NOx, and PM from civil aviation aircraft (t); \( C_{LTO} \) was the number of LTO of civil aircraft; \( EF \) was the emission factor (kg/LTO).

For all non-road mobile sources, the SO2 emission was calculated according to the sulfur content in the fuel, from:

\[ E_{SO2} = (2 \times Y \times S) \times 10^{-6} \]
where $E_{SO_2}$ was the emission amount of SO$_2$ (t); $Y$ was the fuel consumption (kg); $S$ was the sulfur content (g/kg fuel), 0.35 g/kg fuel.

2.3. Emission factors

The emission factors of the non-road mobile source were the average emission coefficients recommended by the GUIDE (Table 1). The data sources included measurement [6], material balance [5], and literature [1,6].

| Table 1. Emission factors of non-road mobile source and their data sources. |
|-------------------------------------------------|
| Source category / fuel type | CO (g/kg fuel) | HC (g/kg fuel) | NO$_x$ (g/kg fuel) | PM (g/kg fuel) |
|-----------------------------|----------------|----------------|-------------------|----------------|
| Construction machinery / Diesel | 10.72 | 3.39 | 32.79 | 2.09 |
| Agricultural machinery / Diesel | 10.94 | 3.37 | 35.04 | 1.74 |
| Ship | Diesel | 23.80 | 6.19 | 47.60 | 3.81 |
| Fuel oil | 7.40 | 2.70 | 79.30 | 6.20 |
| Railway locomotive / Diesel | 8.29 | 3.11 | 55.73 | 2.07 |
| Civil aviation aircraft / Aviation fuel | 9.14 | 2.68 | 16.29 | 0.54 |

2.4. Activity levels

The activity level data of non-road mobile source was mainly from statistical yearbooks, actual field survey, literature, etc. According to the results of the survey, statistic, and accounting, the amounts of fuel consumption of non-road mobile machinery, ship, railway locomotive, and civil aviation aircraft in Tianjin in 2018 were 2.46×10$^5$ t, 2.38×10$^7$ t, 1.04×10$^4$ t, and 1.40×10$^5$ t, respectively. In addition, the amount of land and taking-off of civil aviation aircraft was 1.70×10$^5$ t.

3. Results and discussions

3.1. Emission inventory results

3.1.1. Emissions of pollutants. The total non-road mobile source emission of Tianjin in 2018 is listed in Table 2. In 2018, the emissions of CO, HC, NO$_x$, PM, and SO$_2$ from non-road mobile sources in Tianjin were 6.72×10$^3$ t, 2.85×10$^3$ t, 3.59×10$^4$ t, 1.63×10$^3$ t, and 1.69×10$^4$ t, respectively.

| Table 2. Total non-road mobile source emission of Tianjin in 2018 (t). |
|-----------------|------|------|------|------|
| Source category | CO   | HC   | NO$_x$ | PM   |
| Non-road mobile machinery | 2699.60 | 897.51 | 8250.98 | 444.11 |
| Ship | 3181.00 | 1695.06 | 25798.61 | 1110.52 |
| Railway locomotive | 59.73 | 35.11 | 485.44 | 26.33 |
| Civil aviation aircraft | 775.00 | 227.24 | 1381.27 | 45.79 |
| Total | 6715.33 | 2854.92 | 35916.30 | 1626.75 |

3.1.2. Emission proportion. The emission proportion of the ship was the highest, accounting for 75.64% of all non-road mobile source emission. The second was the non-road mobile machinery, accounting for 19.46%. Emissions from the civil aviation aircraft and the railway locomotive were relatively small, accounting for 3.95% and 0.96%, respectively.

The contribution of different non-road mobile sources to different pollutants is shown in Figure 2. The ship was the largest contributor to the emission of CO, HC, NO$_x$, PM, and SO$_2$ from the non-road mobile source, accounting for 47.37%, 59.37%, 71.83%, 68.27%, and 98.36%, respectively. The second was the non-road mobile machinery, accounting for 40.20%, 31.44%, 22.97%, 27.30%, and 1.02%, respectively.
Figure 2. Contribution of different non-road mobile sources to different pollutants.

From the analysis results of further subdivision of the non-road mobile machinery (Figure 3), it could be found that the emission from the agricultural machinery accounted for 62.90% of all types of non-road mobile machinery, mainly the tractors (32.30%) and the agriculture trucks (19.98%). While the emission from the construction machinery accounted for 37.10%, mainly the excavators (13.56%) and the road rollers (9.11%).

From the analysis results of further subdivision of the ship (Figure 4), it could be found that the emission from the offshore and ocean-going vessel accounted for 90.53% of all types of ships. This was mainly due to the relatively developed port shipping industry in Tianjin. Tianjin port was the world's highest class and China's largest artificial deep-water port, and also the fourth comprehensive port in the world in terms of throughput [7]. The frequent activity of ships in the port area had caused a large number of pollutant emissions. In comparison, the inland river ships and fishing ships had small ownership and small load, so the emission ratios were also low, only 9.47%.

Figure 3. Emission proportion of different types of non-road mobile machinery.

Figure 4. Emission proportion of different types of ships.
3.2. Temporal and spatial distribution of emission inventory

The spatial and temporal distribution of emission inventory was obtained based on the actual activity level of various non-road mobile sources, such as quantity, technical level, operation time, activity area, fuel consumption, time of inbound and outbound, throughput, number of land and taking-off, etc.

3.2.1. Temporal distribution. The monthly change tendency of the emissions from different non-road mobile sources is shown in Figure 5. In general, emissions from non-road mobile source rose from March through November, and were relatively low at the end of each year and the beginning of the following year.

The pollutant emission of non-road mobile machinery was obviously affected by seasons, which was relatively high from March to November and relatively low in January, February, and December. This was mainly due to the construction and agricultural production mainly concentrated in spring, summer, and autumn, but the production activity was less in winter. Therefore, the emission of pollutants from both of the construction machinery and the agricultural machinery also showed a corresponding trend. The pollutant emission from the ship also increased from March and gradually decreased at the end of the year, which was basically consistent with the changing trend of port throughput. Among them, June to September was the prohibited fishing period of the Bohai Sea, fishing vessels entered the fishing port, resulting in a lower level of activity, during which the total amount of pollutant emission by ship would be reduced to a certain extent. Because the passenger and freight schedules of railway locomotive and civil aviation aircraft were relatively fixed and fluctuate little, the monthly change tendency of the emissions from both of them was relatively stable.

3.2.2. Spatial distribution. According to the activity characteristics of all kinds of non-road mobile sources and their distribution of sites, farmland, ports, railways, and airport, the gridding emission inventory of non-road mobile sources was generated by using GIS technology, shown as Figure 6.

For the non-road mobile machinery (Figure 6(a)), the emission from agricultural machinery was mainly distributed in the suburbs farming and aquaculture districts and counties, e.g. Wuqing, Baodi, Jizhou, Ninghe, Jinghai, etc.; while the emission of construction machinery was mainly distributed in Central city, Binhai and Jinnan where urban construction and crowd activities were concentrated.

For the ship (Figure 6(b)), the emission was mainly concentrated in the Tianjin Port and its waterway in the Binhai New Area, but less in the inland rivers.

For the railway locomotive (Figure 6(c)), the emission was mainly concentrated along the passenger and freight railway lines.

For the civil aviation aircraft (Figure 6(b)), the emission was mainly concentrated on the runways of Tianjin Binhai International Airport, and the near ground and low altitude of its surrounding areas, which was located in Dongli District.
4. Conclusions

According to the collected activity level data for 2018, the emission inventory of non-road mobile sources in Tianjin was updated with the method recommended by the ministry of environmental protection. In 2018, the emissions of CO, HC, NOx, PM, and SO2 from the non-road mobile source in Tianjin were $6.72 \times 10^3$ t, $2.85 \times 10^3$ t, $3.59 \times 10^4$ t, $1.63 \times 10^3$ t, and $1.69 \times 10^4$ t, respectively. Among all kinds of non-road mobile sources, emissions of ship were the largest, followed by non-road mobile machinery; civil aviation aircraft and railway locomotive were relatively small. In general, emissions from non-road mobile source rose from March through November, and were relatively low at the end of each year and the beginning of the following year. The discharge of pollutants was concentrated in rural areas and counties with developed agriculture, urban center with dense population and municipal construction, port area, railway lines and airports.

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