

**BEFORE THE NATIONAL GREEN TRIBUNAL**  
**WESTERN ZONE BENCH AT PUNE.**

APPEAL No. 15 OF 2023

**IN THE MATTER OF :**

Federation of Rainbow Warriors and Ors. ... Appellants

V/s.

Union of India and Ors. ... Respondents

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Pune,

Dated : 31.08.2023.



(Advocate for Respondent No. 3)



**BEFORE THE NATIONAL GREEN TRIBUNAL  
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**IN THE MATTER OF :**

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**REPLY ON BEHALF OF RESPONDENT No. 3,**

**MORMUGAO PORT AUTHORITY**

The Respondent No. 3, Mormugao Port Authority  
(MPA) most respectfully states and submits as follows :

1. The present Appeal is filed against the Environment Clearance and CRZ Clearance dated 11.01.2023 granted to

South West Port Ltd. (SWPL) for terminal capacity enhancement at Berths 5A & 6A of Mormugao Port for handling coal and coal products, iron ore and limestone including unutilized and steel products.

2. Respondent No. 3 is filing the present Reply mainly to place on record the pollution control measures adopted at the Mormugao Port and the true and correct factual situation existing at the Port. Nothing specifically denied in this Reply should be construed as admission of any of the facts, pleading or submissions as made in the Appeal.

3. As regards Berth No. 5A & 6A, MPA (formerly known as Mormugao Port Trust) has entered into a Licence Agreement dated 11<sup>th</sup> April, 1999 with South West Port Ltd., which extends for a period of 30 years.



4. MPA has and is taking sufficient steps and measures to ensure that the pollution levels on account of the cargo handling at are minimal and within the permissible limits.

5. It is stated that the Goa State Pollution Control Board has stipulated various measures and conditions in the respective Consents to Operate in order to minimize the pollution levels due to the cargo handling at the Berths. MPA regularly supervises and monitors that all the conditions and measures as stipulated in the respective Consents to Operate are duly followed and complied with by the said South West Port Ltd. at Berth Nos. 5A & 6A.

6. It is stated that within the Port area, there is one Source Monitoring Station (National Air Monitoring Stations), inside operational area on the Terrace of Fire Station Building and Two nos National Ambient Air Monitoring Stations at Electricity Department, Fuse Call office at Vasco City and another on the terrace of B Type quarters at Baina installed.



commissioned and monitored by the Goa State Pollution Control Board . In addition to these Air Monitoring Station , MPA has installed and commissioned Continuous Ambient Air Quality Monitoring Stations ( CAAQMS ) near the Mormugao Port Institute Complex at Vasco City . So also, Adani Mormugao Port Terminal Pvt. Ltd. has installed and commissioned an CAAQMS at Upper Jetty near MPA , D type Qtrs and another by M/s SWPL near Ship building Institute , Bogda . The Real Time One line data of all these Three nos CAAQMS are transmitted to GSPCB and CPCB Server .

7. The said Air Monitoring Stations continuously and regularly monitor the particulate matter present in the air i.e. PM10 and PM2.5. The data recorded in the Air Monitoring Stations commissioned by MPA, South West Port Ltd. and AMPTPL are transmitted directly to Central Pollution Control Board (CPCB) and GSPCB Server. The data recorded at the National Ambient Air Monitoring Stations commissioned by



the Goa State Pollution Control Board are manually processed by the Officials of the Goa State Pollution Control Board.

8. It is stated that the permissible daily limits stipulated by the Central Pollution Control Board for PM 10 is 100 micrograms per cubic meter and average annual permissible limit is 60 micrograms per cubic meter.

It is stated that the permissible daily limits stipulated by the Central Pollution Control Board for PM 2.5 is 60 micrograms per cubic meter and average annual permissible limit is 40 micrograms per cubic meter.

9. It is stated that the regular monitoring through the said CAAQMS Air Monitoring Station commissioned by the MPA is being undertaken since about August, 2017. It may also be pertinent to note that the said Air Monitoring Station records not only the activities in the Port but also activities in the surrounding local areas.



10. Vide Communication dated 26<sup>th</sup> July 2019, the Regional Director of the Central Pollution Control Board informed the Member Secretary of the Central Pollution Control Board that a team of officials from Central Pollution Control Board, Goa State Pollution Control Board and Officials from Mormugao Port Trust have made field survey at nine locations during July 24<sup>th</sup> and 25<sup>th</sup>, 2019 out of which one location at No. 75-V, Housing Quarter, MPT at Baina was found to be suitable for relocating the NAMP (National Air Monitoring Program) Station operated at MPT premises ( which was declared as Source Station by CPCB ) and suggested to shift the said Monitoring Station operated in the operational areas of MPA to the Housing Quarter at Baina, within the time suggested in the enclosed Report.

11. In compliance with the said directives, the Goa State Pollution Control Board has installed a new Air Monitoring Station on the terrace of Housing Quarter No. 75-V,



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MPT at Baina and the said Air Monitoring Station has become operational since last week of August, 2019.

12. It is stated that MPA has deployed a truck mounted Road Sweeper to sweep all the roads within the Port area and this is done on a daily basis in shifts and also occasionally sweeping of City Roads during dry season . This helps in reducing the loose particles accumulated on the roads on account of the handling of not only coal but other cargo in the Port area.

13. It is stated that on an average about 10 Nos of water tankers are deployed by MPA everyday to sprinkle water in the operational area, besides sprinkling of water on Roads within the operational areas by Coal/ Coke handling operators at Berth no 5A, 6A and Berth no. 7 respectively, which also helps in controlling the fugitive dust emanating during the cargo handling operations.



14. It is stated that MPA has also installed a Mist Canon Spray which sprays the water on the cargo stacks. All this is in addition to the measures implemented by the Private Terminal Operators as mandated in the respective Consents to Operate.

15. It is stated that MPA has also erected Wind Curtains of a height of about 12 mts. along the periphery of the Port area. So also, regular Tree Plantation is being carried out on an annual basis to increase the greenery within the Port area.

16. It is stated that the MPA is seriously concerned to minimize the pollution levels on account of the cargo handling at the Berths and is adopting all possible measures to ensure that the pollution levels are minimal.

17. It is stated that there have been continuous allegations as regards the pollution caused in the Vasco city due to the coal / coke handling at the Mormugao Port. In this



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respect, MPA requested the Goa State Pollution Control Board to appoint a reputed Expert in the field like the Indian Institute of Technology, Bombay to conduct a proper study and to suggest mitigation measures. The Goa State Pollution Control Board forwarded to MPA the proposal for Source Apportionment study by IIT Mumbai proposed at Vasco. The MPA was also required to pay for the said study.



18. It is stated that the main purpose of the Source Apportionment Study to be undertaken by IIT, Bombay is to quantify the contribution of emissions of various sources on the ambient air quality in the Vasco – da – Gama region of Goa. The said study will comprise of identification of emission sources and assessment of extent of the contributions of significant sources on ambient air environment.

19. It is stated that IIT Bombay has submitted its Final Report dated 21.12.2021 of Particulate Source Apportionment

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Study for Air Quality in Vasco da Gama, Goa, a true copy whereof is hereto annexed and marked "EXHIBIT R1".

20. The said Final Report is a comprehensive study of the particulate source apportionment for air quality in Vasco and the said Report indicates that the four factors identified were vehicular emissions, road dust, port related activities and biomass burning, and marine aerosols.

21. It is stated that MPA have borne the Costs towards undertaking the said Source Apportionment Study and has, deposited Full amount of Rs. 94.50 Lakhs with the IIT, Bombay .

22. Based on the IIT Recommendation , comprehensive Environmental Management Plan ( EMP ) has been formulated for implementation by MPA and both the Coal/ Coke handling Terminal Operators . The said EMP was



furnished to Goa State Pollution Control Board. The details of EMP are hereto annexed and marked "EXHIBIT R2".

23. It is stated that various steps and decisions have been taken to ensure that there is minimal pollution at the Mormugao Port on account of handling of coal / coke and other cargo. The Best Environmental practices cum Environmental protection measures are being adopted by both the Coal handling operators to control the fugitive emission and to maintain the Ambient Air and water quality within the permissible limits, the details whereof are hereto annexed and marked "EXHIBIT R3".

24. MPA had established Environment Monitoring Cell in the Civil Engineering Department to monitor various environmental activities of the Port. The said Environment Cell is headed by an Executive Engineer and the functions of the Environment Cell are as follows :



- i) Identification of Ambient Air Quality Stations (AAQS) both within Port area and also outside Port area and residential areas;
- ii) Recording and monitoring of CAAQMS data;
- iii) Monitoring of harbor water quality
- iv) Submission of compliance reports of the conditions put forth by GSPCB / CPCB as per the EC and CTO Conditions



25. It is stated that an action plan on environment management has also been drawn up and the same was implemented by MPA .

**Short term plan**

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- To reduce fugitive dust, agents have to cover the coal stack with tarpaulin,
- Usage of truck mounted fog cannons while loading / unloading;
- Construction and operation of wheel wash (truck tyre clearing system ) at the interface of Port and city road;
- Operation and maintenance of CAAQM stations at identified area of Port.



#### **Medium term plan**

- Setting up of Dust barriers at the interface of Port and city;
- Sweeping of roads within Port and City Roads by Mechanical Sweeping Machine;

- Upgradation and Concretization of internal Roads including their shoulders;
- Setting up of settlement tanks by the PPP operators.

**Long term plan ( Under Implementation )**

- Massive plantation programme to increase the Green cover;
- Development of dedicated cruise terminal.

26. Besides MPA has taken the the following Major initiative in the Year 2023-2024 for implementation of Green Port Policy Guidelines ( Harith Sagar ) issued by Ministry of Ports , Shipping and Waterways ( MoPSW ) to reduce the carbon emission .
- i. Setting of Solar FARM on over 20,000m2 area for generating 3.5 kw of Renewable Energy.
  - ii. Plantation of over 5000 nos local tree species to increase the green cover.



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iii. Supply of Treated Water from Sewerage Infrastructure Development Corporation of Goa Limited (SIDCGL) for dust suppression system, thereby reducing and total elimination and usage of potable and ground water for dust suppression.

iv. Installation of Eight additional Continuous Ambient Air Quality Monitoring parameters with Real Time transmission to CPCB and GSPCB server.



27. It may be pertinent to note that a PIL Writ Petition No. 24/2018 is pending in the Hon'ble High Court of Bombay at Goa filed by Sherwyn Filipe Francisco Correia (Petitioner No.1), Sanjay Ankush Redkar (Petitioner No. 2), Parshuram Sonurlekar (Petitioner No. 2), Old Cross Fishing Canoe Owners Co-op Society Ltd. (Petitioner No. 4), The Concerned Citizen (Petitioner No. 5) and Goa Foundation (Petitioner No. 6). Mormugao Port Authority is Respondent No. 3 and South West Port Ltd. is Respondent No. 4 in the said Petition. The main relief prayed for in the said PIL Writ Petition No. 24/2018 is to cancel all permissions, minutes, consents, clearances, if granted

for coal/coke handing at MPT and for increases thereof including the letters of the MOEF & CC dated 08.05.2018 and 18.05.2018.

28. It is respectfully submitted that the Environment Clearance and CRZ Clearance dated 11.01.2023 granted to South West Port Ltd. (SWPL) for terminal capacity enhancement at Berths 5A & 6A of Mormugao Port for handling coal and coal products, iron ore and limestone including unutilized and steel products, does not suffer from any legal illegality or legal infirmity.

29. It is respectfully submitted that the present Appeal deserves to be dismissed.

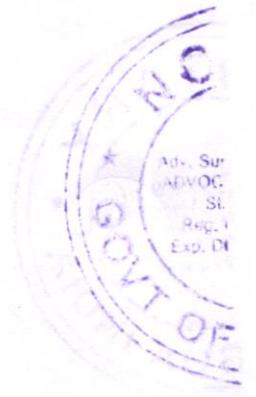
Dated : 30.08.2023

  
**Mr. Santosh A. Naik**

**Santosh Anand Naik**  
**Law Officer & Constituted**  
**Attorney of the Board of**  
**Mormugao Port Authority**

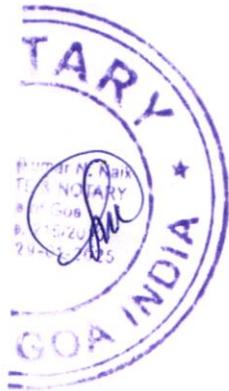
(Constituted Attorney of Respondent No. 3)

  
(Advocate for Respondent No. 3)



**VERIFICATION**

I, Mr. Santosh A. Naik, aged 57 years, residing at Vasco da Gama, Law Officer Gr. I and Constituted Attorney of the Respondent No. 3 abovenamed say that the statements of facts made in the Reply are on the basis of information derived from records to which I have access and submissions made therein are on the basis of legal advice which I believe to be true and submissions made therein are on the basis of legal advice which I believe to be true.



Vasco-da-Gama, Goa.

Dated : 30.08.2023

**(Mr. Santosh A. Naik)**  
**Santosh Anand Naik**  
**Law Officer & Constituted**  
**Attorney of the Board of**  
**Mormugao Port Authority**



Executed before me  
by Mr Santosh  
A- Naik Law Officer & Attorney  
of MPA  
which I attest

**Adv. Surajkumar N. Naik**  
**NOTARY**  
**STATE OF GOA**  
**36, Ground Floor, Apra Bazar, Bldg.,**  
**VASCO-DA-GAMA, GOA - 403 802**  
Date : 30/08/2023  
Reg. No.: 13897/2023

# EXHIBIT R1

Project Study Report

# Particulate Source Apportionment Study for Air Quality in Vasco da Gama, Goa

Prepared by

Air Pollution Research Laboratory  
Environmental Science and Engineering Department



**IIT Bombay**

for



**GSPCB – MPT**

**Goa**



December 21, 2021

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#### **Annexure I**

#### **Acknowledgements**

# Chapter 1

## Introduction

### 1.1 Introduction

Air pollution problem becomes complex due to multiplicity and complexity of air polluting sources such as, but not limited to, industries, automobiles, generator sets, domestic fuel burning, road side dust, construction activities, and biomass burning. A cost-effective approach for improving air quality in polluted areas involves (i) identification of emission sources; and (ii) assessment of extent of contribution of these sources on ambient environment. Source apportionment (SA) exercise relates the source emissions to their quantitative contribution on ambient air pollution.

Source apportionment is largely performed in complementary ways. The traditional approach used is dispersion modeling, where a pollutant emission rate and meteorological information are used as input data in a computer model. The resulting pollutant concentration at a point in space and time is generated as output from such models, which often include chemical transformations during dispersion for reactive species. An alternative approach is receptor modeling, in which the concentration measurements at a receptor are used as input data in a mathematical model. The number of possible sources and their quantitative contribution at the receptor is generated as the output from these models. There are numerous studies conducted worldwide on the characterization of PM and source apportionment to address air quality management issues in urban areas. Results from these studies have been used to formulate policy guidelines for the effective control of pollution from sources at local and regional levels.

Due to activities of dusty cargo handling in the Mormugao Port area, GSPCB invited a source apportionment study to be conducted in Vasco da Gama, with a view to address primarily the issue of Particulate Matter, with specific attention to the potential and extent of influence of port activities of coal cargo handling as the source of emissions. The work orders and administration details for the approved proposal are included as Annexure I.

GSPCB initiated an air pollution source apportionment study in Vasco da Gama with a view to primarily address the issue of Particulate Matter in the ambient air (Annexure I). The funding agency for the project is MPT, Vasco da Gama. The study was carried out by IIT Bombay.

## 1.2 Project Timeline

Work order date	: 8 November 2017
Project Duration	: 18 months
End date	: May 7, 2019
Status	: Phase One - Completed (July 2019); Revised: September 11, 2019 : Phase Two - <ul style="list-style-type: none"> <li>○ Sampling campaign November 11 to December 2, 2019</li> <li>○ March 2020 – present: Lockdown related delays</li> <li>○ EC-OC Analyses carried out at NEERI Nagpur</li> <li>○ Interim Report submitted on December 1, 2020</li> <li>○ EDXRF analyses (April, 2021) and IC analyses (July, 2021)</li> <li>○</li> </ul>
Status of Reports	: Final Report Draft Submitted August 22, 2021 : Discussions with GSPCB on September 21, 2021 : Final Report including Experts Advice submitted on December 11, 2021

## 1.3 Project Budget

Budget outlay	: Total Project	Rs. 94,50,000 + Taxes
First Instalment	: A 03/11/2017 : B 14/12/2017	Rs. 69,75,000 (Project Funds) Rs. 12,55,500 (Taxes)
Second Instalment	: C1 24/11/2021 : C2 24/11/2021	Rs. 16,50,000 (Project Funds) Rs. 2,97,000 (18% taxes)
Balance	: D	Rs. 8,25,000 + Taxes Due on submission of Final Report (Invoice to be prepared and sent from IIT Bombay to MPT through GSPCB)

## 1.4 Overview of Project Activities

### 1.4.1 Phase I

- A. A preliminary field sampling was carried out in the study area in November 2017, where co-located PM sampling was carried out with the CAAQMS in JSW coal handling area, with the intent to compare the CAAQMS station measurements and instruments that are to be used for long term seasonal sampling. Along with this, a loop study was carried out in Vasco da Gama during the morning (6:00 AM to 10:00 AM), afternoon (12:00 noon to 3 PM) and evening (5:00 PM to 10:00 PM) hours in which multiple representative locations were selected to understand the spatial and temporal variation of PM pollution levels in the Vasco city area at different times of the day.

- B. A survey was carried on February 20, 2018 by personnel from GSPCB, MPT and IIT Bombay to identify possible locations for the sampling as proposed in the project scope. The choice of sampling points was such that the entire Vasco city area would be represented, and also include all different types of locations such as residential locations, commercial locations, and mixed sources locations.
- C. A pre-monsoon sampling campaign was carried out during May 2018. Sampling locations were selected based on model results as described next. Fifth-Generation Penn State/NCAR Mesoscale Model (MM5) data (meteorology) were procured (for 2016-17 period) and used as input in the regulatory atmospheric dispersion model (AERMOD). This was intended to understand the expected contribution of pollutants from the port operations as the source.
- D.  $PM_{10}$  and  $PM_{2.5}$  samples were collected on both Quartz and Teflon filters from May 1 to May 14, 2018.
- E. AERMOD runs were carried out for both annual and seasonal meteorological conditions. Attempt was made to use the source strength adopted for the dispersion model (AERMOD) runs from the USEPA document for emission factors (EF's).
- F. In December 2018, preliminary  $PM_{10}$  samples were collected at the berths with ongoing operations in JSW (Limestone) and Adani (Coal) for estimating the source strength for the AERMOD. The source contributions were used as representative of emission during cargo handling during the period of the sampling (in December 2018) and AERMOD runs were carried out with the revised emission estimations.
- G. There has been a concern whether the “nuisance” value of particulate matter is due to the dry deposition of wind-blown particulate matter. These are largely not accounted for when ambient sampling is carried out for  $PM_{10}$  and  $PM_{2.5}$ . Under normal meteorological conditions large particles travel for a short distance from the source and therefore likely to be a local concern only. Along with the 24-hour sampling study, a few coupon samples were also taken to get a sense of deposits of fugitives in and the near vicinity of the port.
- H. The historical ambient air quality monitoring data for stations in Vasco da Gama and stations in other parts of Goa were provided by GSPCB and were used to study the seasonal and historical pattern of PM levels in the Vasco and neighboring areas.
- I. Ten samples of  $PM > 10 \mu m$  were provided by GSPCB for 5 dates, two samples for each day (one from Fire Brigade Station NAMP sampler and the other from Fuse Call Office NAMP

Sampler). Thermo-gravimetric analyses (TGA) were carried out on 4 samples (from two days) to understand the content of the samples in terms of volatile and fixed carbon content.

- J. There had been a delay in the procurement of the samplers. These were received at the end of June 2019 and were calibrated and deployed in November 2019 (after the monsoons and during 21 days of November-December 2019) for the sampling campaign in Vasco da Gama (Details in Chapter 2).

#### 1.4.2 Phase II

- A. Gravimetric Analysis for the Teflon and quartz samples was carried out during December 2019 to February 2020.
- B. Historical and activities data collection, compilation and analyses were carried out as:
- a. Port Activity Data Nov 2019 to Jul 2020
  - b. Ambient Air Quality Monitoring Data (ongoing)
    - i. NAMP Data
    - ii. CAAQMS Data
    - iii. Wind Data from MPT
- C. EC-OC Analysis for PM samples carried out at NEERI Nagpur during July 2020 to October 2020. Analyses based on EC-OC content were carried out (Chapter 2).
- D. Study of the Pollution Levels during Lock-down Period was carried out November 2019 data to July 2020 data.
- E. EDXRF Analysis carried out at ARAI, Pune during Mar 2021 to April 2021
- F. PMF based source apportionment was carried out based on EC-OC and EDXRF data.
- G. AERMOD simulation were made for monthly resolution based on the highest activity level during the sampling campaign.
- H. Discussion on the status of progress held with GSPCB on July 2, 2021
- I. IC analyses for ions was carried out at ARAI Pune during May 2021 to Jul 2021
- J. AERMOD simulation were additionally carried out for season based time frame, as well as potential doubling of the activities (Results are presented in Chapter 3)
- K. PMF based source apportionment exercise was repeated based on EDXRF, IC and EC-OC data sets (Results are presented as Chapter 4).
- L. Summary and Conclusions are presented in Chapter 5.

#### 1.5 Organization of the Report

The report is organized in 5 chapters. Chapter 2 includes all the gravimetric data from the field sampling, the EC-OC data and analyses, and some of the activity data that were available from MPT. Chapter 3 includes the development of the basis for the dispersion model simulations (literature

validations, meteorology, sources and emission rates). Month specific and season specific simulation results are presented as isopleths plots. Chapter 4 includes the results of the source apportionment analyses based on the samples collected during the November 2019 sampling campaign. Chapter 5 presents the summary and conclusions.

# Chapter 2

## Gravimetric and Elemental Carbon-Organic Carbon(EC-OC) Analyses

### 2.1 Field Sampling Campaign

A 21-day Source Apportionment Sampling (SAS) campaign was carried out at 9 locations (Table 2.1, Figure 2.1) in Vasco da Gama, Goa. The foci of the field sampling campaign were two-fold:

- a) To collect samples for source apportionment analyses
- b) To study whether the coal operations at the port were affecting the locations that were reported to be affected by “coal dust”.

The duration of the campaign was November 11, 2019 to December 2, 2019. A total of 5 locations were used for PM<sub>10</sub> and PM<sub>2.5</sub> on Teflon and Quartz filters (20 Airmetrics samplers from IITB), while additional 4 locations were sampled for TSP using eight IITB Airmetrics samplers and two GSPCB High-Volume samplers.

A total of 28 samplers were used. The samplers are Federal Reference Method Airmetrics “mini-volume samplers” with a calibrated flow rate of 5 lpm. The samples were all taken as 24-hour averages, with new sample filters being replaced every day at the same time at each location.

Gravimetric analyses were conducted on the samples collected during SAS sampling for the matrix of the sampling locations and the types of samples collected (Appendix A). The actual gravimetric results are voluminous, and are therefore presented in the form of time-series plots for PM<sub>10</sub>, PM<sub>2.5</sub> and TSP, and relevant ratios and comparisons based on locations.

**Table 2.1 Details of Nine Sampling Locations**

<b>Sr. No.</b>	<b>Sampling Locations</b>	<b>Latitude</b>	<b>Longitude</b>	<b>PM<sub>2.5</sub></b>	<b>PM<sub>10</sub></b>	<b>TSP</b>	<b>RSPM</b>
1	Fuse Off Call Office	15.3976	73.8116	Yes	Yes	-	-
2	Goldsmith House	15.4053	73.8031	Yes	Yes	Yes	-
3	MPT Guest House	15.4109	73.7905	Yes	Yes	-	-
4	Fire Brigade Station	15.4095	73.7969	Yes	Yes	-	-
5	Khariwada	15.4025	73.8151	Yes	Yes	-	-
6	Upper Jetty	15.4061	73.7981	-	-	Yes	-
7	Lower Jetty	15.4072	73.7975	-	-	Yes	-
8	Mangor Hill	15.3901	73.8147	-	-	Yes	Yes*
9	Chicalim	15.3985	73.8443	-	-	Yes	Yes*

\* Using GSPCB High-volume Samplers



**Figure 2.1: Map of area of Vasco da Gama with the 9 locations for sampling. (Yellow for PM<sub>10</sub> and PM<sub>2.5</sub> (20 samplers), and others for TSP) (Please see Table 2.1 for the list)**

## 2.2 Gravimetric Results at the Nine Locations in Vasco da Gama

PM<sub>10</sub>, PM<sub>2.5</sub> and TSP gravimetric measurements were plotted for the sampling period of November 11 to December 2, 2019.

### 2.2.1 Time series for PM10, PM2.5 and TSP and Sensitivity to the Sampling Locations

For the five locations (1 to 5 in Table 2.1), Figure 2.2 (a to c) show the time series results for PM<sub>10</sub>, PM<sub>2.5</sub> and TSP on Teflon filters, and Figure 2.3 (a to c) show the results for PM<sub>10</sub>, PM<sub>2.5</sub> and TSP on quartz filters. The dashed lines indicate the 24-hour NAAQS standards for PM<sub>10</sub> and PM<sub>2.5</sub>.

The PM<sub>10</sub> levels were observed to be higher at the Fire Brigade Station, Goldsmith House and Fuse-off Call Office locations, and this location-based difference is prominent for PM<sub>10</sub> (dust fraction), compared with the PM<sub>2.5</sub> which were observed to be almost independent of the 5 locations.

Figures 2.2(d) and 2.3(d) are plots of PM<sub>10</sub> vs. PM<sub>2.5</sub> on Teflon and quartz filters respectively, and are intended to indicate the ratio of the PM<sub>2.5</sub> to PM<sub>10</sub> for the 5 locations. A higher ratio indicates sources of combustion and finer fraction dominating the particle size distribution (PSD), while a smaller ratio indicates greater contribution of dust, crustal and resuspended materials to the PSD. For both the Teflon and quartz filters, the Fire Brigade Station and Goldsmith House locations indicate a lower ratio throughout; MPT location shows the highest (marine aerosols more than dust); and Khariwada and Fuse off Call office locations are between the two slopes.

Figure 2.2(c) and 2.3(c) indicate the Total Suspended Particles (TSP) levels at 5 locations: three near the port area and two at a significant distant away. TSP is not regulated anymore, and therefore this exercise was carried out to evaluate the levels so as to assess if there was a need for continued TSP measurements in the vicinity of the port. This was included at a later stage of the study and the sampling was carried out with limited number of samplers (Airmetrics and Hi-Vol samplers). The TSP levels at Upper Jetty, Lower Jetty and Goldsmith House locations were found to be consistently higher than the Chicalim and Mangor Hill locations. The 24-hour standard for TSP as SPM (before it was retired) were 500, 200 and 100 µg/m<sup>3</sup> for Industrial, Residential and Sensitive areas respectively (URL01). The SAS measurements indicate an average TSP of about 150 µg/m<sup>3</sup> for the 20 days at the 5 locations, with Goldsmith house being about 200 µg/m<sup>3</sup> on most of the days.

The MPT Guest House sampling site was considered to be a relatively “clean” location with respect to the location as well as lower traffic movement. Thus, a comparison was made between all sites with the MPT GH as the baseline on Quartz and Teflon filters (Figures 2.4 (a & b) for  $PM_{10}$ , and Figures 2.5 (a & b) for  $PM_{2.5}$ ). The Mangor Hill and Chicalim sites were observed to have lower RSPM levels compared to  $PM_{10}$  at MPT GH, while the levels were higher at all other sites. However, such is not the case for  $PM_{2.5}$ , where the concentrations were not sensitive to the sampling location. This is an important observation, indicating that the background concentrations of  $PM_{2.5}$  are similar in the region, while the  $PM_{10}$  are dependent on the locations (and thereby the activities in the vicinity of the respective sites).

### 2.2.2 Comparison with NAMP and CAAQMS Station Measurements

Figure 2.6 (a) shows the locations of the NAMP and CAAQMS stations the results for CAAQMS and NAMP data that are routinely reported. For comparison, the SAS data are plotted for  $PM_{10}$  and  $PM_{2.5}$  as Figures 2.6 (b) and (c) respectively. Since the CAAQMS locations are not the same locations as the SAS selected sites, while the NAMP site are the same (Fuse Call off Office and Fire Brigade Station), plots were made to compare SAS and RSPM data at the two NAMP locations (Figures 2.6 (d) and (e)).

Measurement method in NAMP, CAAQMS and SAS are different from one another and the absolute values are not expected to be similar, however, it is in interest to evaluate the trends. Figures 2.6 (f) and (g) show the correlation of the SAS and NAMP data for  $PM_{10}$  and  $PM_{2.5}$  respectively. The correlation for  $PM_{10}$  are visible, but the same cannot be said about the  $PM_{2.5}$  data. The three CAAQMS data are compared with the SAS measurements at the Fuse-off-Call Office for  $PM_{10}$  and  $PM_{2.5}$  in Figures 2.6(i) and (j).

As stated earlier, TSP (SPM) is no more regulated or monitored as a part of the NAMP efforts. Efforts were made in the present study to understand the levels of TSP in the vicinity of the port area. Goldsmith House location was the only location where a collocated sampling was carried out for  $PM_{2.5}$ ,  $PM_{10}$  and TSP. While the correlation between  $PM_{2.5}$  and  $PM_{10}$  have been shown in Figures 2.2 (d) and 2.3(d), Figure 2.7 shows the results for correlation of TSP against  $PM_{10}$  concentrations at the Goldsmith House location. The correlation is poor and the  $PM_{10}$  levels seems to be independent of the TSP.

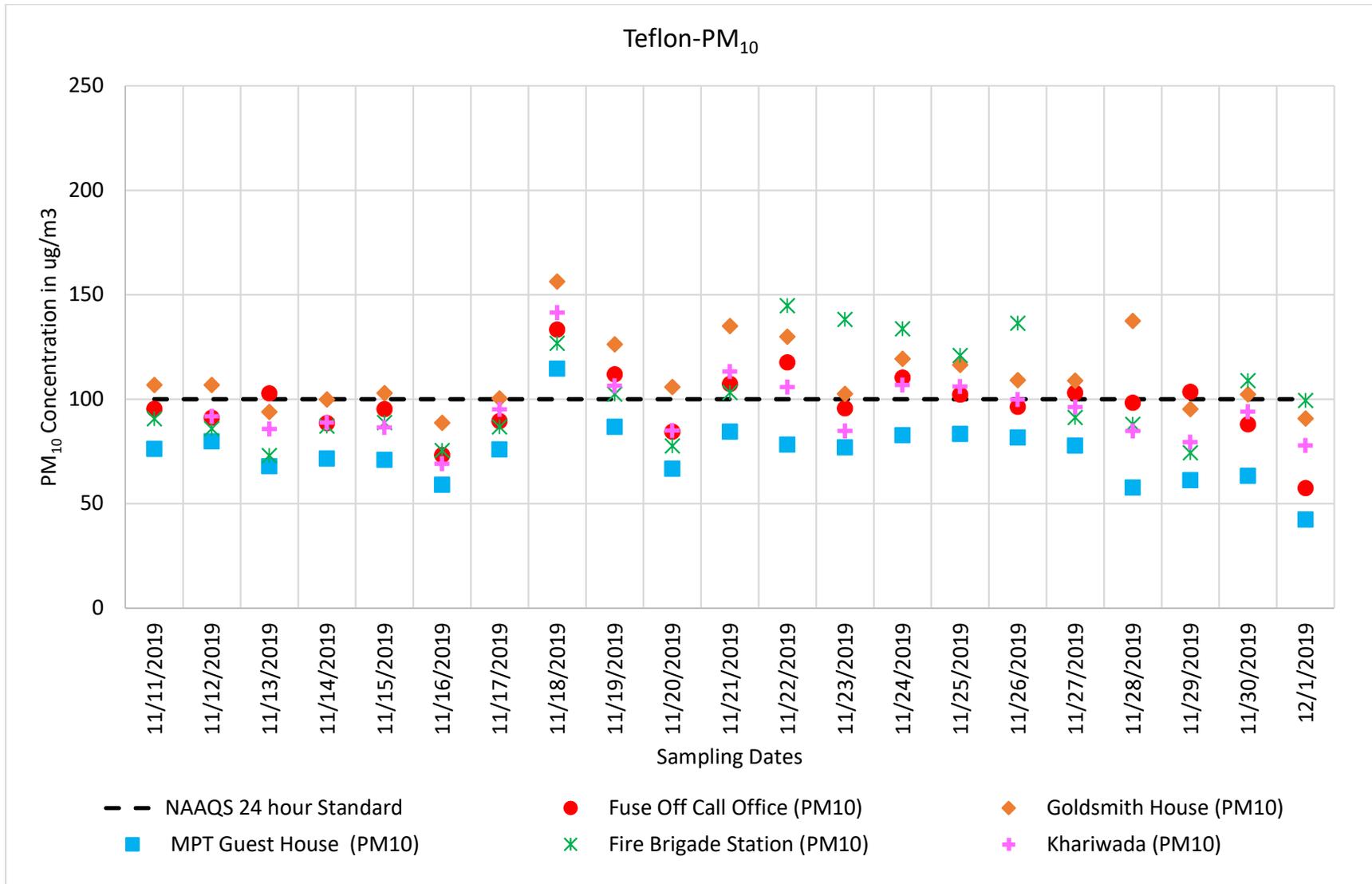
### 2.2.3 Site-Specific Time Series and $PM_{2.5}/PM_{10}$ Ratios

The site-specific time series for the SAS duration are plotted for the 5 locations in Figure 2.8 (a to e). The plots also indicate the  $PM_{2.5}/PM_{10}$  ratios on each day.

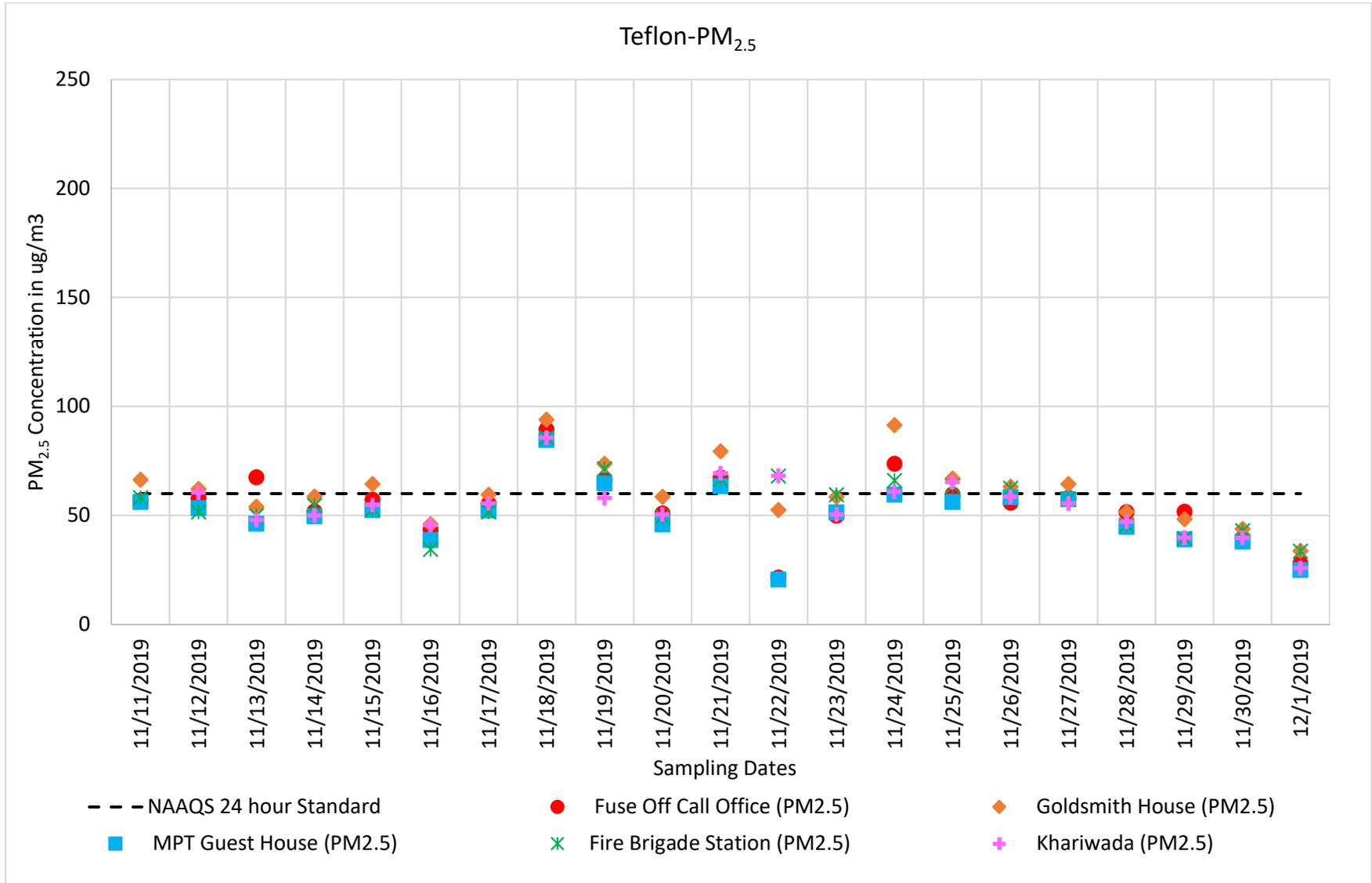
Figure 2.9 shows the  $PM_{2.5}/PM_{10}$  ratios for all the 5 sampling sites plotted against the MPT GH data as the baseline. All the other 4 sites show a lesser ratio than the MPT GH indicating presence of dusty contribution (when compared with MPT that is likely to be largely marine aerosols). Again, Kariwada site being close to the ocean also has a higher ratio as compared to Goldsmith House, Fire Brigade Station and Fuse-Off Call Offices locations.

### 2.2.4 Historical NAMP Data from the Two Stations in Vasco da Gama

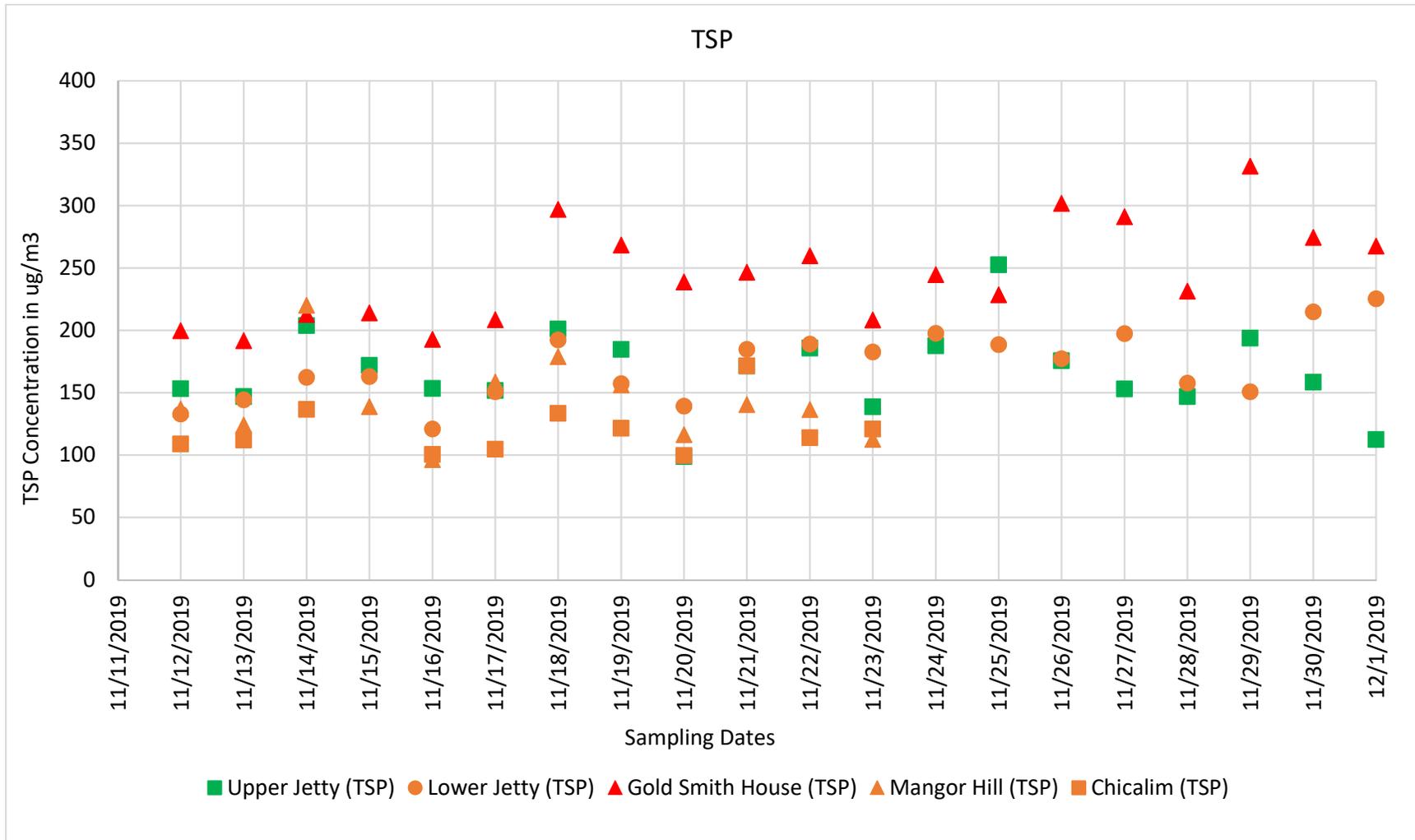
Historical data obtained from the GSPCB website for Fuse-Off Call Office and Fire Brigade Station locations were plotted from the year 2012 to 2019. It is observed that for the 2012-15 time frame, the two locations showed similar seasonal trends and values of RSPM. However, after 2015, two differences are observed : (i) the RSPM levels have increased in both the locations (with similar seasonal trends as in the 2012-15 period; and (ii) the RSPM levels at the Fire Brigade Station location far exceed those at the Fuse-Off Call Office location. These seem to correlate well with the increase in coal activities in the same timeframe as discussed later.



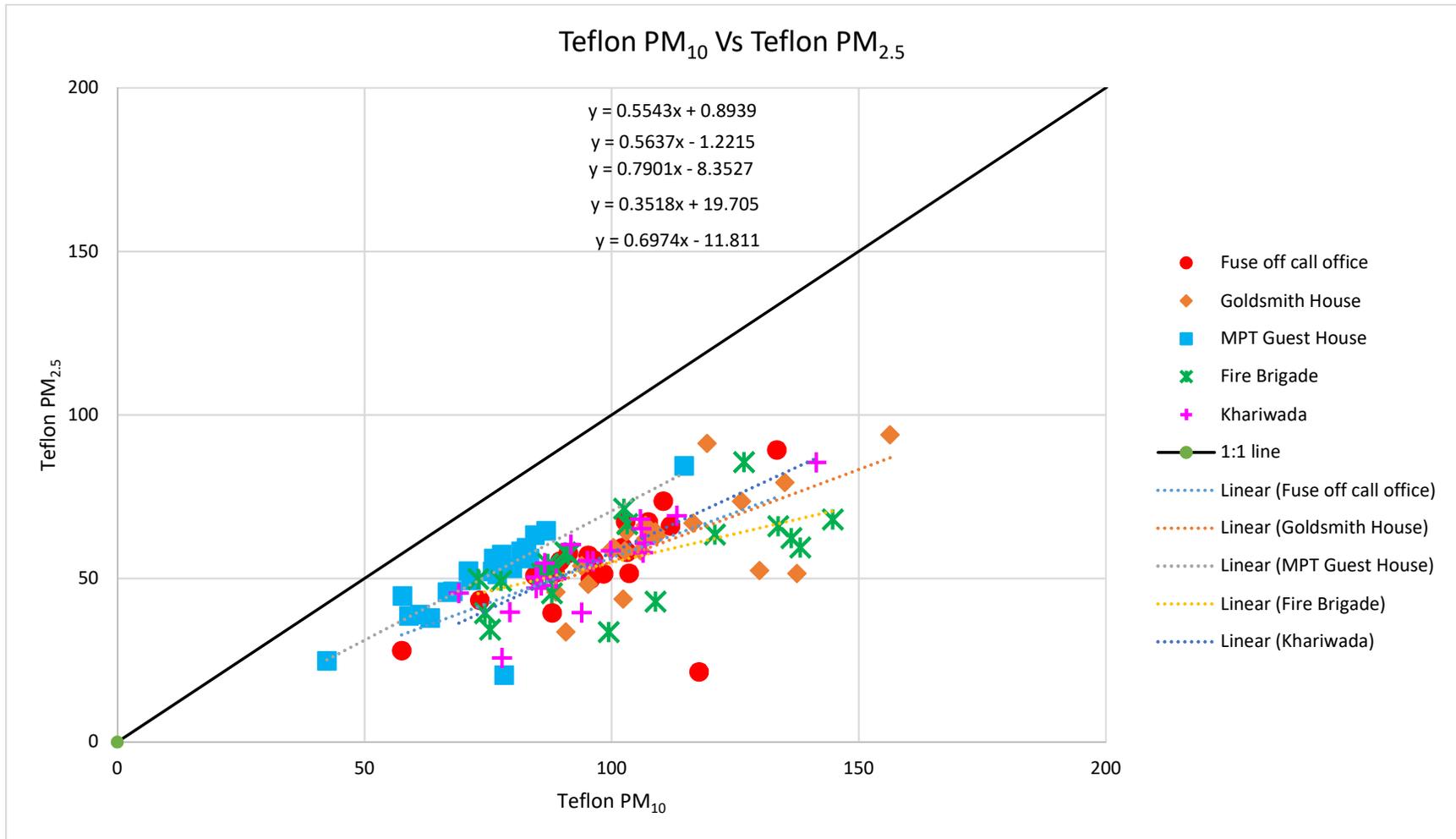
**Figure 2.2 (a): Teflon PM<sub>10</sub> Concentrations: 24-hour average (in µg/m<sup>3</sup>)**



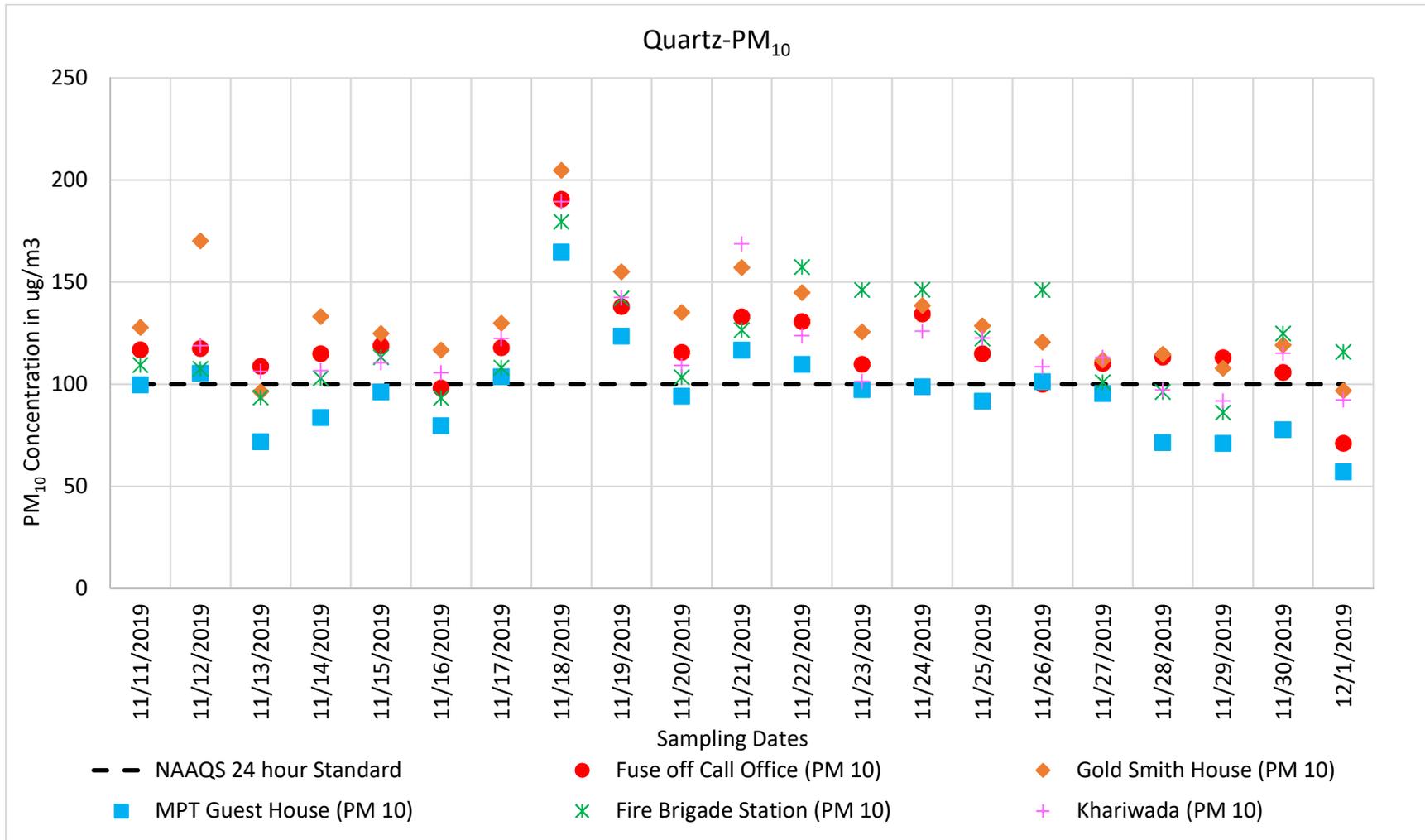
**Figure 2.2 (b): Teflon PM<sub>2.5</sub> Concentrations: 24-hour average (in µg/m<sup>3</sup>)**



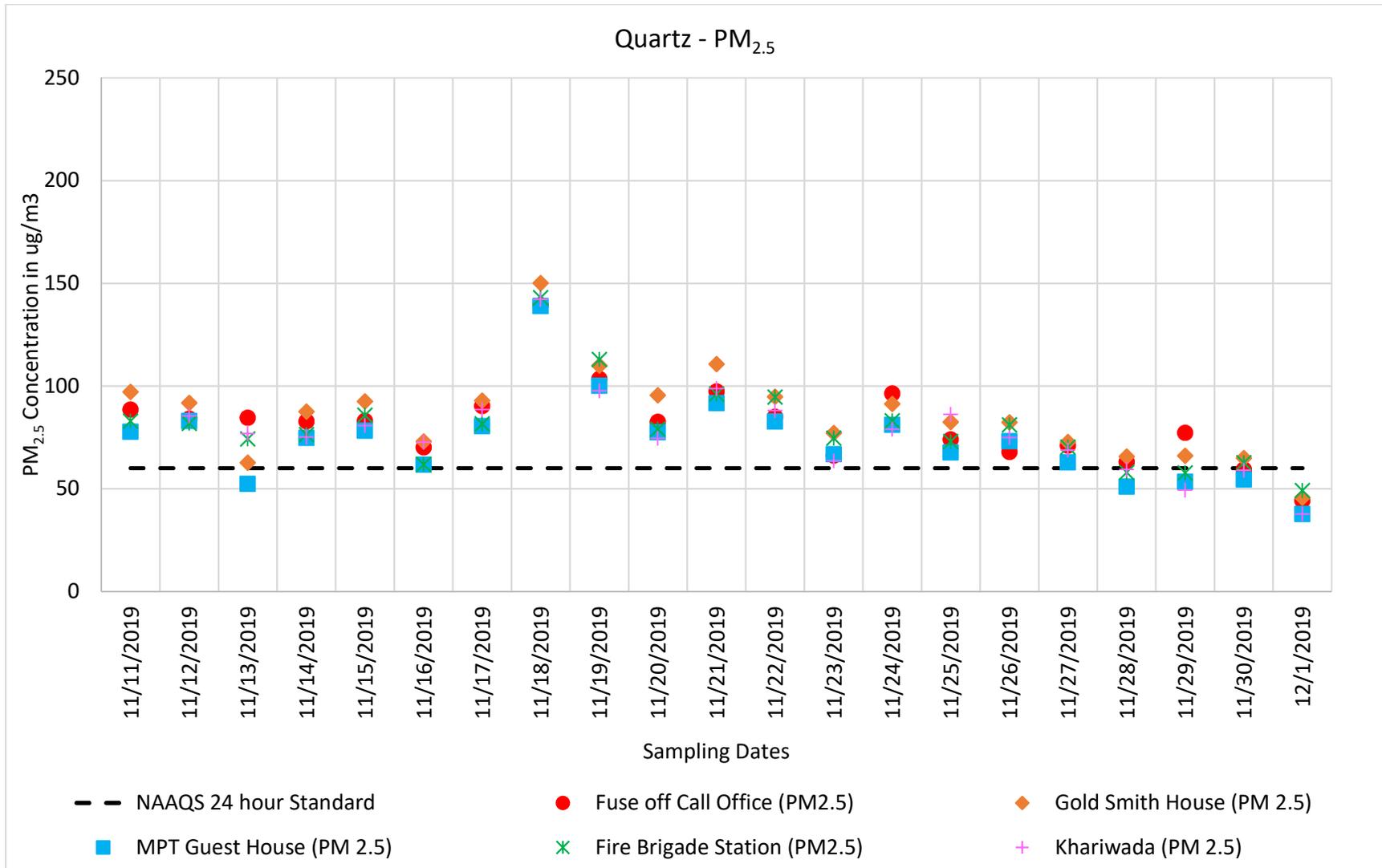
**Figure 2.2 (c): Teflon TSP Concentrations: 24-hour average (in  $\mu\text{g}/\text{m}^3$ )**



**Figure 2.2 (d): Correlation of Teflon PM<sub>10</sub> against PM<sub>2.5</sub> Concentrations**



**Figure 2.3 (a): Quartz PM<sub>10</sub> Concentrations: 24-hour average (in  $\mu\text{g}/\text{m}^3$ )**



**Figure 2.3 (b): Quartz PM<sub>2.5</sub> Concentrations: 24-hour average (in ug/m<sup>3</sup>)**

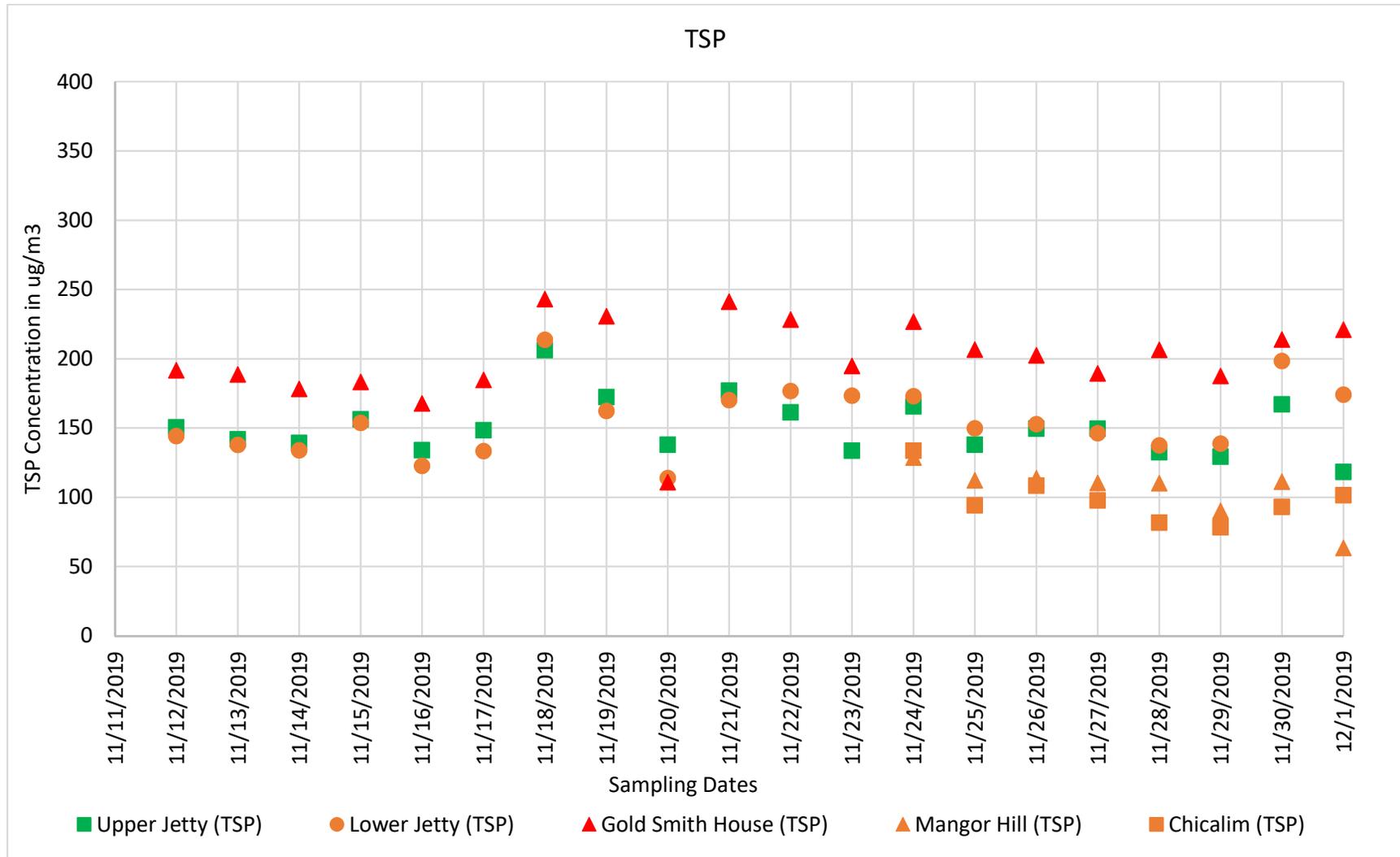
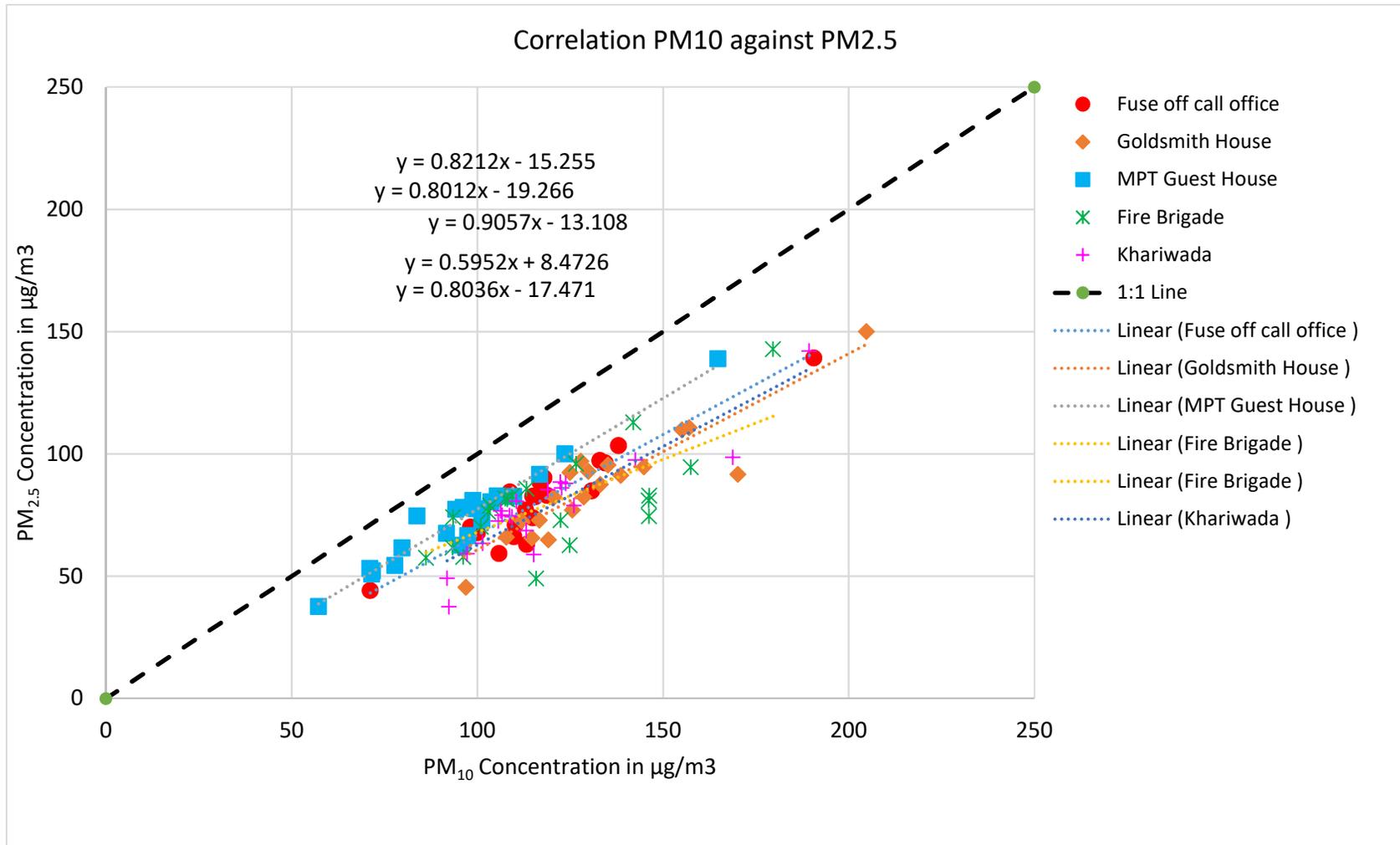


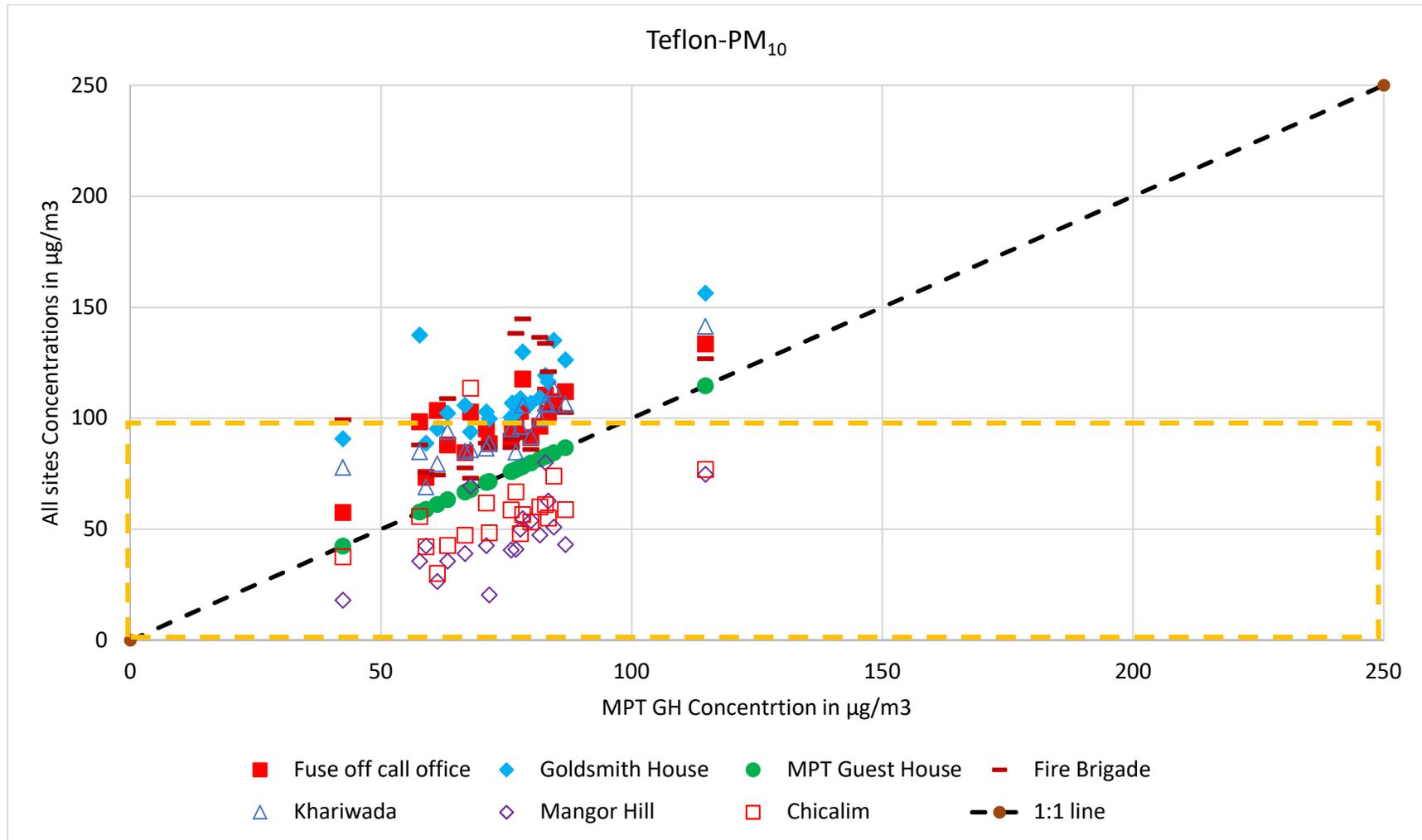
Figure 2.3 (c): Quartz TSP Concentrations: 24-hour average (in  $\mu\text{g}/\text{m}^3$ )



**Figure 2.3 (d): Correlation of Quartz PM<sub>10</sub> against PM<sub>2.5</sub> Concentrations**



**Figure 2.4 (a): Quartz PM<sub>10</sub> Correlation (All sampling Sites Against MPT Guest House)**



**Figure 2.4 (b): Teflon PM<sub>10</sub> Correlation (All Sites Against MPT Guest House)**

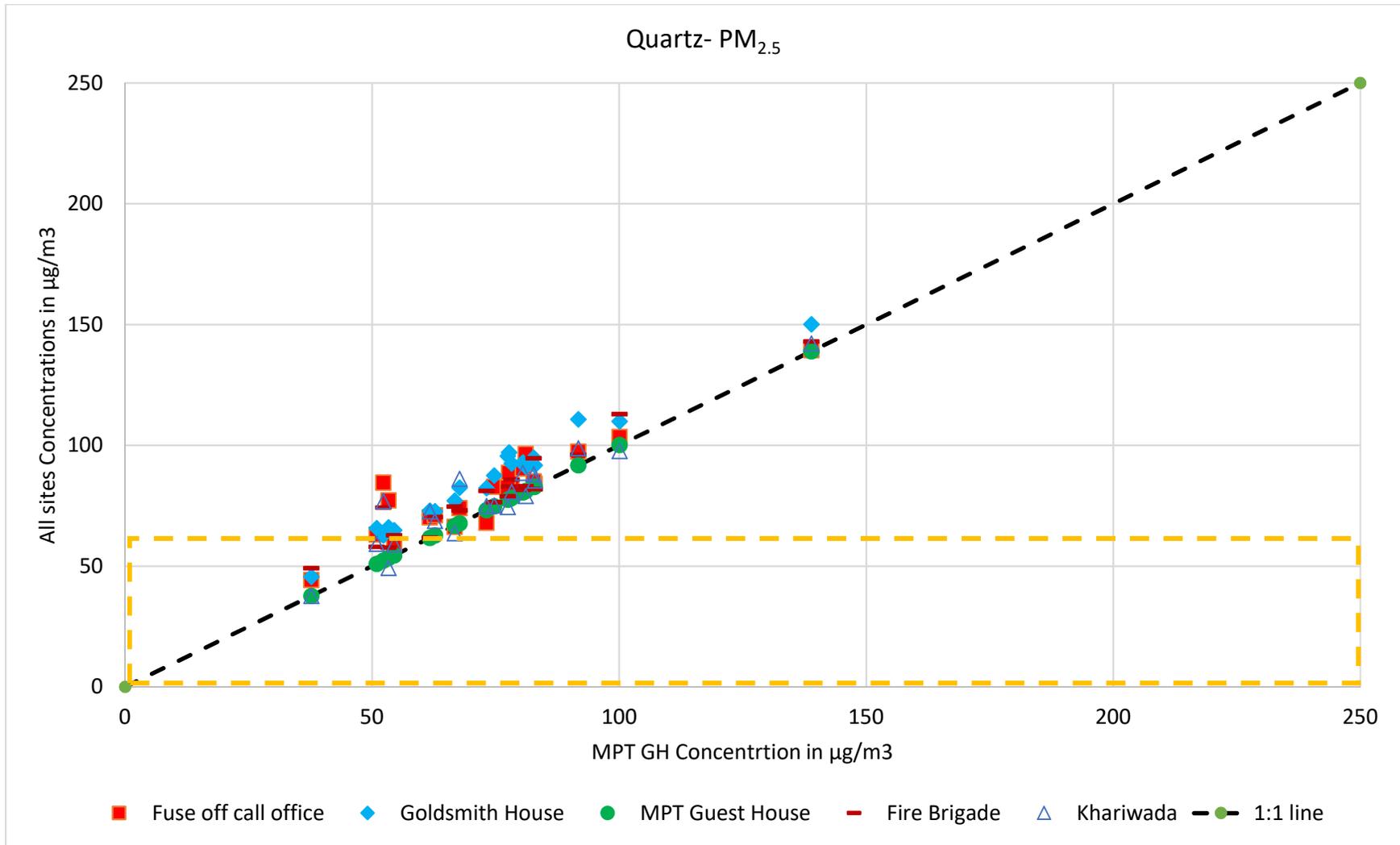
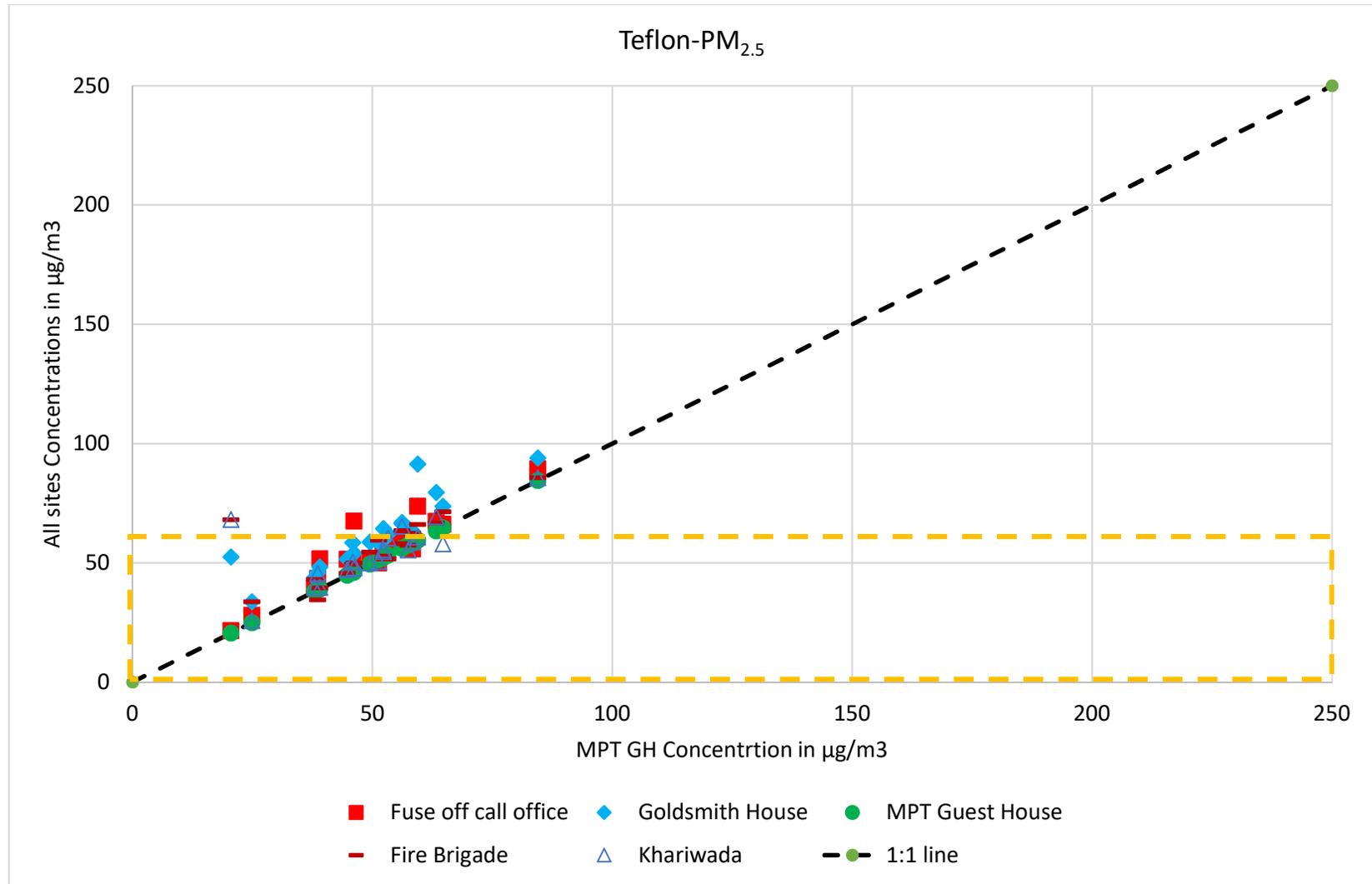
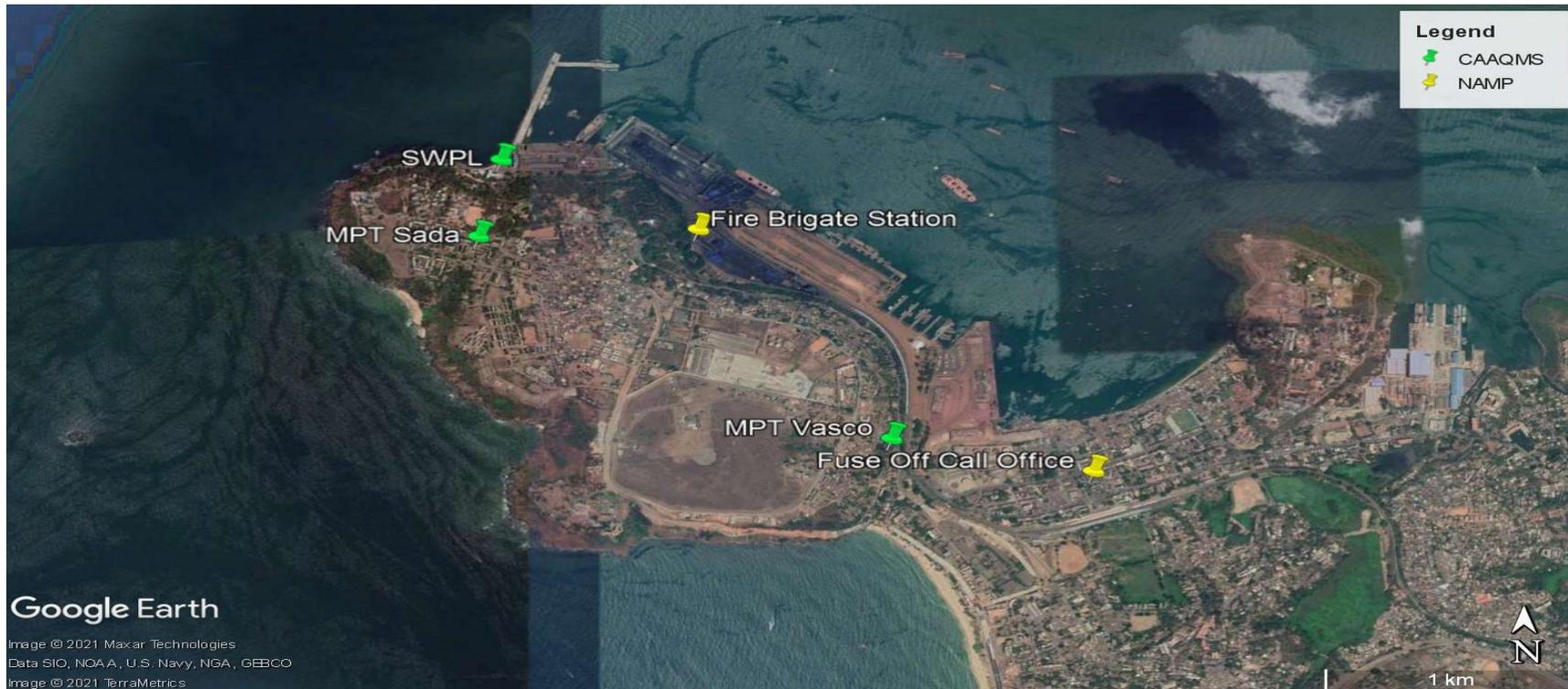


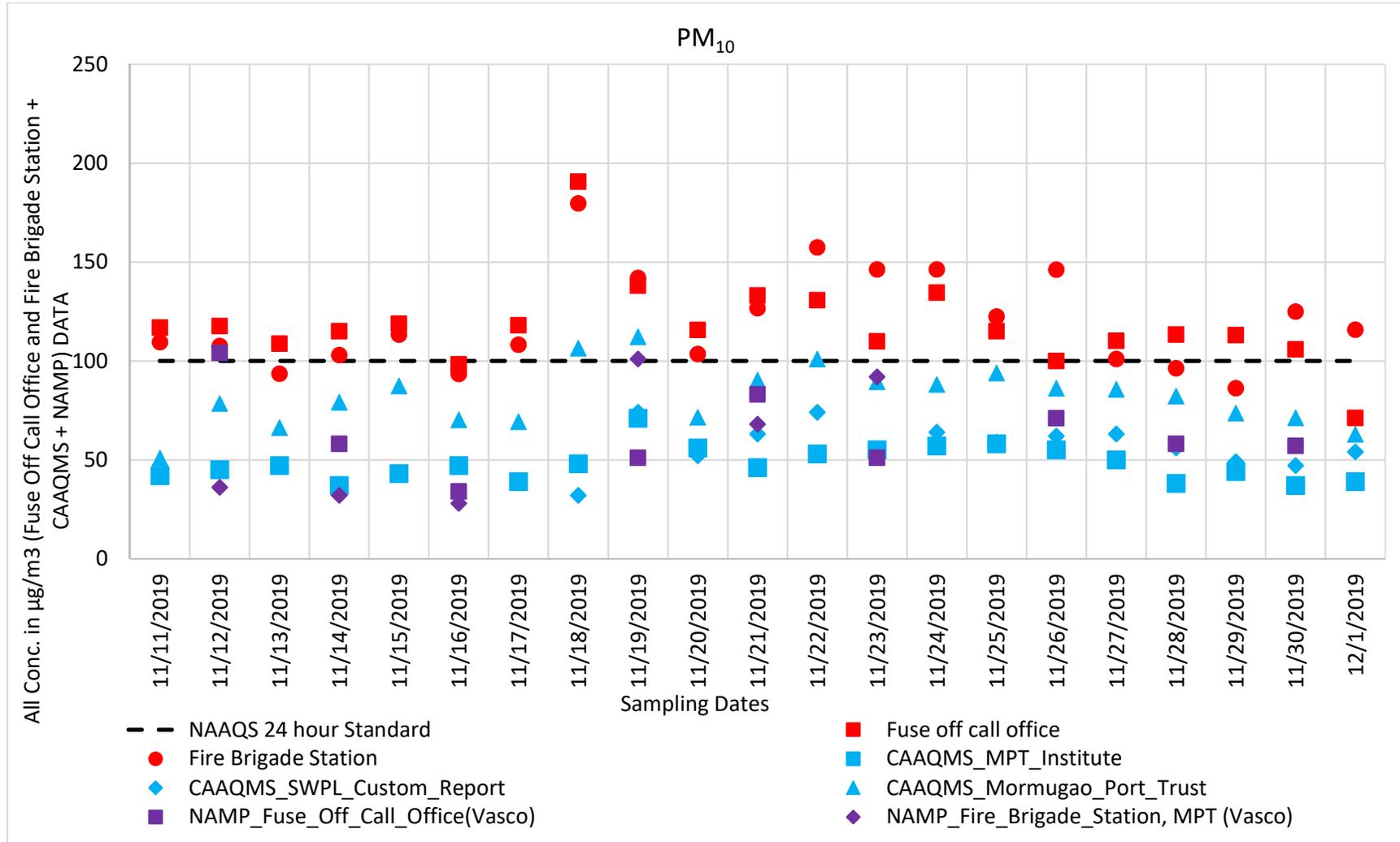
Figure 2.5 (a): Quartz PM<sub>2.5</sub> Correlation (All Sites Against MPT Guest House)



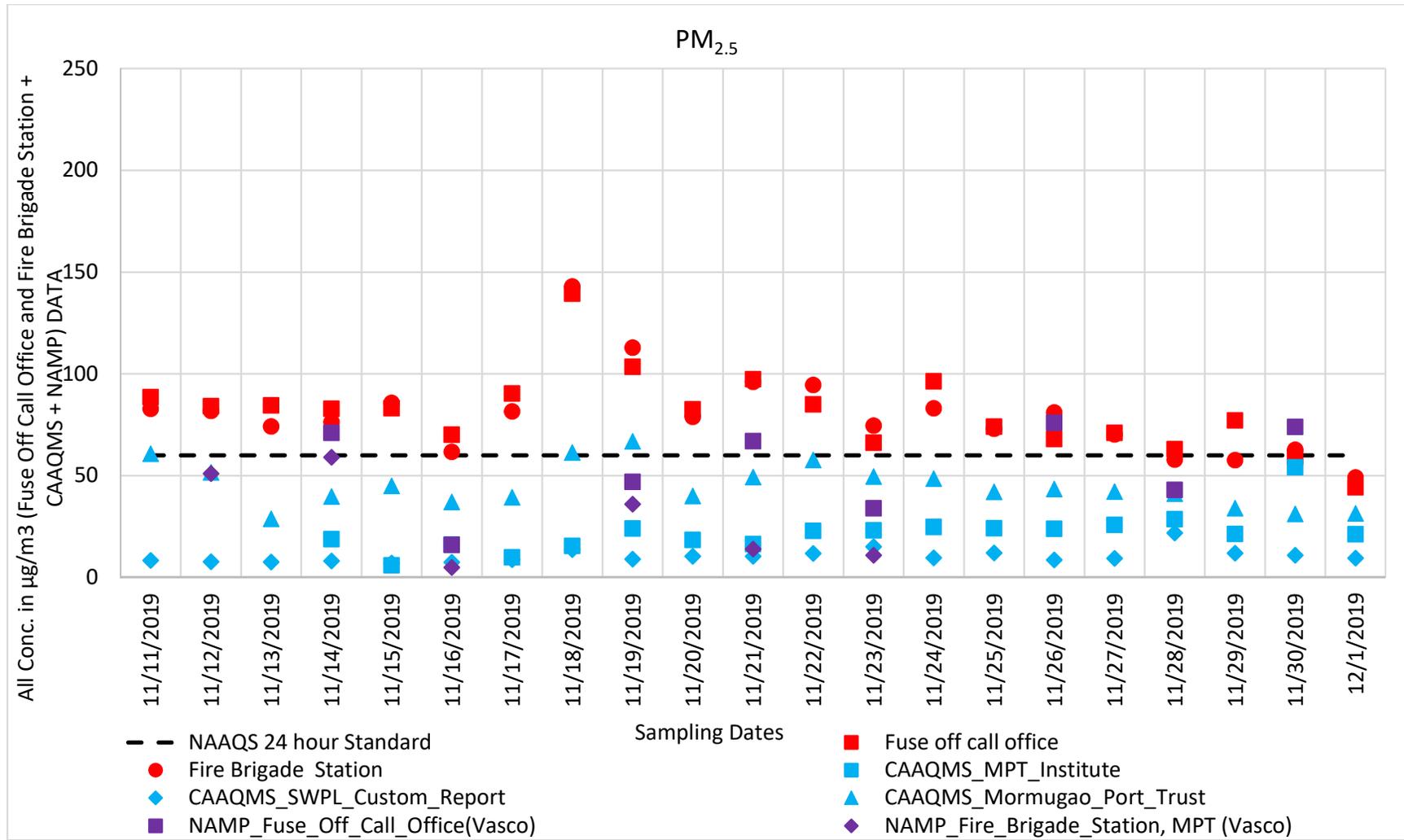
**Figure 2.5 (b): Teflon PM<sub>2.5</sub> Correlation (All Sites Against MPT Guest House)**



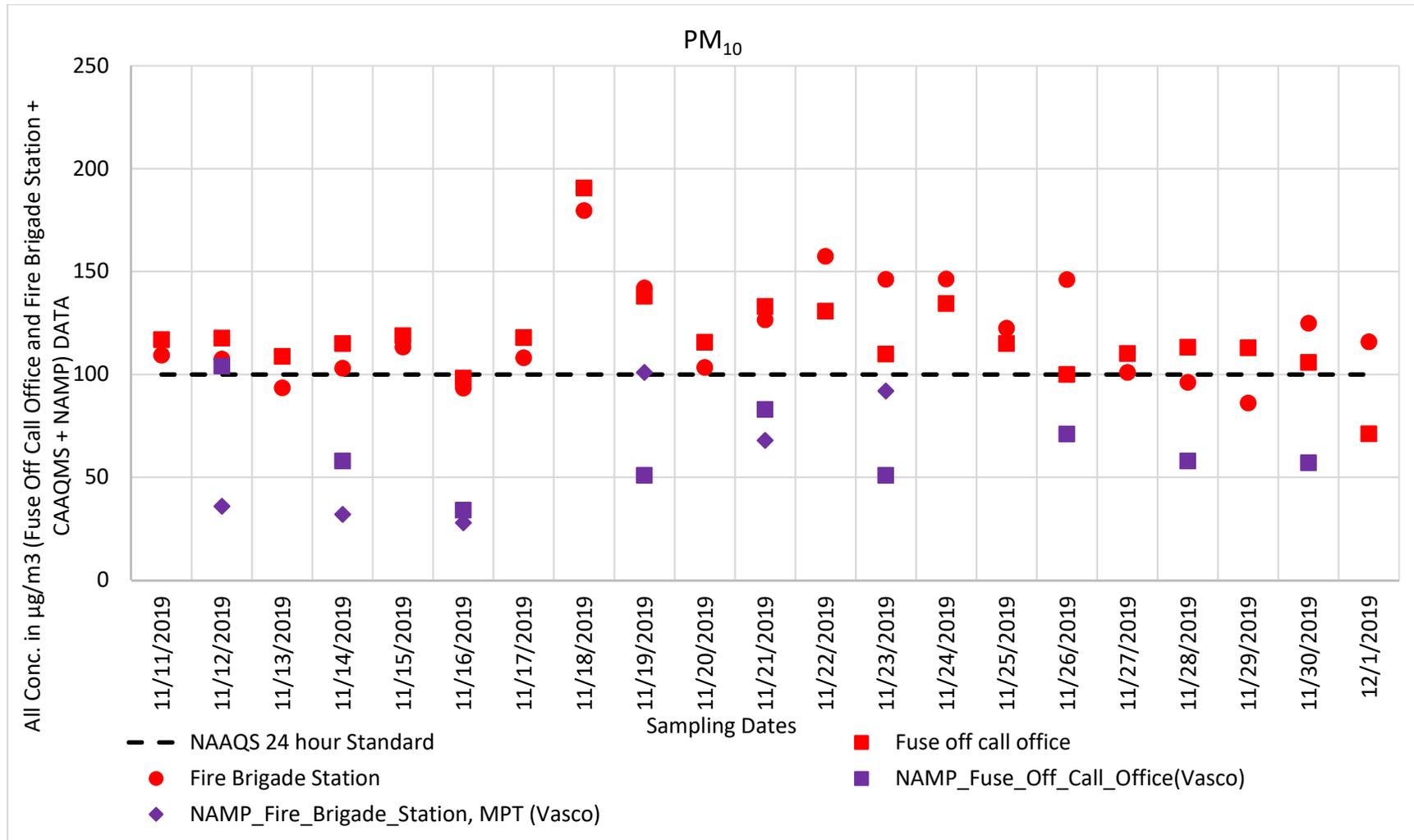
**Figure 2.6 (a): Map of area of Vasco da Gama with 2 locations for NAMP Stations, and 3 locations for CAAQMS Stations (Locations are approximate)**



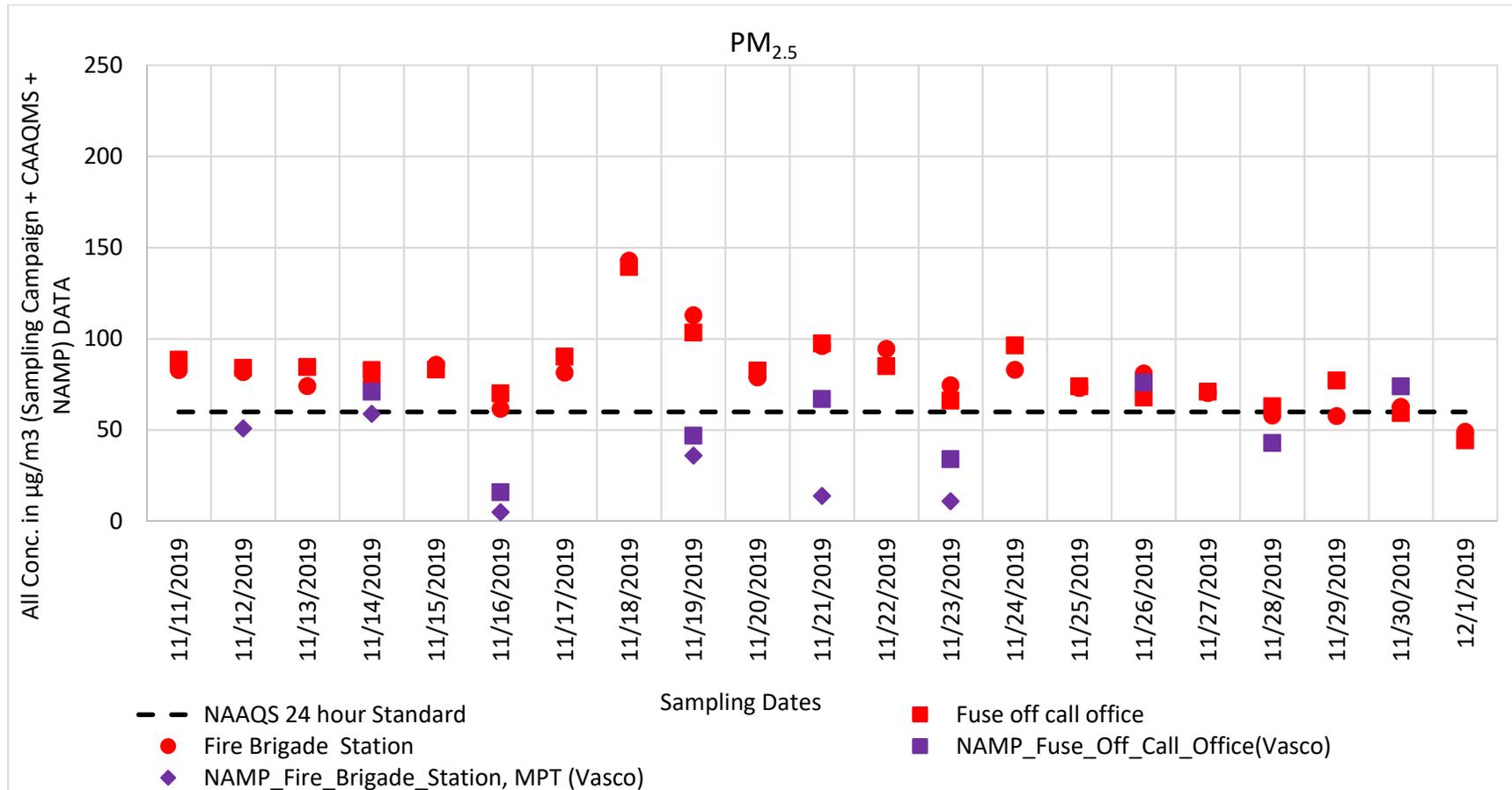
**Figure 2.6 (b): Comparison of (Quartz) during Sampling Campaign PM<sub>10</sub>, CAAQMS and NAMP measurements: 24-hour average (in µg/m<sup>3</sup>)**



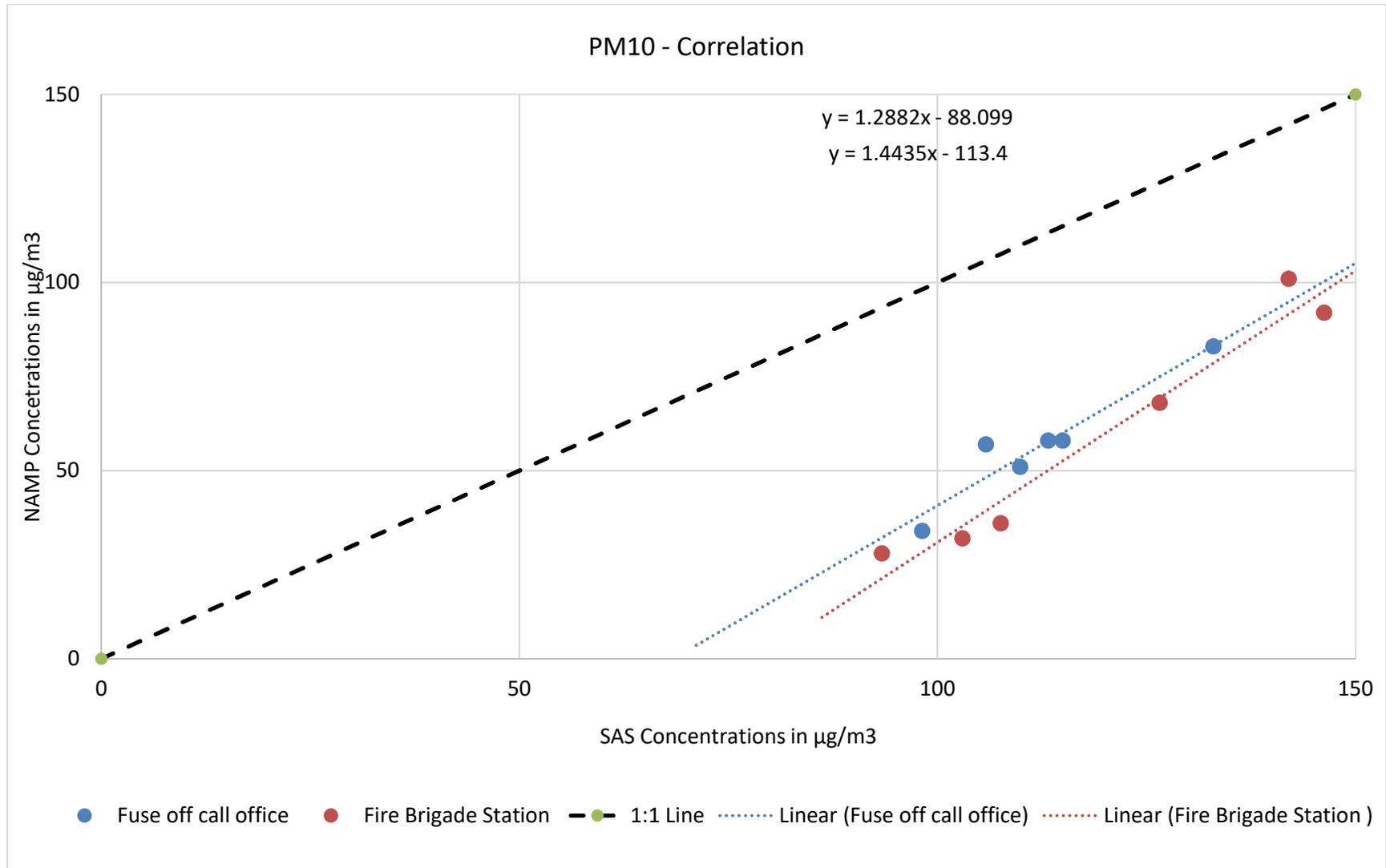
**Figure 2.6 (c): Comparison of (Quartz) during Sampling Campaign PM<sub>2.5</sub>, CAAQMS and NAMP measurements: 24-hour average (in  $\mu\text{g}/\text{m}^3$ )**



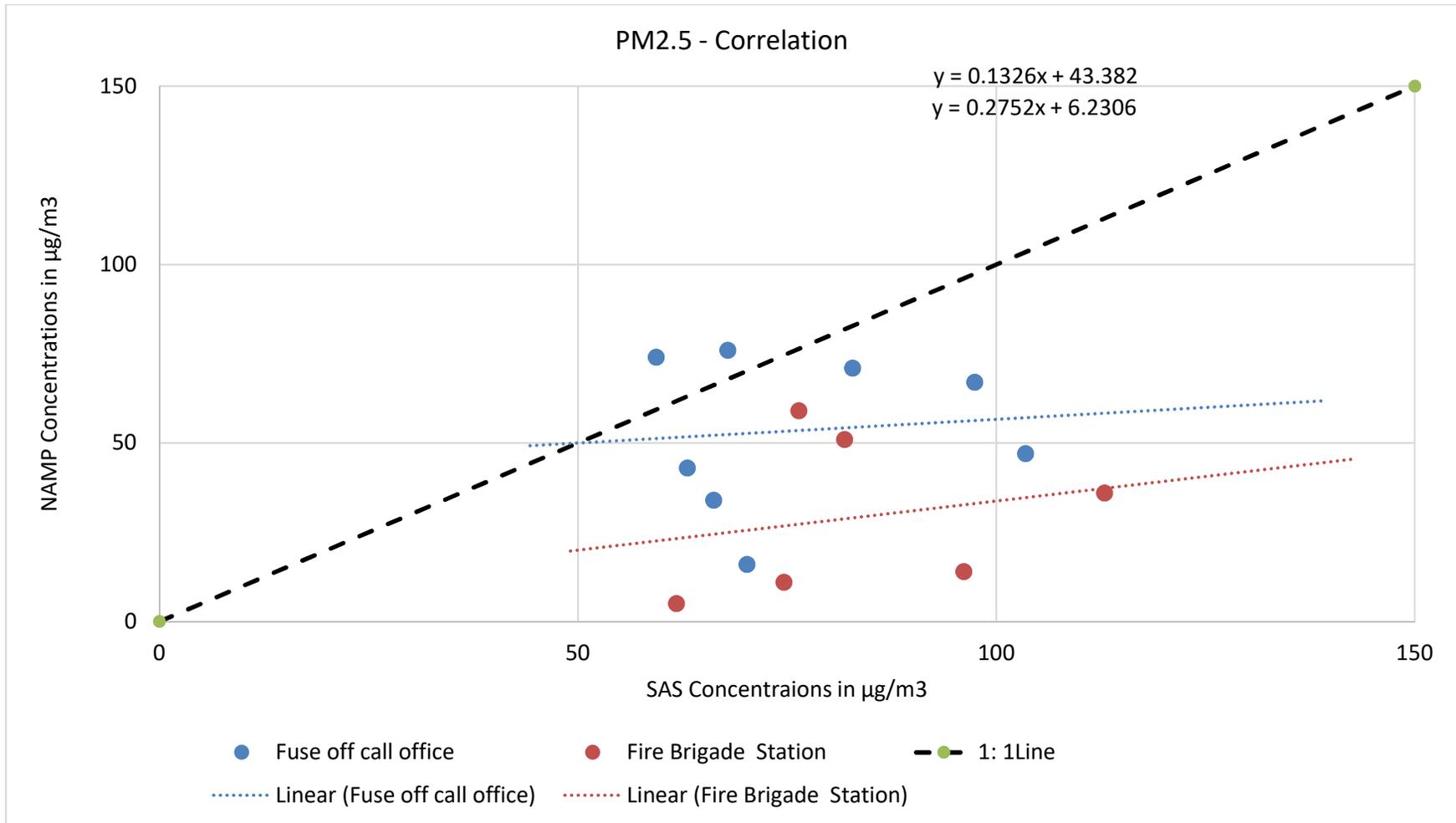
**Figure 2.6 (d): Comparison of PM<sub>10</sub> (Quartz) during sampling campaign with NAMP measurements: 24-hour average (in  $\mu\text{g}/\text{m}^3$ )**



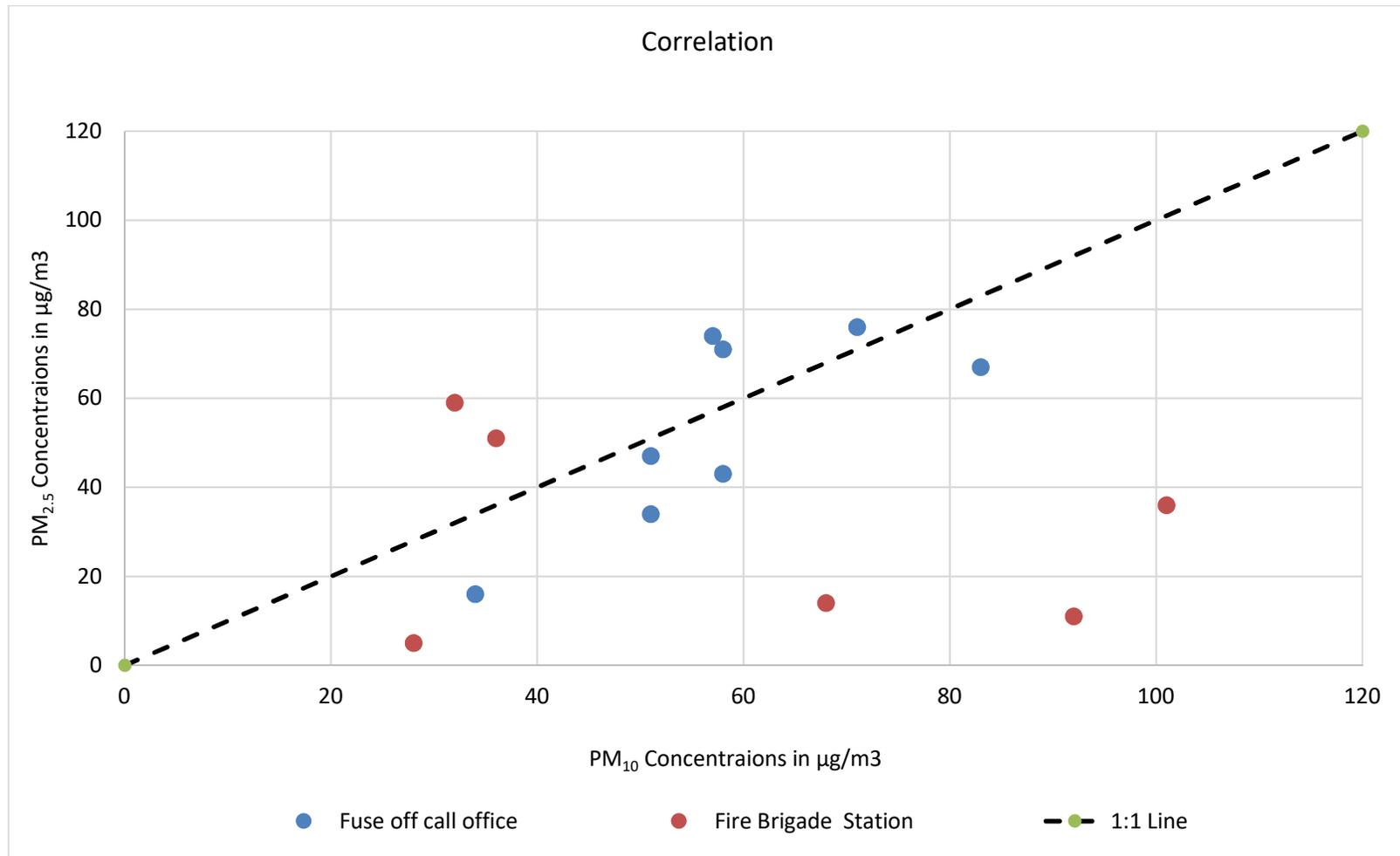
**Figure 2.6 (e): Comparison of PM<sub>2.5</sub> (Quartz) during sampling campaign with NAMP measurements: 24-hour average (in µg/m<sup>3</sup>)**



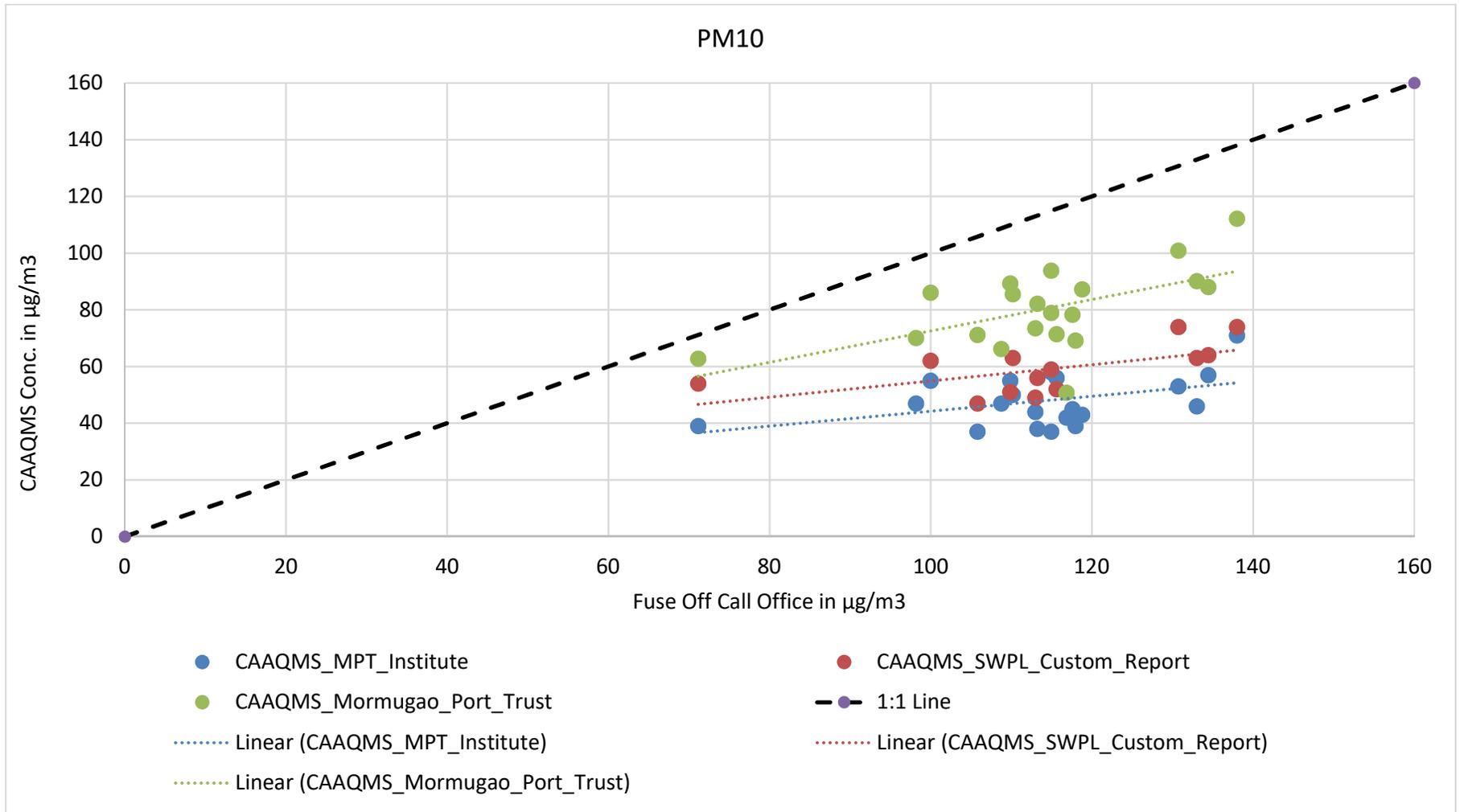
**Figure 2.6 (f): Correlation of PM<sub>10</sub> (Quartz) during sampling campaign with NAMP measurements: 24-hour average (in  $\mu\text{g}/\text{m}^3$ ) with some outliers removed**



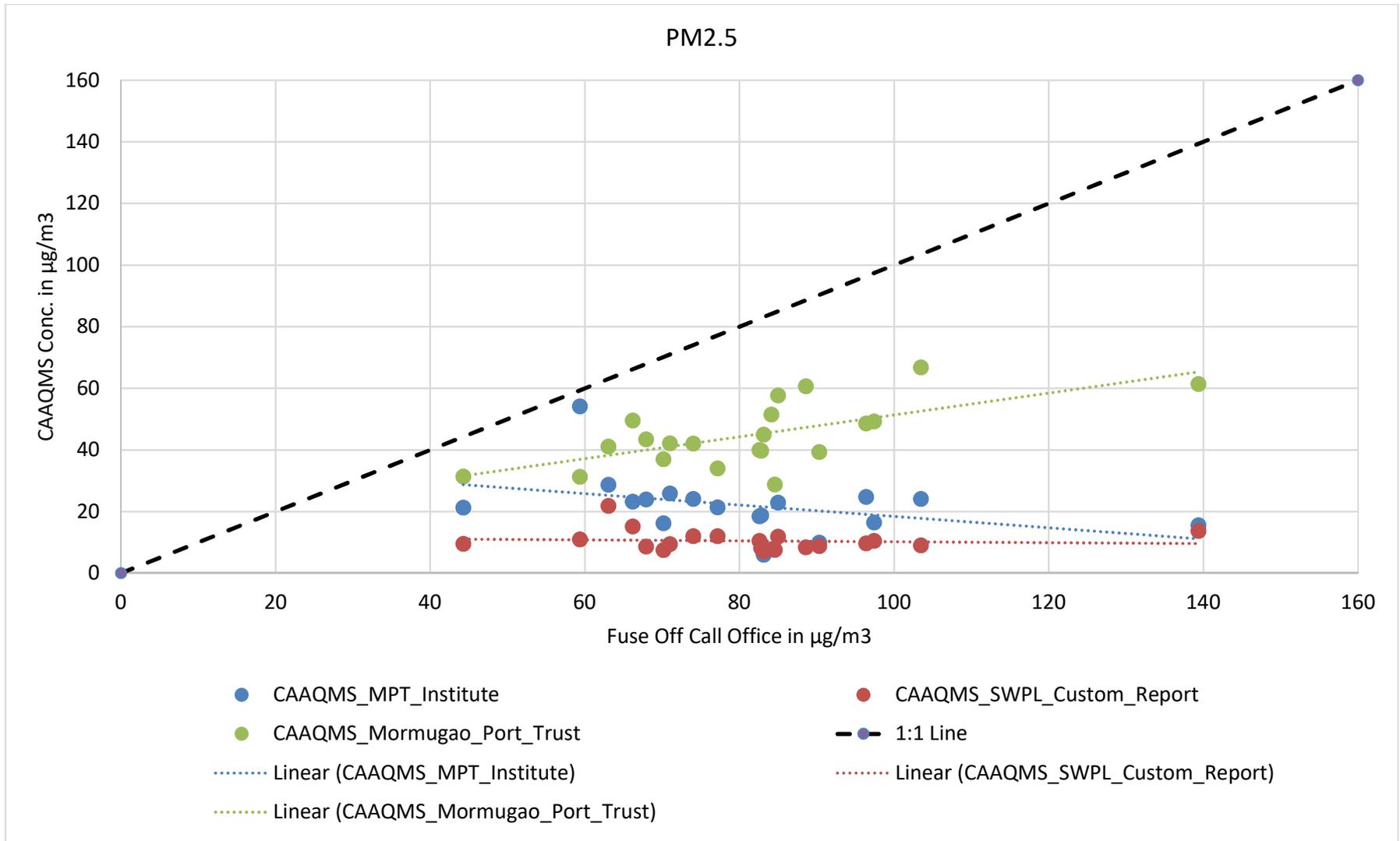
**Figure 2.6 (g): Correlation of PM<sub>2.5</sub> (Quartz) during sampling campaign with NAMP measurements: 24-hour average (in  $\mu\text{g}/\text{m}^3$ )**



**Figure 2.6 (h): Correlation of PM10 Against PM2.5 for the two locations NAMP measurements: 24-hour average (in µg/m<sup>3</sup>)**



**Figure 2.6 (i): Correlation of PM10 against the three CAAQMS data**



**Figure 2.6 (j): Correlation of PM2.5 against the three CAAQMS data**

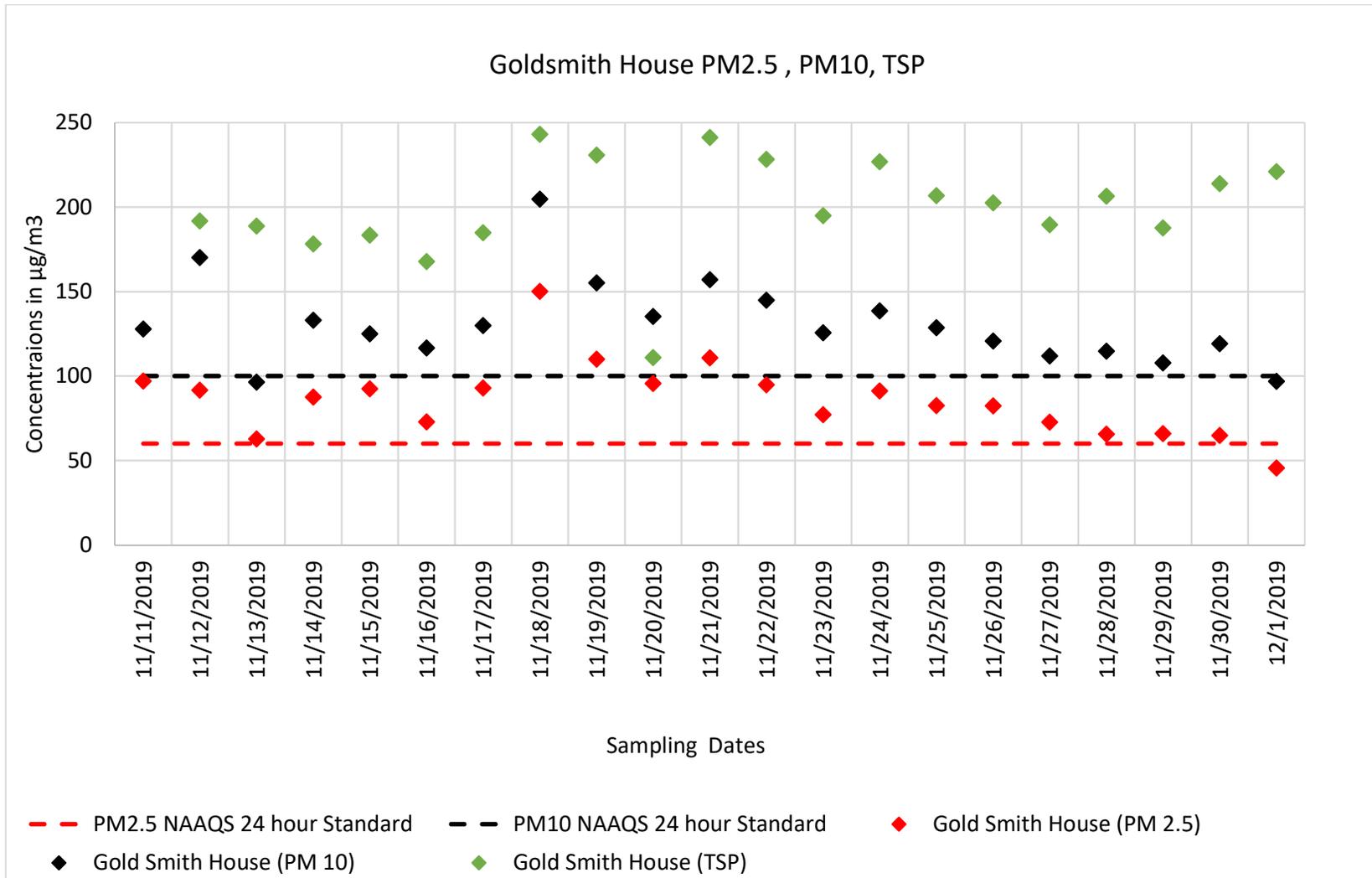
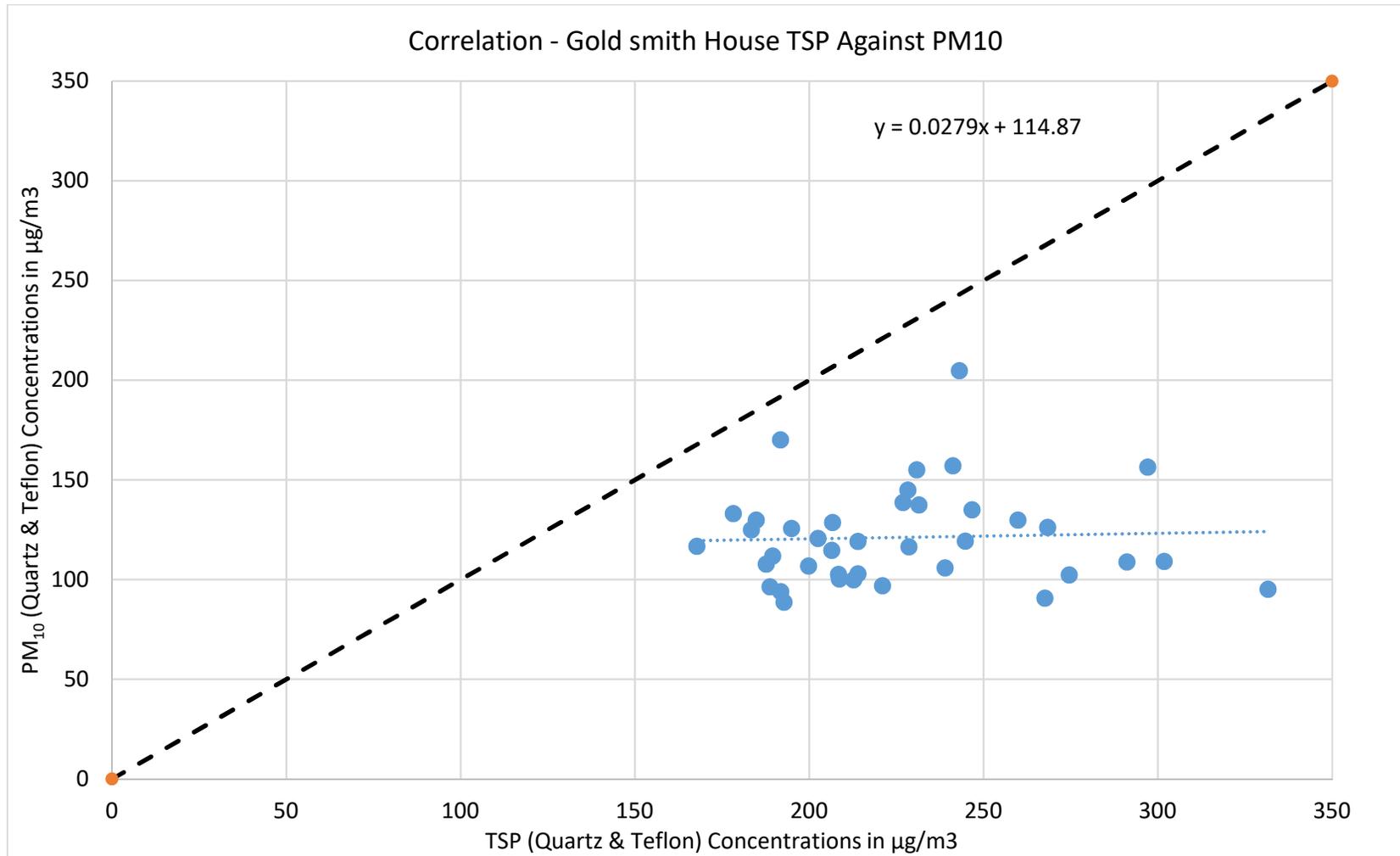
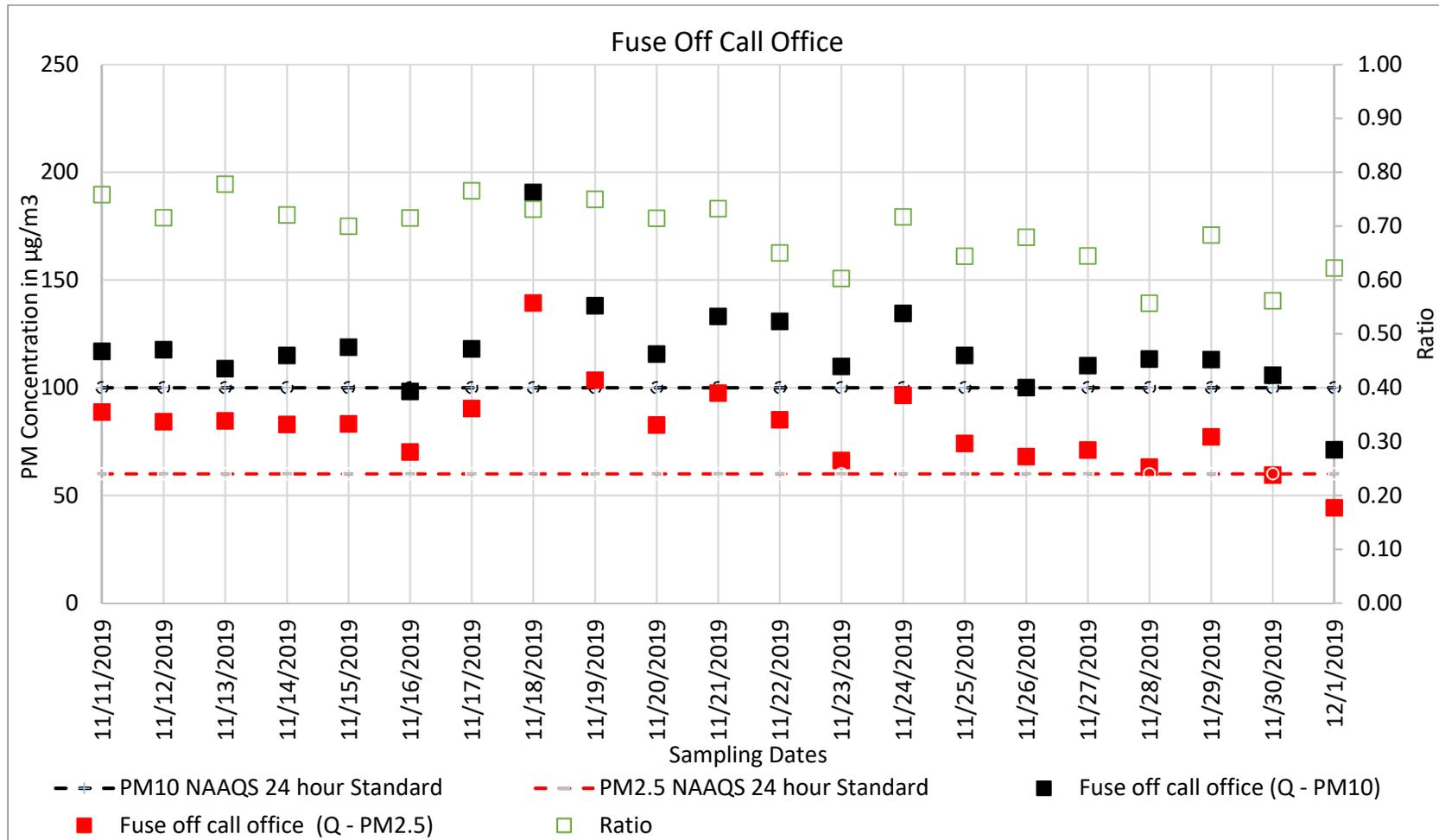


Figure 2.7 (a): Goldsmith House PM<sub>10</sub>, PM<sub>2.5</sub> and TSP



**Figure 2.7(b) : Correlation of TSP and PM<sub>10</sub> at the Goldsmith House**



**Figure 2.8 (a): Fuse Off Call Office PM<sub>10</sub>, PM<sub>2.5</sub> and their Ratio**

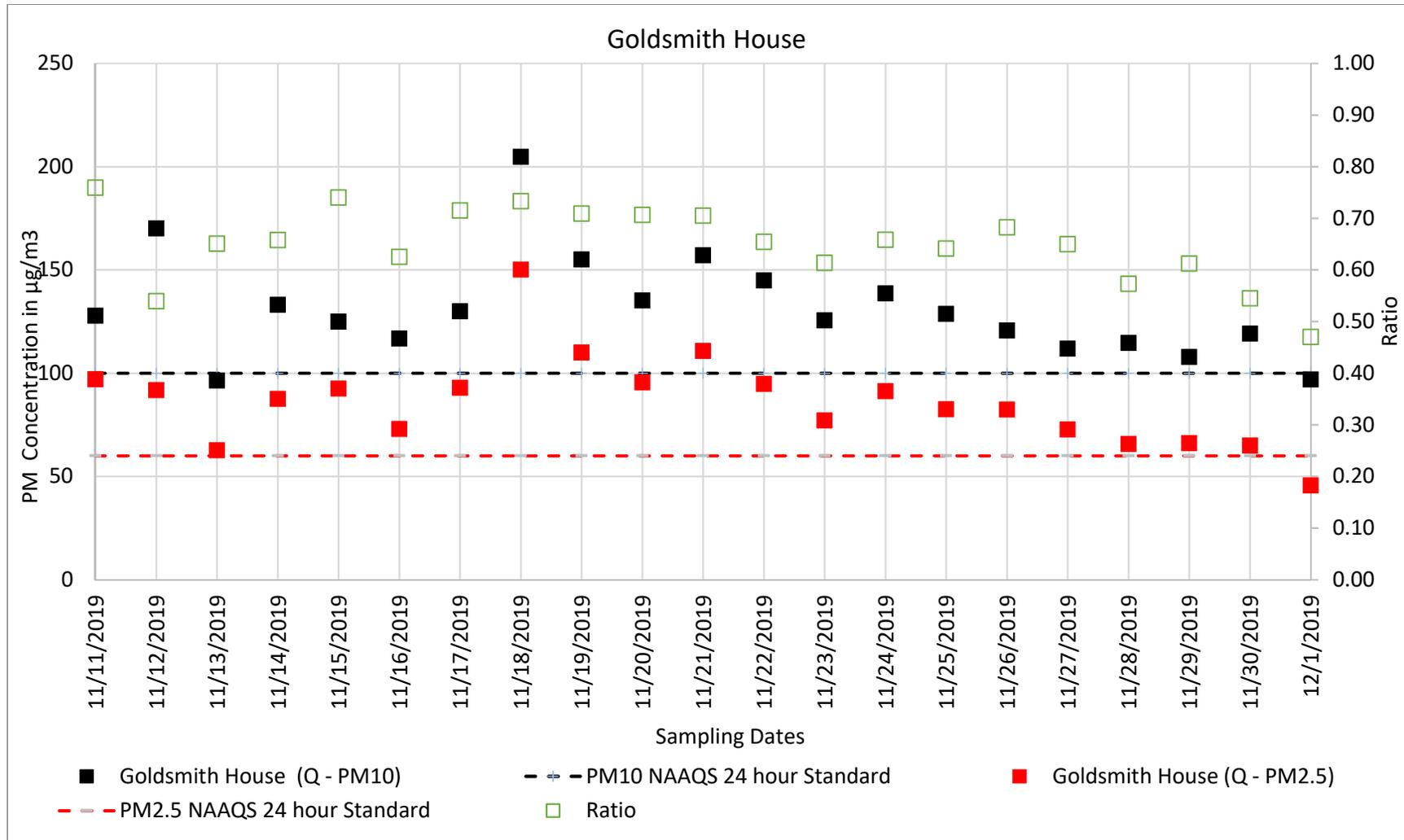
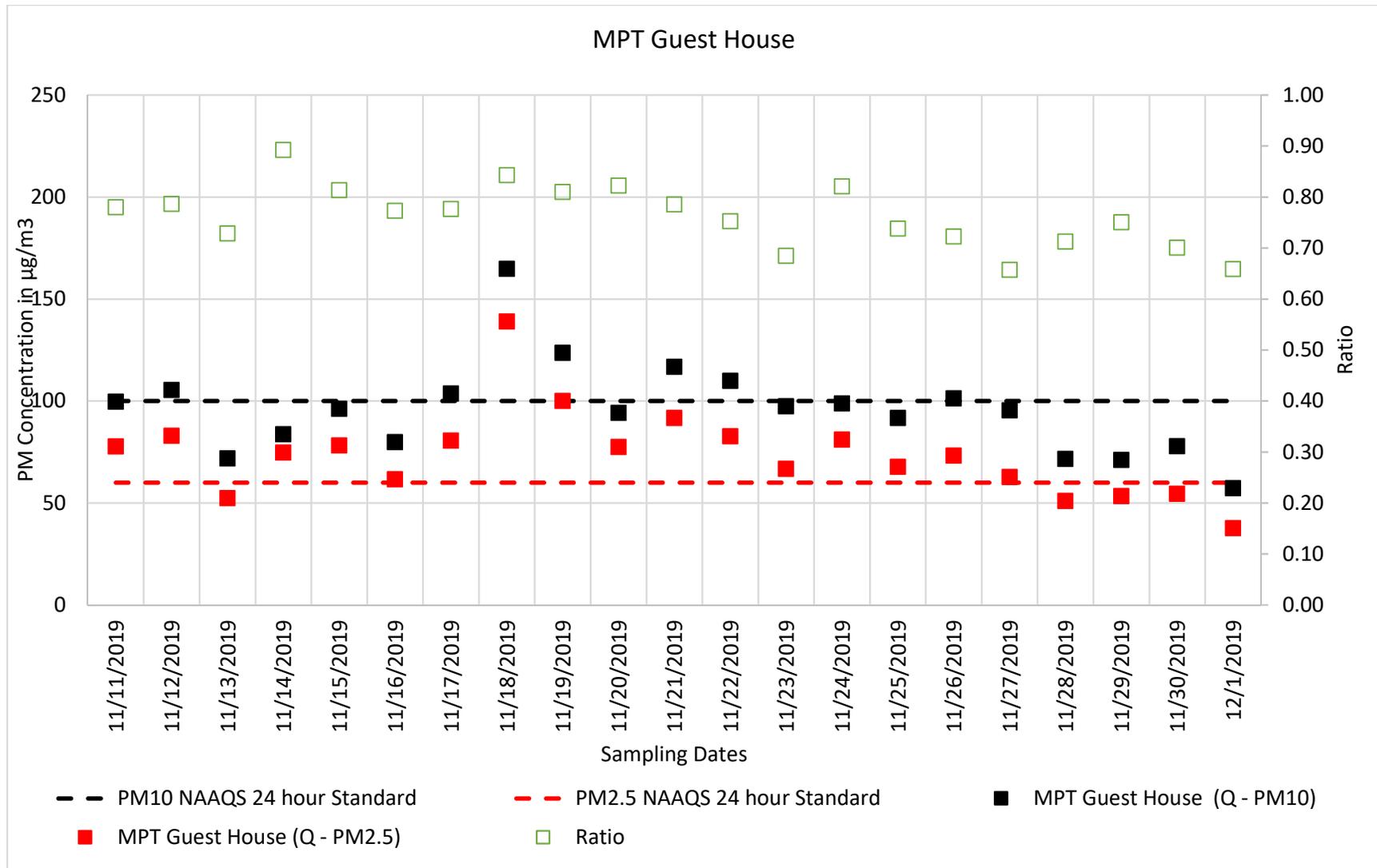
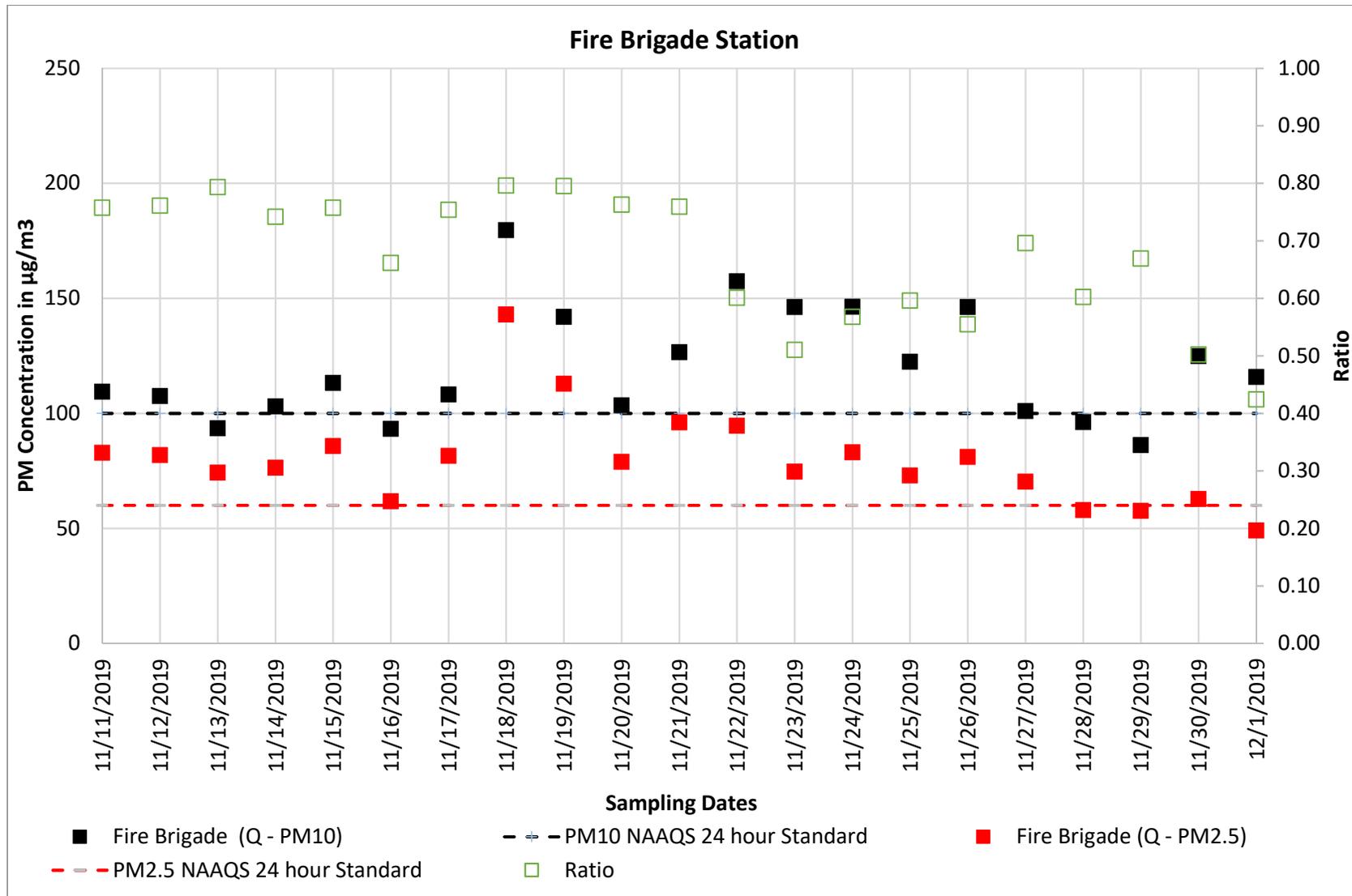


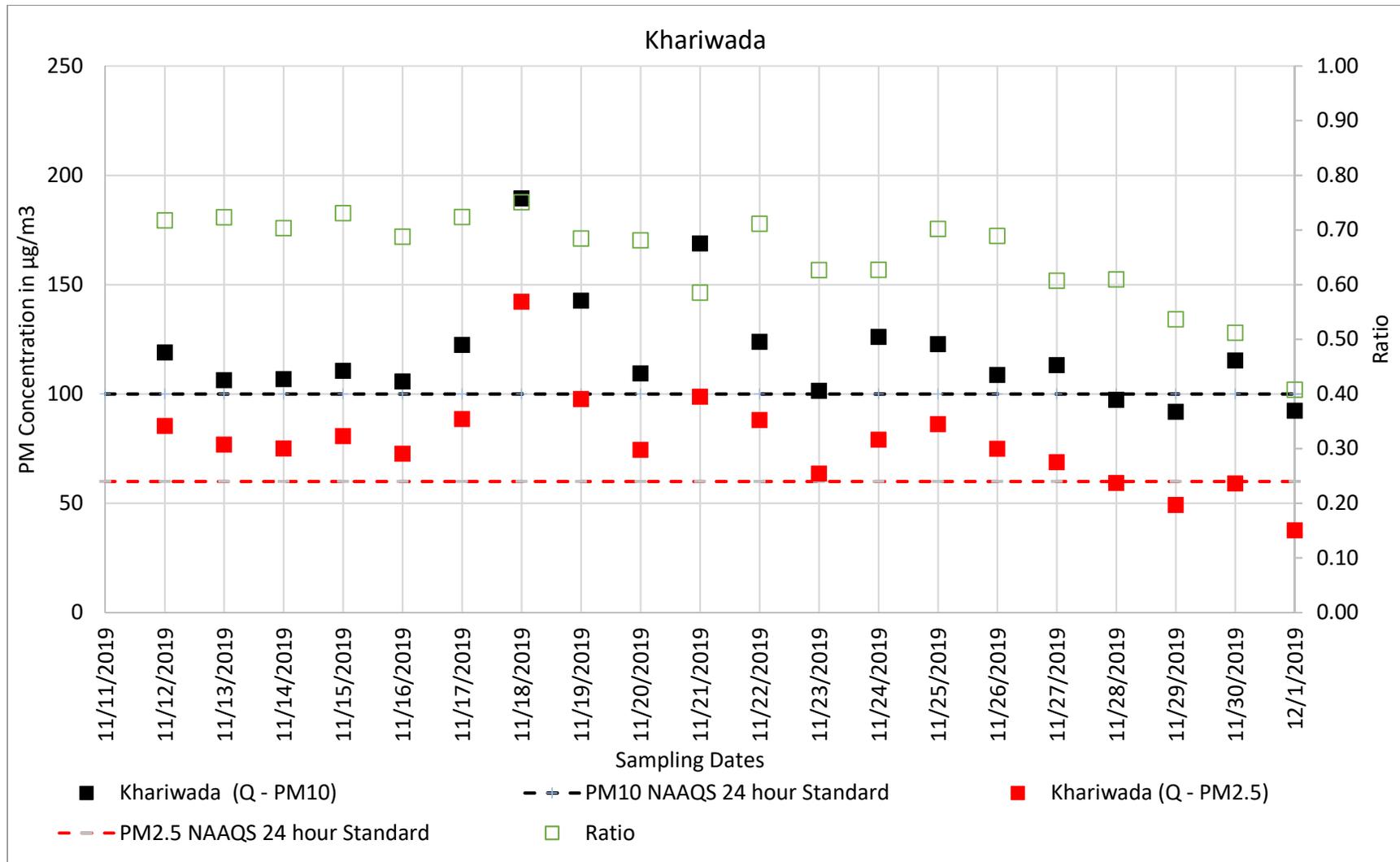
Figure 2.8 (b): Goldsmith House PM<sub>10</sub>, PM<sub>2.5</sub> and their Ratio



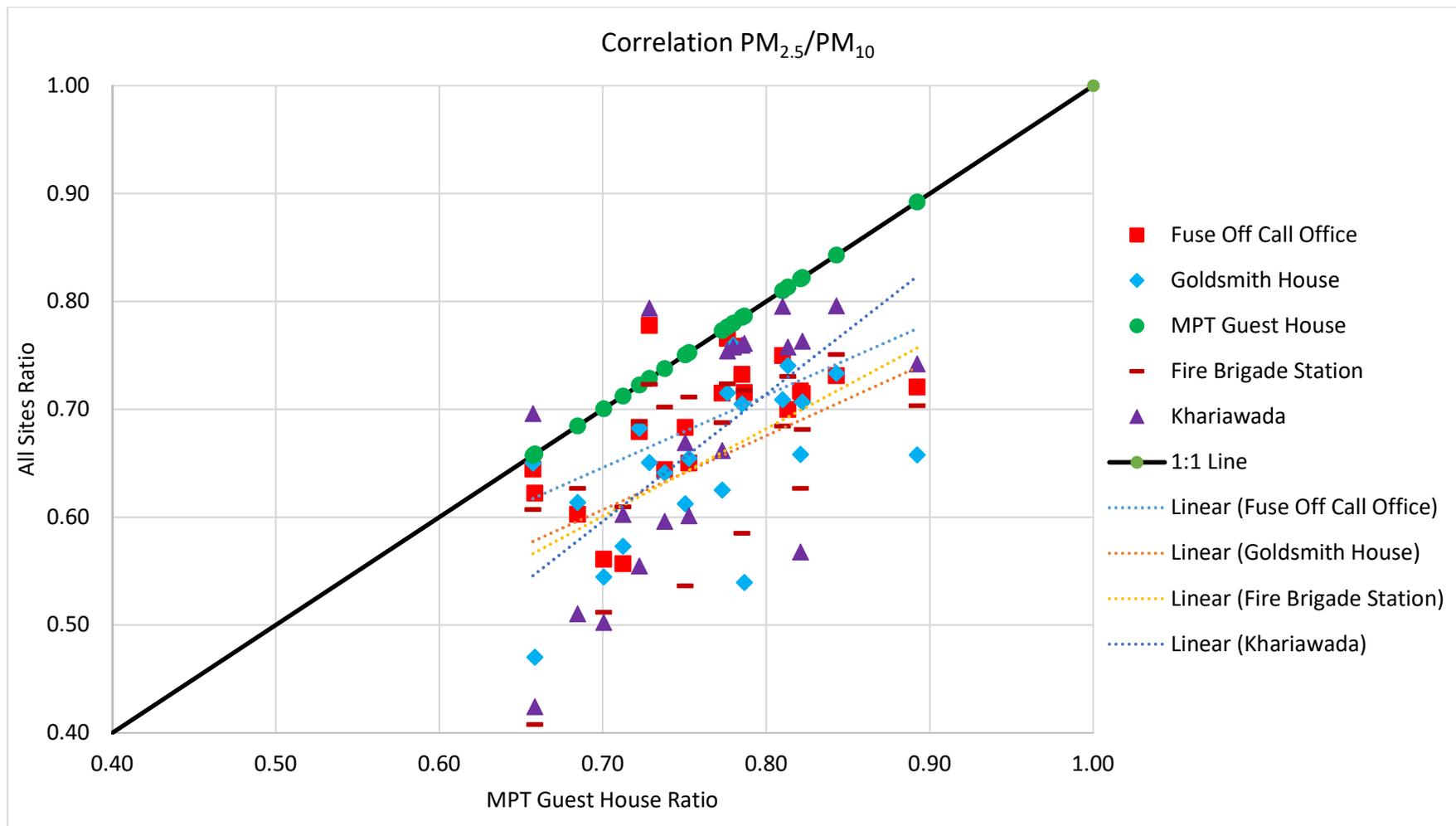
**Figure 2.8 (c): MPT Guest House PM<sub>10</sub>, PM<sub>2.5</sub> and their Ratio**



**Figure 2.8 (d): Fire Brigade Station PM<sub>10</sub>, PM<sub>2.5</sub> and their Ratio**

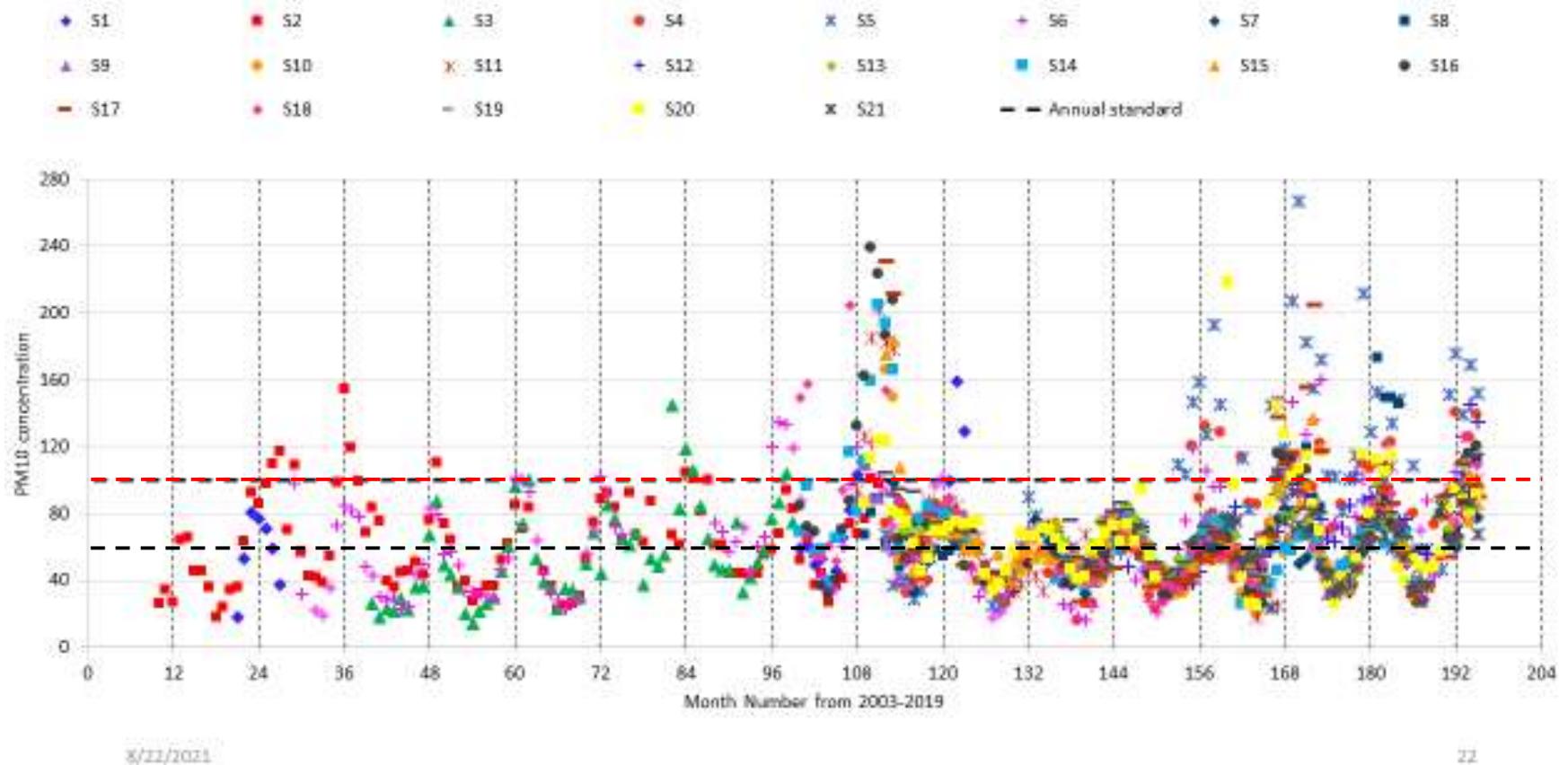


**Figure 2.8 (e): Khariwada PM<sub>10</sub>, PM<sub>2.5</sub> and their Ratio**

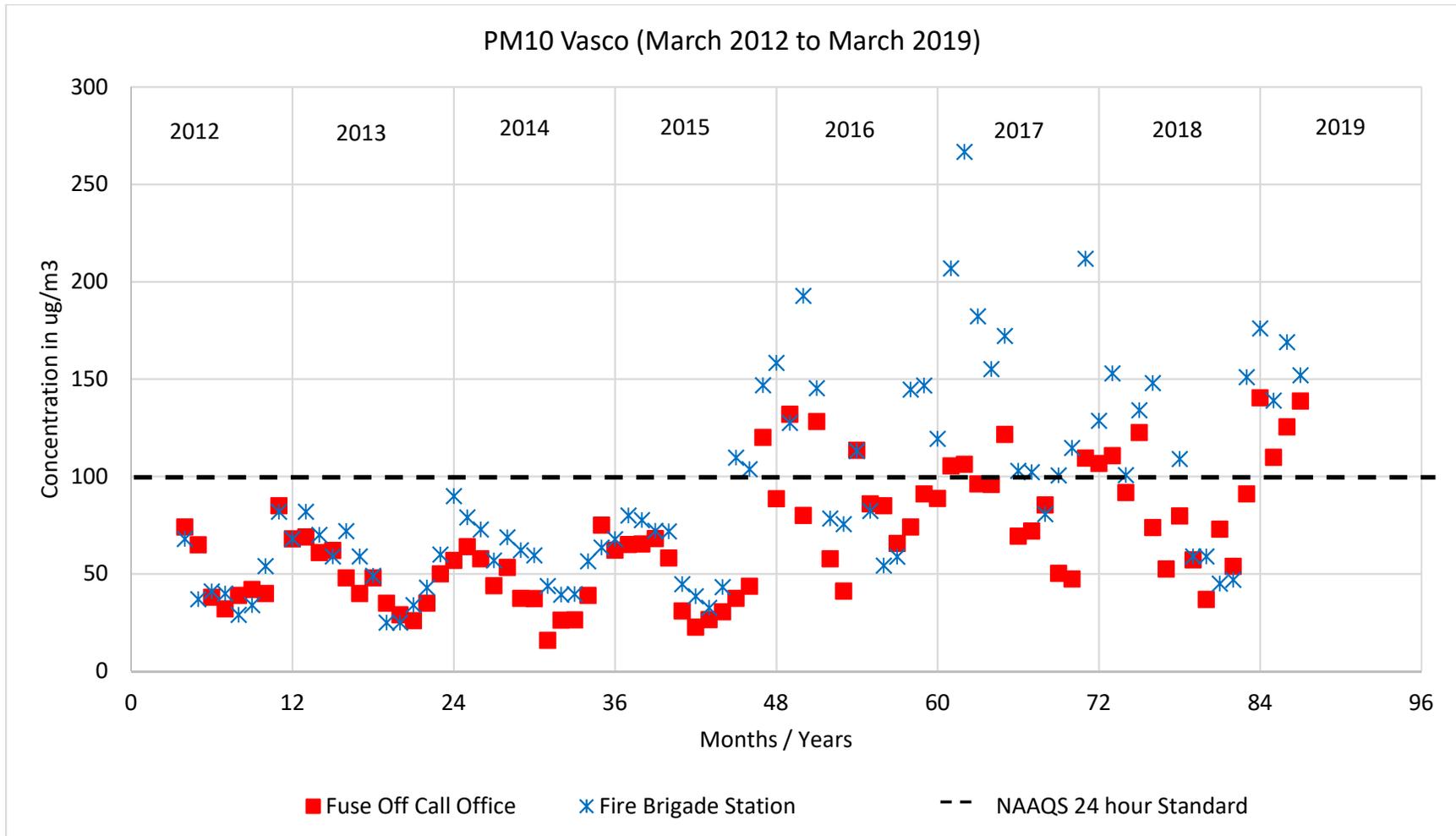


**Figure 2.9: Quartz Correlation of PM<sub>2.5</sub> to PM<sub>10</sub> Ratio (MPT Guest House against All Sampling Sites)**

## Historical Data Plot for the 18 NAMP Stations in Goa



**Figure 2.10(a): Time Series Plots for NAMP Stations in Goa (Details for Vasco Stations are given in Figure 2.10(b))**



**Figure 2.10(b): Time Series Plots for NAMP Stations in Vasco da Gama**

(Source: <http://goaspcb.gov.in/air-quality>)

## 2.3 EC-OC Results

Elemental carbon and organic carbon analyses were carried out on the quartz sample filters. These are typically used to identify the organic content of PM in the atmosphere, and can be used for differentiating various fractions of organic contents based on vapour pressure by controlled vaporization under controlled temperature conditions (without oxygen), and finally the fraction of elemental carbon by combustion in the presence of oxygen (Model DRI, 2005).

Figures 2.11 (a and b) show the EC-OC results for PM<sub>10</sub> and PM<sub>2.5</sub> as raw concentrations of the overall mass, grouped as locations for the entire SAS duration. Figure 2.11(c and d) show the same data as percentage for PM<sub>10</sub> and PM<sub>2.5</sub>.

The EC/OC ratio is used to differentiate sources (EC : Elemental carbon and OC Organic carbon). In this particular case of the locations on Sada Hill, EC is likely to come from vehicular emissions as well as from any coal fugitives, however, possibly with a difference in particle size fractions. EC/OC ratio plots are provided in Figures 2.11 (e and f). The higher EC/OC ratio in PM<sub>10</sub> at the Fire Brigade station is an indicator of the coal content, and more so in the last 8-10 days of the sampling period. The EC/OC ratio for PM<sub>2.5</sub>, interestingly, is not as much influenced by the location, pointing to the likely contribution in the overall Vasco da Gama region from vehicular and other combustion related activities. However, there is a slightly noticeable higher level observed at the Fire Brigade Station and Goldsmith House for PM<sub>2.5</sub> as well.

There were three sites where samples for TSP were collected additionally (Goldsmith House, Upper Jetty and Lower Jetty) to understand the influence of any fugitives from the port activities in the vicinity. To compare these TSP samples were also collected from two distant sites, viz. Chicalim and Mangor Hill locations. Figure 2.11(g) shows the EC/OC content for the TSP at these five locations. The EC/OC at the Lower Jetty location was higher than that at the Upper Jetty and the Goldsmith House locations, while the two distant locations shows much lower levels. For PM<sub>10</sub> sample, as stated above, the highest EC/OC was observed at the Fire Brigade Station site, especially on 8-10 particular days of the 21 days of sampling (Figure 2.11(h)). The EC/OC ratio for PM<sub>2.5</sub> were almost similar for all the sites (Figure 2.11(i)) with slightly higher levels at Fire Brigade station and Goldsmith House.

Correlation of EC/OC ratios at all the sites with that at the Fire Brigade Station are provided in Figure 2.12(a and b) for PM<sub>10</sub> and PM<sub>2.5</sub> respectively. The EC/OC ratio changes greatly for the Fire Brigade station (likely dependence of the coal handling activities) compared to all the other sites which remain

at a nearly constant EC/OC ratio irrespective of the levels of EC/OC at the Fire Brigade Station. The EC/OC ratio for  $PM_{2.5}$ , however, seems to not be sensitive to the locations.

Similar correlation of EC/OC ratio for TSP is provided in Figure 2.12(c) with Goldsmith House as the baseline. The distant Chicalim and Mangor Hill sites indicate low EC/OC ratio values, while the Upper and Lower Jetty sites show a significantly higher EC/OC ratio, indicating presence of coal dust in the TSP.

The effect of coal handling activities at the port was studied. Figure 2.13(a) shows the coal and limestone activities for the duration of the sampling period. Figures 2.13(b, c and d) show the correlation between the coal handling activity and the corresponding EC/OC ratios for  $PM_{10}$ ,  $PM_{2.5}$  and TSP.  $PM_{10}$  and TSP indicate a higher influence of coal handling activity level on the EC/OC ratio for the Fire Brigade Station when compared to other sites. EC/OC ratios for  $PM_{2.5}$  seem to remain unaffected by the level of coal activities.

## 2.4 Appendices

### 2.4.1 Appendix A

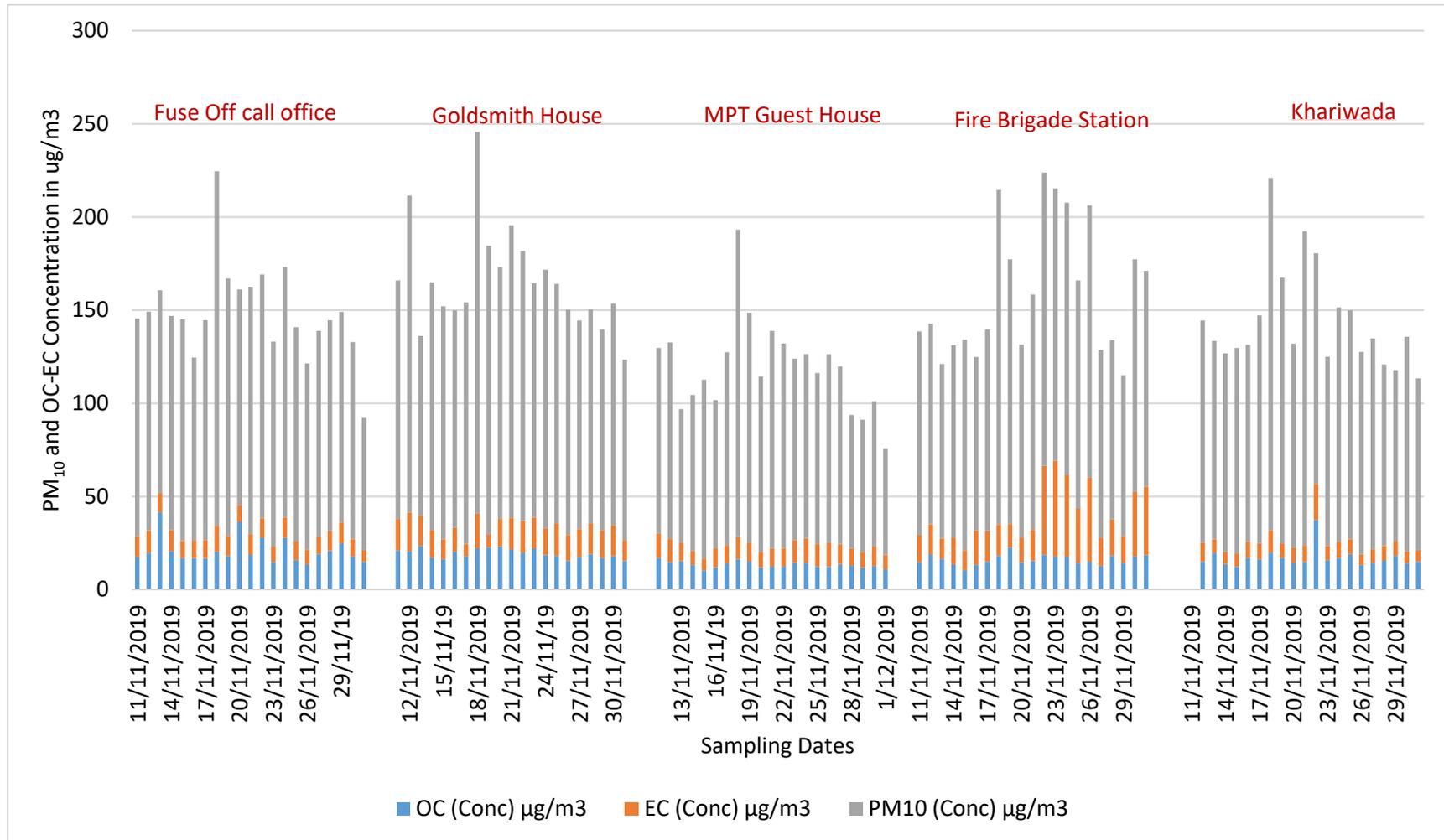
Includes the matrix of the sampling (locations, size fractions and dates) for the study.

### 2.4.2 Appendix B

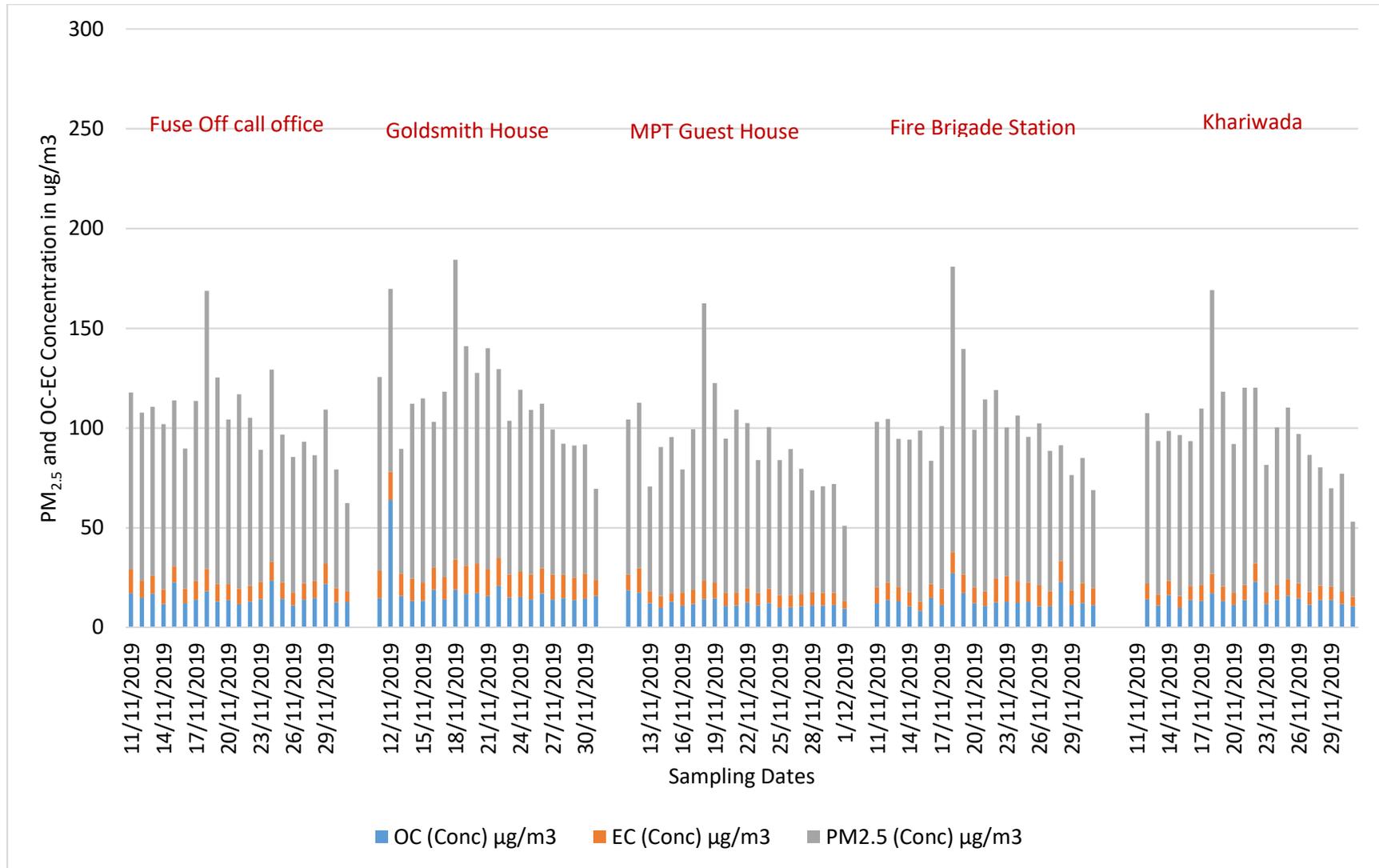
Includes the records of port activity data during the sampling campaign.

### 2.4.3 Appendix C

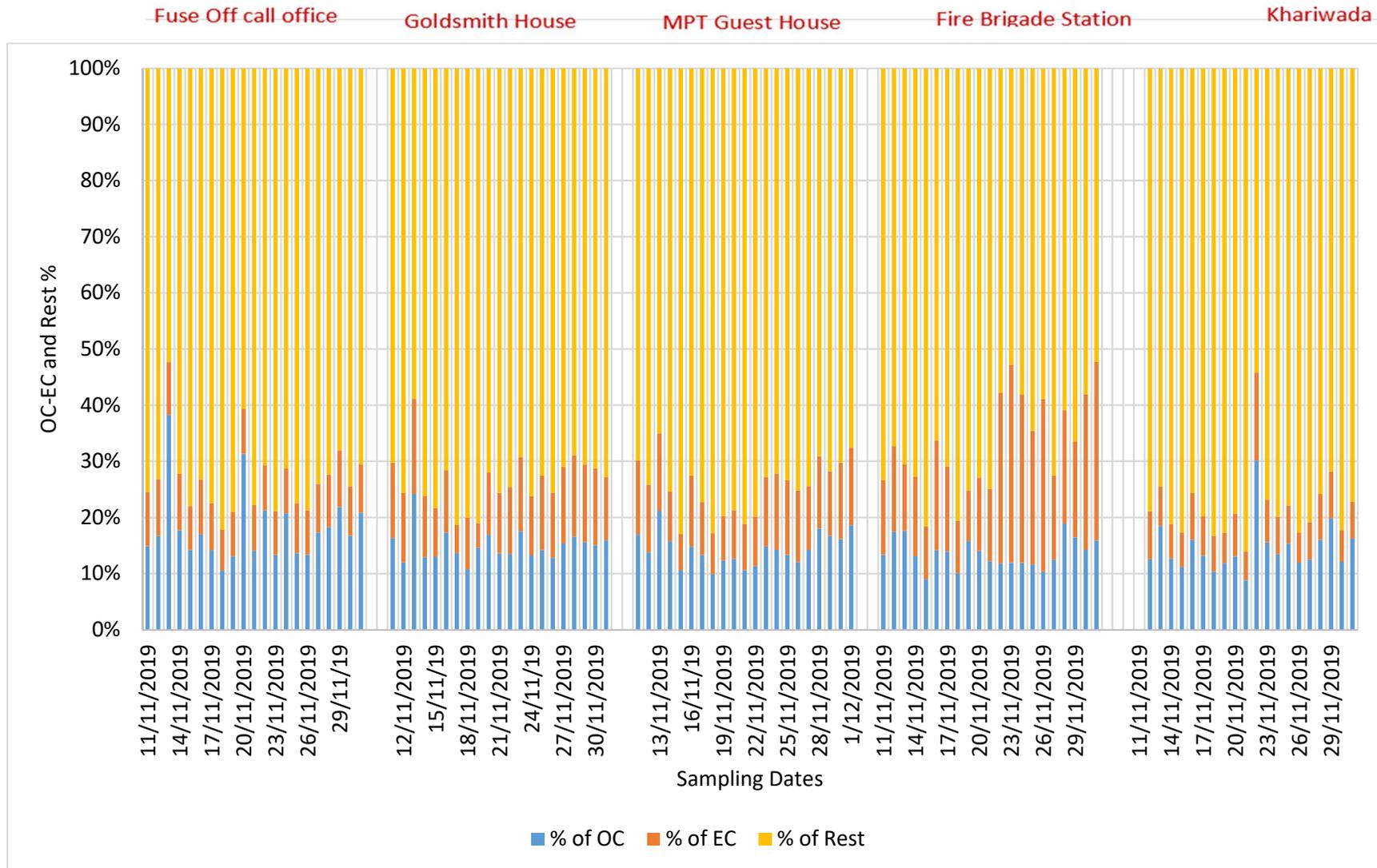
Data from Appendix B were analyzed for comparison of the port activities and the PM observations. The correlation between the number of trucks and wagons with the associated activities were found to be linear. The PM levels have some positive correlation with the activity of trucks, but seems to be independent of the wagon at the sampling locations.



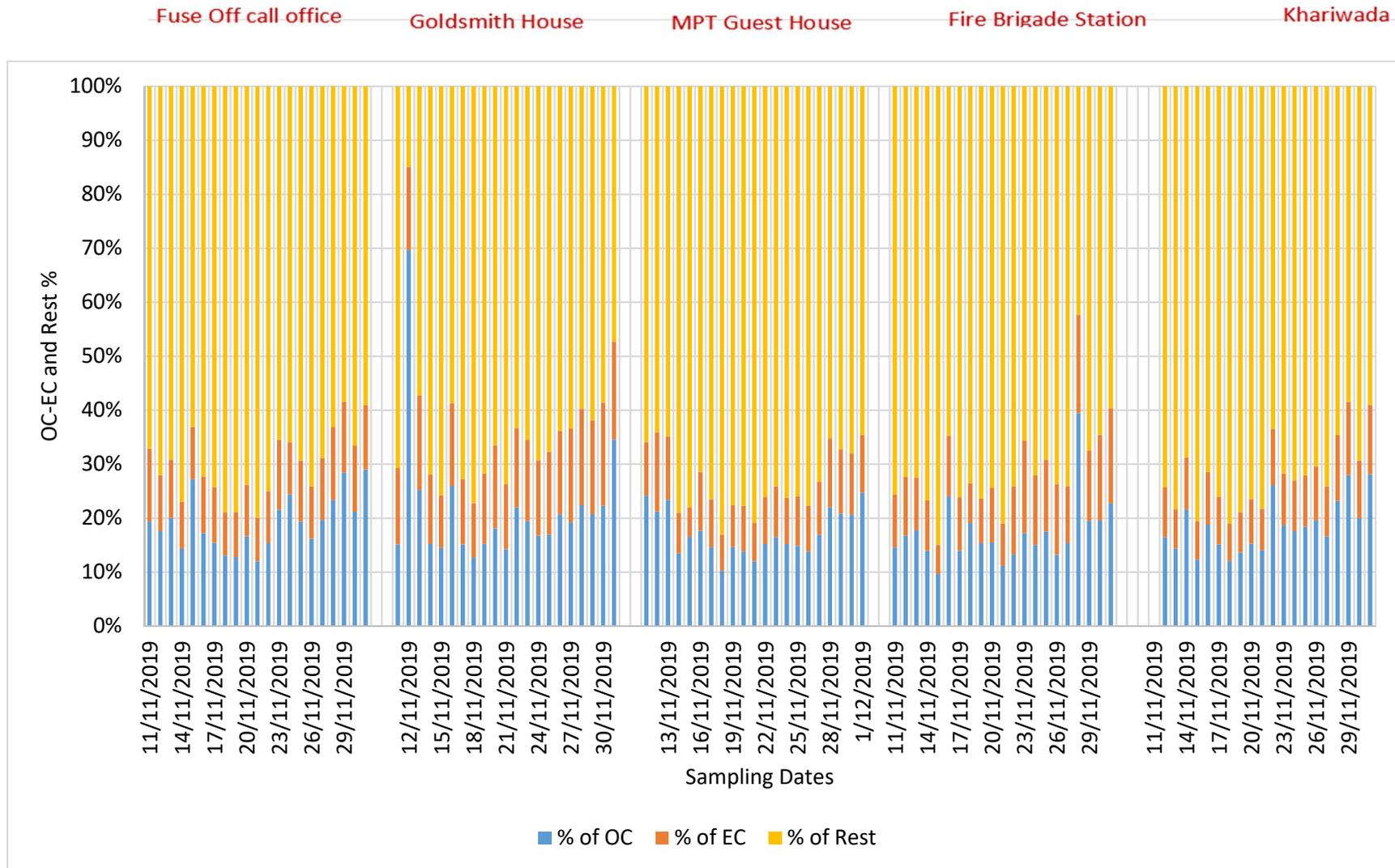
**Figure 2.11 (a): PM<sub>10</sub>, OC-EC concentrations at All 5 locations (Location wise on each Day)**



**Figure 2.11 (b): PM<sub>2.5</sub>, OC-EC concentrations at All 5 locations (Location wise on each Day)**



**Figure 2.11 (c): PM<sub>10</sub> - OC-EC and Rest % at All 5 locations (Location wise on each Day)**



**Figure 2.11 (d): PM<sub>2.5</sub> - OC-EC and Rest % at All 5 locations (Location wise on each Day)**

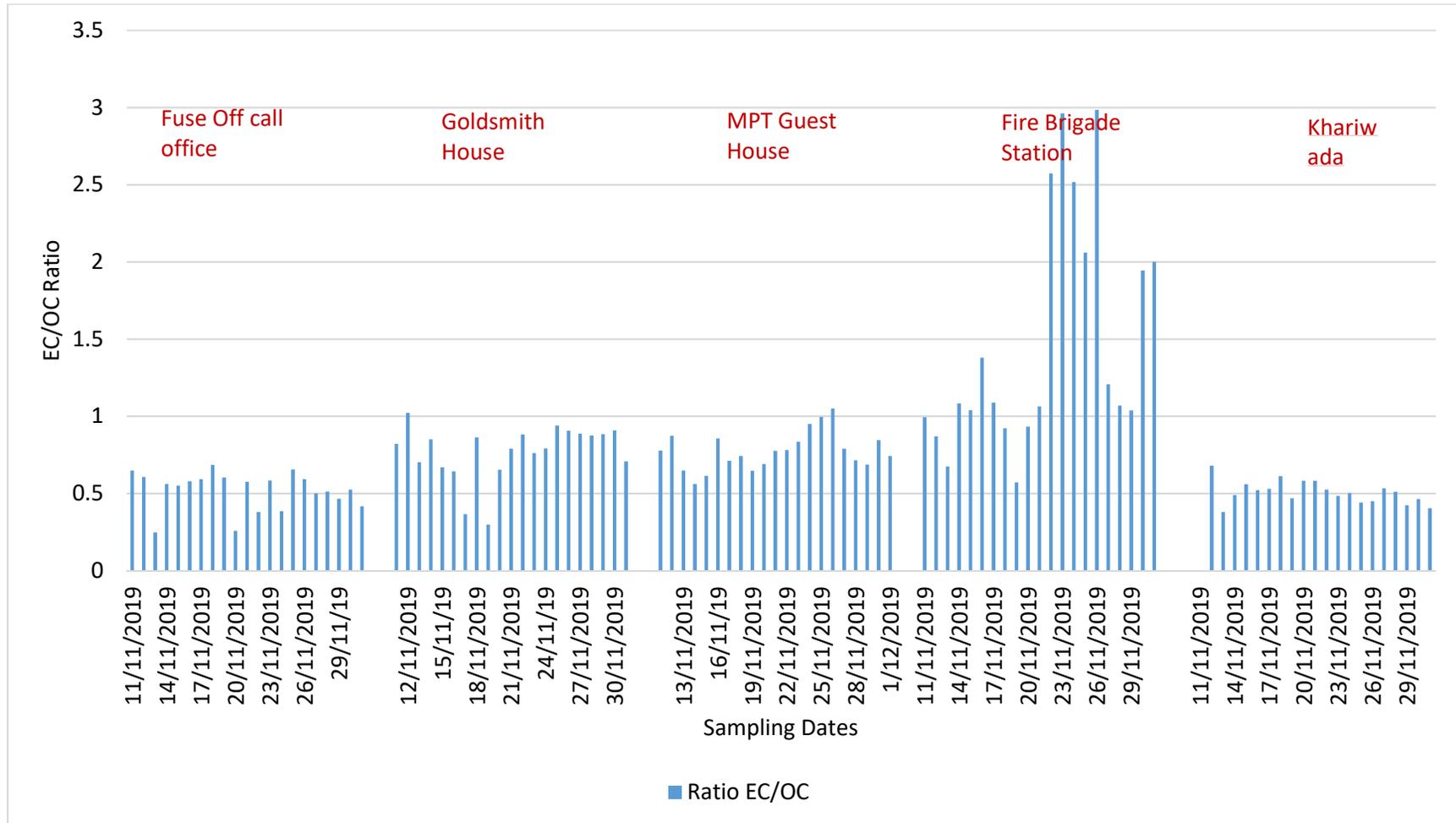


Figure 2.11 (e): PM<sub>10</sub> - EC/OC Ratio at All 5 locations (Location wise on each Day)

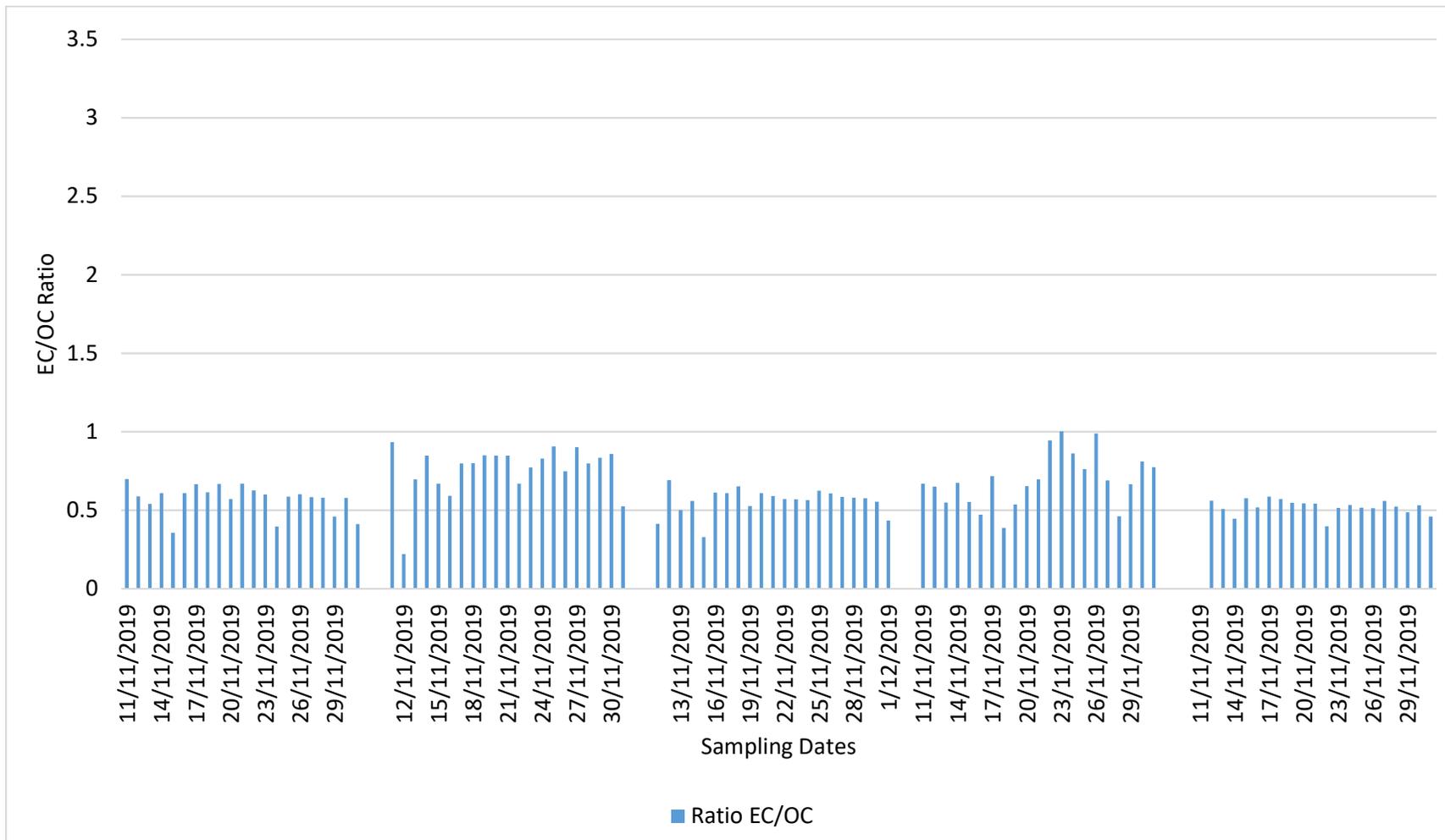


Figure 2.11 (f): PM<sub>2.5</sub>- EC/OC Ratio at All 5 locations (Location wise on each Day)

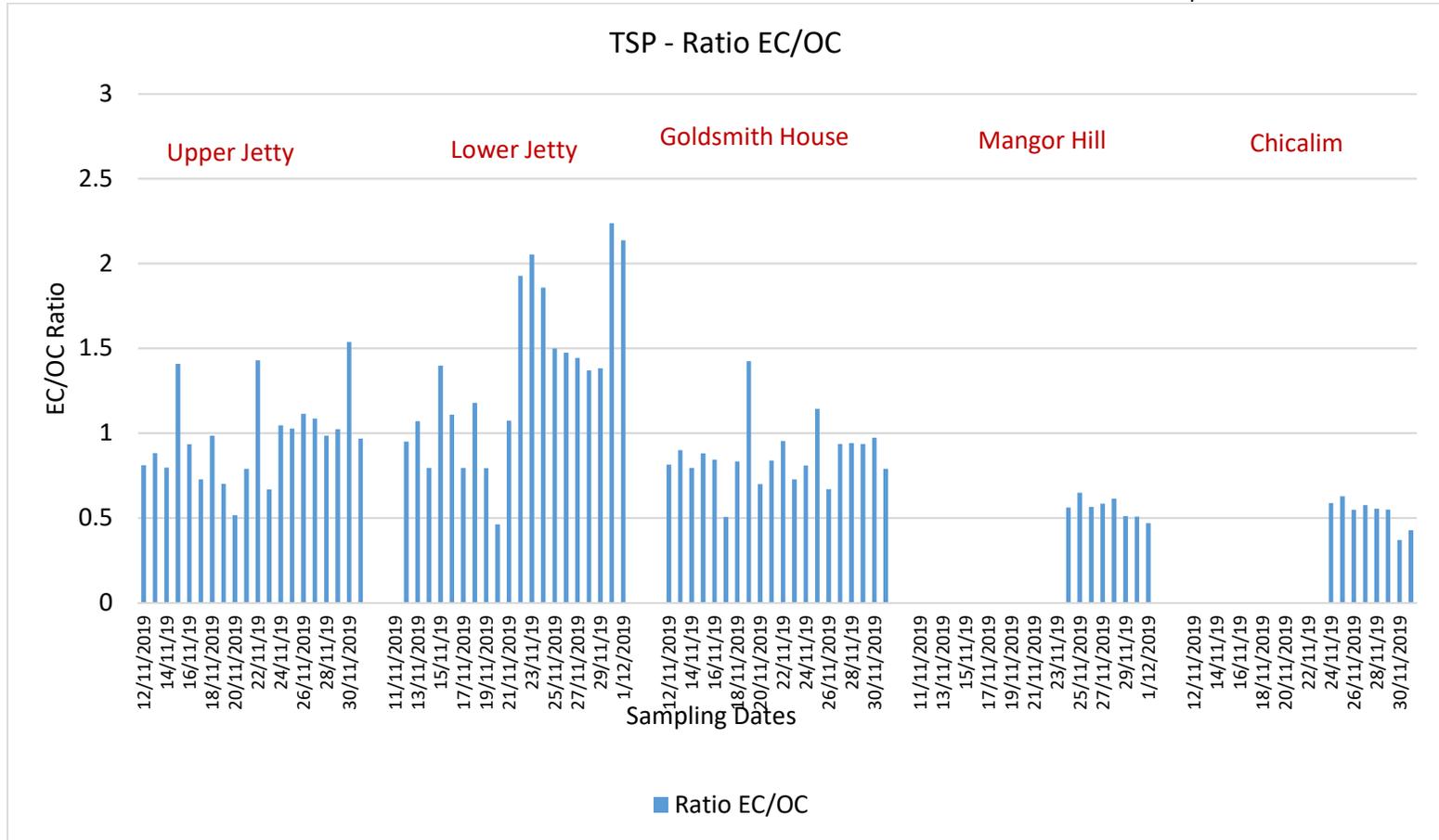


Figure 2.11 (g): TSP - EC/OC Ratio at 5 locations (Location wise on each Day)

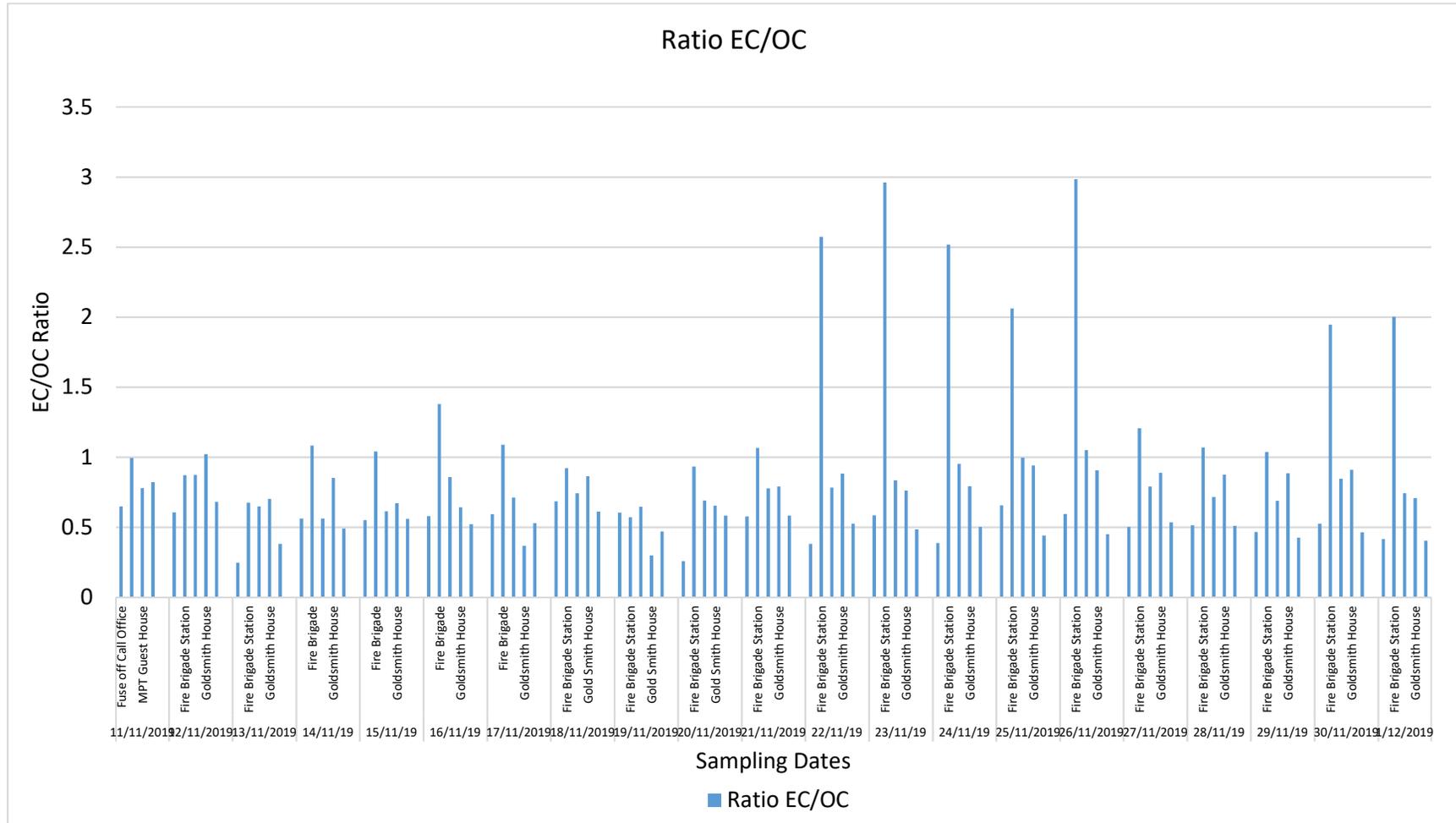
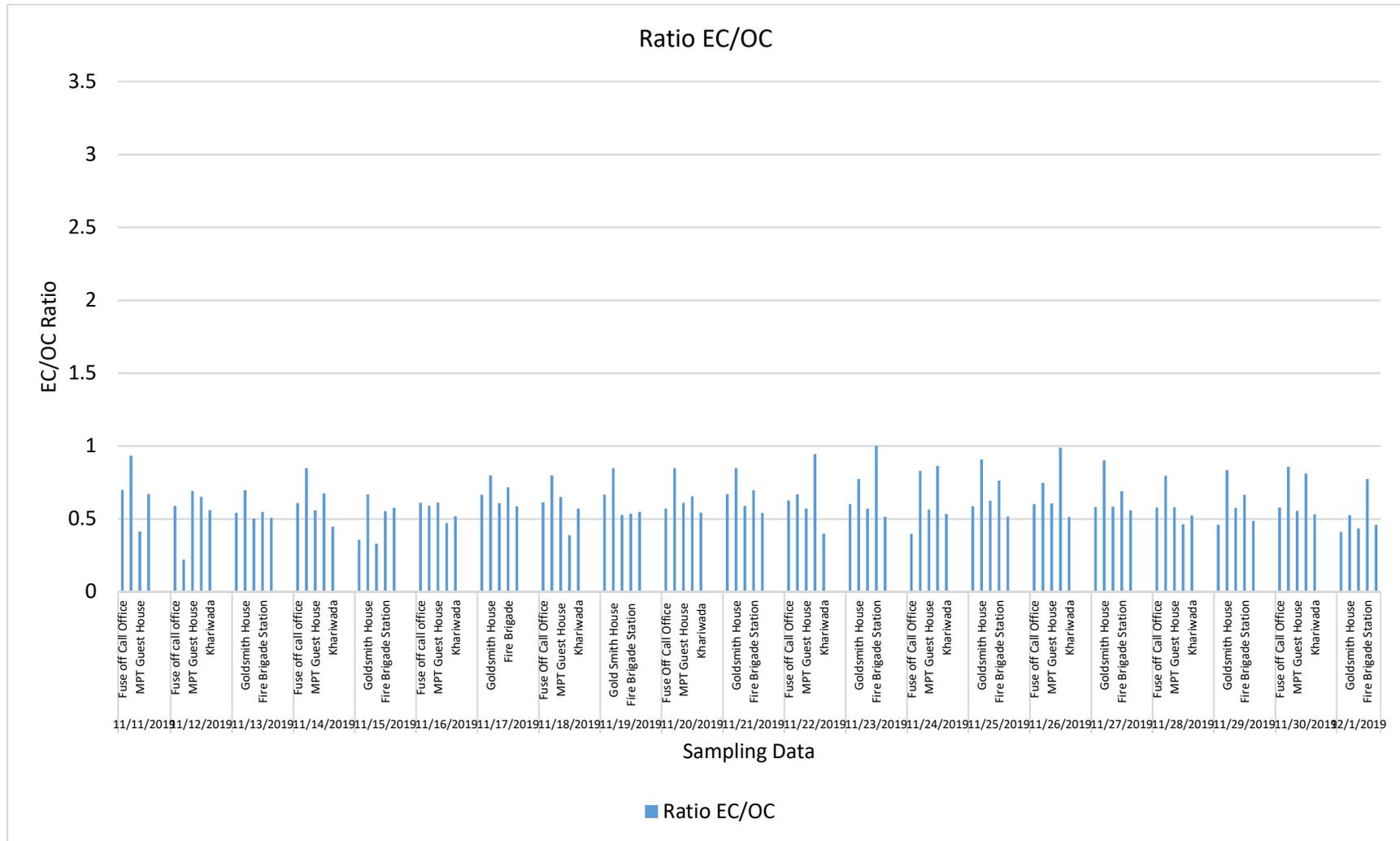


Figure 2.11 (h): PM<sub>10</sub> - EC/OC Ratio at All 5 locations (Day wise On each Location)



**Figure 2.11 (i): PM<sub>2.5</sub> - EC/OC Ratio at All 5 locations (Day wise On each Location)**

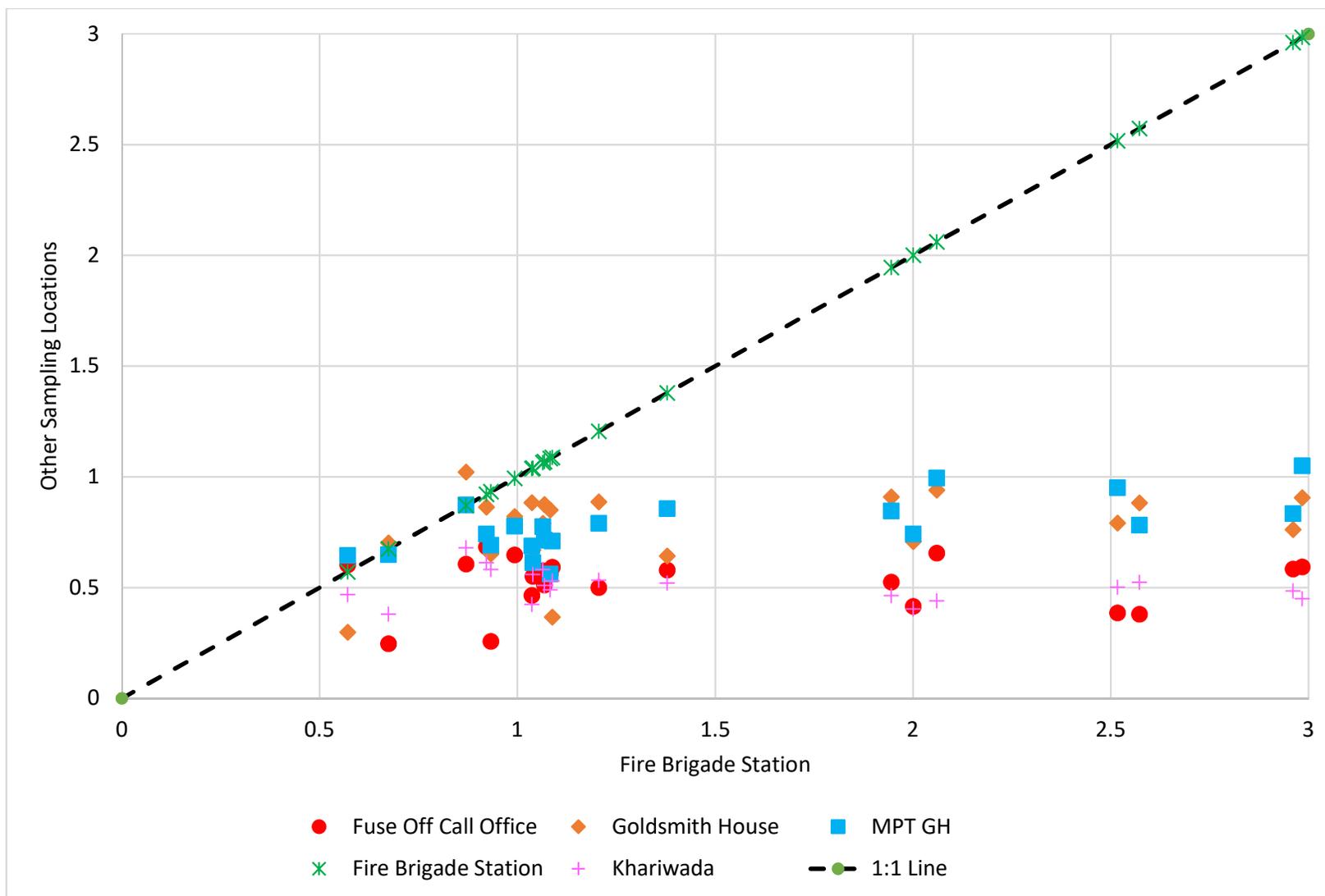
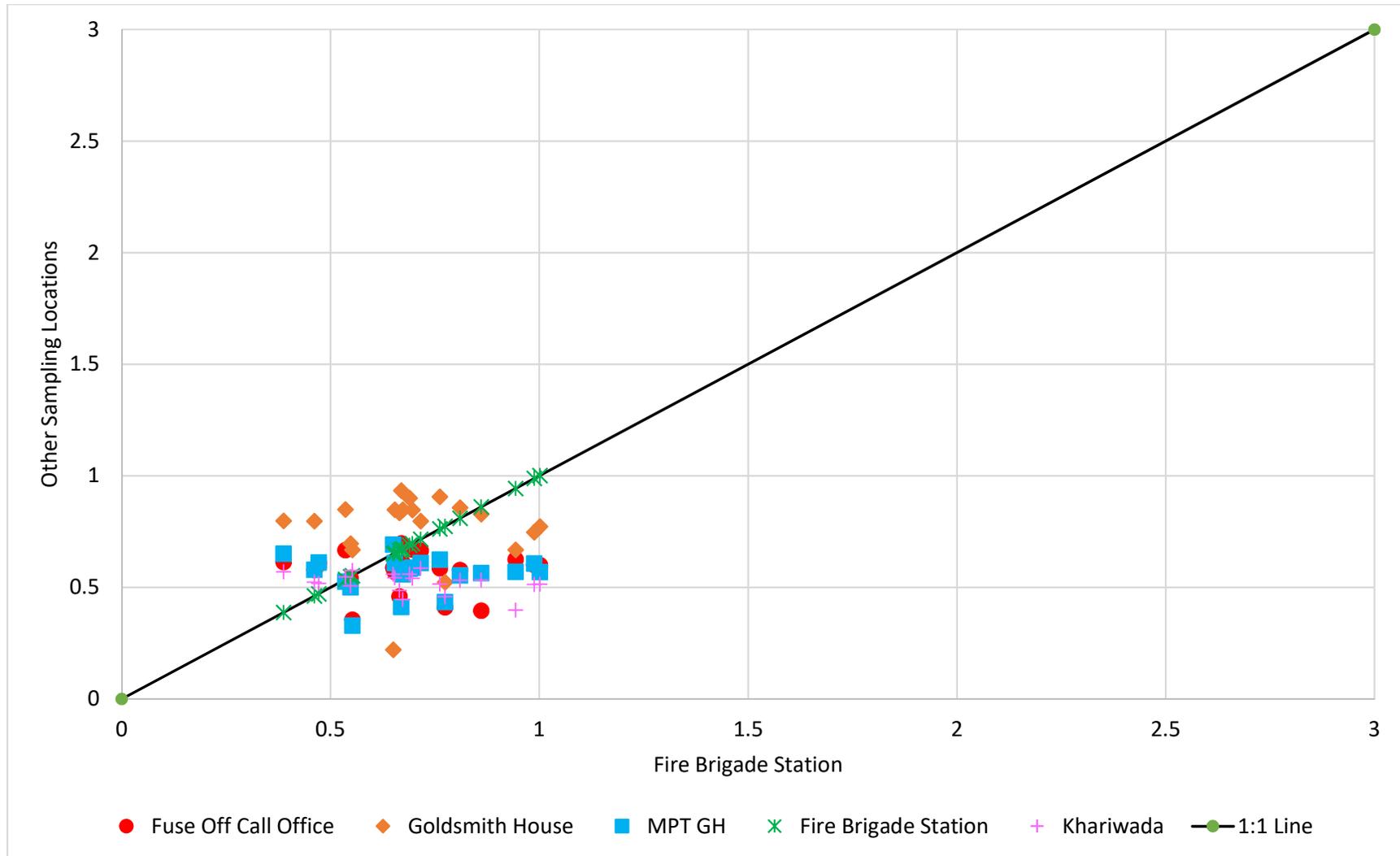
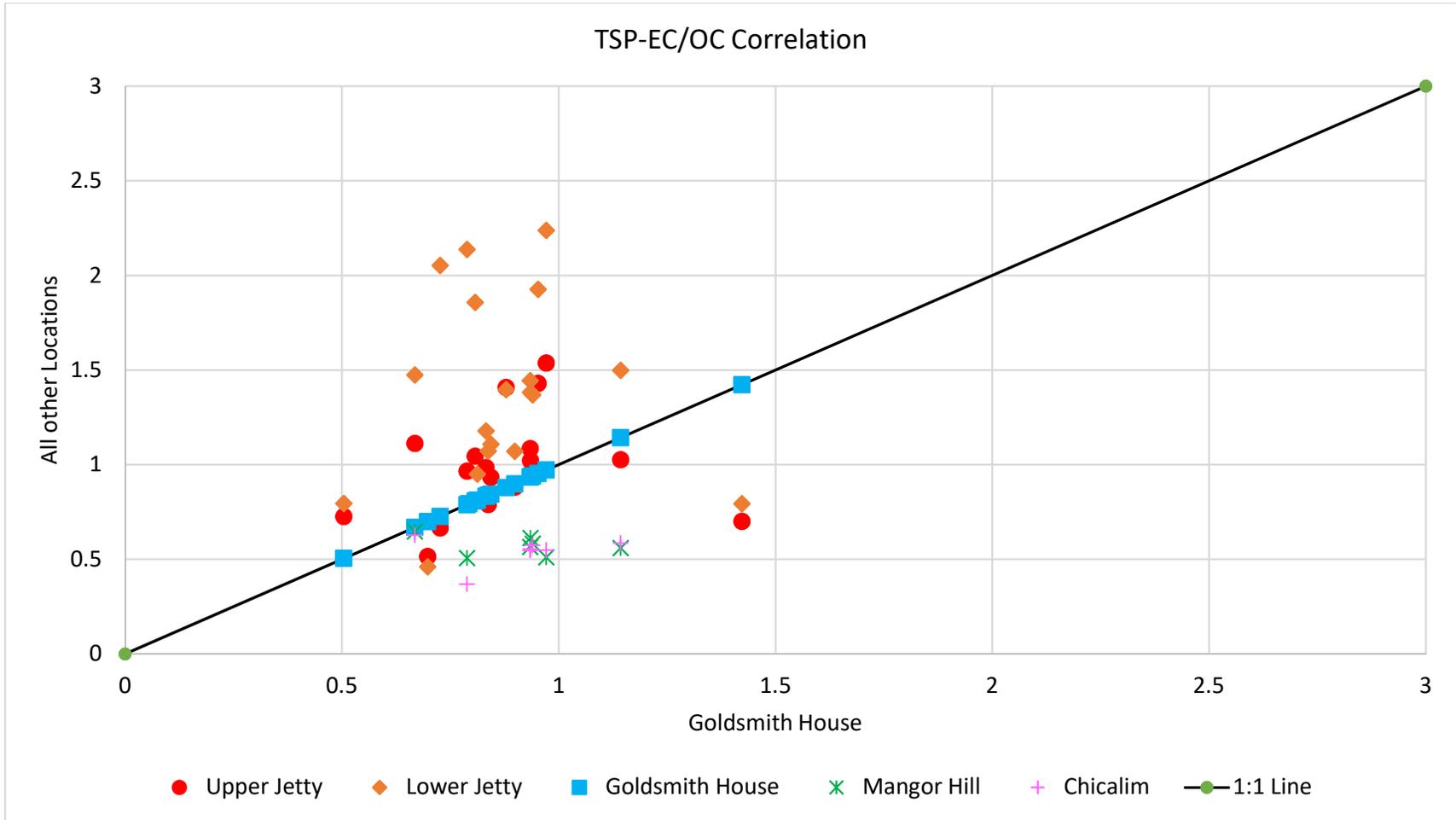


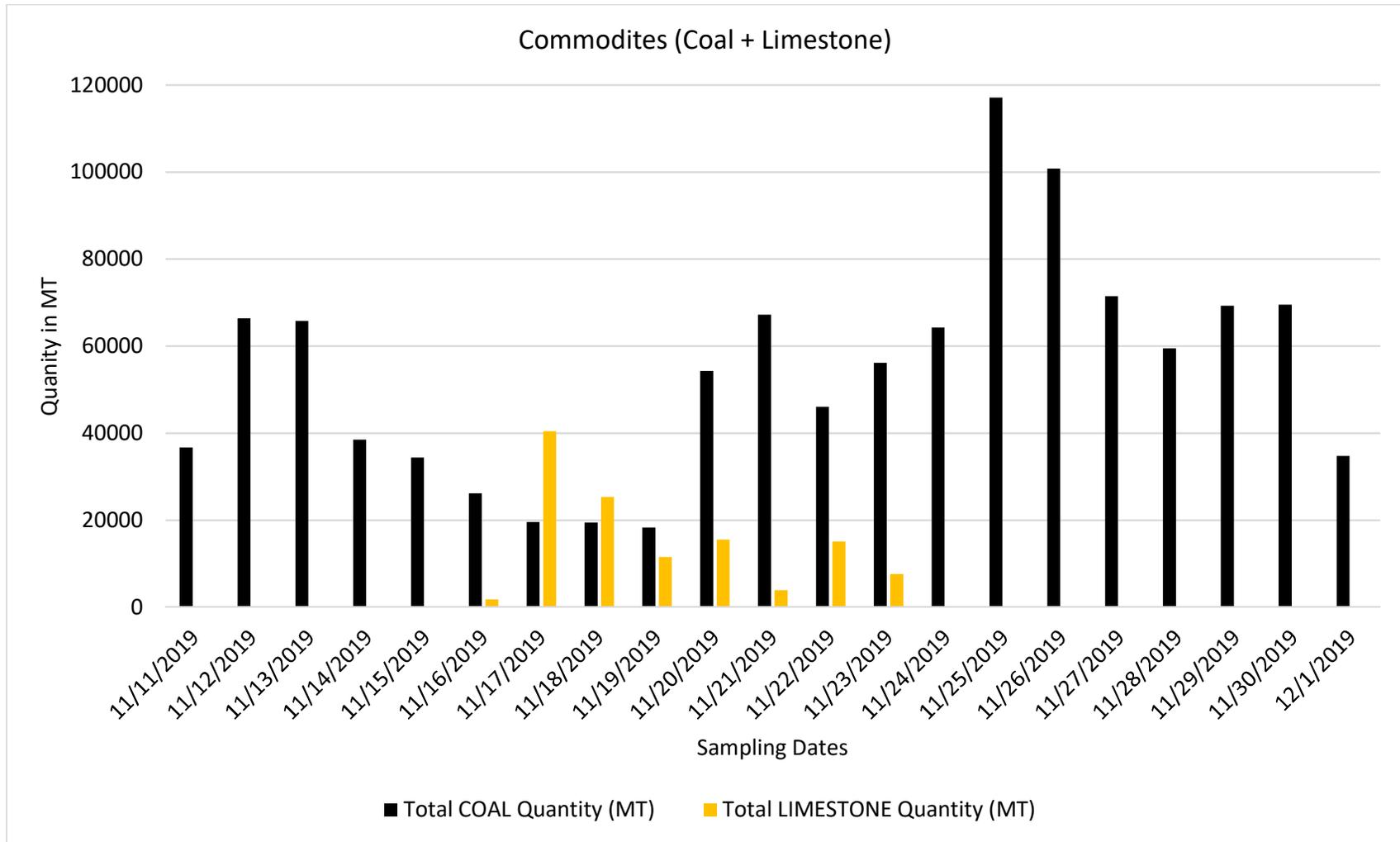
Figure 2.12 (a): Correlation of PM<sub>10</sub> EC/OC Ratio at all 5 locations With Fire Brigade Station



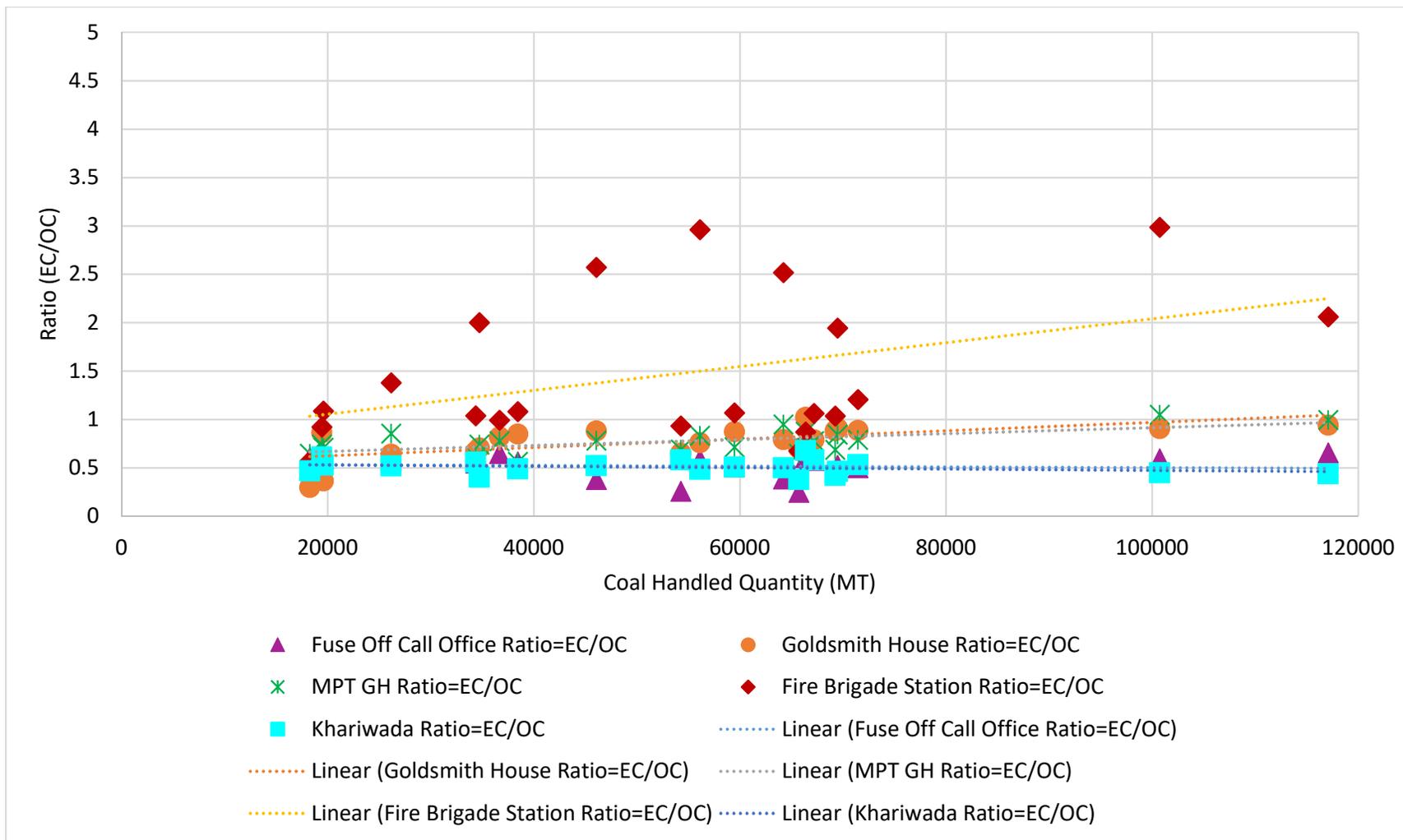
**Figure 2.12 (b): Correlation of PM<sub>2.5</sub> EC/OC Ratio at All 5 locations With Fire Brigade Station**



**2.12 (c): Correlation of TSP EC-OC Ratio at All 5 locations With Goldsmith House**



**Figure 2.13 (a): Commodities (Coal + Limestone) Handling Quantity in MT**



**Figure 2.13(b): Coal Quantity against EC/OC Ratio of PM<sub>10</sub> for all Sites**

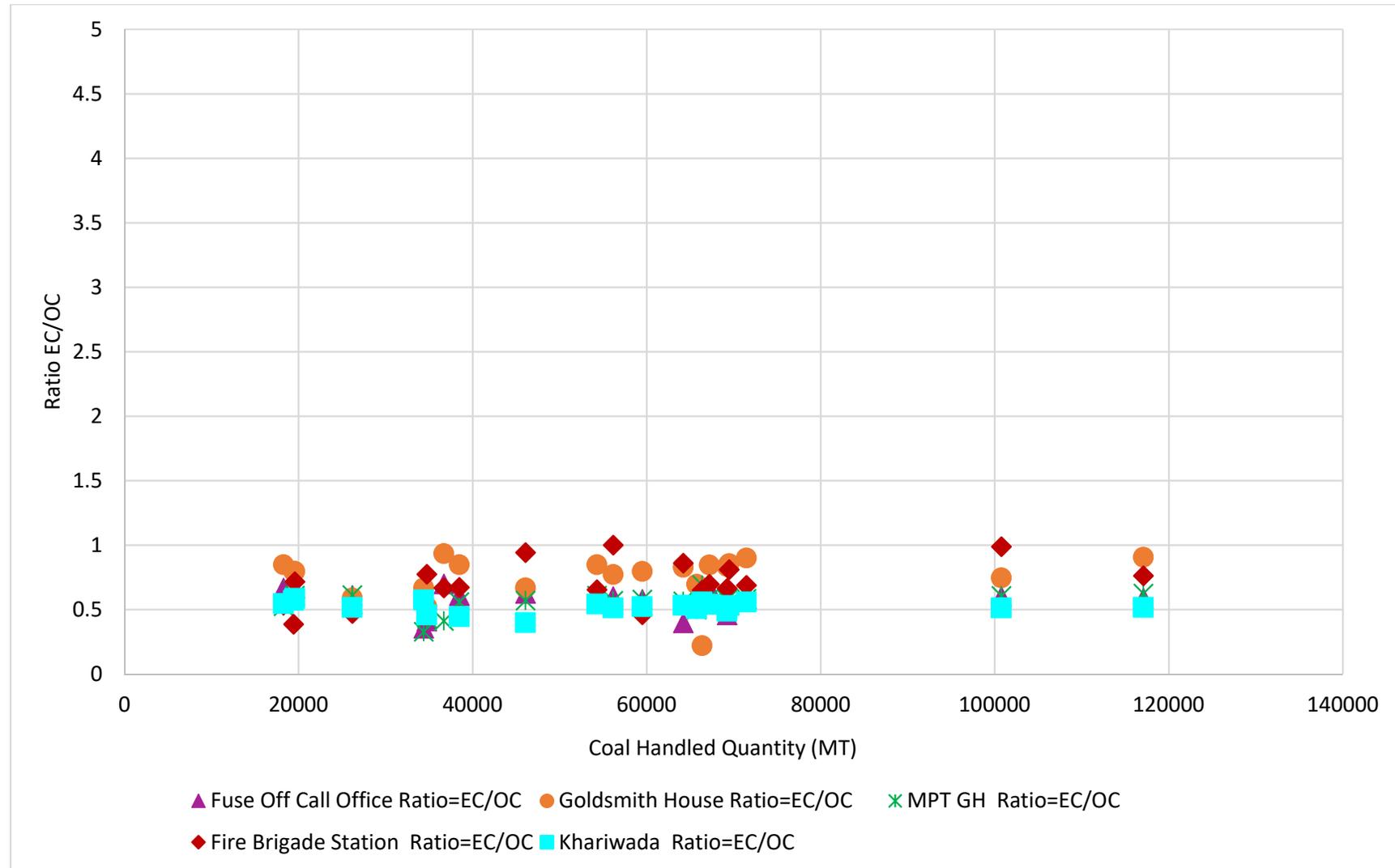
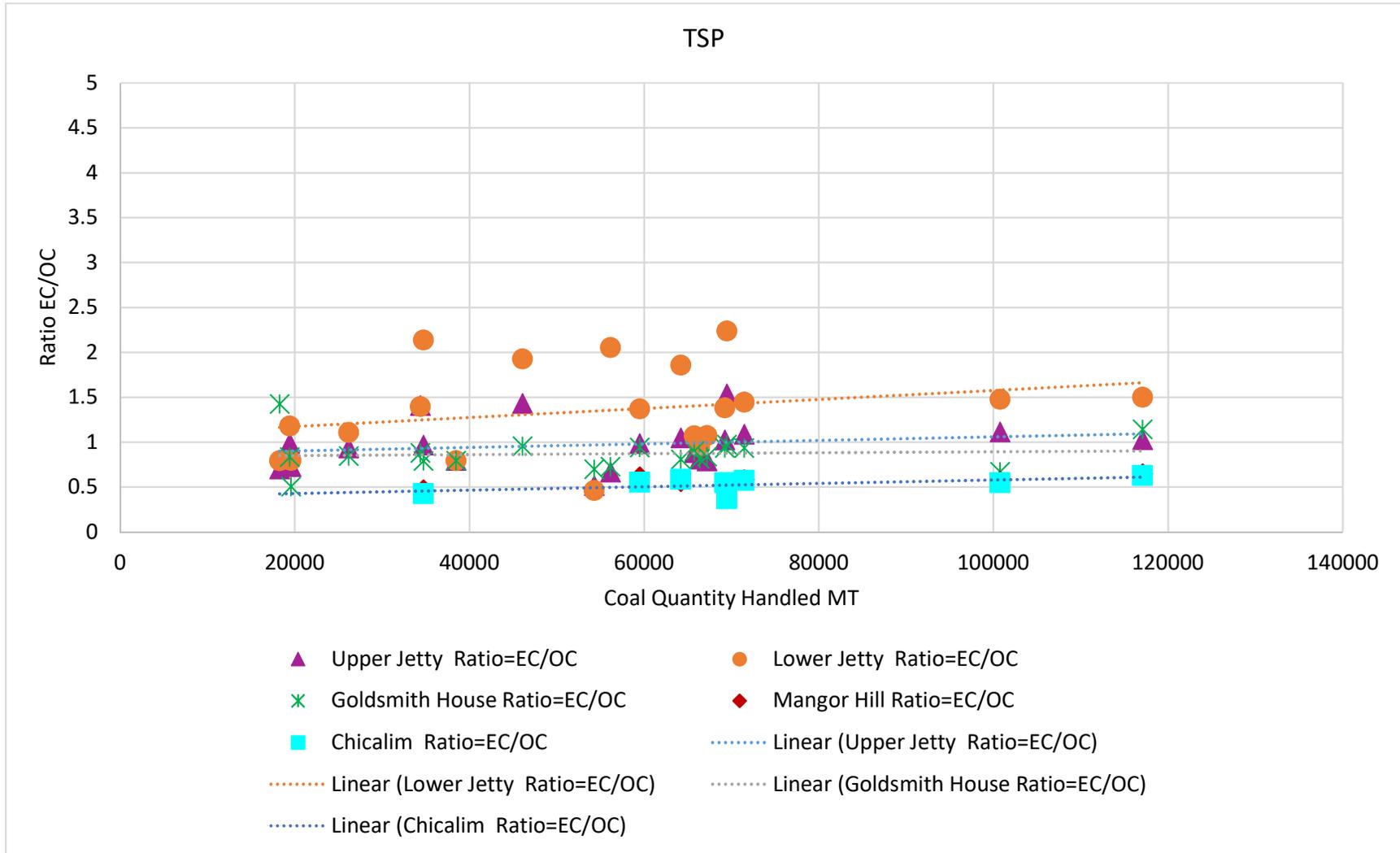


Figure 2.13(c): Coal Quantity against EC/OC Ratio of PM<sub>2.5</sub> for all Sites



**Figure 2.13(d): Coal Quantity against EC/OC Ratio of TSP for all Sites**

# APPENDIX A

## A.1 Matrix of samples taken at the 9 locations with 28 samplers

The samples collected in 9 locations as shown in are shown in Table A (a to i). A total of 28 Mini-Vol samplers (Airmetrics) were used, and GSPCB provided the High Volume samplers at 2 locations.

**Table A.1 (a): Sampling Matrix for Fuse Off Call Office**

Fuse Off Call Office							
Date	PM10		PM2.5		TSP		SPM
	Quartz	Teflon	Quartz	Teflon	Quartz	Teflon	
11-Nov-19	1	1	1	1			
12-Nov-19	1	1	1	1			1
13-Nov-19	1	1	1	1			
14-Nov-19	1	1	1	1			1
15-Nov-19	1	1	1	1			
16-Nov-19	1	1	1	1			1
17-Nov-19	1	1	1	1			
18-Nov-19	1	1	1	1			
19-Nov-19	1	1	1	1			1
20-Nov-19	1	1	1	1			
21-Nov-19	1	1	1	1			1
22-Nov-19	1	1	1	1			
23-Nov-19	1	1	1	1			1
24-Nov-19	1	1	1	1			
25-Nov-19	1	1	1	1			
26-Nov-19	1	1	1	1			1
27-Nov-19	1	1	1	1			
28-Nov-19	1	1	1	1			1
29-Nov-19	1	1	1	1			
30-Nov-19	1	1	1	1			1
1-Dec-19	1	1	1	1			
<b>Total</b>	<b>21</b>	<b>21</b>	<b>21</b>	<b>21</b>			<b>9</b>
<b>Legend</b>							
1	Samples Taken						
	Not in the Sampling Plan						

**Table A.1 (b): Sampling Matrix for Goldsmith House**

<b>Goldsmith House</b>								
Date	PM10		PM2.5		TSP		RSPM	SPM
	Quartz	Teflon	Quartz	Teflon	Quartz	Teflon		
11-Nov-19	1	1	1	1				
12-Nov-19	1	1	1	1	1	1		
13-Nov-19	1	1	1	1	1	1		
14-Nov-19	1	1	1	1	1	1		
15-Nov-19	1	1	1	1	1	1		
16-Nov-19	1	1	1	1	1	1		
17-Nov-19	1	1	1	1	1	1		
18-Nov-19	1	1	1	1	1	1		
19-Nov-19	1	1	1	1	1	1		
20-Nov-19	1	1	1	1	1	1		
21-Nov-19	1	1	1	1	1	1		
22-Nov-19	1	1	1	1	1	1		
23-Nov-19	1	1	1	1	1	1		
24-Nov-19	1	1	1	1	1	1		
25-Nov-19	1	1	1	1	1	1		
26-Nov-19	1	1	1	1	1	1		
27-Nov-19	1	1	1	1	1	1		
28-Nov-19	1	1	1	1	1	1		
29-Nov-19	1	1	1	1	1	1		
30-Nov-19	1	1	1	1	1	1		
1-Dec-19	1	1	1	1	1	1		
<b>Total</b>	<b>21</b>	<b>21</b>	<b>21</b>	<b>21</b>	<b>20</b>	<b>20</b>		
<b>Legend</b>								
	Samples Taken							
	Not in the Sampling Plan							

**Table A.1( c): Sampling Matrix for MPT Guest House**

<b>MPT Guest House</b>								
Date	PM10		PM2.5		TSP		RSPM	SPM
	Quartz	Teflon	Quartz	Teflon	Quartz	Teflon		
11-Nov-19	1	1	1	1				
12-Nov-19	1	1	1	1				
13-Nov-19	1	1	1	1				
14-Nov-19	1	1	1	1				
15-Nov-19	1	1	1	1				
16-Nov-19	1	1	1	1				
17-Nov-19	1	1	1	1				
18-Nov-19	1	1	1	1				
19-Nov-19	1	1	1	1				
20-Nov-19	1	1	1	1				
21-Nov-19	1	1	1	1				
22-Nov-19	1	1	1	1				
23-Nov-19	1	1	1	1				
24-Nov-19	1	1	1	1				
25-Nov-19	1	1	1	1				
26-Nov-19	1	1	1	1				
27-Nov-19	1	1	1	1				
28-Nov-19	1	1	1	1				
29-Nov-19	1	1	1	1				
30-Nov-19	1	1	1	1				
1-Dec-19	1	1	1	1				
<b>Total</b>	<b>21</b>	<b>21</b>	<b>21</b>	<b>21</b>				
<b>Legend</b>								
	Samples Taken							
	Not in the Sampling Plan							

**Table A.1 (d): Sampling Matrix for Fire Brigade Station**

<b>Fire Brigade Station</b>						
Date	PM10		PM2.5		TSP	
	Quartz	Teflon	Quartz	Teflon	Quartz	Teflon
11-Nov-19	1	1	1	1		
12-Nov-19	1	1	1	1		
13-Nov-19	1	1	1	1		
14-Nov-19	1	1	1	1		
15-Nov-19	1	1	1	1		
16-Nov-19	1	1	1	1		
17-Nov-19	1	1	1	1		
18-Nov-19	1	1	1	1		
19-Nov-19	1	1	1	1		
20-Nov-19	1	1	1	1		
21-Nov-19	1	1	1	1		
22-Nov-19	1	1	1	1		
23-Nov-19	1	1	1	1		
24-Nov-19	1	1	1	1		
25-Nov-19	1	1	1	1		
26-Nov-19	1	1	1	1		
27-Nov-19	1	1	1	1		
28-Nov-19	1	1	1	1		
29-Nov-19	1	1	1	1		
30-Nov-19	1	1	1	1		
1-Dec-19	1	1	1	1		
<b>Total</b>	<b>21</b>	<b>21</b>	<b>21</b>	<b>21</b>		
<b>Legend</b>						
	Samples Taken					
	Not in the Sampling Plan					

**Table A.1 (e): Sampling Matrix for Khariwada**

<b>Khariwada</b>								
Date	PM10		PM2.5		TSP		RSPM	SPM
	Quartz	Teflon	Quartz	Teflon	Quartz	Teflon		
11-Nov-19								
12-Nov-19	1	1	1	1				
13-Nov-19	1	1	1	1				
14-Nov-19	1	1	1	1				
15-Nov-19	1	1	1	1				
16-Nov-19	1	1	1	1				
17-Nov-19	1	1	1	1				
18-Nov-19	1	1	1	1				
19-Nov-19	1	1	1	1				
20-Nov-19	1	1	1	1				
21-Nov-19	1	1	1	1				
22-Nov-19	1	1	1	1				
23-Nov-19	1	1	1	1				
24-Nov-19	1	1	1	1				
25-Nov-19	1	1	1	1				
26-Nov-19	1	1	1	1				
27-Nov-19	1	1	1	1				
28-Nov-19	1	1	1	1				
29-Nov-19	1	1	1	1				
30-Nov-19	1	1	1	1				
1-Dec-19	1	1	1	1				
<b>Total</b>	<b>20</b>	<b>20</b>	<b>20</b>	<b>20</b>				
<b>Legend</b>								
	Samples Taken							
	Not in the Sampling Plan							

**Table A.1 (f): Sampling Matrix for Upper Jetty**

Upper Jetty								
Date	PM10		PM2.5		TSP		RSPM	SPM
	Quartz	Teflon	Quartz	Teflon	Quartz	Teflon		
11-Nov-19								
12-Nov-19					1	1		
13-Nov-19					1	1		
14-Nov-19					1	1		
15-Nov-19					1	1		
16-Nov-19					1	1		
17-Nov-19					1	1		
18-Nov-19					1	1		
19-Nov-19					1	1		
20-Nov-19					1	1		
21-Nov-19					1	1		
22-Nov-19					1	1		
23-Nov-19					1	1		
24-Nov-19					1	1		
25-Nov-19					1	1		
26-Nov-19					1	1		
27-Nov-19					1	1		
28-Nov-19					1	1		
29-Nov-19					1	1		
30-Nov-19					1	1		
1-Dec-19					1	1		
<b>Total</b>					<b>20</b>	<b>20</b>		
<b>Legend</b>								
	Samples Taken							
	Not in the Sampling Plan							

**Table A.1 (g): Sampling Matrix for Lower Jetty**

Lower Jetty								
Date	PM10		PM2.5		TSP		RSPM	SPM
	Quartz	Teflon	Quartz	Teflon	Quartz	Teflon		
11-Nov-19								
12-Nov-19					1	1		
13-Nov-19					1	1		
14-Nov-19					1	1		
15-Nov-19					1	1		
16-Nov-19					1	1		
17-Nov-19					1	1		
18-Nov-19					1	1		
19-Nov-19					1	1		
20-Nov-19					1	1		
21-Nov-19					1	1		
22-Nov-19					1	1		
23-Nov-19					1	1		
24-Nov-19					1	1		
25-Nov-19					1	1		
26-Nov-19					1	1		
27-Nov-19					1	1		
28-Nov-19					1	1		
29-Nov-19					1	1		
30-Nov-19					1	1		
1-Dec-19					1	1		
<b>Total</b>					<b>20</b>	<b>20</b>		
<b>Legend</b>								
	Samples Taken							
	Not in the Sampling Plan							

**Table A.1 (h): Sampling Matrix for Mangor Hill**

<b>Mangor Hill</b>								
Date	PM10		PM2.5		TSP		RSPM	SPM
	Quartz	Teflon	Quartz	Teflon	Quartz	Teflon		
11-Nov-19								
12-Nov-19						1	1	1
13-Nov-19						1	1	1
14-Nov-19						1	1	1
15-Nov-19						1	1	1
16-Nov-19						1	1	1
17-Nov-19						1	1	1
18-Nov-19						1	1	1
19-Nov-19						1	1	1
20-Nov-19						1	1	1
21-Nov-19						1	1	1
22-Nov-19						1	1	1
23-Nov-19						1	1	1
24-Nov-19					1		1	1
25-Nov-19					1		1	1
26-Nov-19					1		1	1
27-Nov-19					1		1	1
28-Nov-19					1		1	1
29-Nov-19					1		1	1
30-Nov-19					1		1	1
1-Dec-19					1		1	1
<b>Total</b>					<b>8</b>	<b>12</b>	<b>20</b>	<b>20</b>
<b>Legend</b>								
	Samples Taken							
	Not in the Sampling Plan							

**Table A.1 (i): Sampling Matrix for Chicalim**

<b>Chicalim</b>								
Date	PM10		PM2.5		TSP		RSPM	SPM
	Quartz	Teflon	Quartz	Teflon	Quartz	Teflon		
11-Nov-19								
12-Nov-19						1	1	1
13-Nov-19						1	1	1
14-Nov-19						1	1	1
15-Nov-19						1	1	1
16-Nov-19						1	1	1
17-Nov-19						1	1	1
18-Nov-19						1	1	1
19-Nov-19						1	1	1
20-Nov-19						1	1	1
21-Nov-19						1	1	1
22-Nov-19						1	1	1
23-Nov-19						1	1	1
24-Nov-19					1		1	1
25-Nov-19					1		1	1
26-Nov-19					1		1	1
27-Nov-19					1		1	1
28-Nov-19					1		1	1
29-Nov-19					1		1	1
30-Nov-19					1		1	1
1-Dec-19					1		1	1
<b>Total</b>					<b>8</b>	<b>12</b>	<b>20</b>	<b>20</b>
<b>Legend</b>								
	Samples Taken							
	Not in the Sampling Plan							

# APPENDIX B

## **B.1 Records of Activity Data during the Sampling Campaign**

A 21-page document was received from GSPCB for the various activities (Ship vessels, Wagons and Trucks) with the respective cargo types. The same have been prepared as tables **Table B.1 (a - f)**

Number of Vehicles against Quantity of loaded plotted in **Figure B.1 (a) – B.1 (f)**

Table B.1 (a): Berth No 5A SWPL

BERTH NO 5A SWPL	Page 3 of 21		
DATE	QUANTITY OF STEEL COIL AND SLAB HANDLED (MT)	NO OF WAGONS UNLOADED	NO OF TRUCKS EMPLOYED
9/11/2019	3680	59	7
10/11/2019	0	0	0
11/11/2019	0	104	7
12/11/2019	0	117	7
13/11/2019	0	59	6
14/11/2019	0	0	0
15/11/2019	0	59	7
16/11/2019	0	0	0
17/11/2019	0	59	7
18/11/2019	0	59	8
19/11/2019	0	0	0
20/11/2019	0	0	0
21/11/2019	0	59	8
22/11/2019	0	0	0
23/11/2019	5501	45	7
24/11/2019	4218	0	5
25/11/2019	5315	59	8
26/11/2019	5251	33	7
27/11/2019	5484	0	5
28/11/2019	4932	59	7
29/11/2019	10008	0	5
30/11/2019	6466	0	5
1/12/2019	7269	36	7
2/12/2019	1067	0	4
3/12/2019	0	0	0
4/12/2019			
<b>TOTAL</b>	<b>59191</b>	<b>807</b>	<b>117</b>

Table B.1 (b): Unknown

???	Page 5 of 21							
DATE	CARGO TYPE	QUANTITY OF COAL UNLOADED FROM VESSEL INTO PLOT A (MT)	QUANTITY OF COAL UNLOADED FROM VESSEL INTO PLOT B (MT)	TOTAL QUANTITY OF COAL UNLOADED FROM VESSEL INTO PLOTS (MT) [C=A+B]	QUANTITY OF COAL LOADED INTO WAGON FROM PLOT (MT)	NO. OF WAGON LOADED PER DAY (NOS.)	Quantity OF COAL LOADED BY TRUCK PER DAY(MT)	Adani NO. OF TRUCK LOADED PER DAY
9/11/2019	COKING COAL		5732	5732	11357	175	1564	99
10/11/2019				0	7480	118	1235	88
11/11/2019				0	7615	118	1182	79
12/11/2019	PET COKE	3500		3500	6561	103	1006	67
13/11/2019				0	3845	57	953	65
14/11/2019				0	3909	58	924	64
15/11/2019				0	7919	117	1268	88
16/11/2019				0	7072	106	1229	84
17/11/2019				0	3769	59	1788	126
18/11/2019				0	3669	59	1633	117
19/11/2019				0	0	0	1618	115
20/11/2019				0	0	0	1380	105
21/11/2019				0	7815	116	1612	115
22/11/2019	STEAM COAL		33270	33270	0	0	1328	106
23/11/2019	STEAM COAL		32780	32780	7803	118	1527	117
24/11/2019	KRASNY BROD PCI COAL		23040	23040	7900	117	1783	127
25/11/2019	COAL		40270	40270	7955	117	1659	116
26/11/2019	COAL		30050	30050	7882	117	884	48
27/11/2019	STEAM COAL	27000	750	27750	11815	177	69	4
28/11/2019	STEAM COAL	26500		26500	11582	177	1967	119
29/11/2019	STEAM COAL	32000		32000	15658	233	212	8
30/11/2019	STEAM COAL & COKING COAL	5137	33100	38237	11775	177	716	42
1/12/2019	COKING COAL		12400	12400	14387	235	252	9
2/12/2019	COKING COAL		8747	8747	17471	294	631	24
3/12/2019					25795	409	377	14
4/12/2019					11855	175	334	12
<b>TOTAL</b>		<b>94137</b>	<b>220139</b>	<b>314276</b>	<b>222892</b>	<b>3432</b>	<b>29130</b>	<b>1958</b>

Table B.1 (c): Unknown

Page 7 of 21							
NAME OF VESSEL	CARGO TYPE	QUANTITY OF COAL UNLOADED FROM VESSEL INTO PLOT (MT)	QUANTITY OF COAL LOADED into wagon FROM PLOT (MT)	Coal-No. of wagons loaded per day (Nos)	Quantity of limestone unloaded from vessel into plot (MT)	Quantity of Limestone loaded into wagon (MT)	Limestone-NO. of wagon loaded per day (NOS)
MV MINERAL EDO	HC & SHC COAL	22295	3356	59		15485	236
MV MINERAL EDO	HC & SHC COAL	15052	13010	232		293	4
MV MINERAL EDO	HC & SHC COAL	7307	20586	352			
MV HONEST SKY	SSC COAL	33653	21657	351			
MV HONEST SKY	SSC COAL	38877	22058	352			
MV HONEST SKY	SSC COAL	15470	18162	294			
			25180	410			
MV YASA SATURN	LIMESTONE		17880	294	1817		
MV YASA SATURN	LIMESTONE		14027	236	40431		
MV YASA SATURN	LIMESTONE		14134	235	17502	7811	118
MV TRUST EGILITY	HC & SHC COAL	6148	10504	117		11526	175
MV TRUST EGILITY	HC & SHC COAL	41930	10961	117		15494	234
MV TRUST EGILITY	HC & SHC COAL	35660	22114	352		3879	59
MV TRUST EGILITY	HC & SHC COAL	3972	7505	117		15100	235
			14027	222		7574	118
MV KAPE AMAL	PCI & SSC COAL	12540	18957	294			
MV KAPE AMAL	PCI & SSC COAL	40502	26689	410			
MV KAPE AMAL	PCI & SSC COAL	38848	23081	354			

MV KAPE AMAL	PCI & SSC COAL	16790	15042	236			
			19438	294			
MV LAVINIA OLDENDROFF	SHC COAL	5753	15627	234			
			18758	293			
			7684	118			
			11494	177			
MV GANGA K	LIME STONE		3880	59	30670	7851	117
		<b>334796</b>	<b>395810</b>	<b>6209</b>	<b>90420</b>	<b>85013</b>	<b>1296</b>

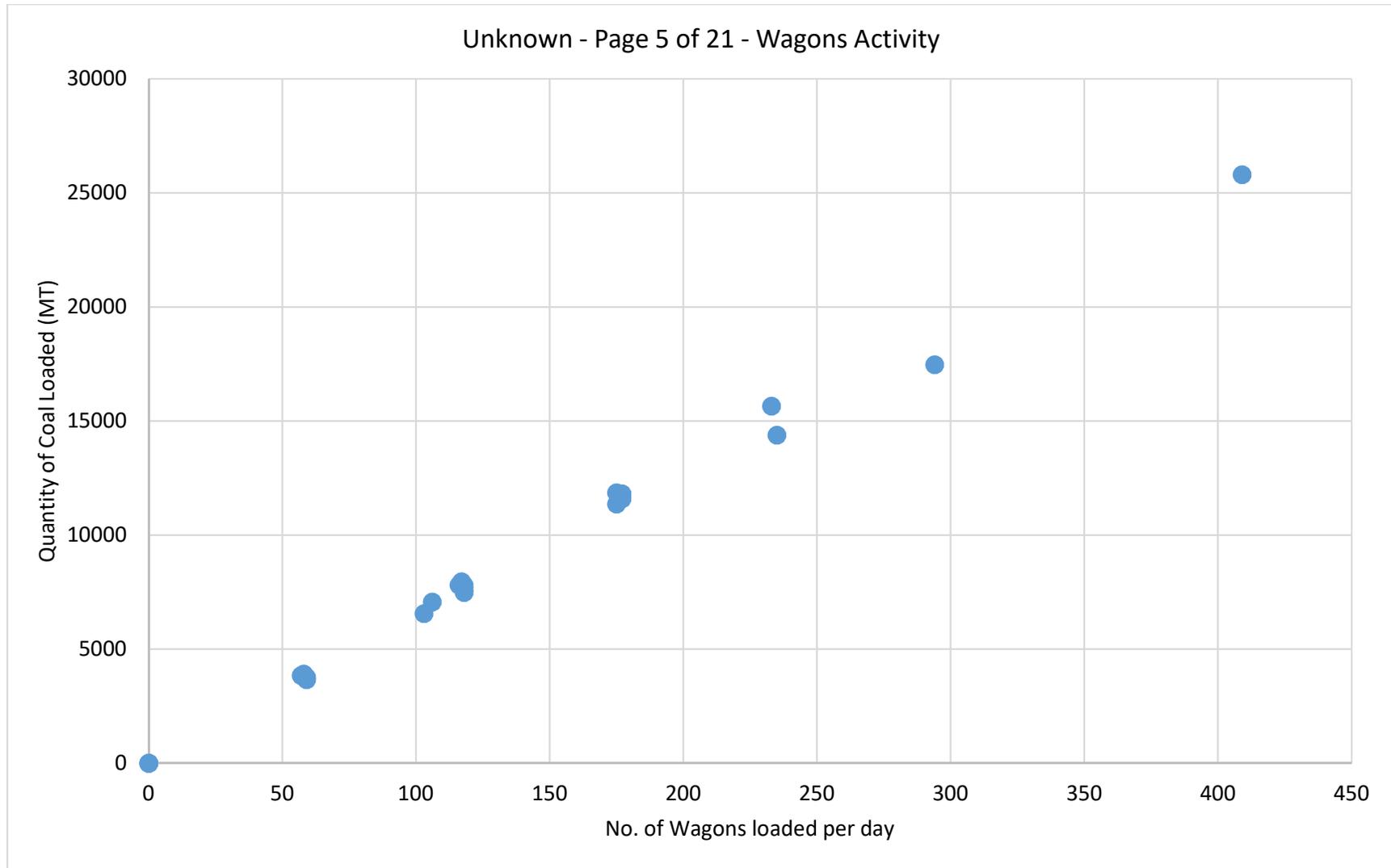
**Table B.1 (d): BERTH NO.10/11 DISPATCHED (MPT)**

Pages 11-17 of 21										
IRON ORE LUMPY	No. of Trucks	QTY (MT)	BENTONITE	No. of Trucks	QTY (MT)	BAUXITE	No. of Trucks	QTY (MT)	TOTAL NO. TRUCKS	TOTAL QTY (MT)
						<input type="checkbox"/>	101	3022	101	3022
						<input type="checkbox"/>			0	0
						<input type="checkbox"/>	82	2314	82	2314
						<input type="checkbox"/>	149	4152	149	4152
<input type="checkbox"/>	17	174				<input type="checkbox"/>	162	4476	179	4650
<input type="checkbox"/>	95	958				<input type="checkbox"/>	107	2969	202	3927
<input type="checkbox"/>	91	926							91	926
<input type="checkbox"/>	87	896				<input type="checkbox"/>	114	3174	201	4070
						<input type="checkbox"/>	3	82	3	82
<input type="checkbox"/>	102	1050				<input type="checkbox"/>	199	5619	301	6669
<input type="checkbox"/>	98	1006				<input type="checkbox"/>	115	3190	213	4196
<input type="checkbox"/>	100	1031							100	1031
<input type="checkbox"/>	72	736	<input type="checkbox"/>	16	419	<input type="checkbox"/>	100	2669	188	3824
<input type="checkbox"/>	32	326	<input type="checkbox"/>	13	341	<input type="checkbox"/>	169	4533	214	5200
			<input type="checkbox"/>	21	613	<input type="checkbox"/>	21	567	42	1180
			<input type="checkbox"/>	22	666				22	666
									0	0
						<input type="checkbox"/>	171	4647	171	4647
						<input type="checkbox"/>	166	4480	166	4480

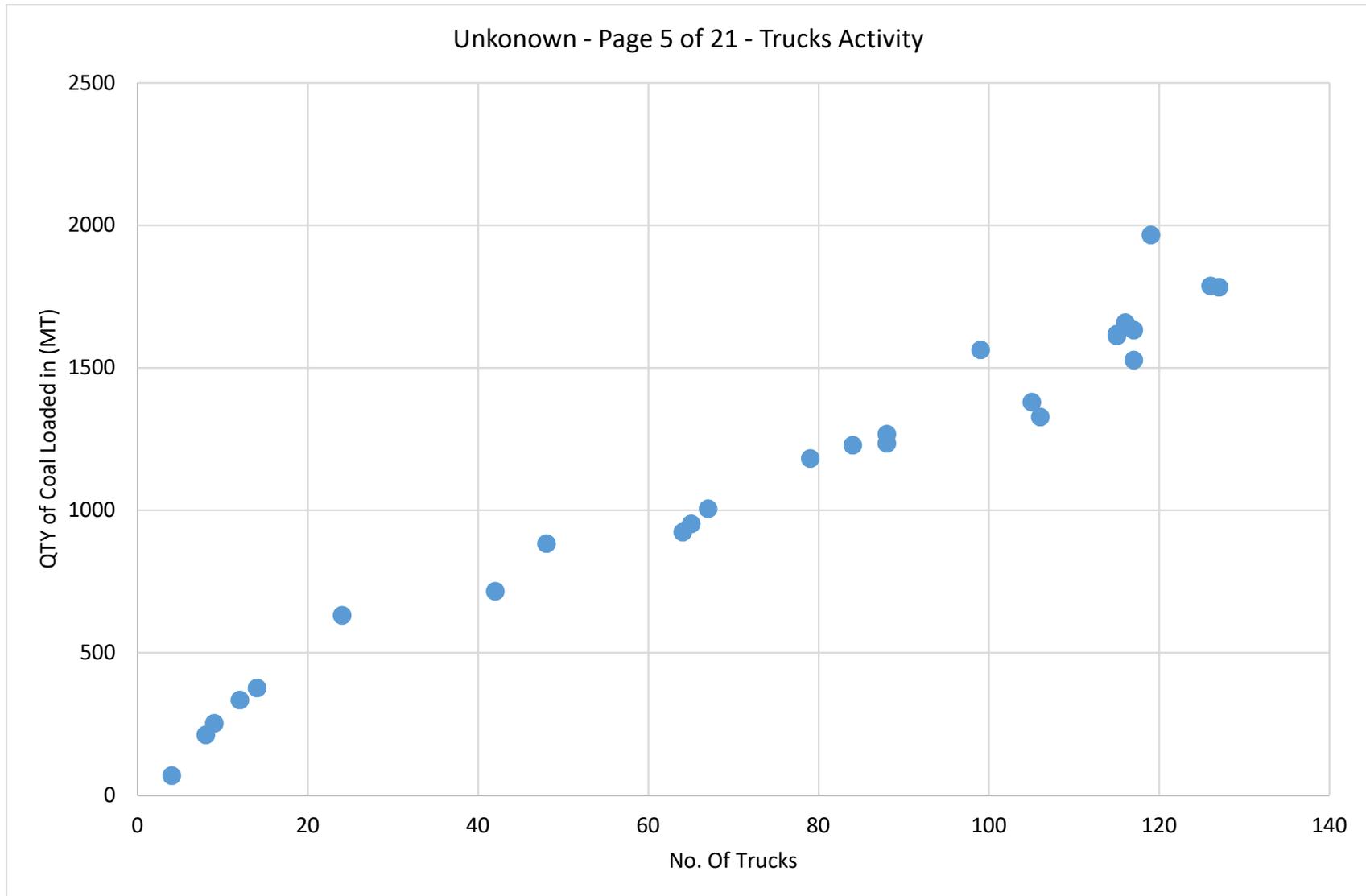


Table B.1 (f): BERTH NO. 8 MPT

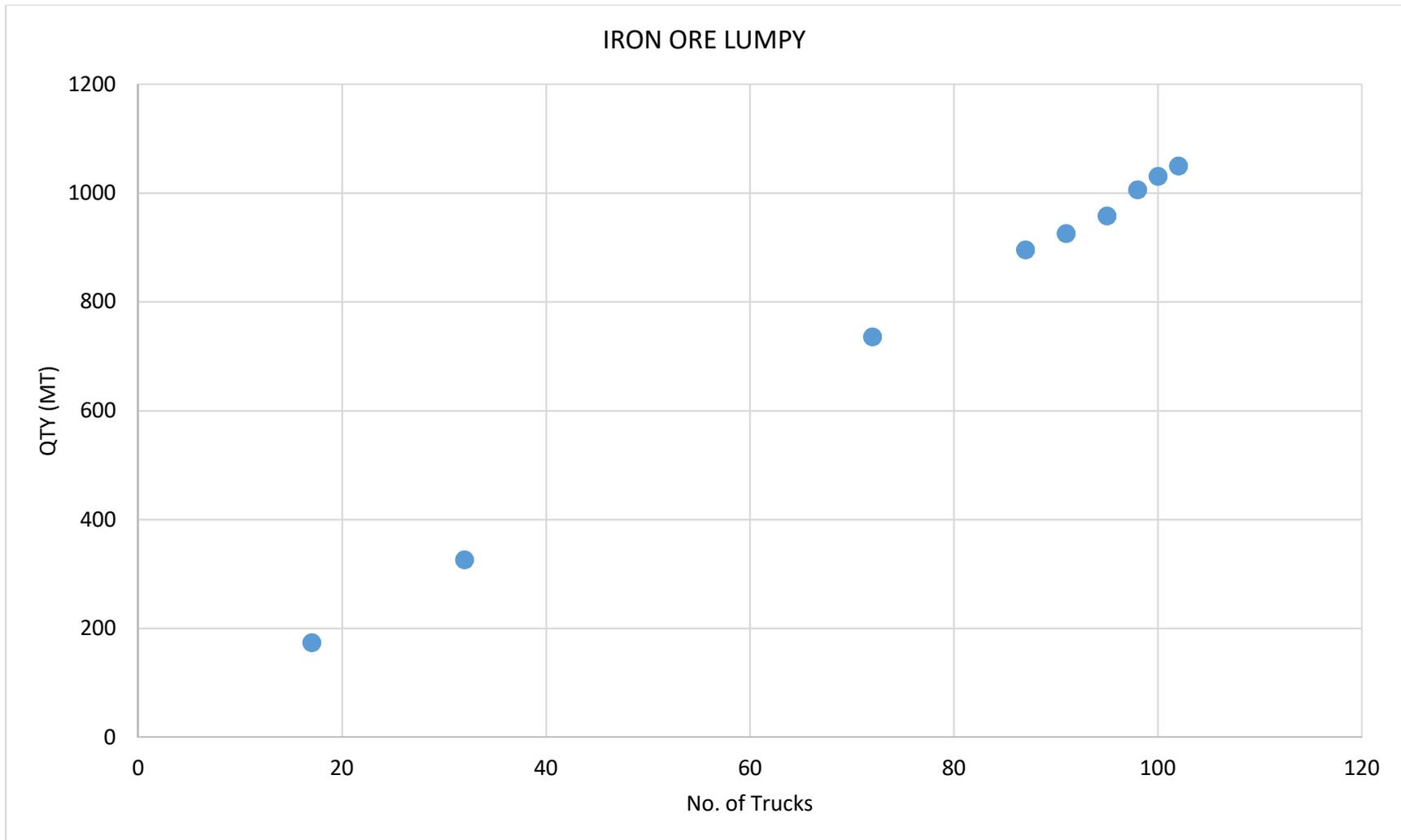
		Page 20 of 21
NAME OF LIQUID CARGO HANDLED	QUANTITY UNLOADED	NO.OF VESSEL UNLOADED
MS	9000	1
HSD	5500	
HSD	7500	
HSD	893	
HSD	4573	1
HSD	3488	
MS	4000	1
MS/HSD	NIL	1
MS	6939	
HSD	5602	
HSD	3506	
	<b>51001</b>	<b>4</b>



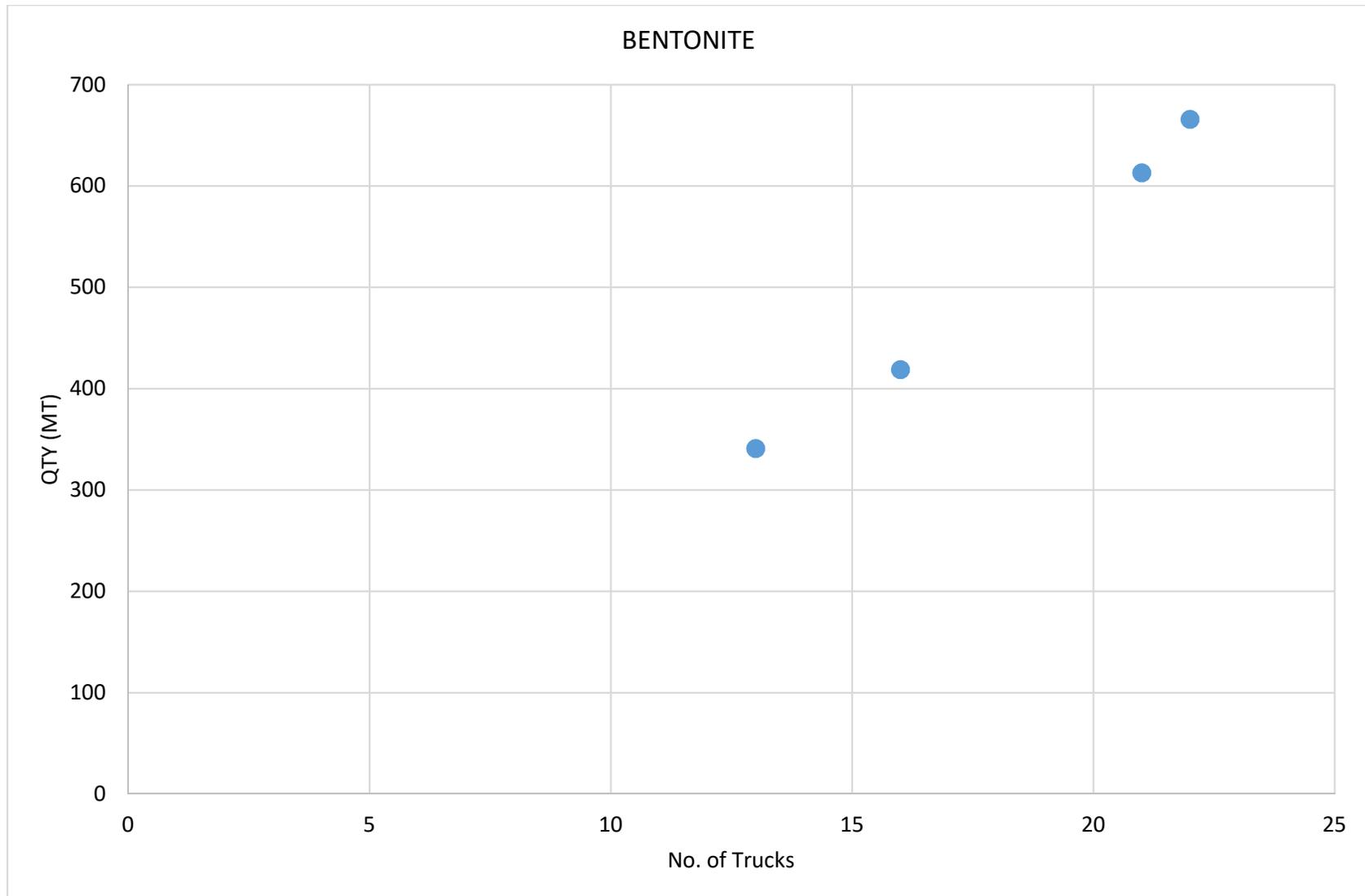
**Figure B.1 (a): No. of Wagons against Quantity of coal loaded**



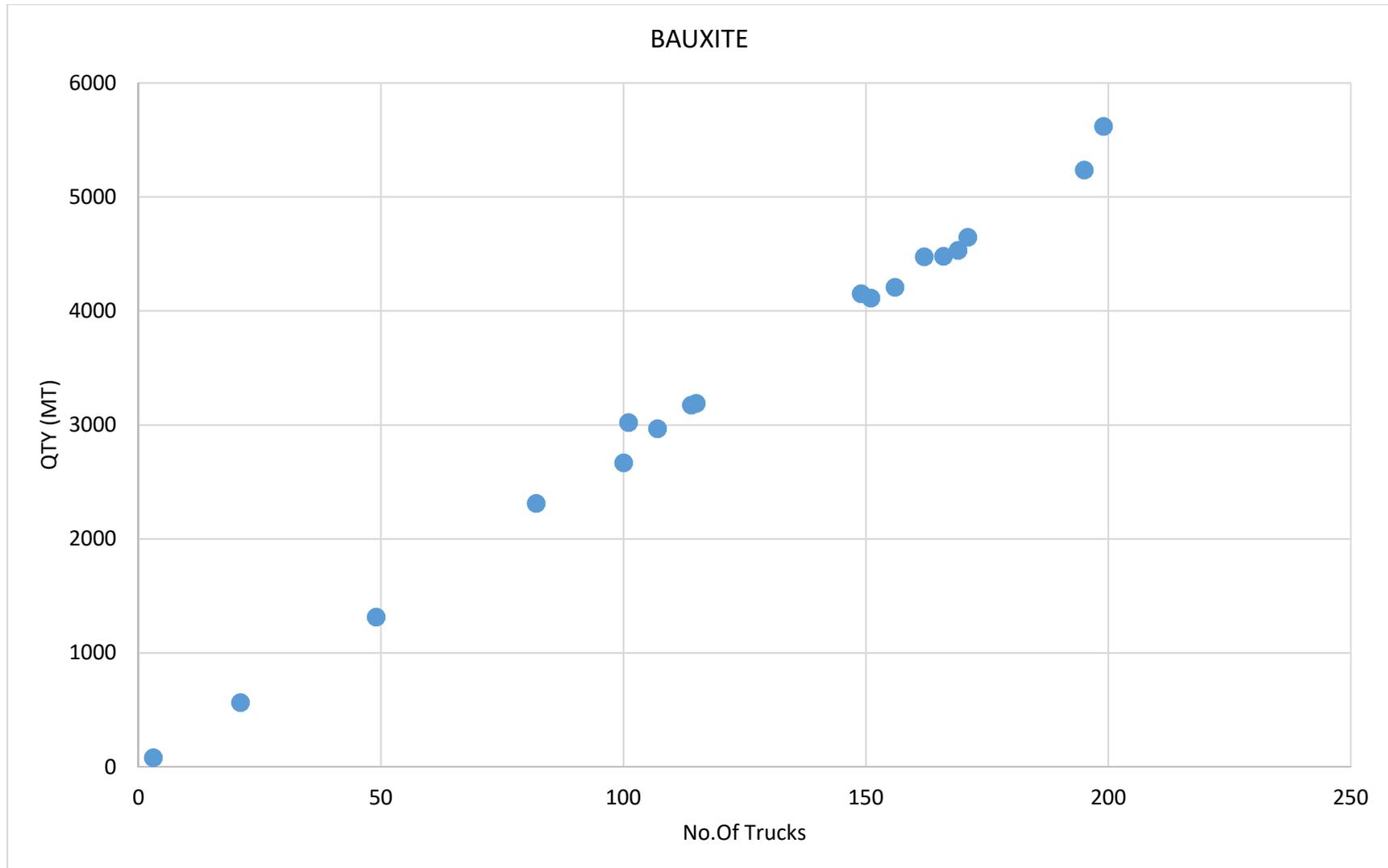
**Figure B.1 (b): No. of Trucks against Quantity of Coal loaded**



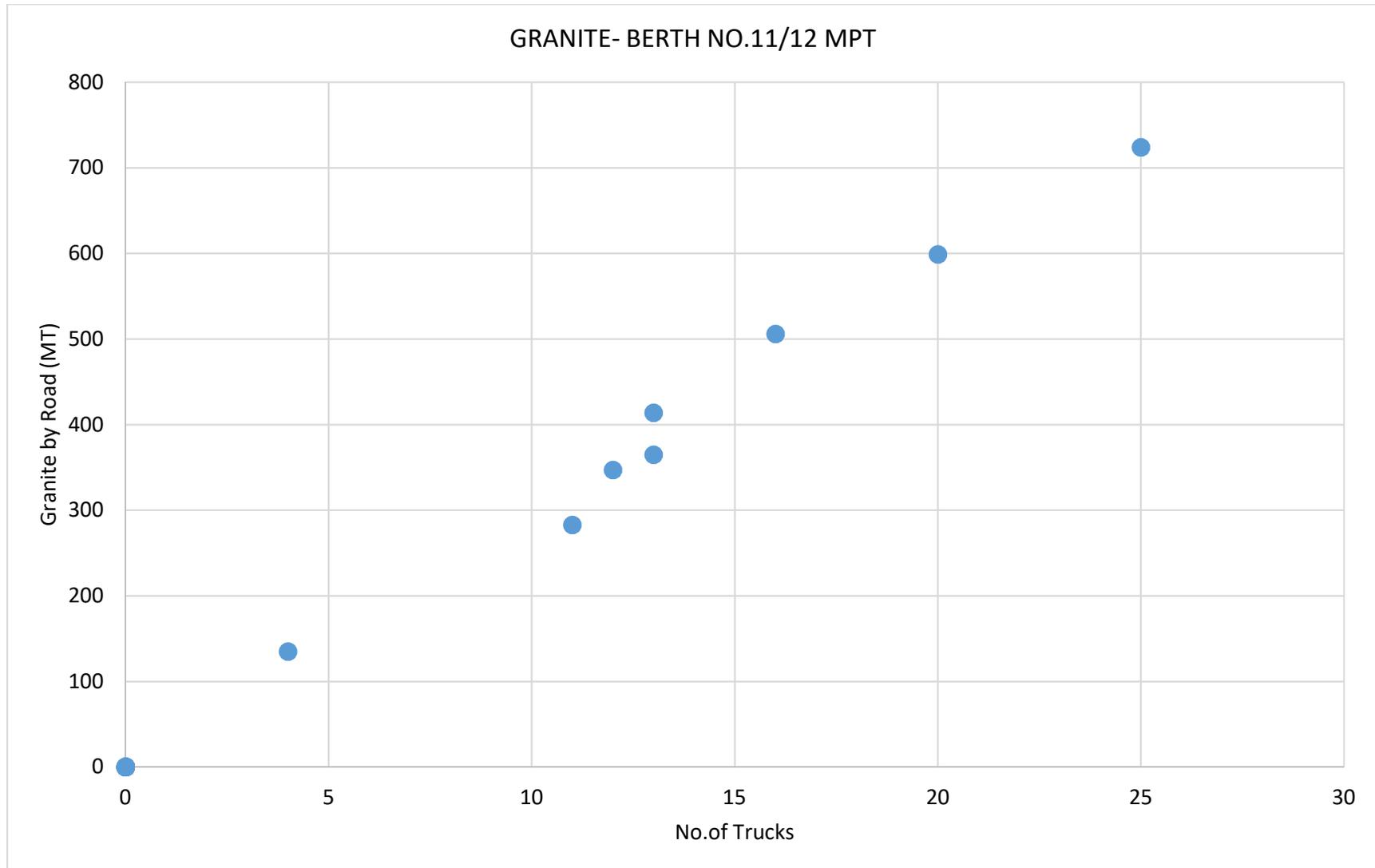
**Figure B.1 (c): No. of Trucks against Quantity of Iron Ore lumpy loaded**



**Figure B.1 (d): No. of Trucks against Quantity of Bentonite loaded**



**Figure B.1 (e): No. of Trucks against Quantity of Bauxite loaded**



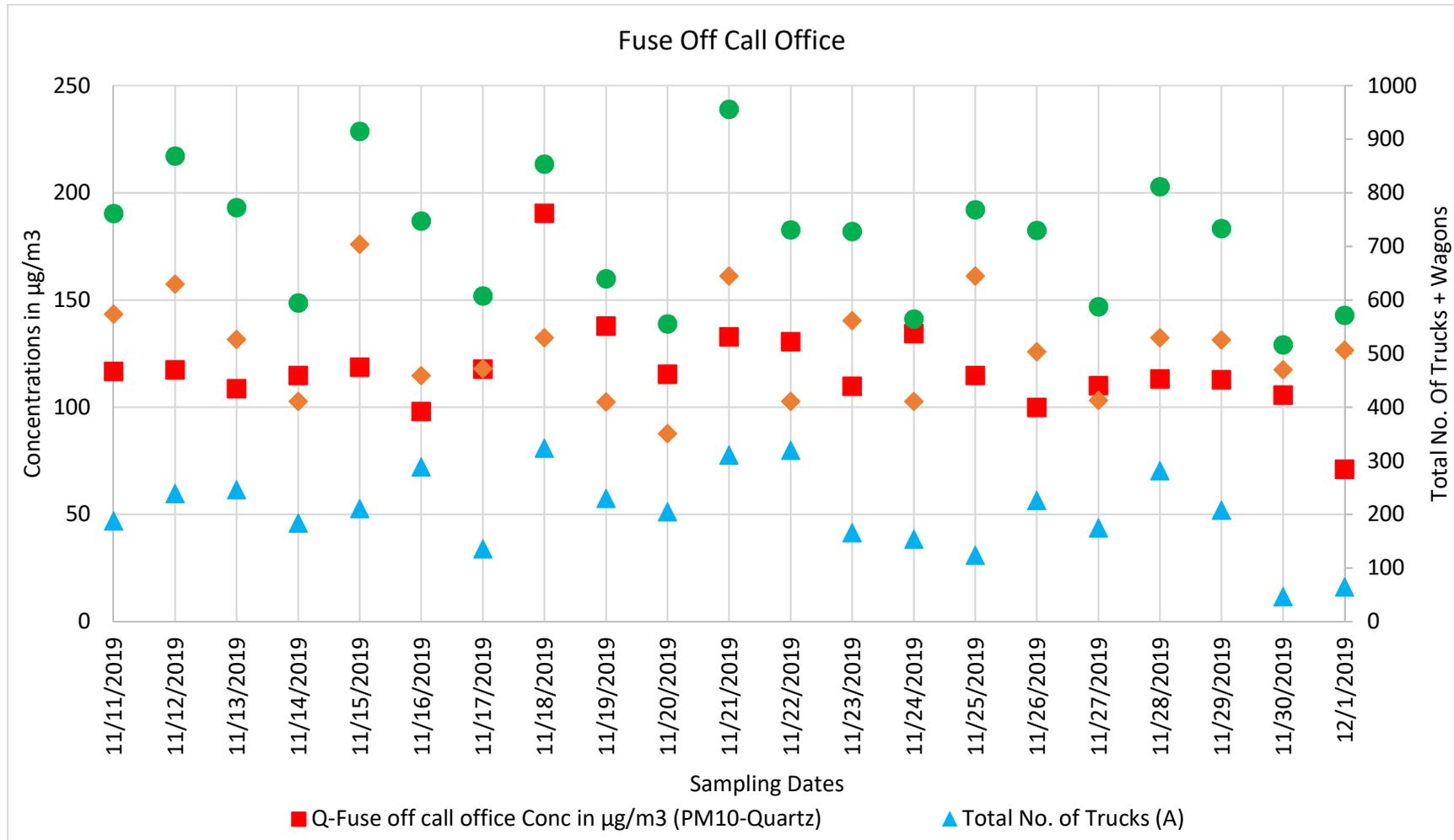
**Figure B.1 (f): No. of Trucks against Quantity of Granite loaded at Berth No. 11/12 MPT**

# APPENDIX C

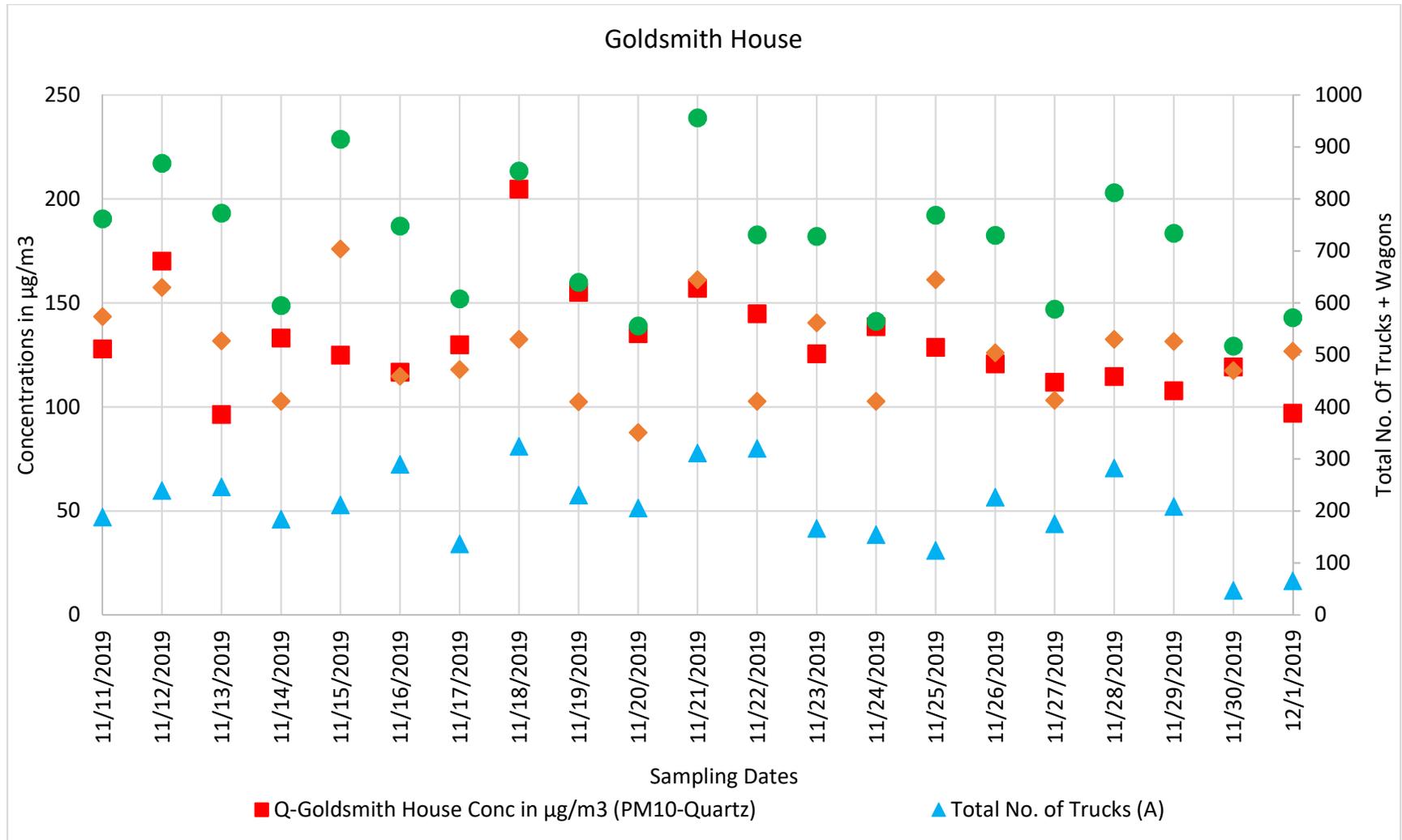
## C.1 Activity and Measurement Comparison

The measured PM and TSP data from the 20 days of sampling, and the activity levels are plotted as time series in **Figures C.1 (a - j)**

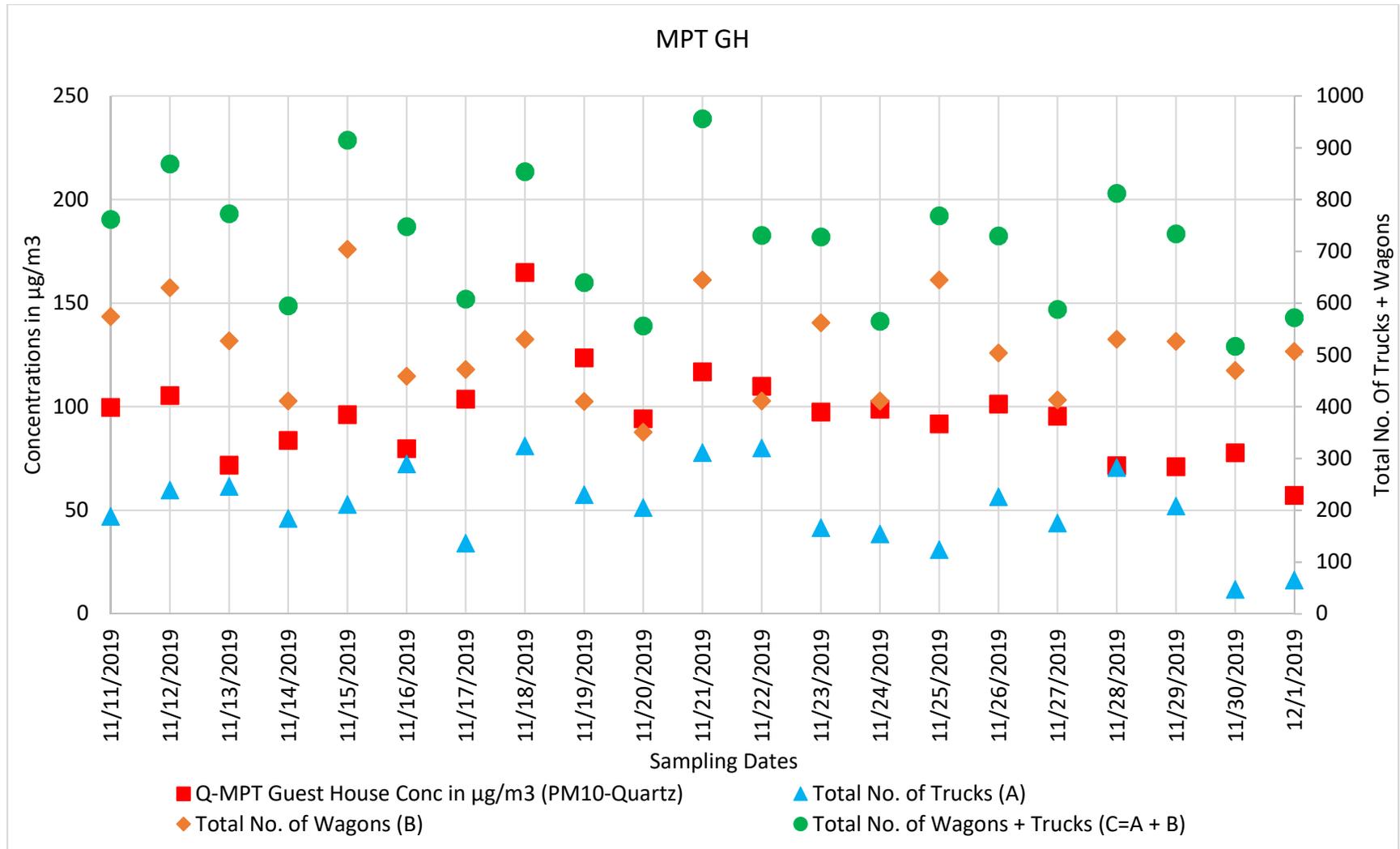
The correlations for the PM and TSP with the activity of trucks alone, wagons alone, and trucks and wagons together, are plotted in **Figures C.1 (k - t)**



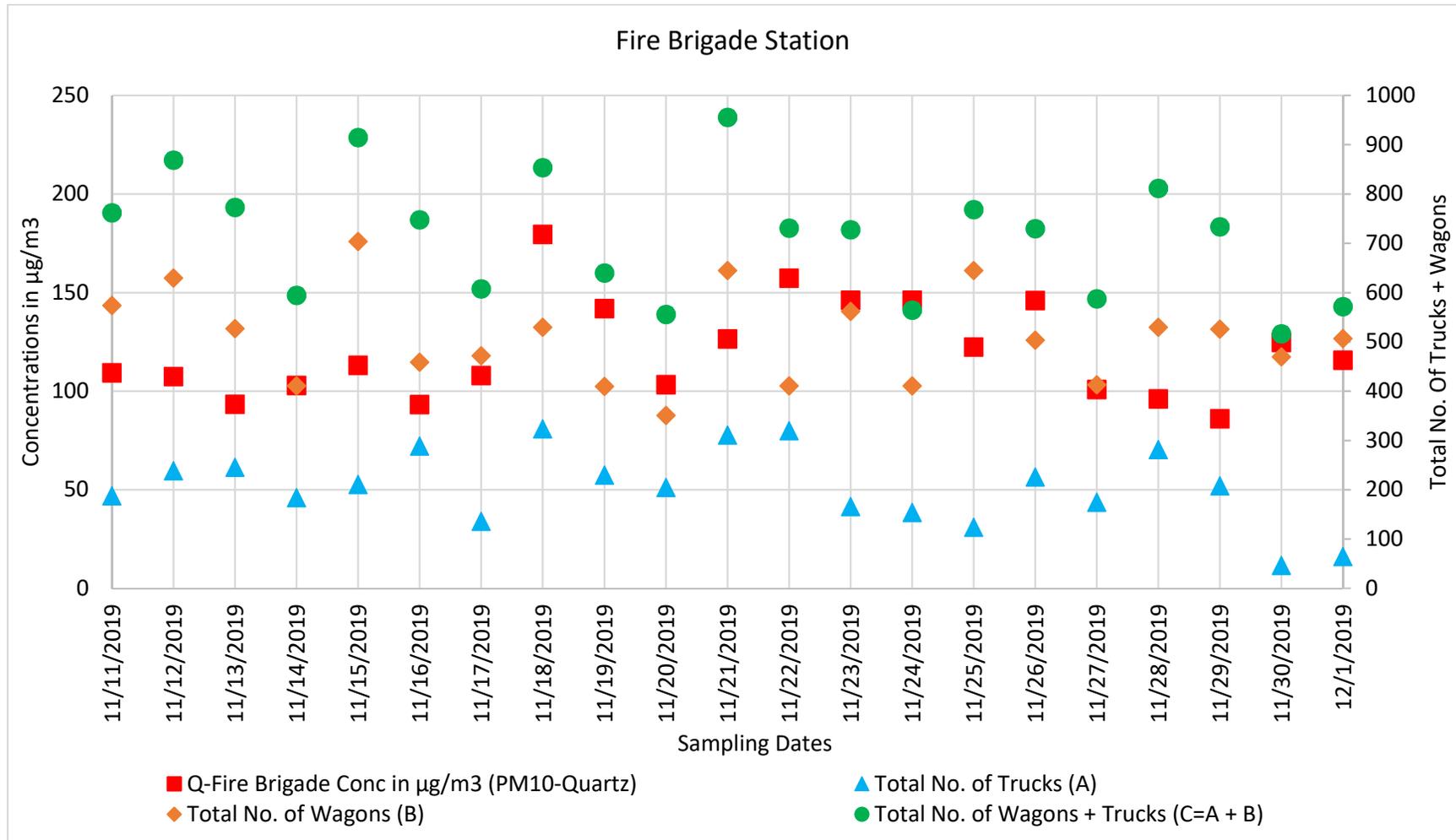
**Figure C.1(a): Activity Data PM<sub>10</sub> Concentrations and Alone No. of Trucks, No. of Wagons, and Trucks and Wagons together (Fuse Off call Office)**



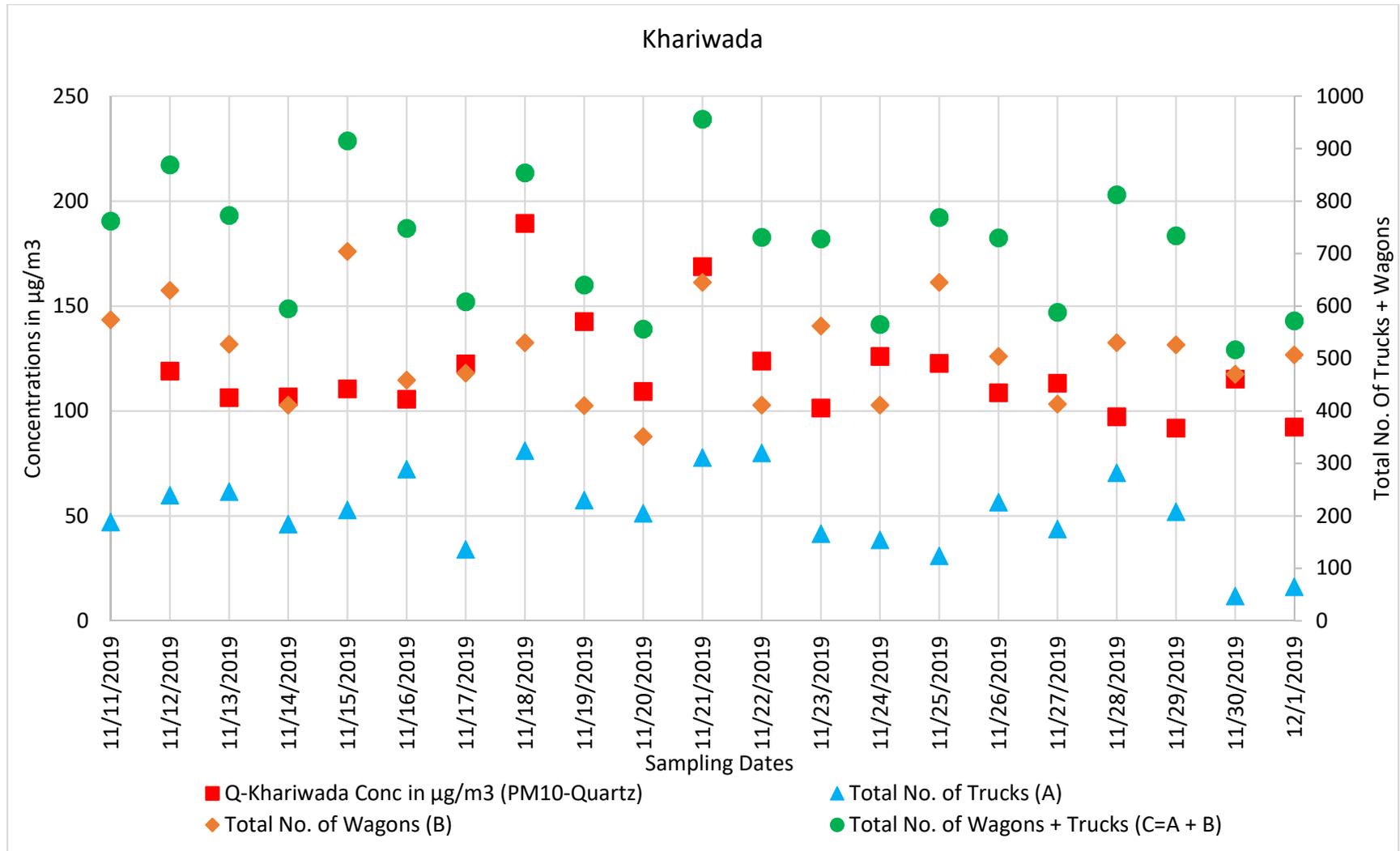
**Figure C.1(b): Activity Data PM<sub>10</sub> Concentrations and Alone No. of Trucks, No. of Wagons, and Trucks and Wagons together (Goldsmith House)**



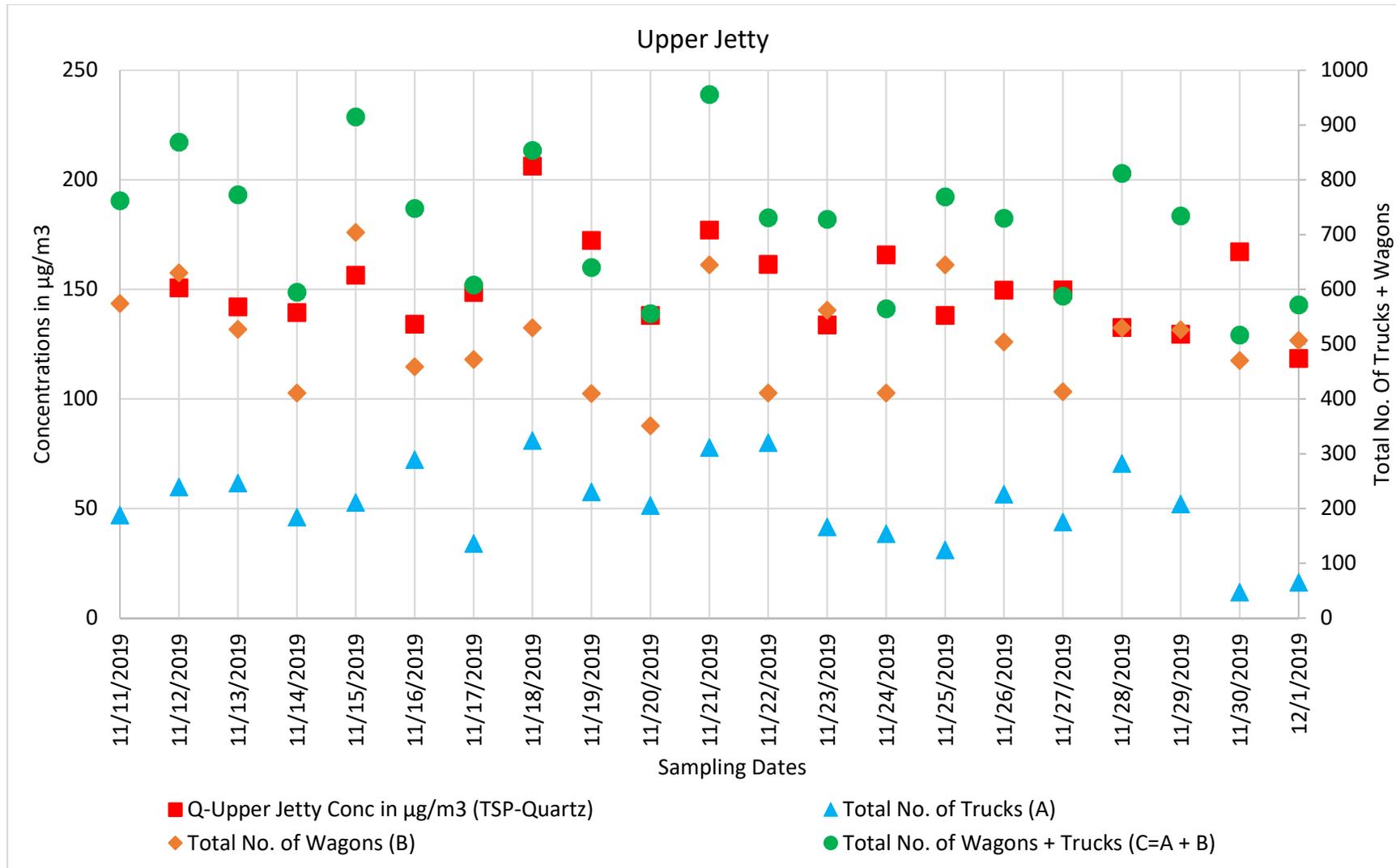
**Figure C.1 (c): Activity Data PM<sub>10</sub> Concentrations and Alone No. of Trucks, No. of Wagons, and Trucks and Wagons together (MPT Guest House)**



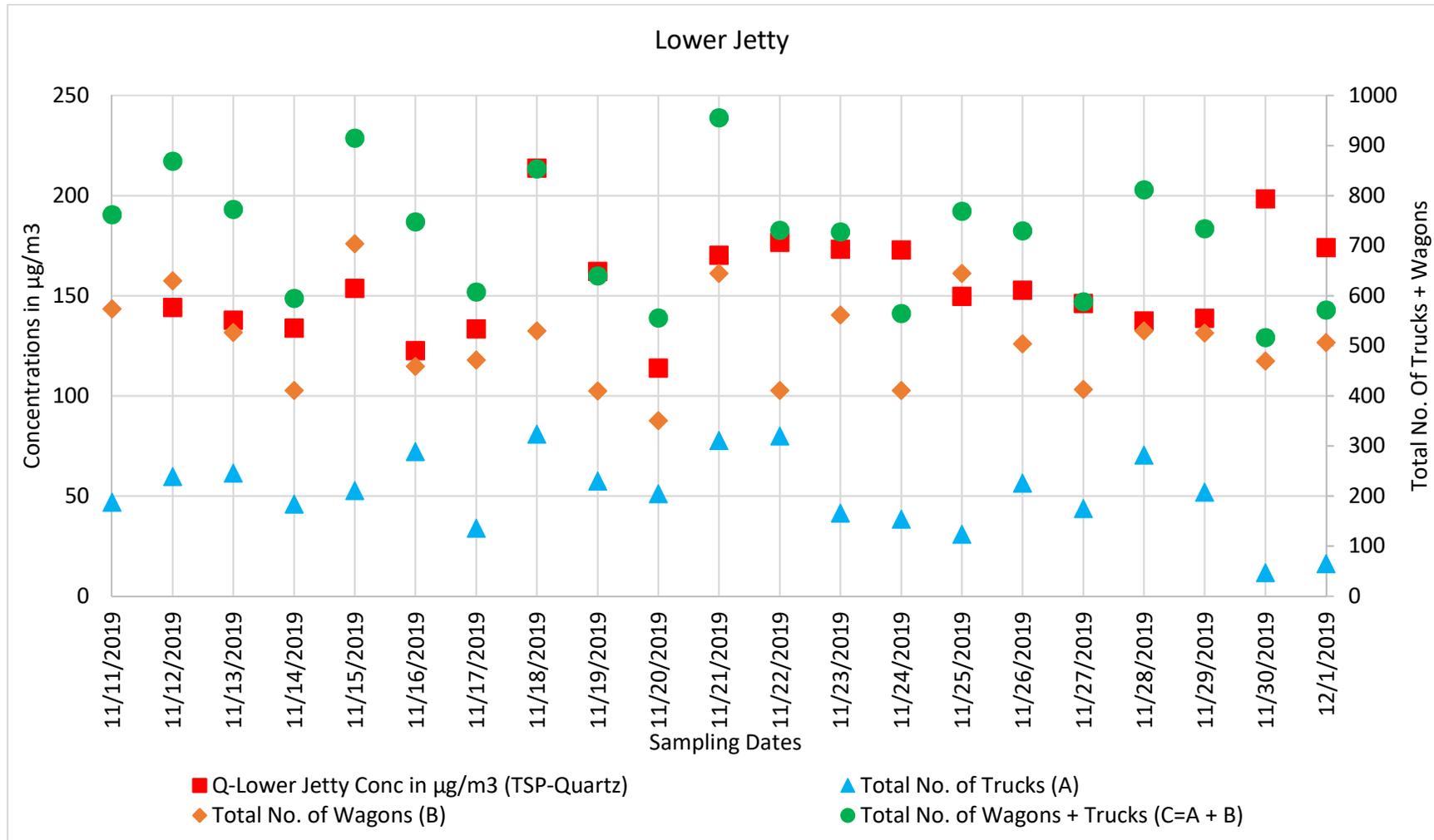
**Figure C.1 (d): Activity Data PM<sub>10</sub> Concentrations and Alone No. of Trucks, No. of Wagons, and Trucks and Wagons together (Fire Brigade Station)**



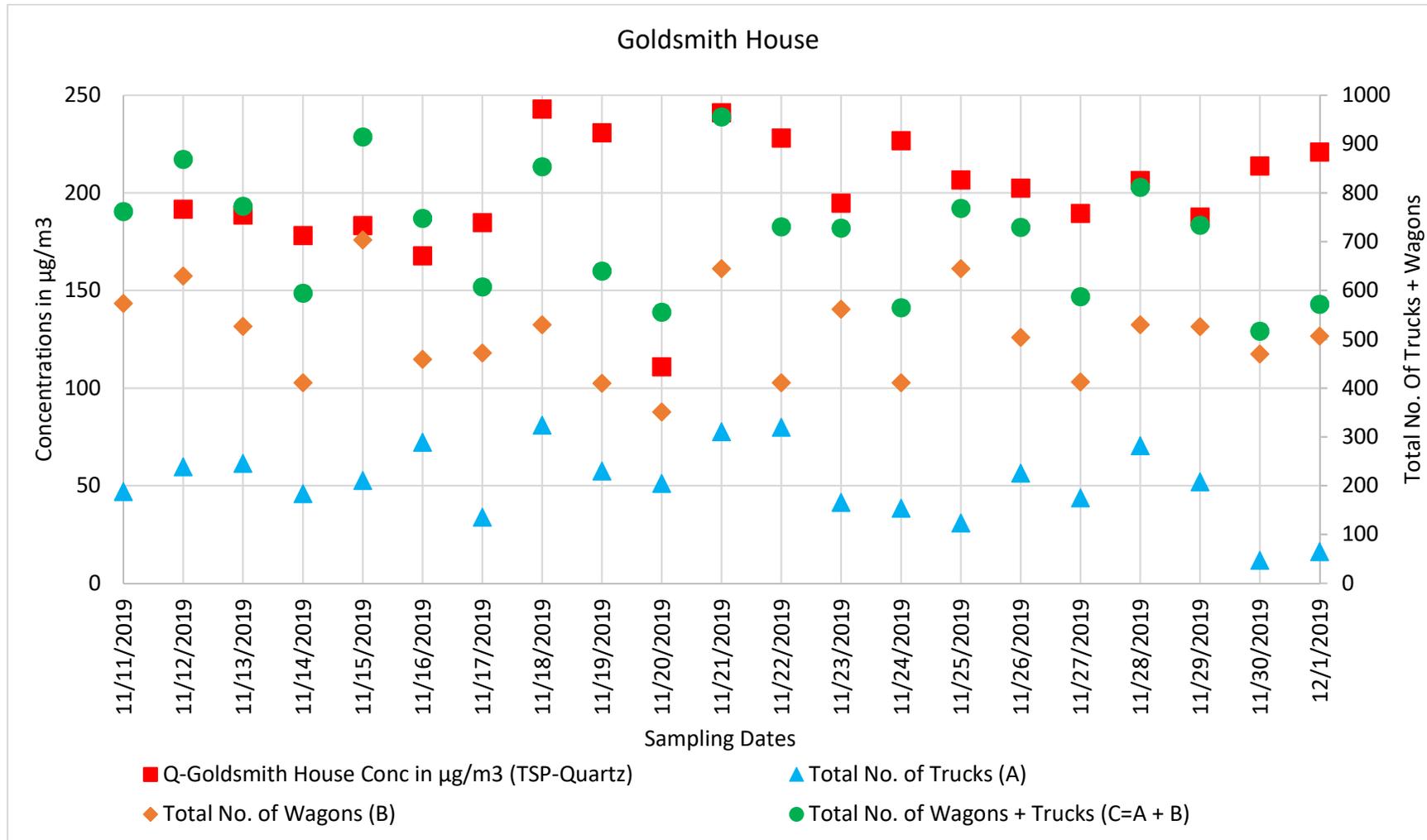
**Figure C.1 (e): Activity Data PM<sub>10</sub> Concentrations and Alone No. of Trucks, No. of Wagons, and Trucks and Wagons together (Khariwada)**



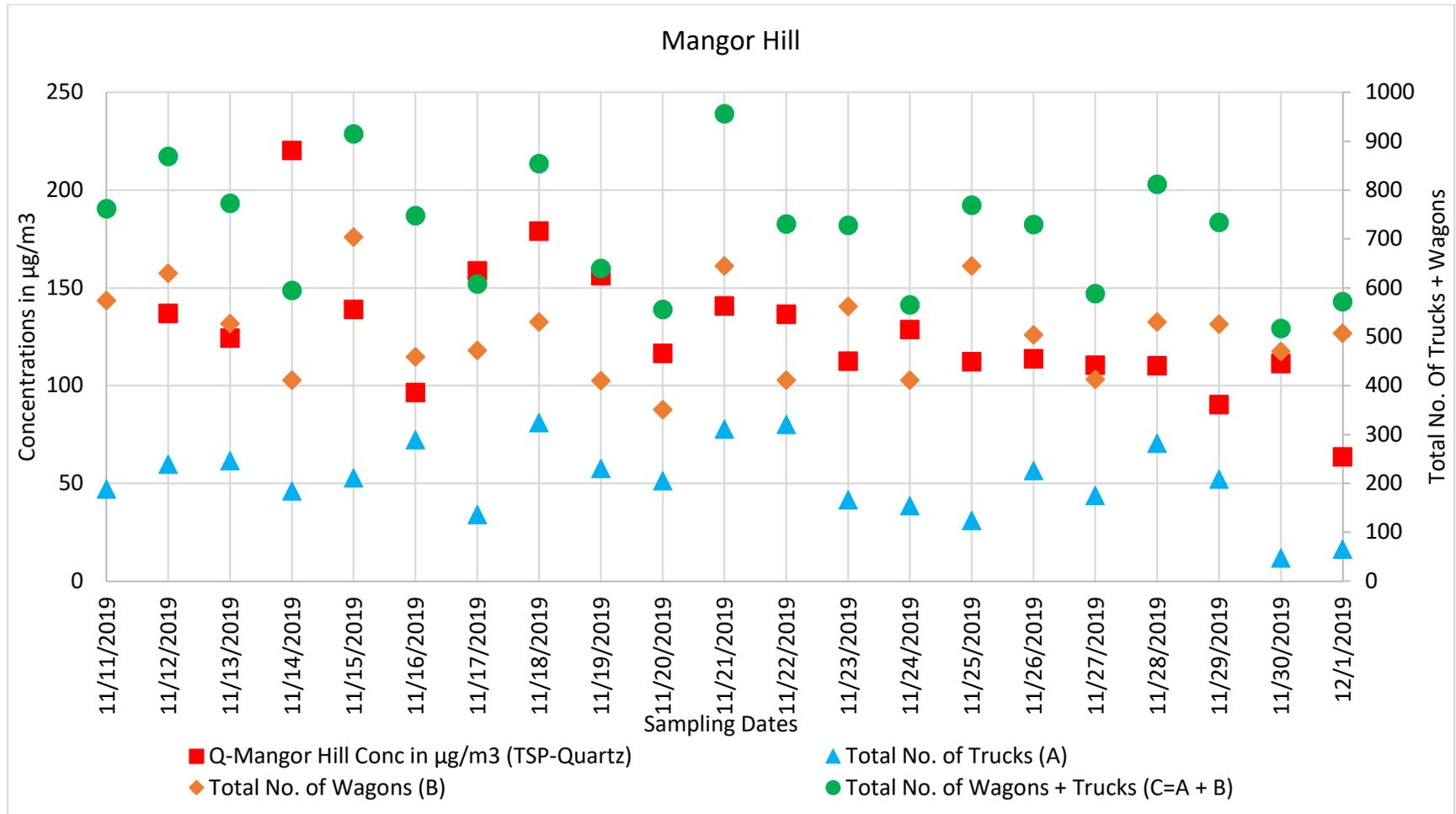
**Figure C.1 (f): Activity Data TSP Concentrations and Alone No. of Trucks, No. of Wagons, and Trucks and Wagons together (Upper Jetty)**



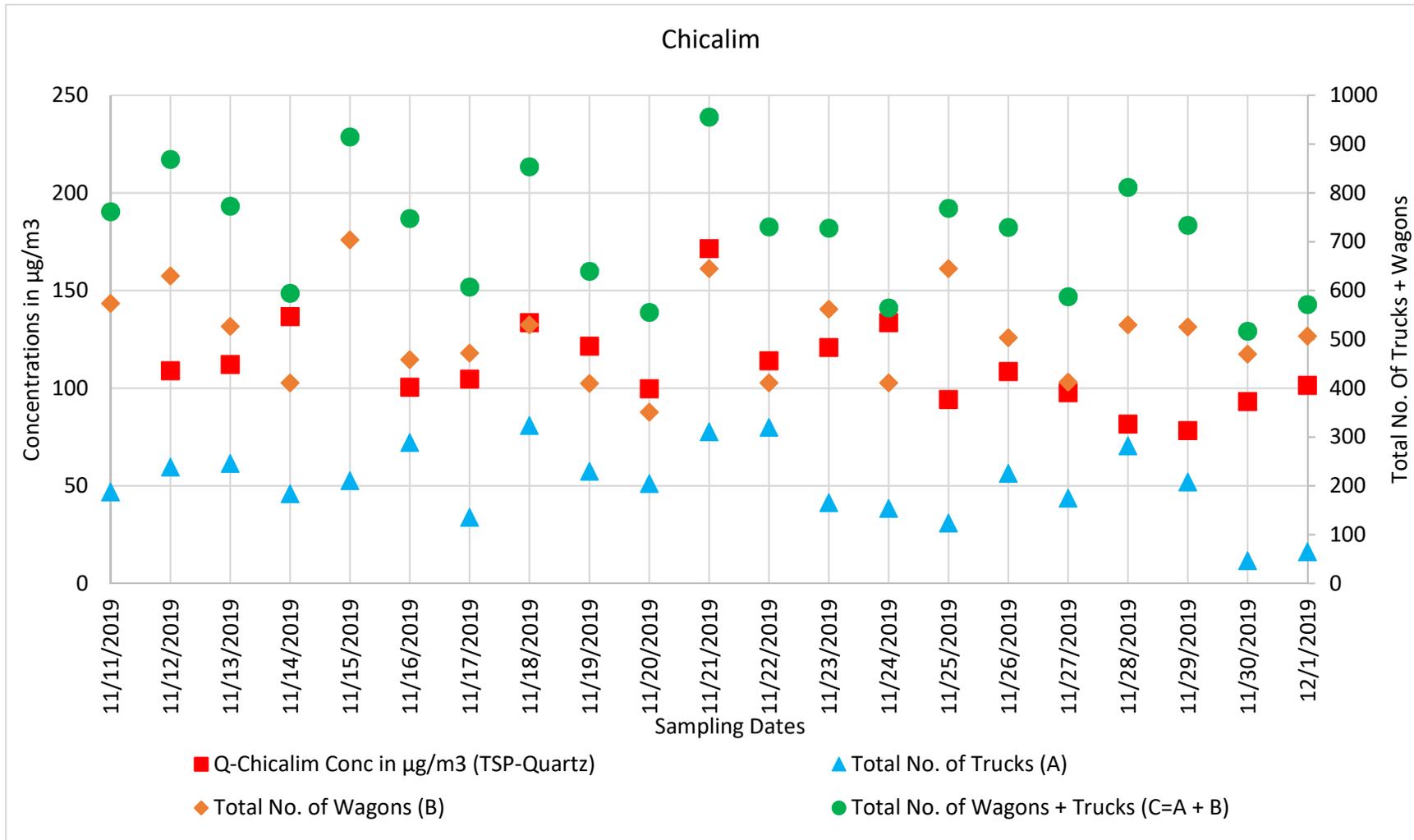
**Figure C.1 (g): Activity Data TSP Concentrations and Alone No. of Trucks, No. of Wagons, and Trucks and Wagons together (Lower Jetty)**



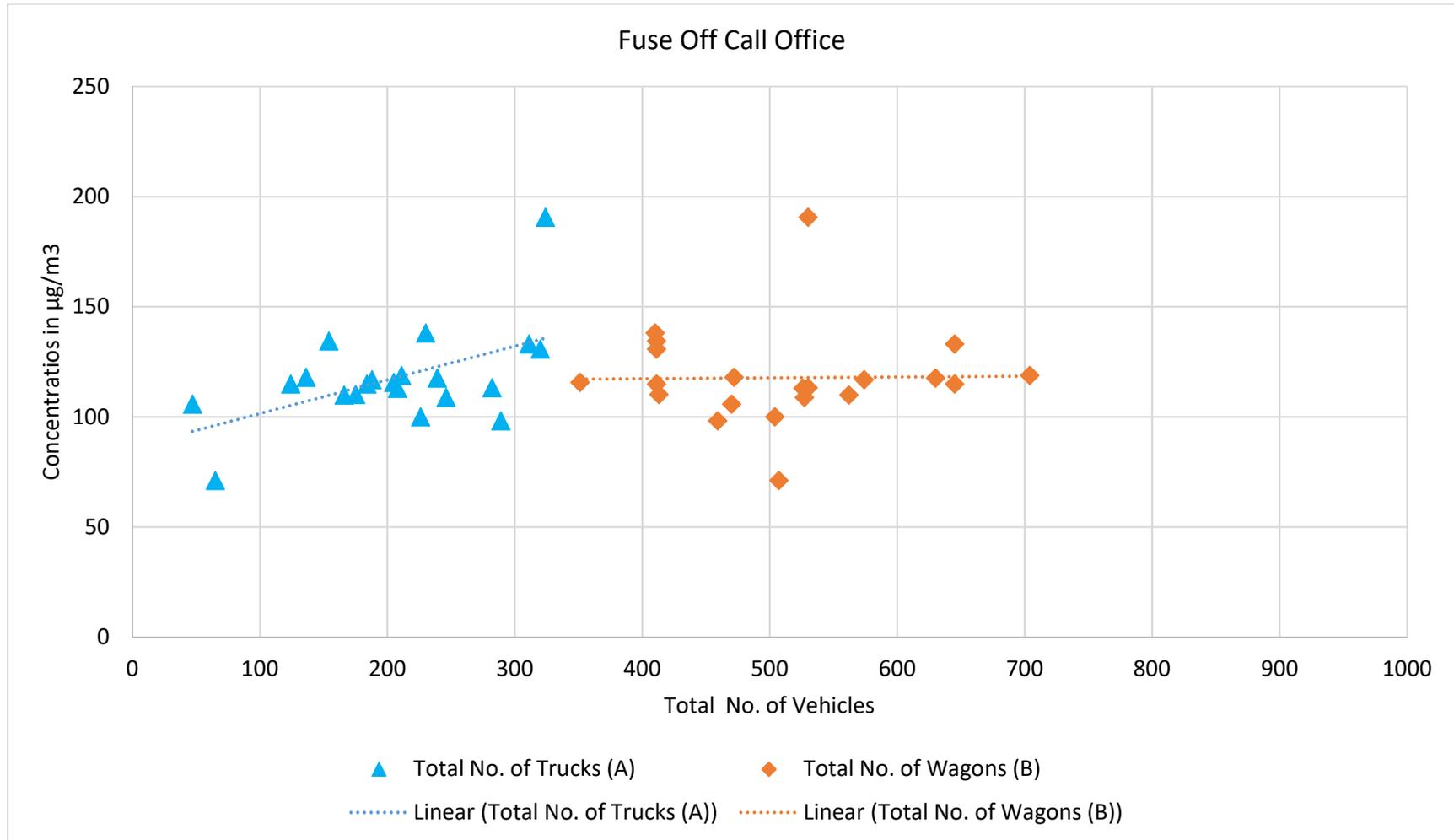
**Figure C.1 (h): Activity Data TSP Concentrations and Alone No. of Trucks, No. of Wagons, and Trucks and Wagons together (Goldsmith House)**



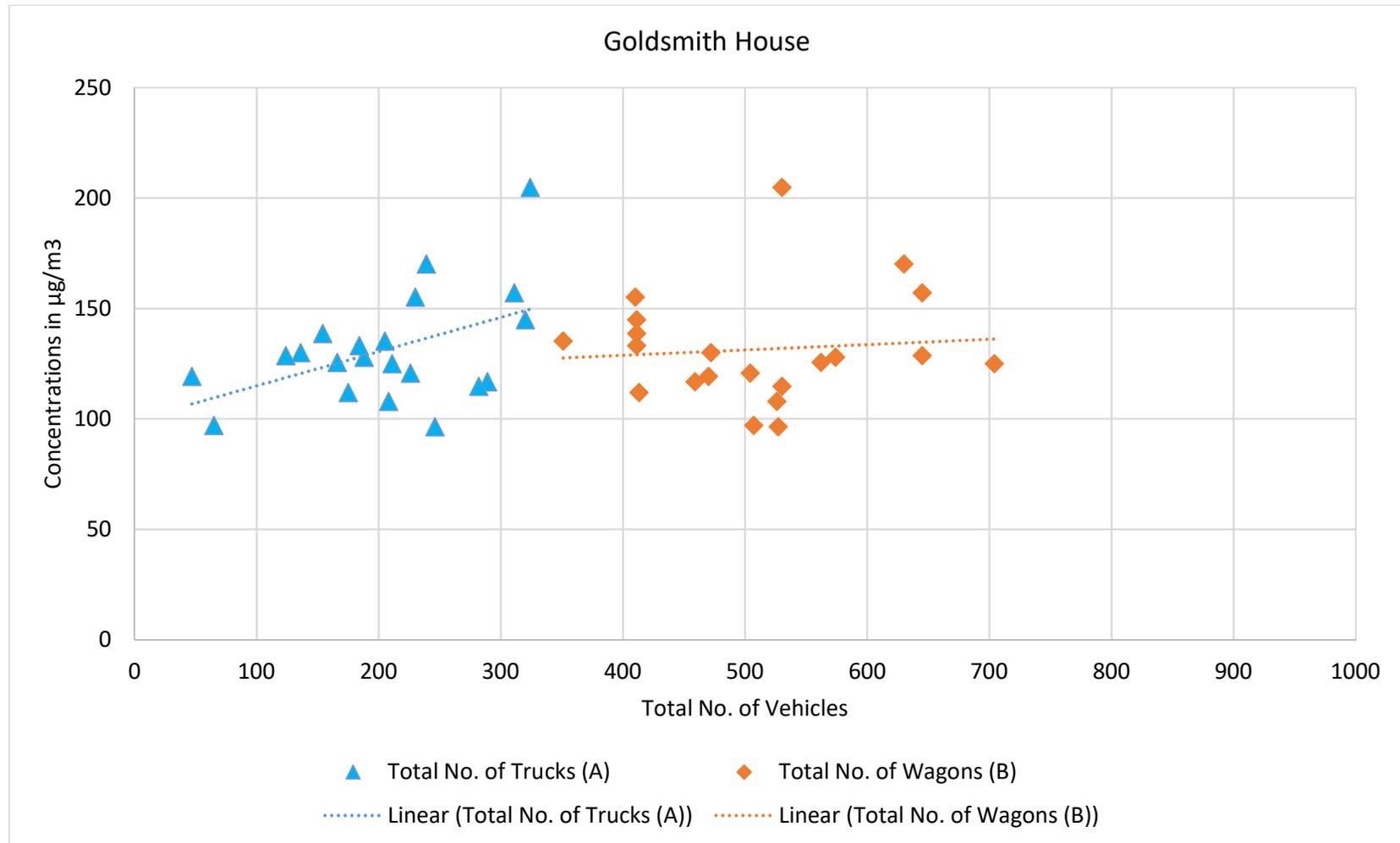
**Figure C.1 (i): Activity Data TSP Concentrations and Alone No. of Trucks, No. of Wagons, and Trucks and Wagons together (Mangor Hill)**



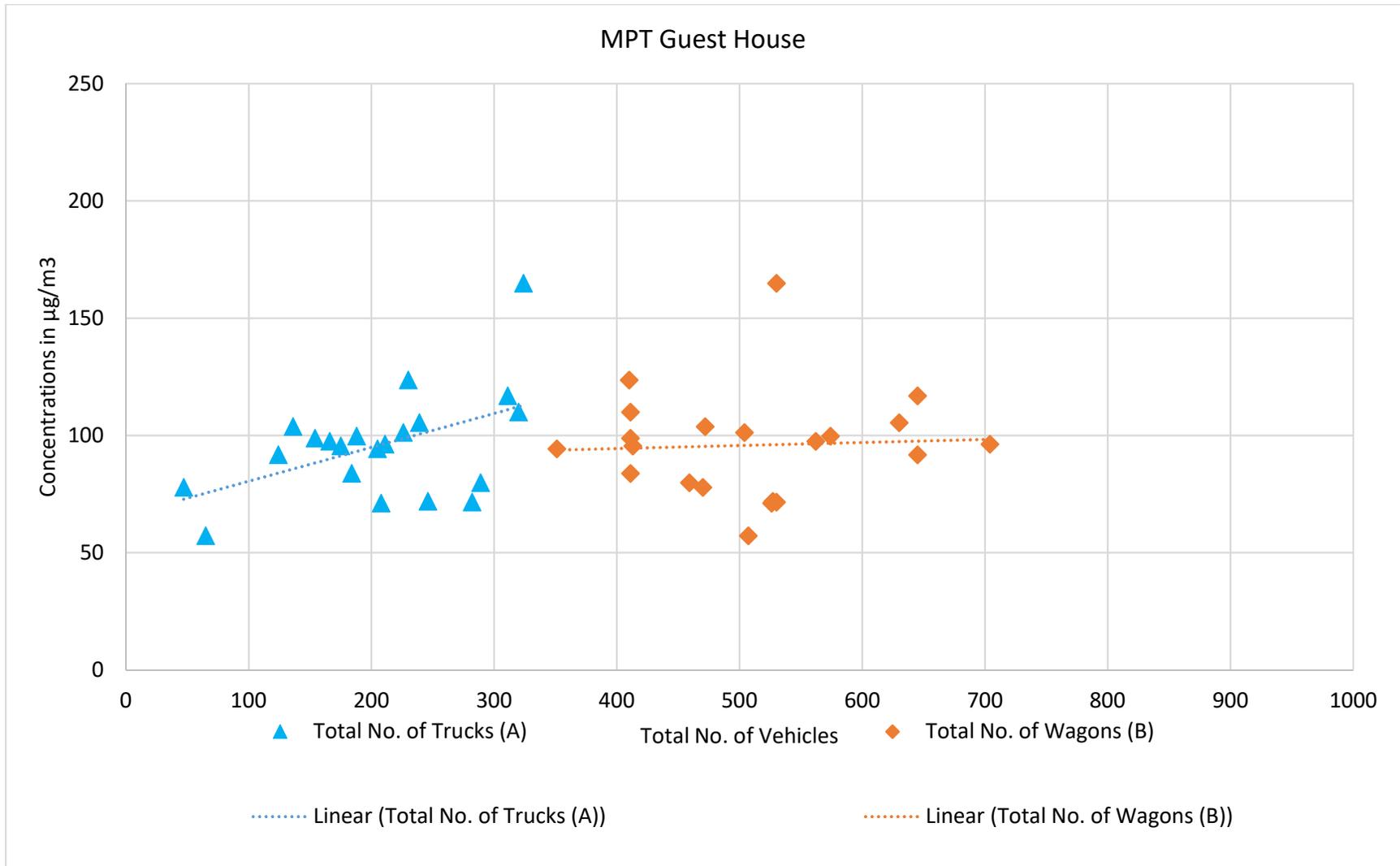
**Figure C.1 (j): Activity Data TSP Concentrations and Alone No. of Trucks, No. of Wagons, and Trucks and Wagons together (Chicalim)**



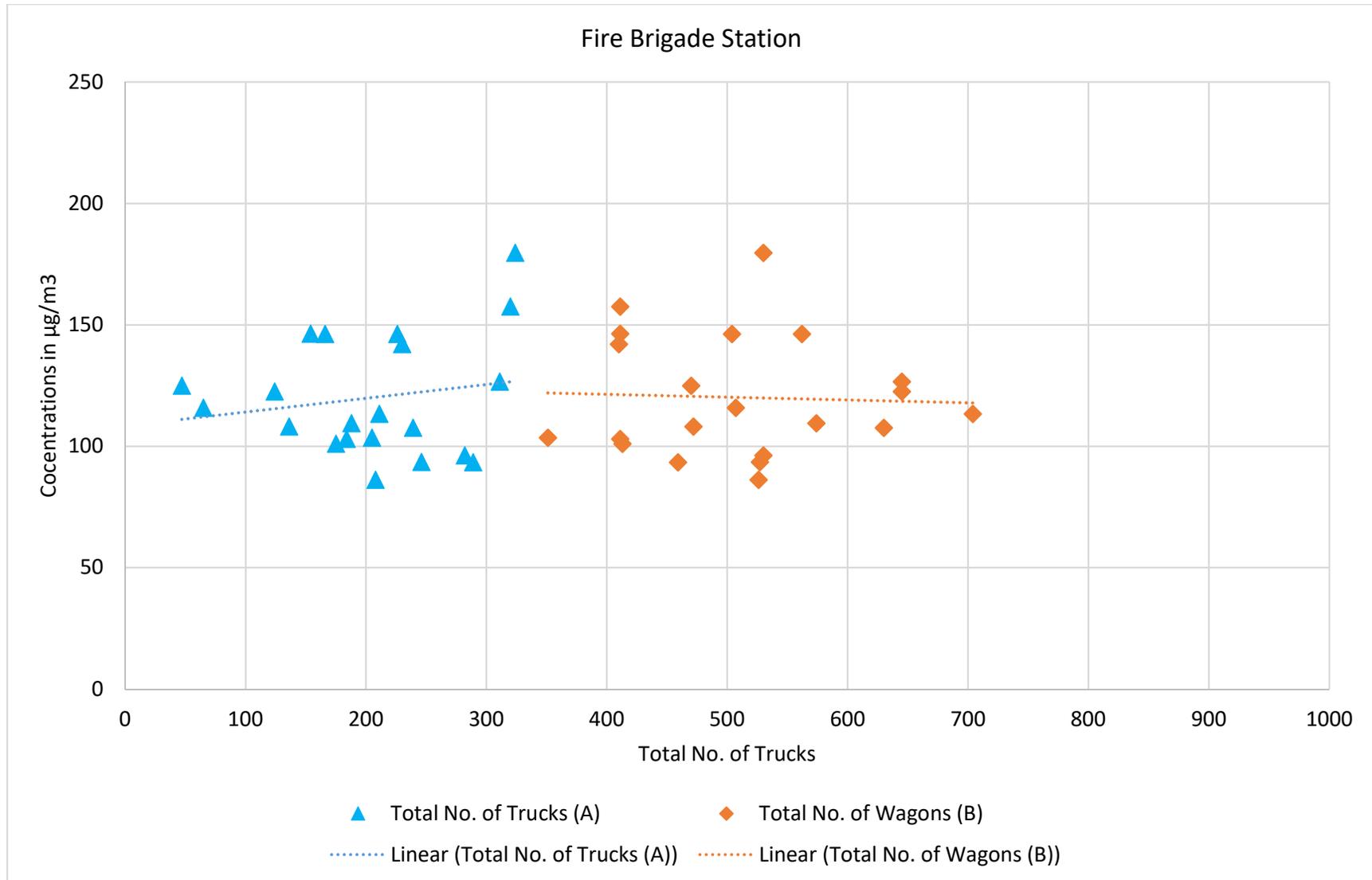
**Figure C.1 (k): Correlation for Total No. of Vehicles against PM<sub>10</sub> Concentrations (Fuse Off Call Office)**



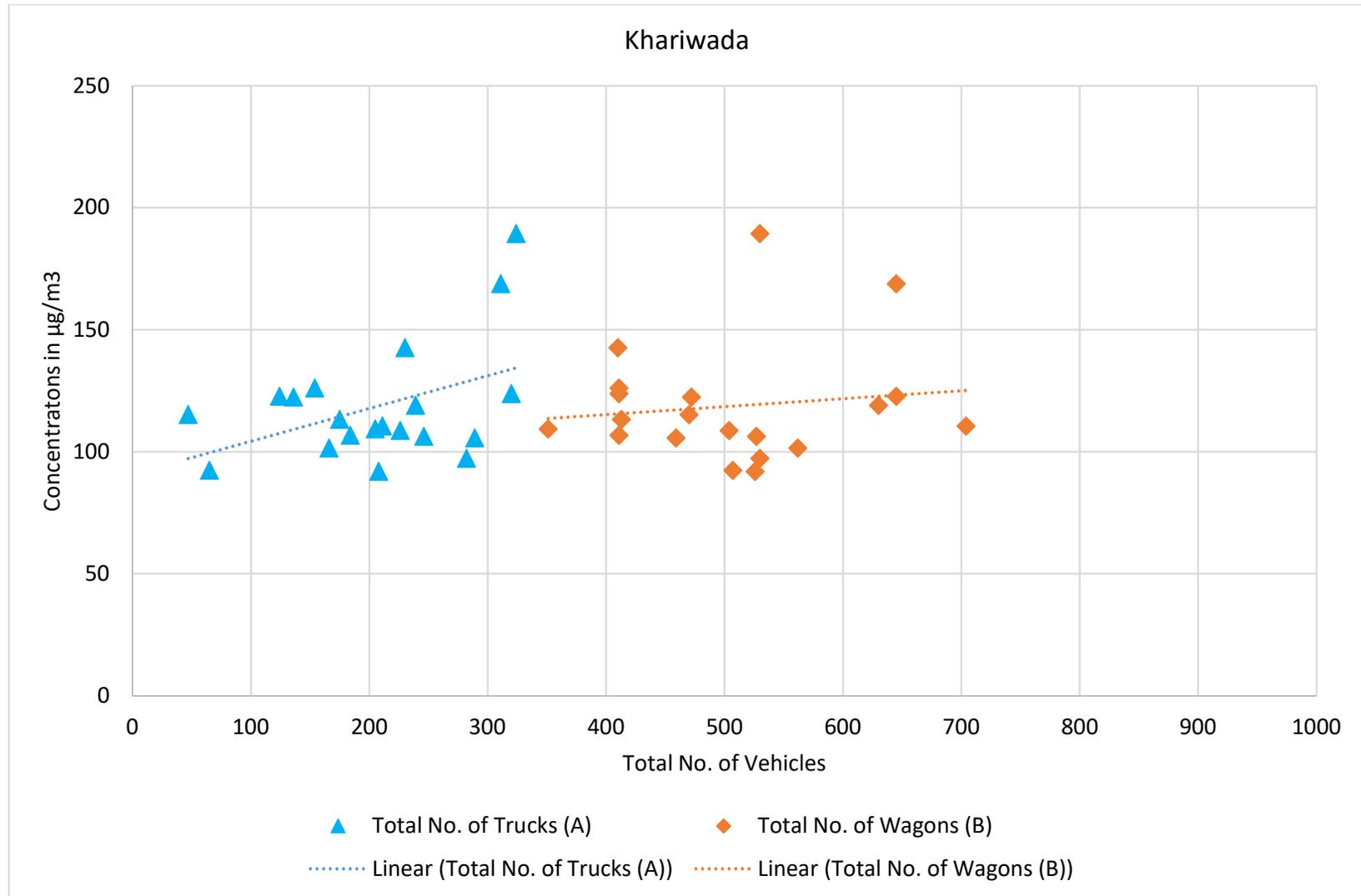
**Figure C.1 (I): Correlation for Total No. of Vehicles against  $\text{PM}_{10}$  Concentrations (Goldsmith House)**



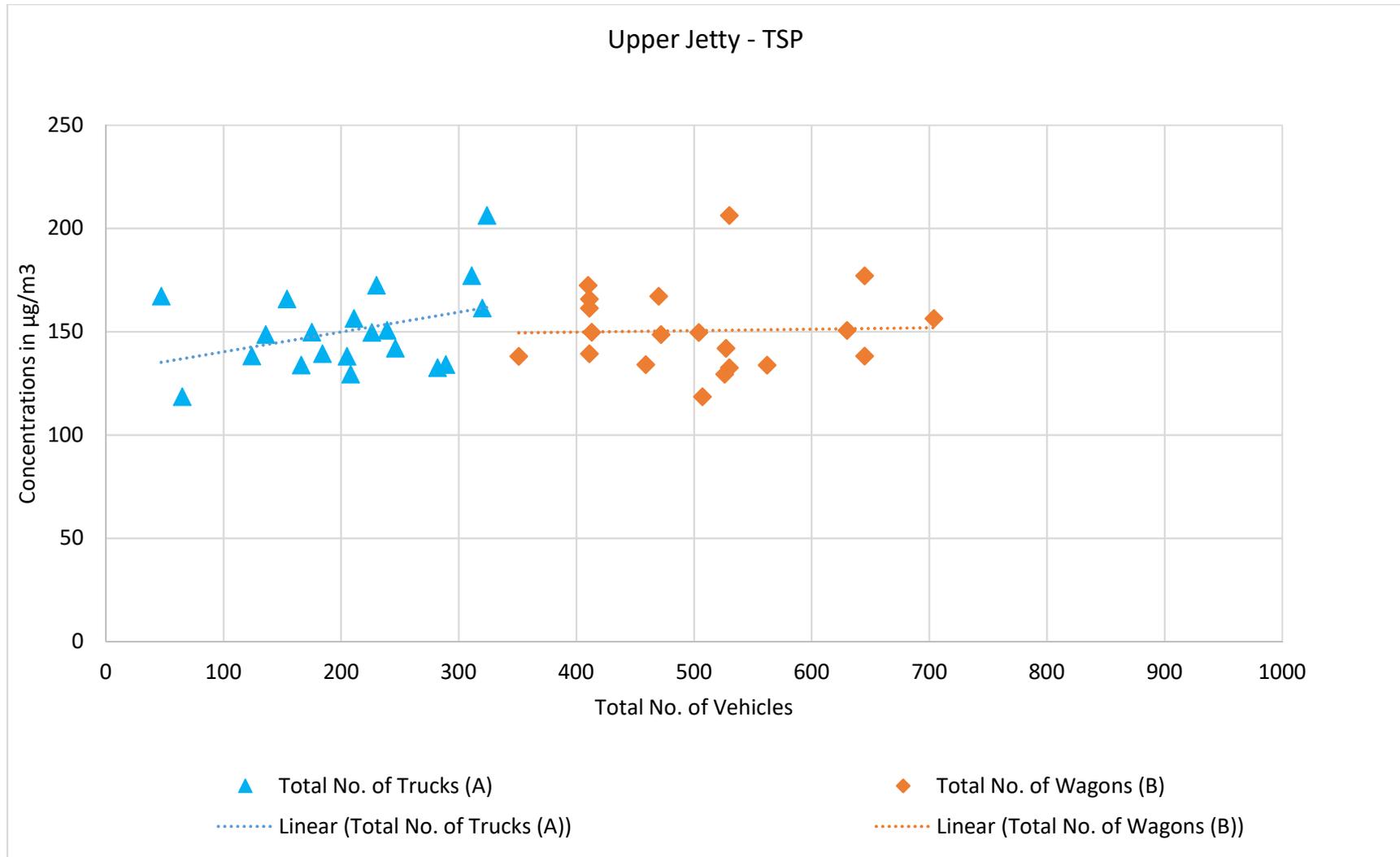
**Figure C.1 (m): Correlation for Total No. of Vehicles against  $\text{PM}_{10}$  Concentrations (MPT Guest House)**

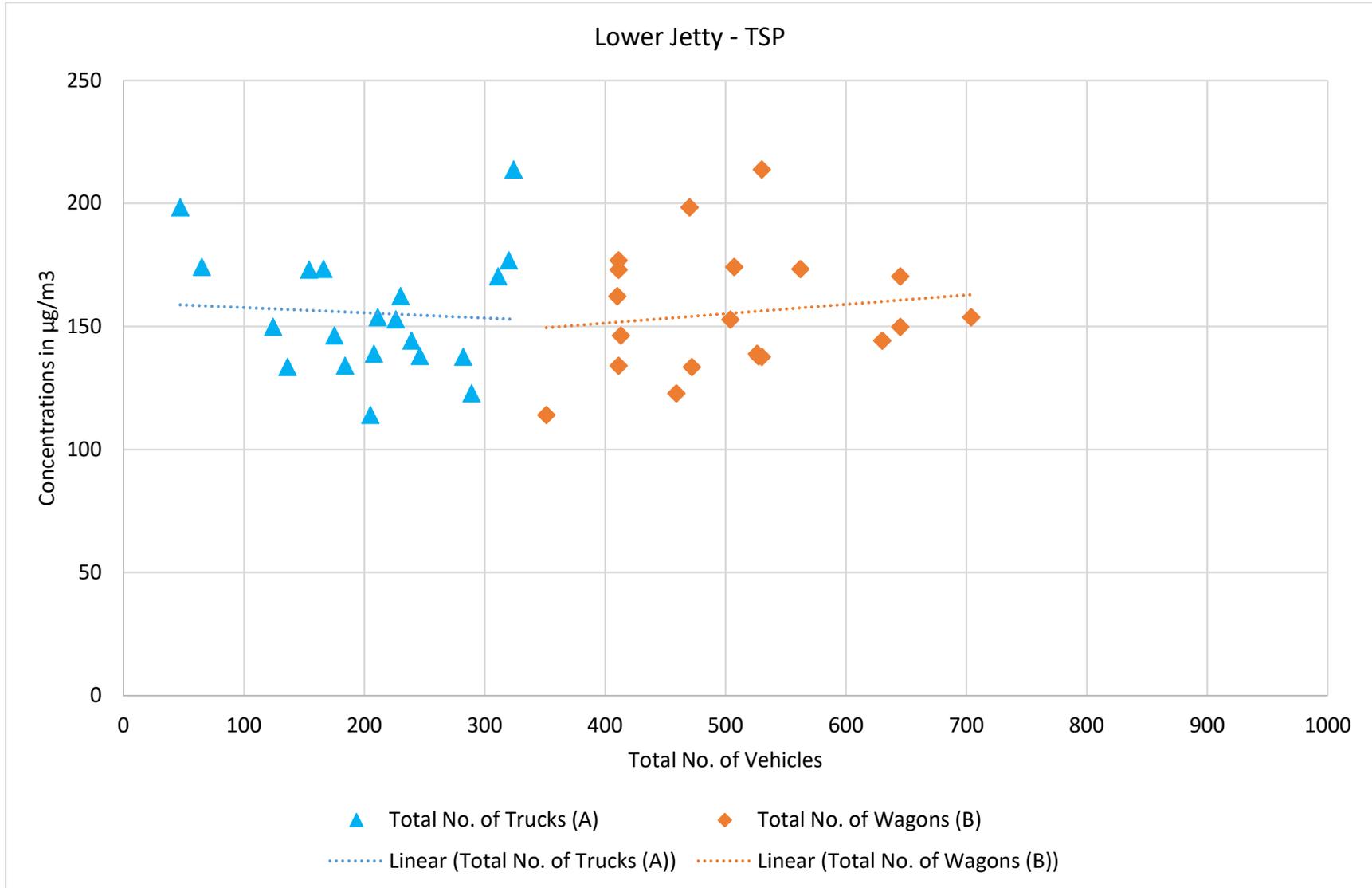


**Figure C.1 (n): Correlation for Total No. of Vehicles against  $\text{PM}_{10}$  Concentrations (Fire Brigade Station)**

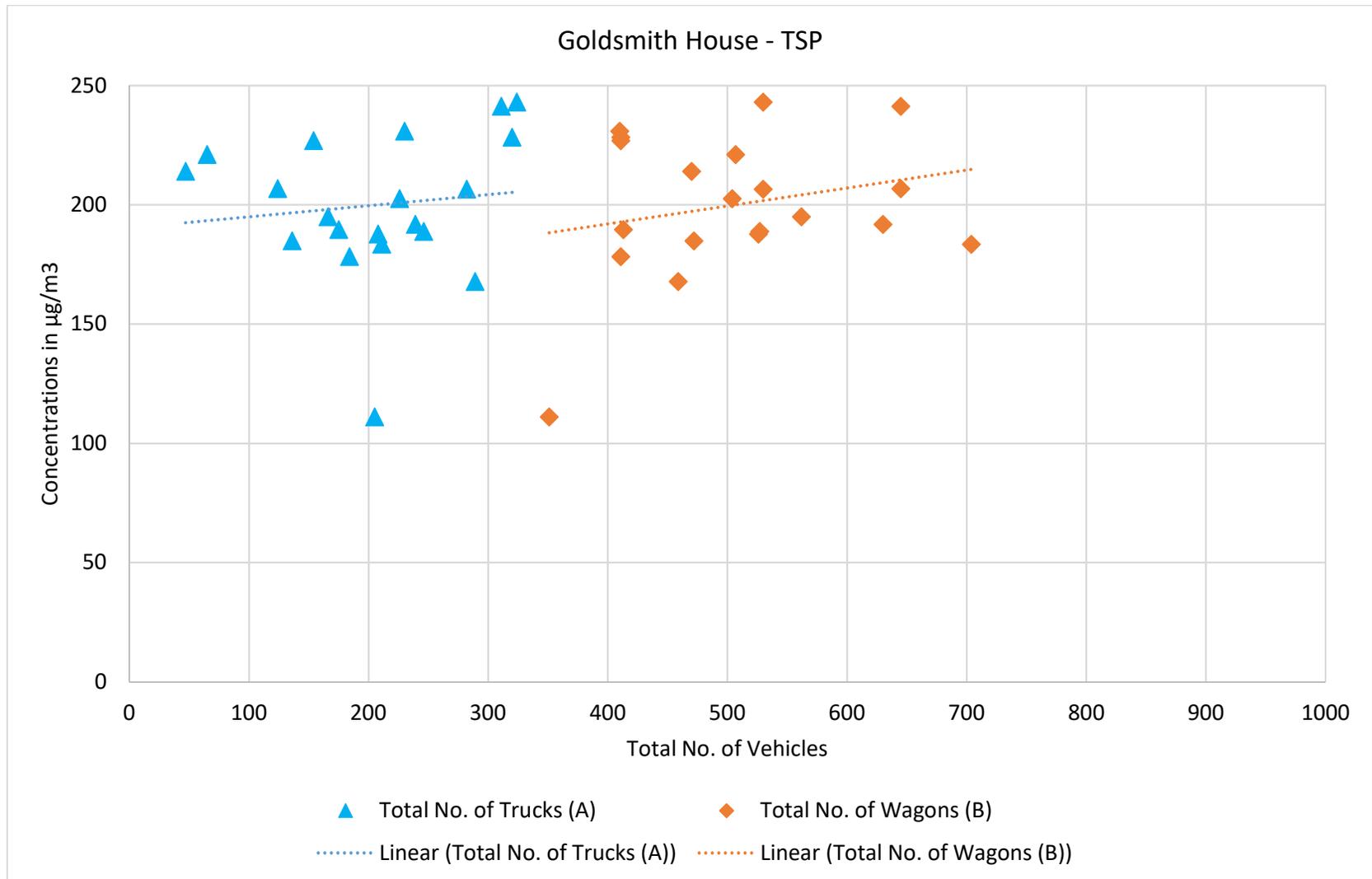


**Figure C.1 (o): Correlation for Total No. of Vehicles against PM<sub>10</sub> Concentrations (Khariwada)**

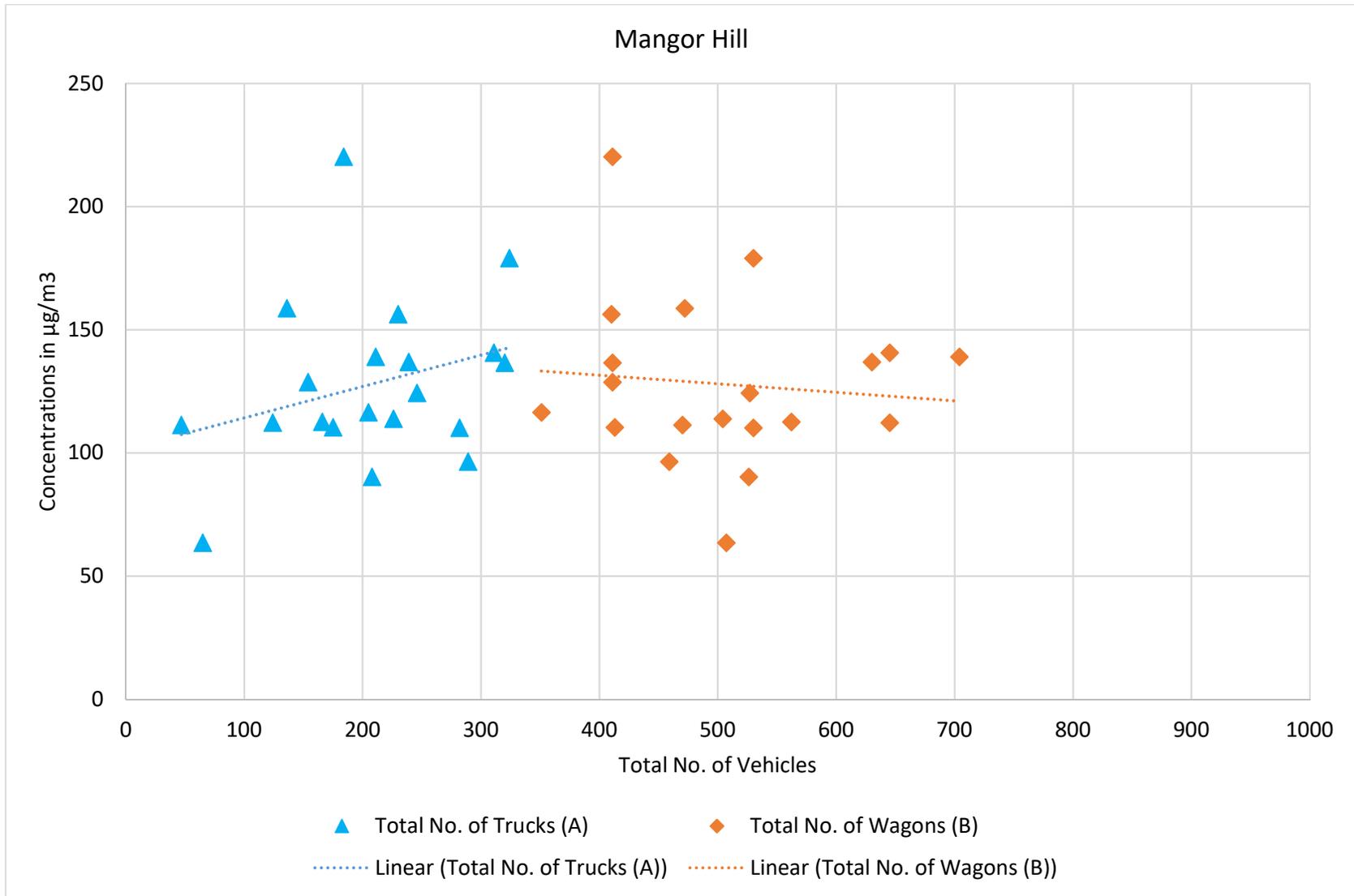




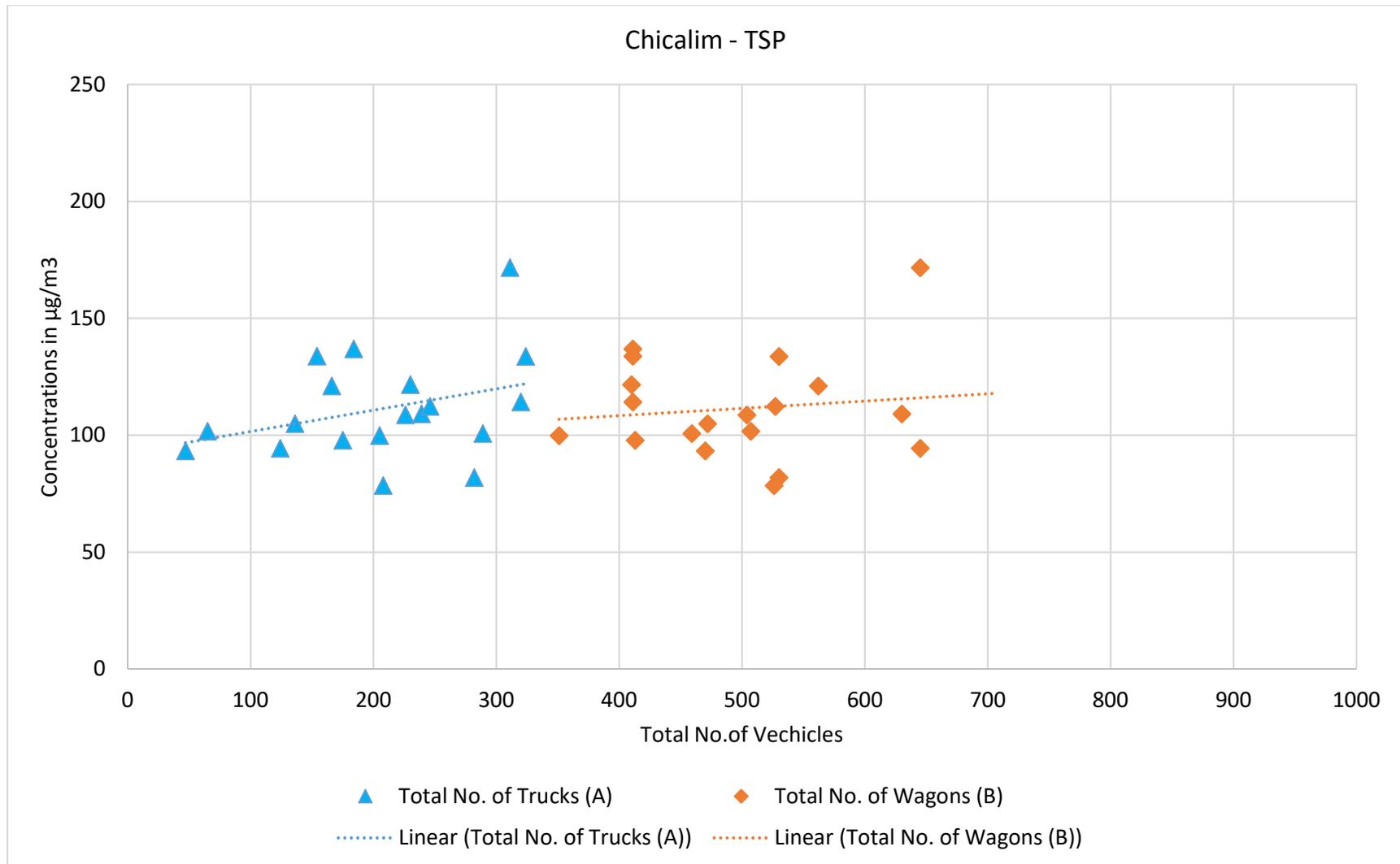
**Figure C.1 (q): Correlation for Total No. of Vehicles against TSP Concentrations (Lower Jetty)**



**Figure C.1 (r): Correlation for Total No. of Vehicles against TSP Concentrations (Goldsmith House)**



**Figure C.1 (s): Correlation for Total No. of Vehicles against TSP Concentrations (Mangor Hill)**



**Figure C.1 (t): Correlation for Total No. of Vehicles against TSP Concentrations (Chicalim)**

## References for Chapter 2

Model, D.R.I., 2005. Thermal/Optical Carbon Analysis (TOR/TOT) of Aerosol Filter Samples–Method IMPROVE\_A. *DRI SOP*, pp.2-216.

### URL01 :

<http://www.indiaenvironmentportal.org.in/content/291574/national-ambient-air-quality-standards-1994/>

Click on "Air.doc"

## Chapter 3

# Study of Influence of Handling of Dusty Cargo on Particulate Matter Levels in Vasco da Gama

### 3.1 Introduction

Handling activities related with dusty cargo take place in the berths of Mormugao Port Trust (MPT), Vasco da Gama, Goa. An attempt has been made to use the AERMOD dispersion modelling tool, a regulatory model used by USEPA and other Pollution Control Boards across the world, to identify the possible extent of influence of emissions from key sources. Assessment was made to identify the seasonal variations of dispersion isopleths due to meteorology in the neighborhood areas of the port activities. This chapter constitutes some related literature review, methodology and the results of AERMOD simulations.

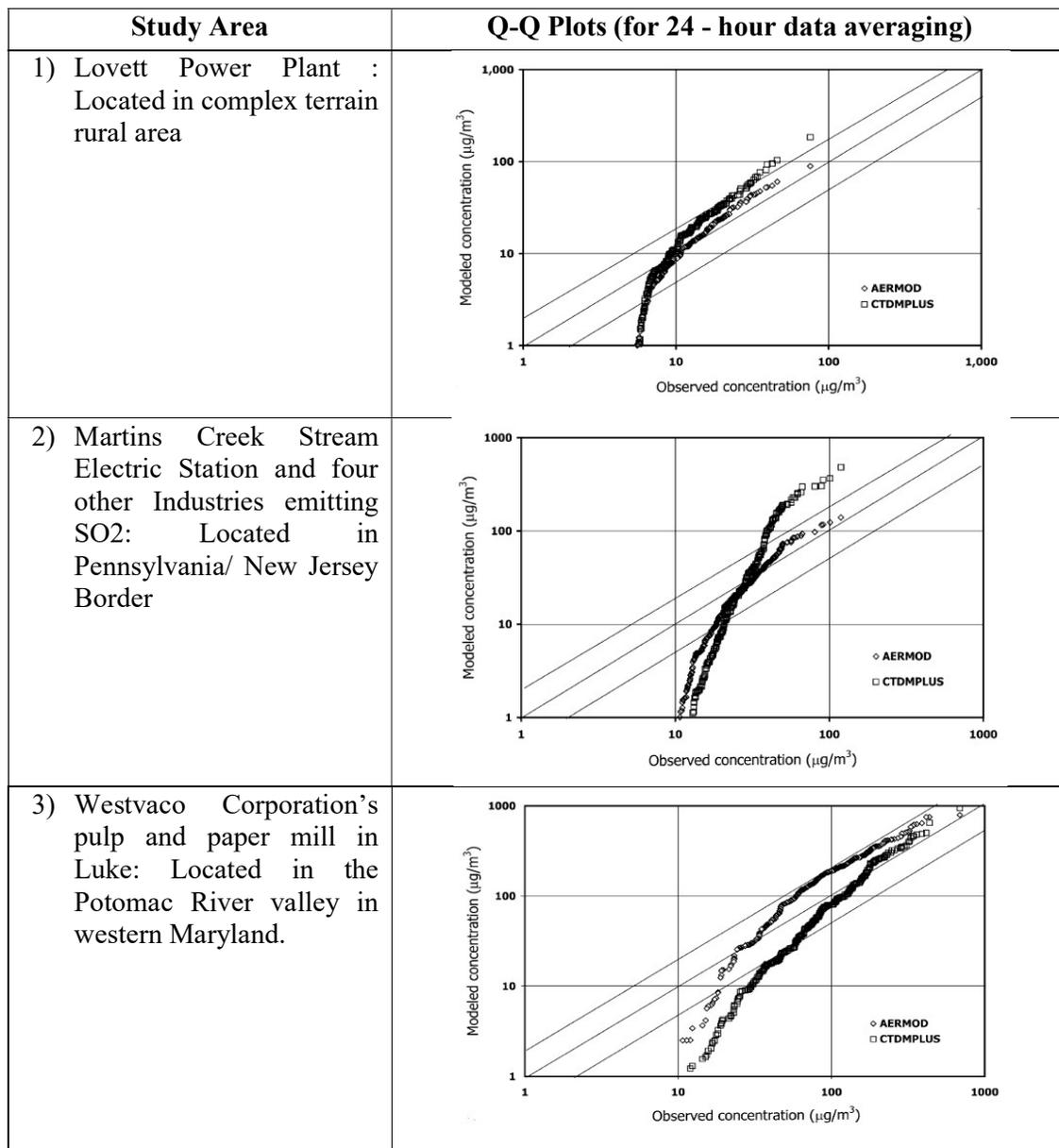
### 3.2 Literature Review

#### 3.2.1 AERMOD Dispersion Modeling

American Meteorological Society (AMS)/Environmental Protection Agency (EPA) AERMOD is a regulatory model adopted by USEPA (USEPA, 2005). The details regarding the schemes considered in the model and the boundary layer characterization are available in Cimorelli et al. (2005) and URL 3.1. The guidelines for dispersion modelling, and the directions to use AERMOD for assessing criteria pollutants in plane and complex terrain is provided in USEPA (2005), where details of acceptability for the use of AERMOD to study dispersion patterns are given. The capability of the model to work under multiple scenarios was assessed, and the model has been validated using field study data, where the measurements were made in the downwind direction of a known source (Venkatram et al., 2001; USEPA, 2005; Perry et al., 2005).

The port in Vasco da Gama is located in the vicinity of a small hillock, and may therefore be regarded as complex terrain. The details of the physics used in AERMOD for the dispersion from a source near a complex terrain have been reported by Venkatram et al. (2001). Dispersion model like CTDM Plus incorporated with other complexities for sources near complex terrain,

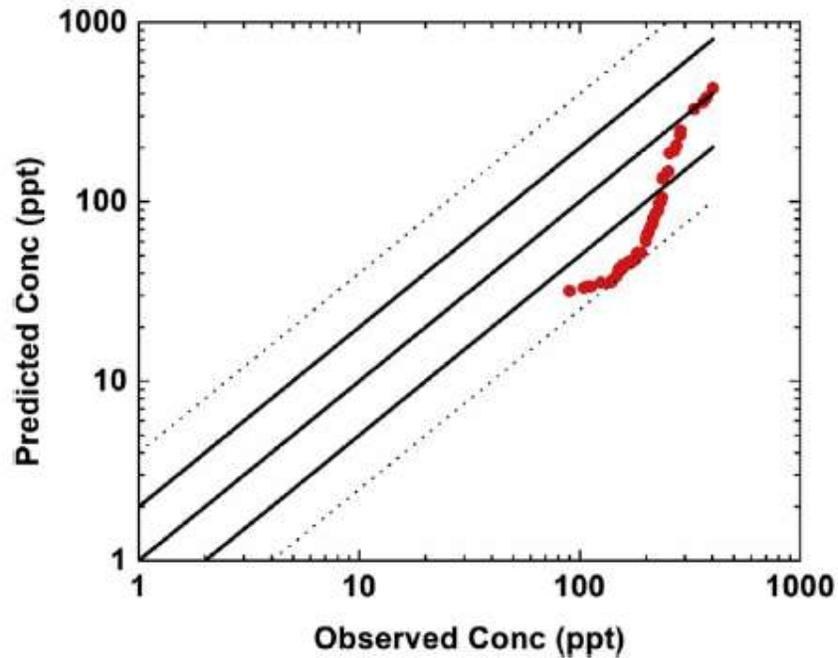
like the amplified vertical turbulence, have been designed in the past (Perry, 1992). However, the evaluation study reported by Venkatram et al. (2001) states that AERMOD works as good as CTDMPPLUS, as the plot between measured data with the modelled data from these two dispersion models falls along the 1:1 line of a quantile-quantile plot (Figure 3.1).



**Figure 3.1: Comparison of AERMOD and CTDMPPLUS performance using Q–Q plots for 24-hour averaged SO<sub>2</sub> concentrations expressed as µg/m<sup>3</sup> for four complex terrain locations (Venkatram et al., 2001)**

Variation was seen for the higher and lower concentrations, which was present in the case of both the models (Venkatram et al., 2001) (Figure 3.1). A study by Haq et al., 2019 reported

that AERMOD performs well under higher pollutant concentrations for a complex terrain (Figure 3.2).



**Figure 3.2: Q-Q plot of predicted vs observed hourly averaged concentrations for 47 discrete sampling points. [Source: Haq et al., 2019]**

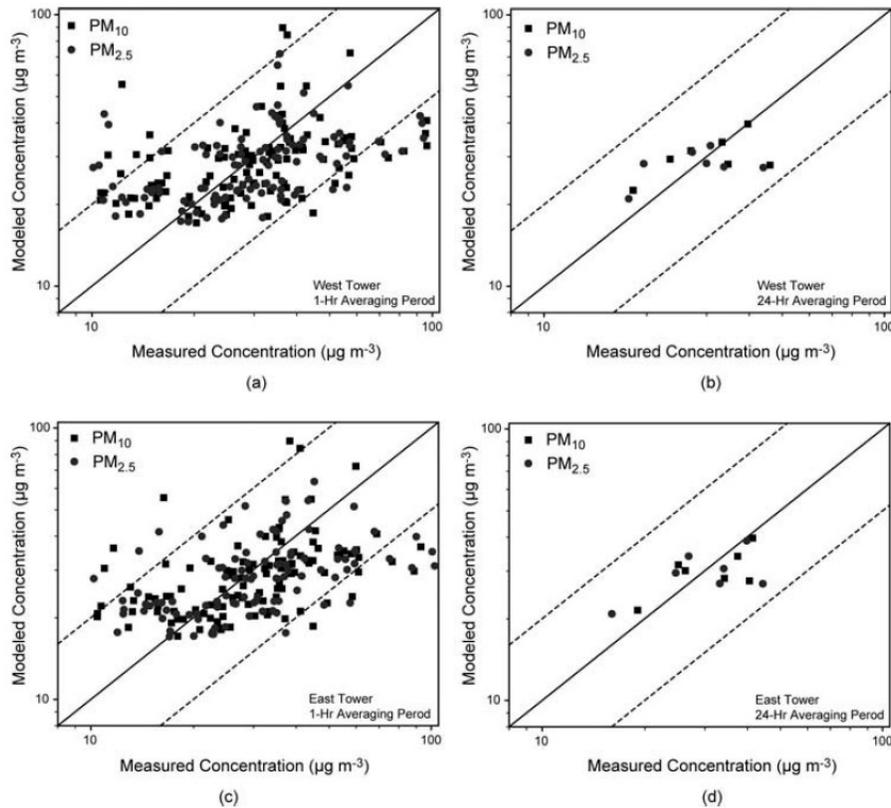
There are limited studies on the performance of AERMOD in coastal complex terrain situation. Latini et al. (2002) studied the performance of AERMOD in the Mediterranean coastal area. The study shows that the hourly maximum NO<sub>x</sub> concentration prediction (48 ppm) from AERMOD matched closely with the observed data (60 ppm).

A study by Hadlocon et al. (2015) simulated the contribution of PM<sub>10</sub> and PM<sub>2.5</sub> from a secluded poultry pullet facility to the nearby vicinity, and the predicted values were observed to be comparable with the measured values. A satellite image of the study area is given in Figure 3.3.



**Figure 3.3 : Satellite picture of the field site showing the commercial poultry farm with two poultry pullet buildings and the locations of measurement towers. [Source: Hadlocon et al., 2015]**

The scale of this study and the pollutant studied matches with that of the present study and the study validates the capability of AERMOD to predict PM concentration. The high frequency field measurement using a real time optical instrument (DustTrak) in Hadlocon et al. (2005), allowed comparison of 1-hour averaged and 24-hour averaged simulations and compare with the field conditions. Comparison of modelled  $PM_{10}$  data with measured  $PM_{10}$  and  $PM_{2.5}$  shows that the performance of AERMOD is acceptable (Figure 3.4) as per the criteria reported for dispersion modelling by Chang and Hann (2004). Hadlocon et al. (2005) used line volume source option to define the source of poultry building.



**Figure 3.4 : Relationship between the measured and modeled 1-hr and 24-hr averages of PM10 and PM2.5 concentration obtained from West downwind location (a and b) and East downwind location after the windbreak (c and d). Broken lines refer to the values within the range of a factor of 2 with respect to the 1:1 [Note: Acceptability criteria as per Chang and Hann (2004)] value represented by the solid line. Scales are logarithmic. [Source: Hadlecon et al. (2005)]**

There are various options to represent a source in AERMOD, which broadly include, point, line, area and volume sources. To get better performance an appropriate source type has to be selected. The Modelling Guidelines for Air Quality Impact Assessments for Santa Barbara air pollution control district reported that a volume source option could be appropriate to define sources like fugitive leaks, multiple vents, sloped conveyor belts (URL 3.2).

### 3.2.2 Emission factor for coal/aggregate handling activities

Emissions for material handling activities are available from two AP42 documents, 1) Supplement no. 14 for compilation of air pollutant emission factors, third edition (Including Supplements 1-7) document (URL 3.3); and 2) aggregate handling and storage piles (URL 3.4), of USEPA. These have been mainly developed for estimating emission from

aggregate/material handling activities including continuous drop (silo) and batch drop (clam shell) activities, and wind entrainment from stock piles. Equations in AP42 are a compiled product of multiple measurements at source locations as a part of different studies. The major focus of the present study is the particulate emissions from dusty cargo handling in the port and its contribution to the particulate matter levels. The emissions at the port are complex, with multiple activities leading to emissions of particulate matter largely as fugitives.

The emission factors (EF) for aggregate/material handling in coal mines or mineral industries are given in Table 3.1, and were used to estimate particulate emission from dusty cargo handling (like coal and limestone). Silt content and moisture content parameters selected for coal and limestone in the present study were on the basis of the data from Table 11.2.3-1 in Supplement 14 (URL 3.3) of AP42 (Page No. 11.2.3-2). Table 3.2 gives the particle size multiplier for the batch drop and continuous drop equations. In the present study, particle size less than 30  $\mu\text{m}$  have been considered. Table 3.3 gives the ranges of all the parameters of the EF equation.

**Table 3.1 : Table of Equations for Emission Factors for Aggregate Handling [Note : Range of these parameters are available in the Table 3.4 and Table 3.5]**

Sl. No	Activity	Empirical Equation	Unit of EF	Parameter	Reference
1	Clam shell (Batch drop)	$EF = k * (0.0018 * (S/5) * (u/5) * (H/5)) / ((M/2)^2 * (Y/6)^{1/3})$	lb/ton	EF = suspended particulate (<30 μm diameter) emissions (lb/ton of material unloaded) k = Aerodynamic particle size multiplier (Refer Table 3.2) S = material silt content (%) u = wind speed (mph) - 5 yr avg. H = material drop height from unloading device (ft) - Estimate M = material moisture content (%) - Technical Guide: 3-24 Y = batch dumping device capacity (yd <sup>3</sup> )	AP42 supplement 14 (1983), Page 11.2.3-3 (URL 3.3)
2	Silo loading (Continuous drop)	$EF = k * (0.00018 * (S/5) * (u/5) * (H/10)) / (M/2)^2$	lb/ton	EF = uncontrolled suspended particulate (<30 μm diameter) emissions (lb/ton of material unloaded) S = material silt content (%) u = wind speed (mph) - Conservative estimate of wind in enclosure H = material drop height from unloading device (ft) M = 5 material moisture content (%)	AP42 supplement 14 (1983), Page 11.2.3-4 (URL 3.3)
3	Active storage pile emissions (Wind erosion and maintenance)	EF = 0.72u	lb/(acre)(hour)	u = wind speed (mph)	Section 11.9, Supplement E (1998), Table 11.9-1, Page 11.9-5 (URL 3.4)

**Table 3. 2 : Aerodynamic particle size multiplier (k) for batch drop and continuous drop equations in Table 3.1**

Activity	Size→	<30 µm	<15 µm	<10 µm	<5 µm	<2.5 µm
Batch drop		0.73	0.48	0.36	0.23	0.13
Continuous drop		0.77	0.49	0.37	0.21	0.11

**Table 3. 3 : Ranges of source conditions for batch drop and continuous drop equations in Table 3.1**

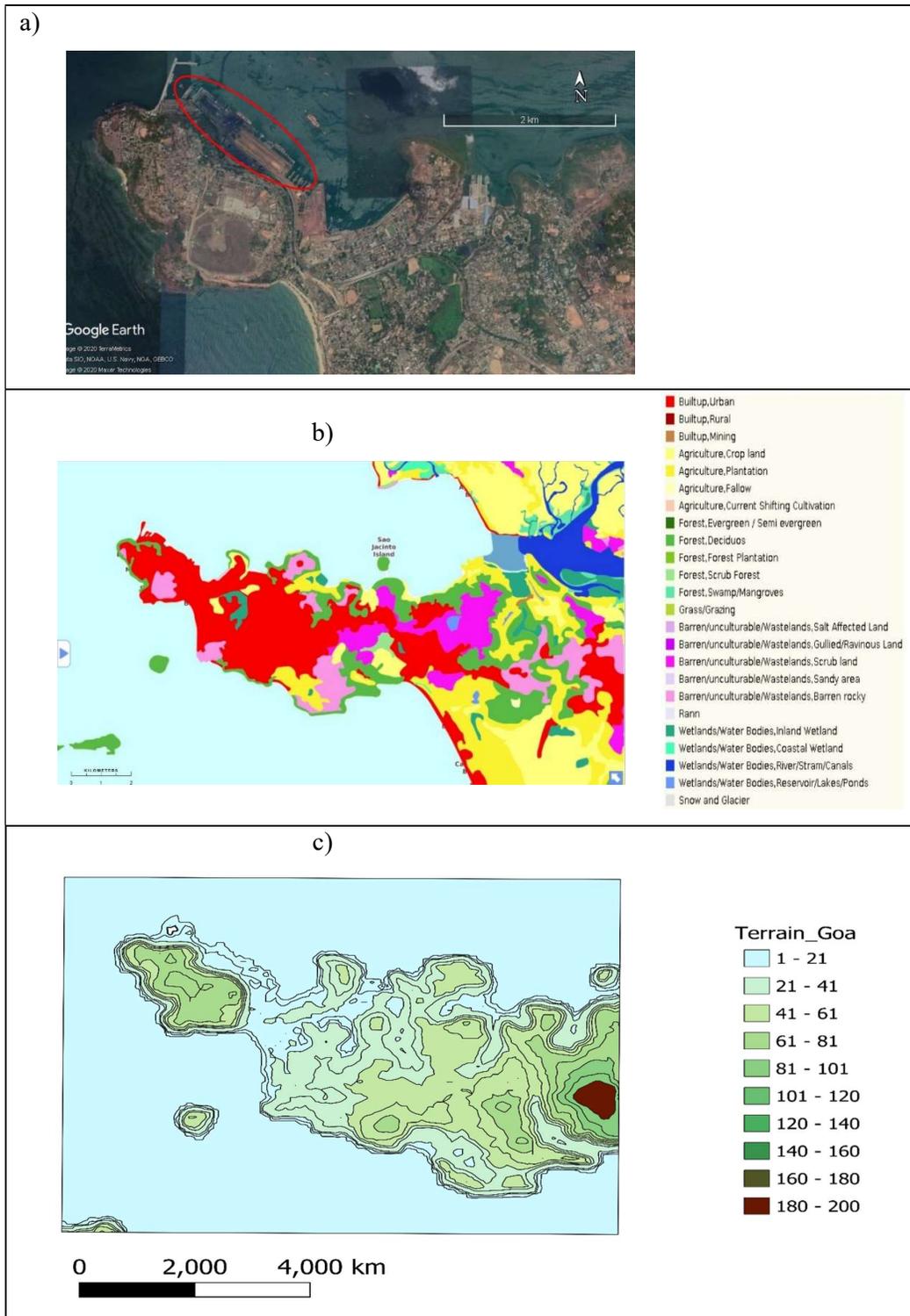
Equation for	Silt Content S (%)	Moisture Content M (%)	Dumping Capacity (Y)	Drop height (H)
			m <sup>3</sup>	m
Batch drop	1.3-7.3	0.25-0.7	2.1-7.6	NA
Continuous drop	1.4-19	0.64-4.8	NA	1.5-12

### 3.3 Materials and Methods

To assess the possible zone of influence of dusty cargo handling activities from the port area, on the PM levels in the vicinity, a dispersion model based study using AERMOD was carried out.

#### 3.3.1 Study Area

The port under study is located in the western coast of India. Figure 3.5 (a) shows the location map of the study area. Three sides of the study area are covered by the sea, and the land is developed semi-urban region. Figure 3.5 (b) shows the land use map of the area. The terrain of the study area varies and there is a sharp rise due to a hill just at the edge of the port area (Figure 3.5 (c)).



**Figure 3.5 : a) Map of the study area (Red ellipse indicates specifically the MPT port area); b) land use and land cover map from URL 3.6; and c) the topography map of the study area developed using AERMOD View (legend units are in m).**

### 3.3.2 Historical Data for Cargo Handling Activities in the Port

Cargo handling activities in the port since 2001 were analyzed to observe any historical pattern (Figure 3.6). It was observed that iron ore and coal were the major cargo handled in this port till 2012 (URL 3.5). Later, activities have changed more towards coal and limestone. The amount of iron ore handling in the port has decreased considerably since 2012 and the amount of coal handled has increased gradually since 2004.

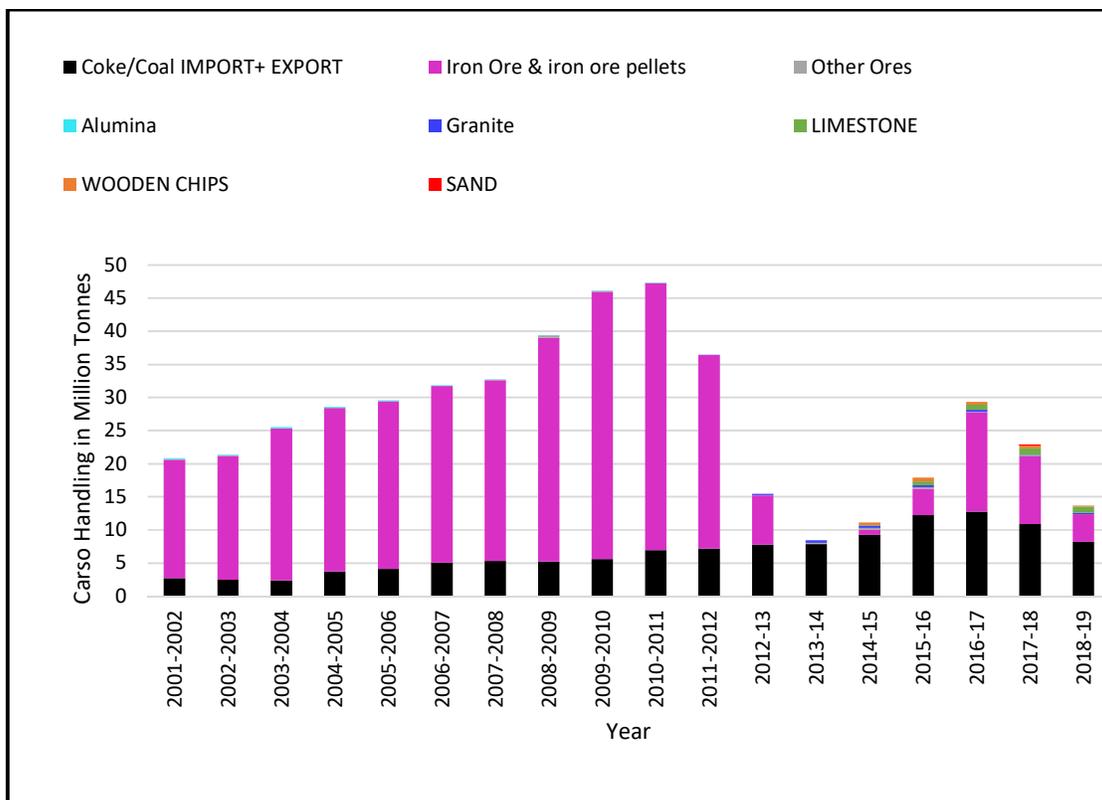


Figure 3.6 : Historical trend of annual cargo handling [URL 3.5]

### 3.3.3 Port Activity During Field Campaign in November 2019

Data for cargo handling activities in port during the November-December, 2019 sampling period were collected from MPT. The activity log records are at a daily resolution. The type of cargo, the number of trucks and wagons and the weight of cargo handled were obtained from these activity data. There were multiple types of dusty cargo that were handled in the port (Figure 3.7 a). The major cargo was coal and the daily variation in the amount of coal cargo is shown in Figure 3.7 b.

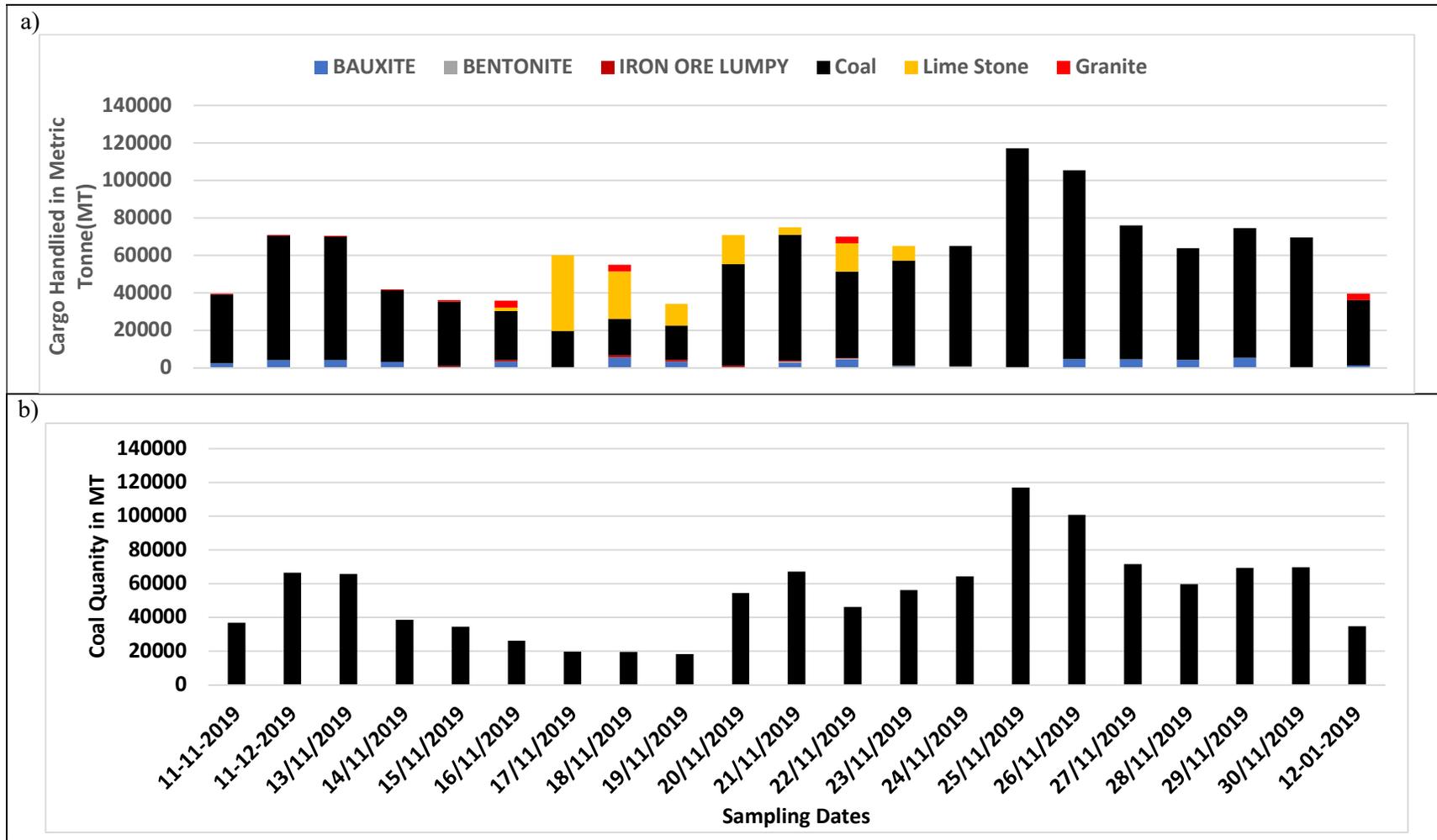
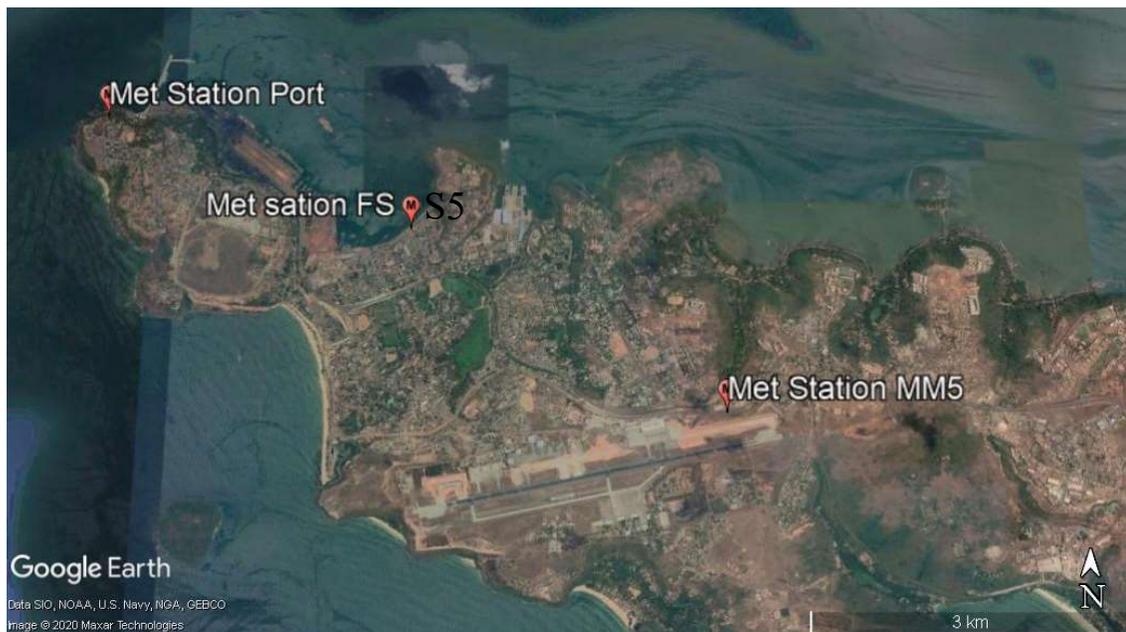


Figure 3.7 : Daily Cargo handling activities during the November-December, 2019 field sampling campaign in metric ton (MT) (a) all dusty cargo and (b) coal only

### 3.3.4 Meteorological Data and Weather Station

Figure 3.8 shows the spatial location of the met stations. A global AERMET ready MM5 (Meso meteorological Model 5) met data, available at 12 km resolution, was procured for the period of June, 2018 to August, 2020 (2 years including the period of the sampling campaign). The MM5 data represents the airport in the study area and the base elevation is 9 m (Met station MM5 in Figure 3.8). Further, meteorological data for the entire sampling period were collected from the MPT weather station. The MPT weather station was located on the top of the hill beside the port area with a base elevation of about 70 m. Additionally, a Davis Pro Weather station (URL3.7) along with the console was installed during the field campaign for 10 days (Met station FS in Figure 3.8) at one of the sampling sites (S5) to measure wind speeds and wind directions. The field campaign weather station (Met station FS) was beside the sea shore with the base elevation around 5m. A comparison of these three datasets were made to ensure the acceptability of using MM5 data for the AERMOD model simulations (Section 3.4.1). The windroses of these three datasets were found to match well with each other (Figure 3.11).



**Figure 3.8 : Location map for the met stations in the study area**

### 3.3.5 AERMOD Model Simulations

AERMOD is a static dispersion model used by US EPA for regulatory operations, and the commercial version of the model from Lakes Environment was used in the present study. A

flow chart for AERMOD simulation is given in Figure 3.9. Meteorological condition, source strength, topography of the region and receptor locations need to be defined to run the model. The simulations were made using the AERMET preprocessed MM5 data and the 90 m resolution global terrain data (freely available along with the AERMOD software) selected and processed using terrain data preprocessor for the study region. To define the source strength, cargo handling activity as per Section 3.2.2 and the emission factor as per Section 3.3.2 were used. The dusty cargo handling areas in the port include heaps of coal and/or limestone, conveyor belt transport of dusty cargo, hoppers and silos, loading into trucks and rail rakes. The major activities leading to the dust emission from the port were identified as:

1. Clam shell unloading from the vessel
2. Silo loading to the trucks and wagons
3. Wind entrainment from the stock piles

As sources in present study include clam shells, silos and stock piles, it was decided to choose multiple volume source to define the port activities, and the final simulations were made by defining the source as a volume source as discussed in Section 3.2.1. During the field campaign in November 2019, one berth was handling coal (Zone B-Berth 7) and the other was handling limestone (Zone A – Berth 6) (Figure 3.10). Details of source strength used for the three volume sources in AERMOD simulation are given in Table 3.4





**Figure 3.10: Location of major dusty cargo handling activity during the November 2019 sampling period**

**Table 3.4 : Details of source strength used in the AERMOD simulations**

Zone	Emission from	Type of Cargo	Amount Handled (MT)	Area of the zone (m <sup>2</sup> )	Wind Speed (m/s)	ER (g/s)	Total ER (g/s)
A	Clamshell	Coal	80770	-	3.15	0.076	4.462
	Silo	Coal	36300	-	3.15	0.002	
	Entrainment from active stock piles	Coal	-	31630	2.76	4.384	
B	Clamshell	Limestone	40430	-	2.56	0.484	12.573
	Entrainment from active stock piles	Limestone	-	87220	2.76	12.089	

Zone A was divided into two volume sources (to accommodate the elongated rectangular into the model) and Zone B was considered as a single volume source. To define the source strength, the emission factors were calculated using the equations for aggregate handling from AP42 as discussed in Section 3.2.2. Emissions from cargo handling activities in the port were identified to be mainly from 1) loading and unloading of the cargo and 2) wind entrainment from the active stock piles. The emission rate for the loading and unloading activity using silo and clam

shell activities at the two zones, Zone A with limestone and Zone B with coal, were based on the maximum amount of cargo handled for a day during November 2019 field campaign period (i.e. the Maximum activity level), as per the data collected from GSPCB (Section 3.3.3). The maximum coal and limestone handled a day during this period was 1,17,075 MT and 40,431 MT respectively. The emissions from stock pile in the port were based on the wind patterns in the port, and thus, an averaged emission rate for the sampling period was selected. A sum of emissions from these two types of activities (unit g/s) was taken as the source strength in the model simulations (Table 3.4).

### **3.4 Results and Discussion**

#### **3.4.1 Acceptability of MM5 Meteorological Data**

A comparison of MM5 wind data, wind data collected from a station installed at a sampling site (S5), and a weather station in MPT premises was made for quality assessment. It was observed that the average wind data (Figure 3.11) for 10 days during the sampling period matched well with each other, daily windrose have slight variations. It was also observed that the wind speed at MPT weather station was higher than that observed in the weather station at S5.

#### **3.4.2 AERMOD Dispersion Study: Monthly Variation of the Dispersion of PM from the Port**

In order to identify the dispersion pattern of port emissions throughout the year, monthly dispersion isopleths were developed. The details of the model inputs are provided in Section 3.3.5.

The monthly dispersion patterns are shown in Figures 3.12 to 3.23. Pink dots on the isopleth figures indicate the locations for sampling during the November 2019 sampling campaign. These data could be looked as the possible areas influenced by the port activities in different months for the specific activity level. A more zoomed-in view of the dispersion pattern along the hill is shown in Figure 3.24.

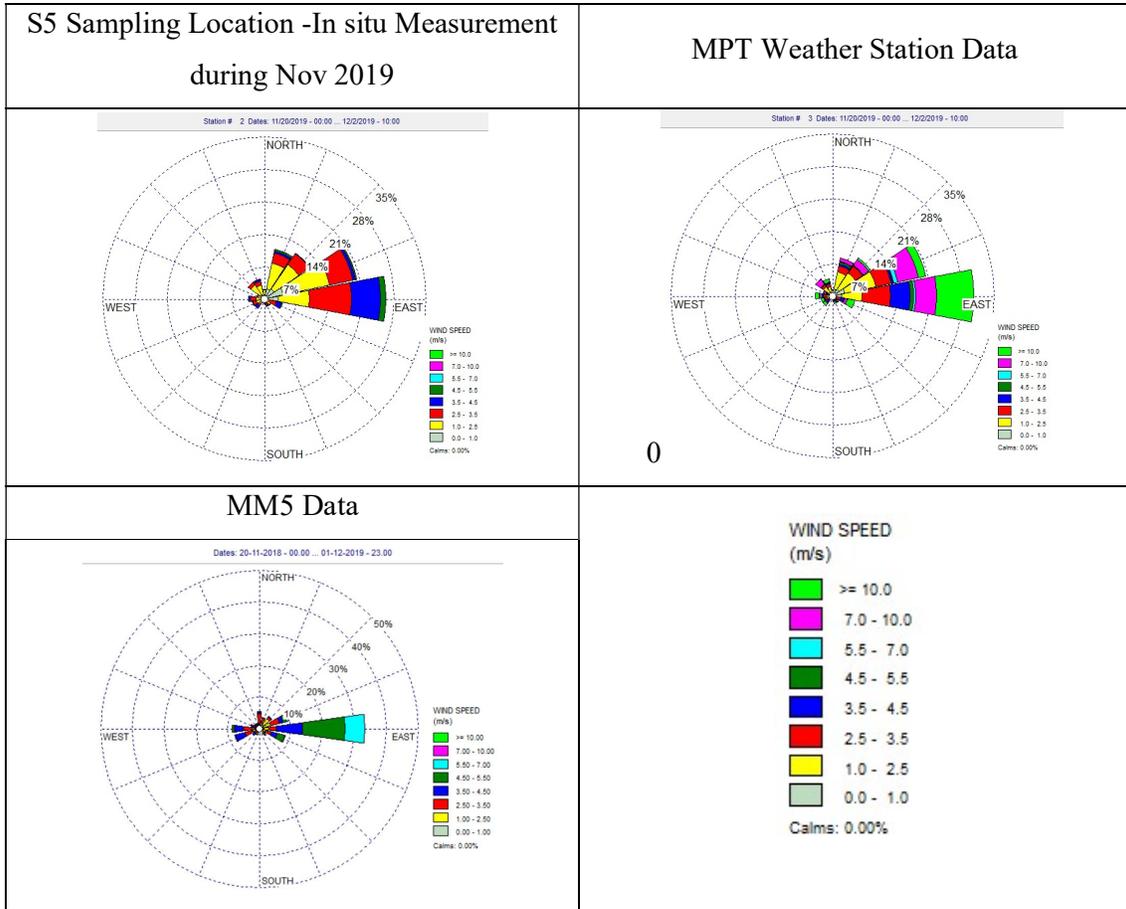


Figure 3.11: Comparison of Windrose for November 2019 Sampling Period at Vasco da Gama

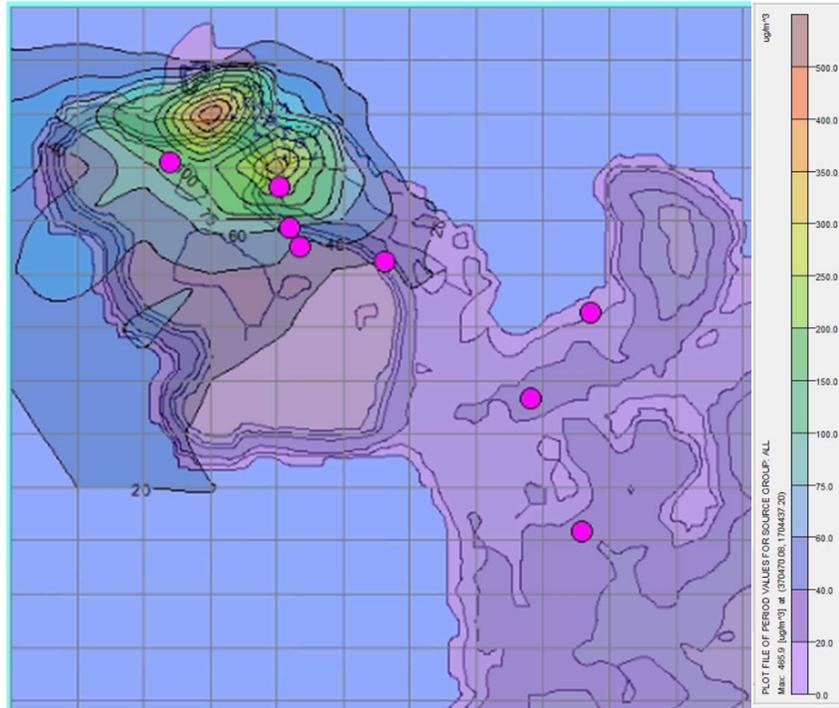


Figure 3.12 : Dispersion isopleths for the port emissions for the month of January. [Pink circles-sites of sampling campaign]

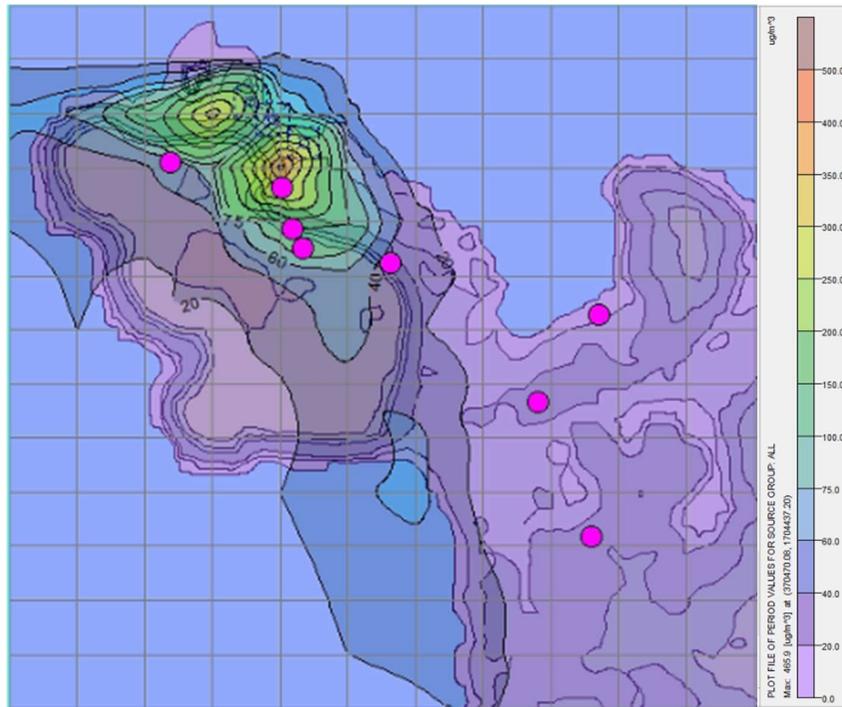


Figure 3.13 : Dispersion isopleths for the port emissions for the month of February [Pink circles-sites of sampling campaign]

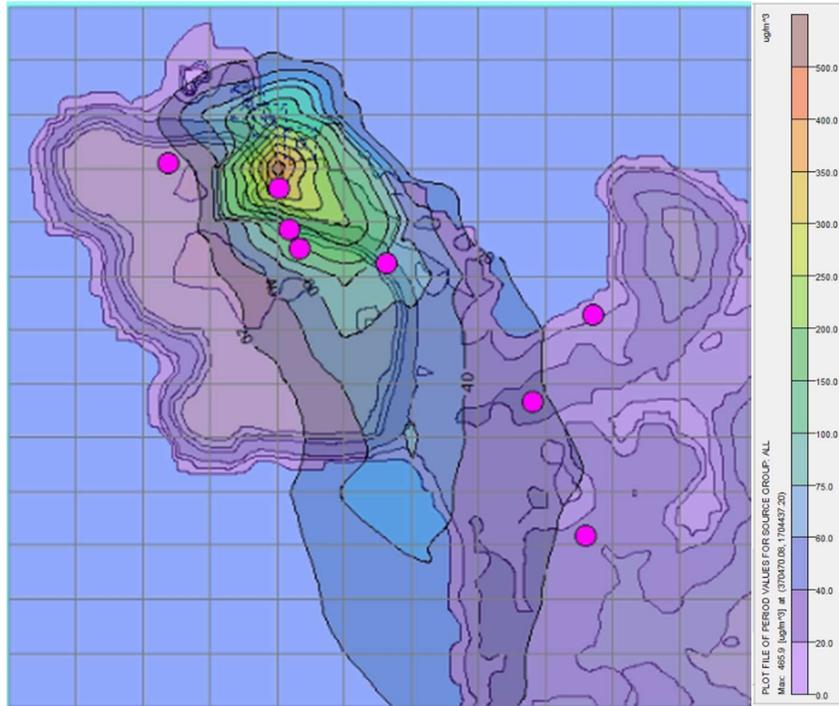


Figure 3.14 : Dispersion isopleths for the port emissions for the month of March February [Pink circles-sites of sampling campaign]

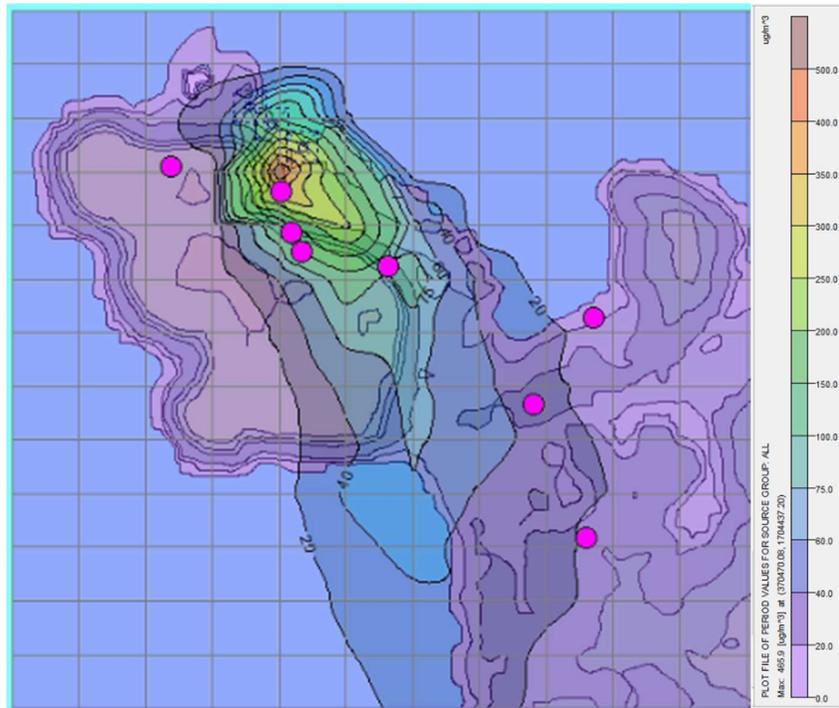
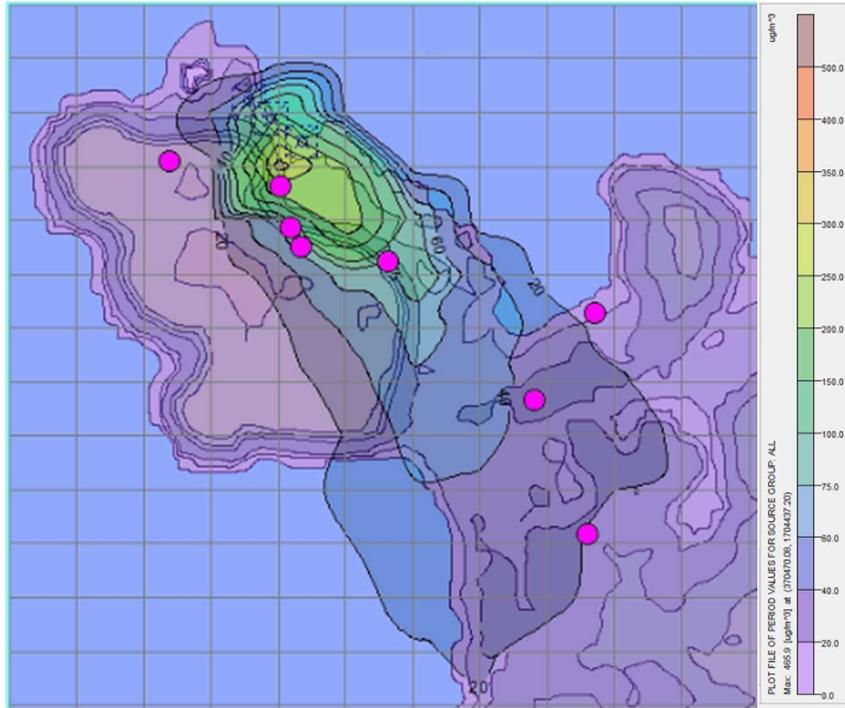
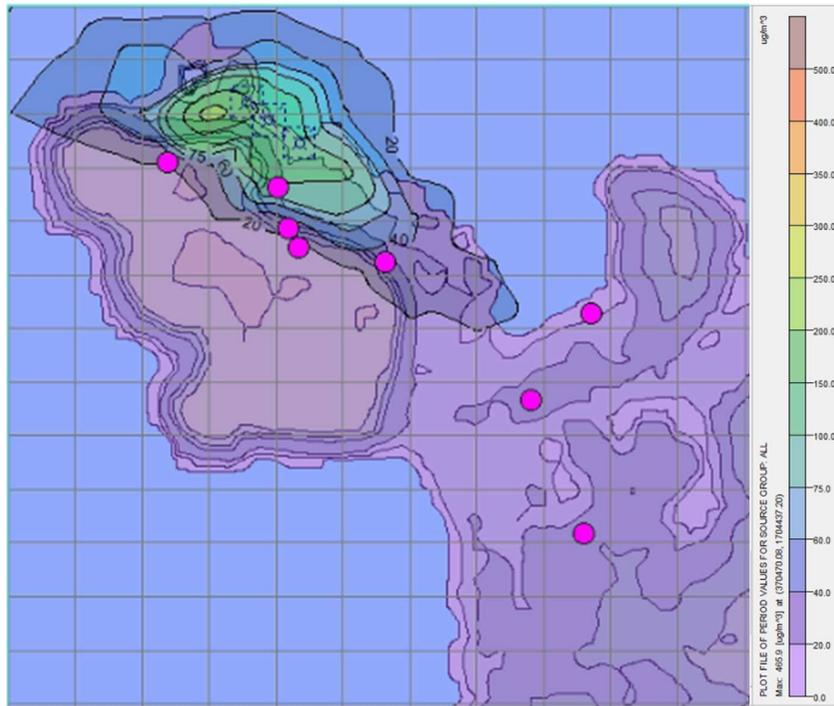


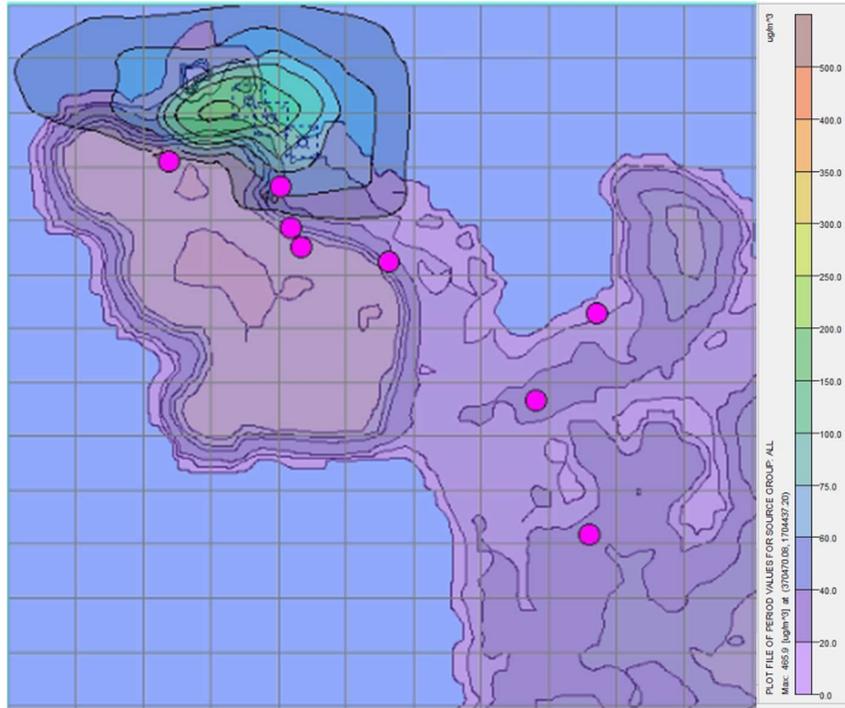
Figure 3.15 : Dispersion isopleths for the port emissions for the month of April [Pink circles-sites of sampling campaign]



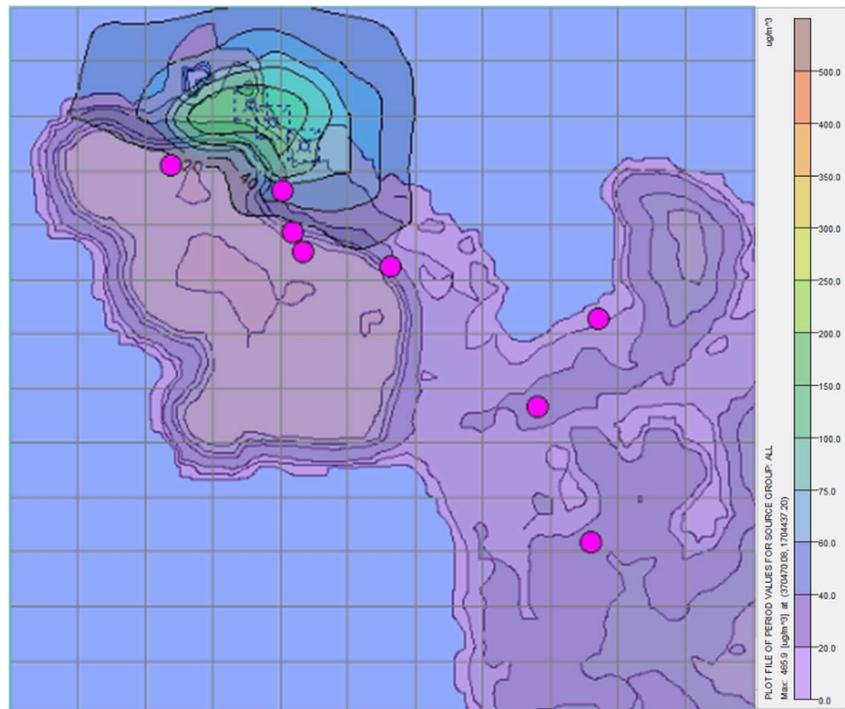
**Figure 3.16 : Dispersion isopleths for the port emissions for the month of May [Pink circles- sites of sampling campaign]**



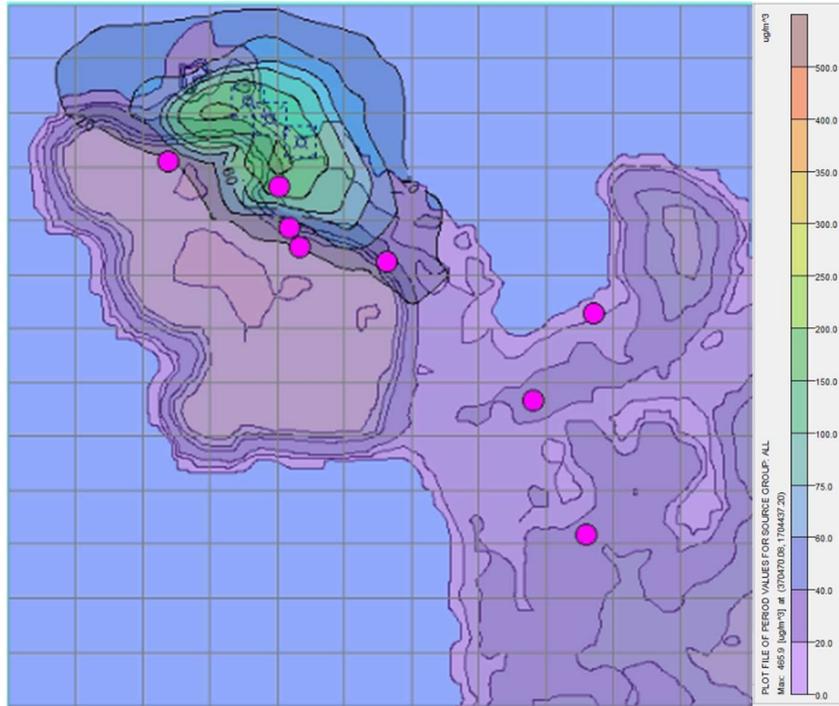
**Figure 3.17 : Dispersion isopleths for the port emissions for the month of June [Pink circles- sites of sampling campaign]**



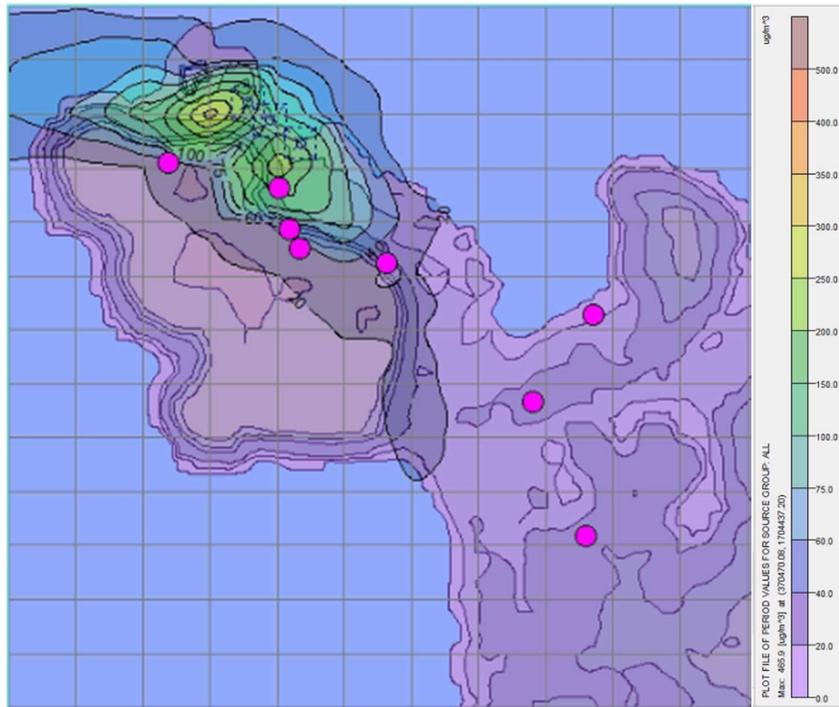
**Figure 3.18 : Dispersion isopleths for the port emissions for the month of July [Pink circles- sites of sampling campaign]**



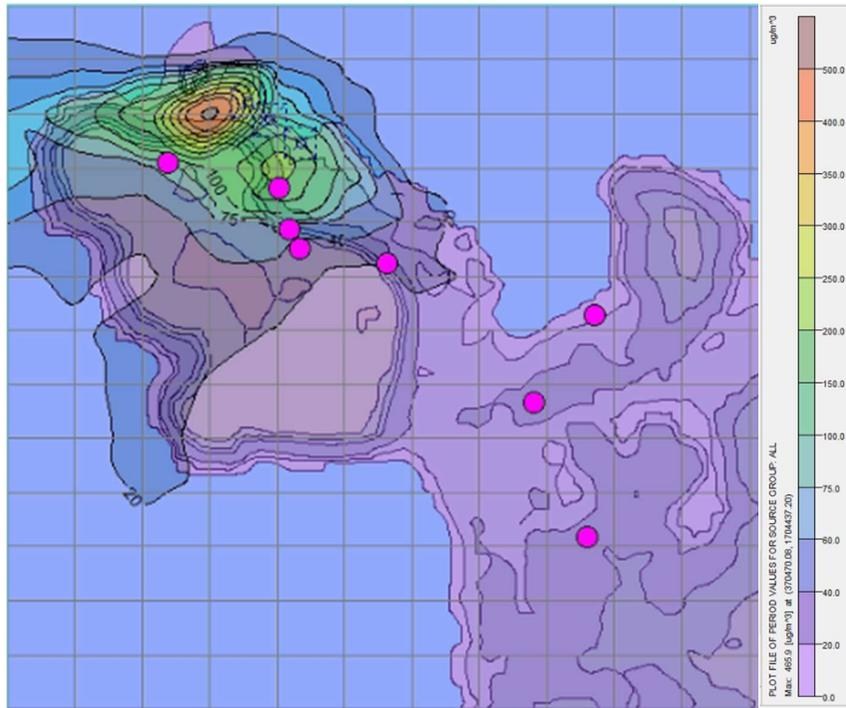
**Figure 3. 19 : Dispersion isopleths for the port emissions for the month of August [Pink circles- sites of sampling campaign]**



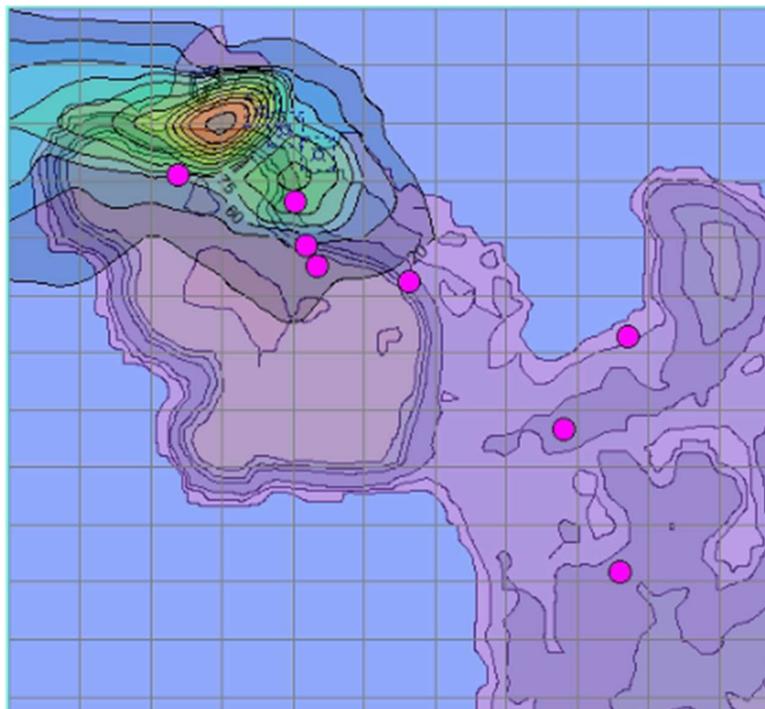
**Figure 3.20 : Dispersion isopleths for the port emissions for the month of September [Pink circles- sites of sampling campaign]**



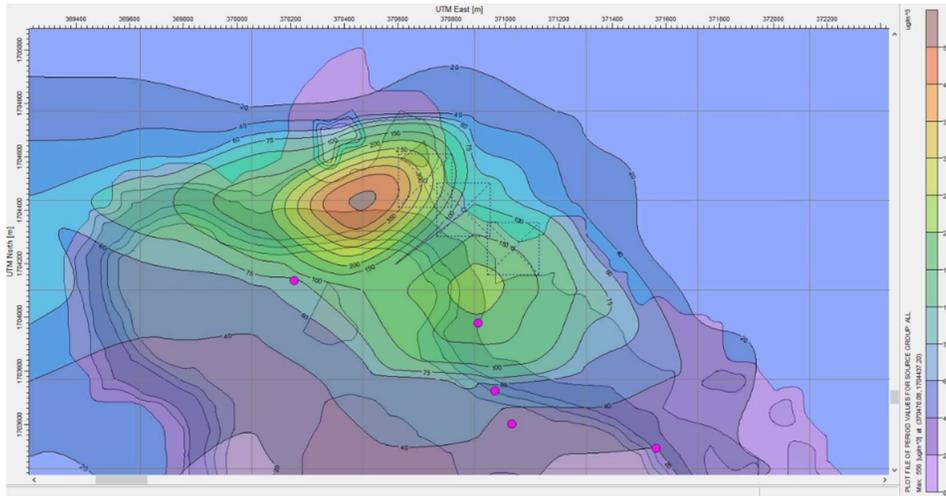
**Figure 3.21 : Dispersion isopleths for the port emissions for the month of October [Pink circles- sites of sampling]**



**Figure 3.22 : Dispersion isopleths for the port emissions for the month of November [Pink circles- sites of sampling campaign]**



**Figure 3.23 : Dispersion isopleths for the port emissions for the month of December [Pink circles- sites of sampling campaign]**

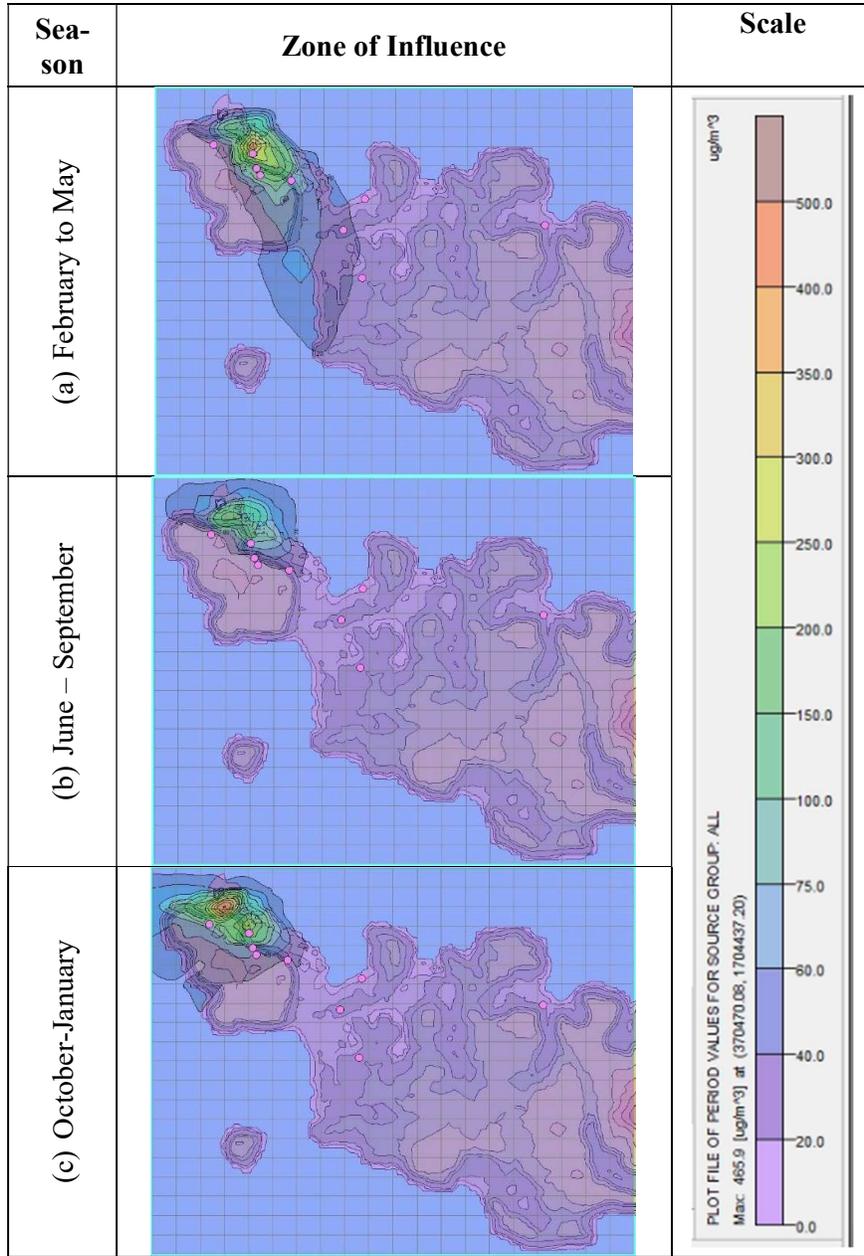


**Figure 3.24 : A zoomed in view of the dispersion isopleths for the port emissions for the month of November, 2019. The major five sampling locations for this study are shown as pink dots for reference**

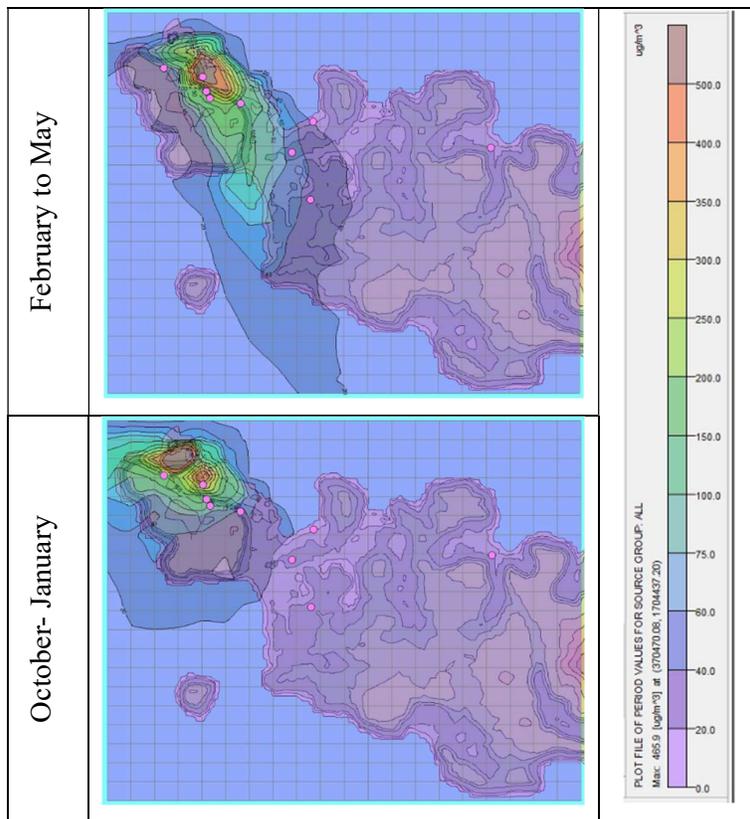
### 3.4.3 Seasonal Zone of Influence

The AERMOD dispersion maps could be used to define the zone of influence of emissions from the port. A set of simulations were made to understand the zones of influence based on seasonal meteorological changes. On the basis of the monthly dispersion patterns in Figure 3.12 to Figure 3.23 the three seasons in the study area was defined as (a) February to May, (b) June to September and (c) October to January.

It was observed that from February to May the dispersion was towards the mainland of Vasco da Gama; June to September the dispersion was away from the land and towards the ocean; and in October -January the hill area in the western half of the Vasco da Gama area is influenced (Figure 3.25). The source strength was maintained to be the same as that of the earlier monthly dispersion simulations. Figure 3.26 shows the dispersion pattern for case where the emission rate was doubled from that of the previous run shown in Figure 3.25. The increased emission rate increases the range of zone of influence based on the concentrations, as the ER and ground level concentrations are linearly related to one another.



**Figure 3.25 : Seasonal Dispersion Isopleths showing the zones of influence of PM Emissions from Dusty Cargo Handling in the Port for the three seasons.**



**Figure 3.26 : Seasonal Dispersion Isopleths showing the zones of influence of PM Emissions from Dusty Cargo Handling in the Port if the emission rate is doubled to that shown in Figure 3.25, for the two seasons in which the dispersion is more towards the land.**

### 3.4.4 Special Considerations

Coastal fumigation aspects gain relevance for any industries located at the ocean shores, where the chimneys for the flue gases are above 65 m in height. Present study area does not have such an elevated source of emissions, as all activities are at near-ground level. Also, there is a hillock just beside the berth area and the thermal boundary would not have adequate “entry” length to even be formed. Thus, the coastal fumigation was considered as per the advice from the expert, and was found to have little effect specifically for the particular location under study. Thus this aspect is not included in the revisions.

Local meteorological measurements are limited to only wind data, even for the data obtained from IMD, and therefore not sufficient to carry out dispersion modelling.

The AERMOD software ready MM5 data were procured specifically for this location for dispersion modelling. MM5 wind data were validated by comparison with local measurements carried out during the sampling period. Thus, the present meteorological parameters are the best possible representative data for the study area.

The exercise for boundary layer conditions in the AERMET software were included by considering the region as two sectors, viz.: i) water covered area and ii) remaining urban developed area.

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[https://www3.epa.gov/ttn/chief/ap42/oldeditions/3rd\\_edition/ap42\\_3rdsup14\\_may1983.pdf](https://www3.epa.gov/ttn/chief/ap42/oldeditions/3rd_edition/ap42_3rdsup14_may1983.pdf). AP42 emission factor details for batch drop and continuous drop.

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URL 3.7: [https://www.davisinstruments.com/product\\_documents/weather/manuals/07395-333\\_IM-6322C-6334.pdf](https://www.davisinstruments.com/product_documents/weather/manuals/07395-333_IM-6322C-6334.pdf). Davis weather station manual

## Chapter 4

### Source Apportionment Study Using EPA PMF v5.0

#### 4.1 Introduction

Positive matrix factorization (PMF) is a receptor modeling tool used for identification and quantification of sources and their contribution (Norris *et al.*, 2014). It is a multivariate statistical approach to factor analysis used for the source apportionment of atmospheric particulate matter (Paatero and Hopke, 2003; Gupta *et al.*, 2012; Das *et al.*, 2015; Cesari *et al.*, 2016; Habil *et al.*, 2016; Sharma *et al.*, 2016; Zhong *et al.*, 2016; Gadi *et al.*, 2019). It requires concentration dataset of samples and associated uncertainty as inputs and gives several variables such as factor profiles, their contribution and error in modeling as output (Polissar, 1998; Paatero and Hopke, 2003; Pakbin *et al.*, 2011). The chemically speciated air samples can be assembled as a data matrix 'X' of  $i \times j$  dimensions, in which  $i$  is the number of samples and  $j$  is the number of chemical species measured during analysis. It is based on chemical characterization of collected particles, are aimed to solve Eq 4.1:

$$x_{ij} = \sum_{k=1}^p g_{ik} f_{jk} + e_{ij} \quad \text{Eq 4.1}$$

where  $p$  is the number of factors contributing to the atmospheric particulate matter,  $x_{ij}$  is the  $j^{\text{th}}$  compound concentration measured in the  $i^{\text{th}}$  sample,  $g_{ik}$  is the gravimetric concentration of the  $j^{\text{th}}$  element in material from the  $k^{\text{th}}$  source, and  $f_{kj}$  is the airborne mass concentration ( $\text{mg}/\text{m}^3$ ) of material from the  $k^{\text{th}}$  source contributing to the  $i^{\text{th}}$  sample and  $e_{ij}$  is the residual for each species, difference between the measured and calculated amount.

PMF is a weighted least square problem in which a certain number of factors have to be determined in order to minimize an 'object function' as shown in Eq 4.2. Factor contributions and profiles are calculated by minimizing the object function 'Q' in the PMF model.

$$Q = \sum_{i=1}^n \sum_{j=1}^m \left( \frac{x_{ij} - \sum_{k=1}^p g_{ik} f_{kj}}{u_{ij}} \right)^2 \quad \text{Eq 4.2}$$

Where,  $u_{ij}$  is an estimate of uncertainty in the  $j^{\text{th}}$  variable in  $i^{\text{th}}$  sample.  $Q$  is a significant parameter in the PMF model for which two values,  $Q$  (true) and  $Q$  (robust), are calculated in the model results. The apportionment technique relies on many trial attempts to arrive at an acceptable solution (Reff *et al.*, 2007; Jiang *et al.*, 2015). More description with results analysis of the apportionment approach is included in Section 4.2; technical details can be found elsewhere (Paatero and Hopke, 2003; Pakbin *et al.*, 2011; Jiang *et al.*, 2015).

## 4.2 Methodology

For the present study EPA PMF v.5.0 developed by US EPA (URL 1) was used. This model predicts the source profiles or fingerprints as Factors, relative contributions, and uncertainties for identification of sources and their positive contributions to ambient air pollution.

The study was carried out for representative samples of  $PM_{2.5}$  and  $PM_{10}$  collected during the 11 November, 2019 to 1 December, 2019 sampling campaign. The studies were carried out for 7 cases based on sampling locations as discussed in Table 2.1 and clustering of receptors that were likely to have similar source activities:

1. Fuse off Call Office(S1)
2. Gold Smith House (S2)
3. MPT Guest House (MPT) (S3)
4. Fire Brigade Station (FBS) (S4)
5. Khariwada (S5)
6. Cluster Studies
  - a. Goldsmith House + MPT + FBS (S2+S3+S4)
  - b. Goldsmith House + MPT (S2+S3)
7. All Location (S1+S2+S3+S4+S5)

The concentration and uncertainty data were obtained from the gravimetric analysis (PM<sub>2.5</sub> and PM<sub>10</sub>); Elemental carbon and Organic carbon analysis; Elemental analysis by ED-XRF (44 elements - Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Mo, Rh, Pd, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, La, W, Au, Hg, Pb and In); and Ionic Analysis (12 ions: Na<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, F<sup>-</sup>, Cl<sup>-</sup>, NO<sub>2</sub><sup>-</sup>, Br<sup>-</sup>, NO<sub>3</sub><sup>2-</sup>, PO<sub>4</sub><sup>3-</sup> and SO<sub>4</sub><sup>2-</sup>) for both PM<sub>10</sub> and PM<sub>2.5</sub> for all cases (1-5) as listed above.

EPA PMF requires 2 input files : ‘Concentration’ file and ‘Uncertainty’ file. The input file is prepared using concentration data set of samples and associated uncertainty and both these data sets should be in same format (csv or xls) with all the elements analysed for the study in same units (µg/m<sup>3</sup>). The Concentration file is prepared by multiplying the concentration data as well as the uncertainty (i.e., standard deviation of analysis) obtained in µg/cm<sup>2</sup> with area of Filter paper ( i.e., 17.3065 cm<sup>2</sup> @ 47mm φ) from the ED -XRF and ionic analysis and then dividing the mass by the flow rate of Mini volume samplers (7.2 m<sup>3</sup> , taking the sampling time as 24 hours @ 5lpm. Here note that PMF works on non-negative aspect so if the concentration of any species is below detection limit or zero then that value needs to be replaced by 0.5 x Minimum Detection Limit (MDL) of that species. The MDL of all the elements is given in Table 4.1.

The uncertainty for measured values of elemental, ionic, gravimetric and EC-OC Analysis are calculated with Eq. 4.3 (Norris *et al.*, 2014). This calculation includes field as well as analytical uncertainty. If the value of uncertainty is missing it can be replaced by 5/6 x MDL (Norris *et al.*, 2014).

$$\begin{aligned}
 & \text{Unc} \\
 & = \text{Max} \left( \frac{\sqrt{((\text{Blank ion} + \text{conc of ion} * \text{Del relativity})^2 + \text{smp unc}^2 + \text{conc of ion}^2)}}{\text{smp vol}}, \sigma \right) \quad \text{Eq 4.3}
 \end{aligned}$$

Where, Unc = Uncertainty of ion, µg/m<sup>3</sup> ; Blank ion = Respective ion in Blank, filter ug/ml ;  
 Conc of ion = Concentration of ion, µg/m<sup>3</sup>; Del relativity = Delta Relativity ~ 5%, Smp Unc  
 = Sampling uncertainty ~5% ; Smp vol = Respective Sampling volume, m<sup>3</sup>; σ =Standard  
 Deviation of analytical methods, µg/m<sup>3</sup>

**Table 0.1: Minimum Detection Limit (MDL) of target analytes**

Elements (a)	µg/cm <sup>2</sup>	µg/m <sup>3</sup> #	Elements (a)	µg/cm <sup>2</sup>	µg/m <sup>3</sup> #
Na	0.0876	0.211	Ag	0.0192	0.046
Mg	0.0414	0.1	Cd	0.0260	0.063
Al	0.0128	0.031	Sn	0.0488	0.118
Si	0.0050	0.012	Sb	0.0700	0.169
P	0.0134	0.032	Te	0.0866	0.209
S	0.0090	0.022	I	0.1176	0.283
Cl	0.0100	0.024	Cs	0.0040	0.01
K	0.0162	0.039	Ba	0.0092	0.022
Ca	0.0048	0.012	La	0.0054	0.013
Sc	0.0074	0.018	W	0.0060	0.014
Ti	0.0020	0.005	Au	0.0022	0.005
V	0.0042	0.01	Hg	0.0020	0.005
Cr	0.0020	0.005	Pb	0.0056	0.013
Mn	0.0110	0.026	In	0.0274	0.066
Fe	0.0102	0.025	<b>Ions (b)</b>	<b>PPM</b>	<b>µg/m<sup>3</sup>#</b>
Co	0.0044	0.011	Na <sup>+</sup>	0.008	0.001
Ni	0.0030	0.007	NH <sub>4</sub> <sup>+</sup>	0.009	0.001
Cu	0.0050	0.012	K <sup>+</sup>	0.02	0.003
Zn	0.0020	0.005	Mg <sup>2+</sup>	0.02	0.003
Ga	0.0020	0.005	Ca <sup>2+</sup>	0.03	0.004
Ge	0.0010	0.002	F <sup>-</sup>	0.002	0.0002
As	0.0092	0.022	Cl <sub>s</sub>	0.005	0.001
Se	0.0010	0.002	NO <sub>2</sub> <sup>-</sup>	0.01	0.001
Br	0.0010	0.002	Br <sup>-</sup>	0.02	0.003
Rb	0.0102	0.025	NO <sub>3</sub> <sup>2-</sup>	0.02	0.003
Sr	0.0086	0.021	NO <sub>3</sub> <sup>2-</sup>	0.06	0.008
Y	0.0090	0.022	PO <sub>4</sub> <sup>3-</sup>	0.02	0.003
Zr	0.0100	0.024	SO <sub>4</sub> <sup>2-</sup>	0.02	0.008
Mo	0.0104	0.025	<b>EC-OC (c)</b>	<b>PPM</b>	<b>µg/m<sup>3</sup>#</b>
Rh	0.0108	0.026	EC	0.06	0.063
Pd	0.0126	0.03	OC	0.45	0.013

#Based on nominal air sampled @ 5LPM per sampling day

(a) ED- XRF; (b) IC ; (c) Based on DRI SOP for EC-OC (URL 2)

These two files are then used as input for EPA PMF v5.0 software. The model uses input files to display the summary of concentration data species in the form of minimum value, 25<sup>th</sup>, 50<sup>th</sup> and 75<sup>th</sup> percentile value, maximum value and 'Signal to Noise' (S/N) ratio. Based on this ratio the species are assigned as strong, weak or bad, as error is minimum in strongest variable and maximum in weakest variable, those labelled bad are excluded from the analysis (Paatero and Hopke, 2003; Jiang *et al.*, 2015). The Species having S/N ratio more than 3 are assigned Strong, ratio between 1 to 3 are assigned as weak and species with ratio less than 1 are assigned as bad species for running of the model. Species with 80% values below MDL are considered Bad species.

The model requires many trial and error attempts to arrive at the solutions. Thus, a wide range of factors (3-7 in number) were tried, and trial runs of 100 with a random start were attempted each time. The ratio  $Q_{\text{true}}/Q_{\text{robust}}$  has also been used to assess the modelled results.  $Q_{\text{true}}$  is estimated by considering entire data whereas  $Q_{\text{robust}}$  is estimated excluding outliers (Waked *et al.*, 2014). This ratio when close to 1.0, signifies good solution and negligible influence of outlier whereas if ratio is greater than 1.5 indicates, non-negligible influence (Waked *et al.*, 2014; Jiang *et al.*, 2015). Hence for the present study the recommended protocol of convergence of all the runs and factors were selected for the cases where  $Q_{\text{robust}} < 1.5 Q_{\text{true}}$  (Jiang *et al.*, 2015; Zhong *et al.*, 2016; Gadi *et al.*, 2019). Also, the correlation coefficients ( $R^2$ ) between measured and modelled metal concentration were checked for  $>0.80$ , which indicate better fit of the model to the measured data.

PMF can produce non-unique solutions because of many possible rotations of the solutions (Paatero *et al.*, 2002; Norris *et al.*, 2014), also referred to as rotation ambiguity. Rotating a given solution and investigating how rotated solution fill the solution space is one way to minimize the number of solutions. F-peak, a parameter for rotation of solution, is controlled to ensure minimum change in Q to produce unique solution. F-peak values were varied between  $-3$  and  $3$  and Q-values were monitored. The lowest Q-value indicated negligible presence of rotational ambiguity and thus solution at that F-peak was considered. The results are then check for mapping of the factors with respect to base model. Near to 100% mapping indicates that model is showing the efficiency of model results. If unmapped factors are more then, base factors and other parameters may need to be revised for getting better results. For the present work mapping of factors above 95% were accepted for all the cases.

Bootstrapping is a technique to estimate uncertainty in the solution by using series of dataset that are modified version of the original data (Norris *et al.*, 2014). Bootstrap runs indicated less than 5% variability in percentage of species. Minimum correlation value of 0.8 was selected with the default block size for every case. The above criteria, with reasonable control over numerous statistical parameters, substantiate that the solutions arrived were acceptable.

After matching all the criteria as described above, the model runs were considered for further analysis. The factor fingerprints, factor profiles and contribution obtained from these optimized runs were matched with the standard factor fingerprints and previous studies (Maykut *et al.*, 2003; Gupta *et al.*, 2012; Sharma *et al.*, 2016; Zhong *et al.*, 2016; Taghvaei *et al.*, 2018) to identify the sources. Also, all the results from various run and error estimation were obtained in the form of datasheets which were used for further analysis to obtain percentage contributions of each source at receptor locations and percentage of elemental contribution from that source.

Road dust samples were also collected and analysed for elements and ions using ED-XRF and IC analysis respectively. These dust profiles were used to validate the resuspended road dust source and to compare the profiles of dust at different locations for understanding the influence of port activities at all sampling sites mentioned in Table 2.1.

## 4.3 Results

The results of 7 cases mentioned in Section 4.2 are presented in this section.

### 4.3.1 Fuse off call office (S1):

The study was carried out for both PM<sub>10</sub> and PM<sub>2.5</sub> samples at the Fuse off call office sampling location. After the EPA PMF run analysis, 4 factors were identified in the study location for both the cases. The Factor finger prints are shown in Figure 4.1(a & b). Factor 1 was indicated by Zn, Mn, Fe, Ba (contributions ~ 8%, 7%, 8%, 7 %), as major elements which are indicators of Vehicular emissions. Emissions arising from road vehicles are generally contributed by a mixture of tailpipe emissions, and wear and tear of tyres. Zn is usually used as an additive in lubricating oil in two-stroke engines and is also a major trace metal component of tyre (Banerjee *et al.*, 2015; Landis *et al.*, 2017). Si, S, Fe and Zn are major indicators for emissions from heavy duty diesel trucks (Schauer *et al.*, 1999; Mool *et al.*, 2019). Also, EC & OC were present in this factor indicating emissions from burning of fossil fuel from vehicles. The said major contributing metals are tracers of vehicular exhaust emissions as shown by various previous studies (Gaga *et al.*, 2018; Hao *et al.*, 2019; Hu *et al.*, 2009; Querol *et al.*, 2007; Shukla *et al.*, 2017).

Factor 2 was identified with indicator elements such as Na, Cl, Na<sup>+</sup> and Cl<sup>-</sup> (~9%, 10%, 9%, 10%) as major species markers along with F<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-</sup> as minor markers which indicated the source to be Marine aerosols (Maykut *et al.*, 2003; Gupta *et al.*, 2012; Sharma *et al.*, 2016; Zhong *et al.*, 2016; Taghvaei *et al.*, 2018). Sea spray is a source of sulphates (Kothai, 2011).

Factor 3 was identified at this sampling location with major marker such as EC, OC, S, SO<sub>4</sub><sup>2-</sup> & NH<sub>4</sub><sup>+</sup> (~8%, 8%, 7%, 10%, 10%) and minor markers like Fe, Ca, K, K<sup>+</sup> (~3%, 4%, 7%, 5%) which are indicators of Port related activities and Biomass burning (Gupta *et al.*, 2012; Sharma *et al.*, 2016; Siddiqui *et al.*, 2020; URL3). The major activities in the port area are coal handling which is identified with EC and S along with lime stone and iron ore handling which explains Fe and Ca. Also, the biomass is being used as fuel in nearby area indicating K, OC, SO<sub>4</sub><sup>2-</sup> & K which is a prominent marker for Biomass burning (Chen *et al.*, 2010; Gupta *et al.*, 2012; Sharma *et al.*, 2016; Taghvaei *et al.*, 2018; Gangwar *et al.*, 2019) which can be validated by Biomass open burning which was also observed during sampling campaign. Ship idling was also observed during the sampling duration which is a contributor of S and EC trucks

(Schauer *et al.*, 1999; Mool *et al.*, 2019). The model could not distinguish between these two sources differently as the sources are in close proximity and tracers are common between these two sources.

Factor 4 was identified as Road dust with major markers such as Al, Si, Ti, Ca and  $\text{PO}_4^{3-}$  (~8%, 8%, 9%, 8%, 15%) along with minor contributions from Na, Ga, Fe, Cr and Zn. Al is a very good tracer of road dust re-suspension, road dust gets re-suspended due to natural gust of winds or moving objects like vehicles (Zhang, 2008; Kothai, 2011; Goix *et al.*, 2014; Banerjee *et al.*, 2015; Habil *et al.*, 2016; Landis *et al.*, 2017; Ashrafi *et al.*, 2018). Also, Si and Ti are indicators of crustal dust (Habil *et al.*, 2016; Sharma *et al.*, 2016; Taghvaei *et al.*, 2018). Substantial amount of paved road dust is being resuspended by vehicular movements which is indicated by minor markers such as Zn, Fe and Mn (Hao *et al.*, 2019; Hu *et al.*, 2009; Querol *et al.*, 2007). Agricultural activities can also lead re-suspension of soil but absence of any major hotspots in the agricultural land use rules out any such re-suspension.

The road dust analysis also showed the major elements such as Fe, Ca,  $\text{Ca}^{2+}$ , Si, Al (~54%, 8%, 7%, 8%, 4%) in the sample which were in comparable percentage as found in road dust profile from PMF analysis. These dust profiles are also well comparable with the dust profiles developed for six Indian cities (Patil *et al.*, 2013) in terms of major elements. Along with that road dust from this sampling site also showed traces of K (~4%) which is an indicator of biomass burning (Gupta *et al.*, 2012; Sharma *et al.*, 2016; Siddiqui *et al.*, 2020). Also, the profile showed traces of Cu, Pb, Zn and Ni which are indicators of vehicle wear and tear (Zhang, 2008; Goix *et al.*, 2014; Banerjee *et al.*, 2015; Landis *et al.*, 2017). The dust profile indicated more amount of Fe which indicates the iron ore handling as a major port activity over past years, and limestone handling over the sampling duration as shown in Figure 3.4 and Figure 3.5 respectively.

The major contributors for both  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  samples at Fuse Off Call Office were found to be Road Dust which is followed by Port Activities, Vehicular and Marine Source as seen in Figure 4.1(c). Fuse off call office is located in city center with main road passing nearby (Swatantra Path) and bus stand in near vicinity as shown in Figure 2.1 so the contribution of Road dust is well acceptable. It is indicated from the Table 4.2 that the % contribution of the Road dust and Port related activities is more in  $\text{PM}_{10}$  fraction and Vehicular source is more in  $\text{PM}_{2.5}$  fraction.

Table 0.2: Percentage Source Contribution for Fuse Off Call Office

	Most likely source(s)	%Contribution	
		PM <sub>2.5</sub>	PM <sub>10</sub>
Factor 1	Vehicular emission	28.3	25.5
Factor 2	Marine aerosols	27.1	23
Factor 3	Port related activities and Biomass burning	23.8	25.9
Factor 4	Road dust	20.8	25.6

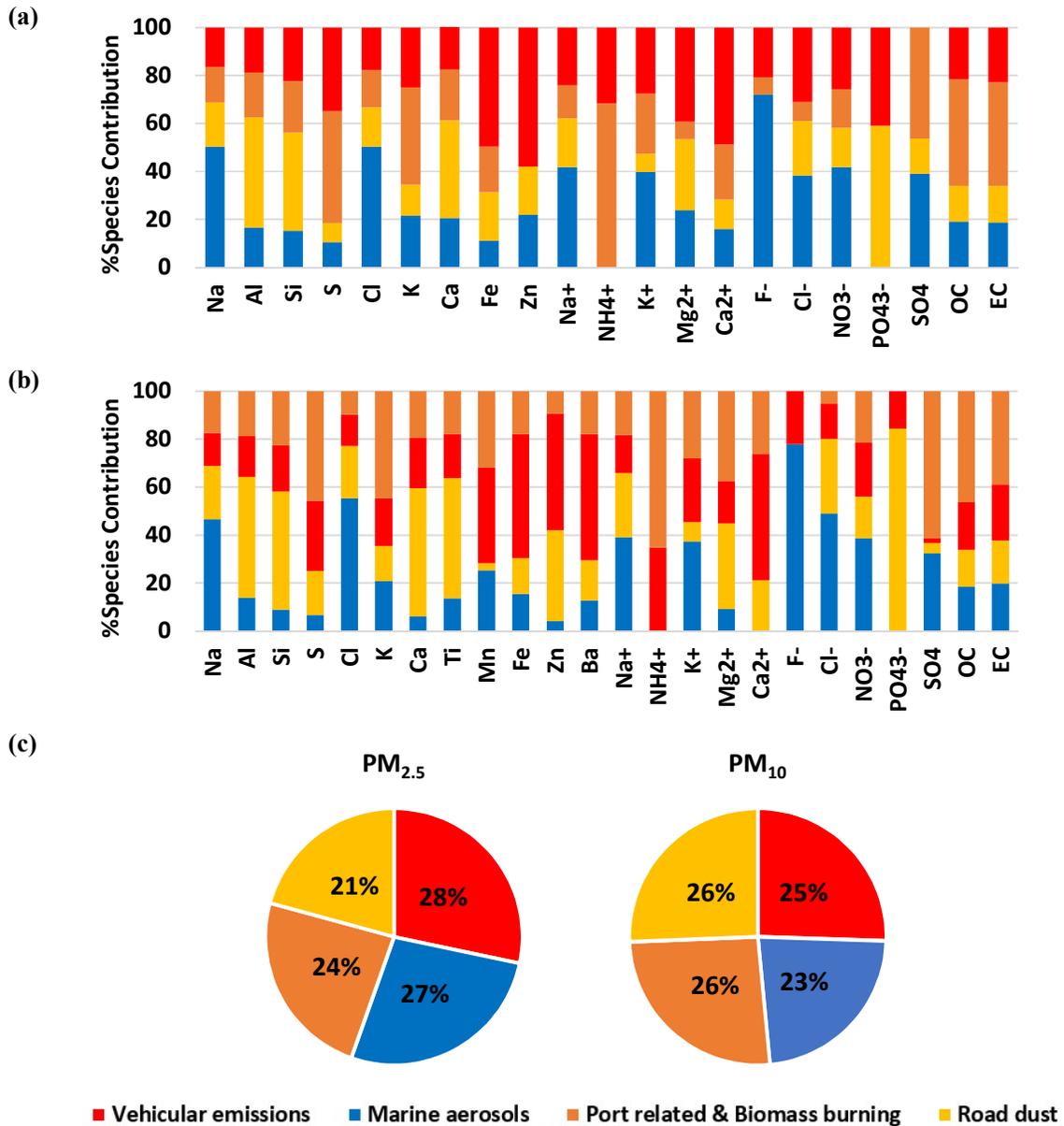


Figure 4.1: Factor Fingerprints for Fuse Off Call Office for a) PM<sub>2.5</sub>, b) PM<sub>10</sub>, c) Percentage Contribution of Sources

### 4.3.2 Goldsmith House (S2)

The study was carried out for both PM<sub>10</sub> and PM<sub>2.5</sub> samples at the Goldsmith House sampling location. After the EPA PMF run analysis, 4 factors were identified in the study location for both the cases. The Factor finger prints are shown in Figure 4.2(a & b). Based on factor finger prints and source profiles Factor 1 was indicated by Zn, Mn, Fe, Ba (contributions ~ 9%, 10%, 12%, 7 %), as major elements with some minor indicators like EC, OC and Mn which are indicators of Vehicular emissions. Factor 2 was identified with indicator elements such as Na, Cl, Na<sup>+</sup> and Cl (~9%, 10%, 9%, 10%) as major species markers along with F<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-</sup> as minor markers which indicated the source to be Marine aerosols.

Factor 3 was identified at this sampling location was with major marker such as EC, Ca, S, SO<sub>4</sub><sup>2-</sup> & NH<sub>4</sub><sup>+</sup> (~8%, 8%, 9%, 8%, 12%) and minor markers like Fe, Ca, K & K<sup>+</sup> (3%, 4%, 5%, 6%) which are indicators of Port related activities and Biomass burning. The Goldsmith house is within ~1Km of the vicinity of nearby port as shown in Figure 2.1. The major activity at the port area are Coal and limestone handling. Biomass open burning and . Ship idling was also observed during the sampling duration influencing this factor. Factor 4 was identified as Road dust with major markers such as Al, Si, Ti, Ca and PO<sub>4</sub><sup>3-</sup> (~ 6%, 6%, 6%, 7%, 14%) along with minor contributions from Na, Ga, Fe, Cr and Zn. Road dust is resuspended due to vehicular activities such as movement of heavy-duty trucks.

The road dust analysis also showed the major elements such as Fe, Ca, Ca<sup>2+</sup>, Si, Al (~60%, 8%, 8%, 10%, 6%) in the samples which were found in road dust profiles from PMF Analysis. This profiles also showed trace elements such as K (~3%) which can be considered as minor indicator of biomass burning (Gupta *et al.*, 2012; Sharma *et al.*, 2016; Siddiqui *et al.*, 2020). The dust profile indicated more amount of Fe which indicates the iron ore handling as a major port activity over past years and limestone handling over the sampling duration as shown in Figure 3.4 and Figure 3.5 respectively

The major contributor for PM<sub>10</sub> samples was Road dust and Port related activities and biomass burning whereas for PM<sub>2.5</sub> samples was Port related activities & biomass burning which is followed by Marine aerosols as seen in Figure 4.2(c). Goldsmith House is located in the nearby vicinity of the MPT port so the contribution of Port related activities and marine are probable sources to impact this site which is indicated from the Table 4.3.

Table 0.3: Percentage Source Contribution for Goldsmith House

	Most likely source(s)	%Contribution	
		PM <sub>2.5</sub>	PM <sub>10</sub>
Factor 1	Vehicular emission	23.2	23.8
Factor 2	Marine aerosols	26.5	21.8
Factor 3	Port related activities and Biomass burning	28.1	26.4
Factor 4	Road dust	22.2	28

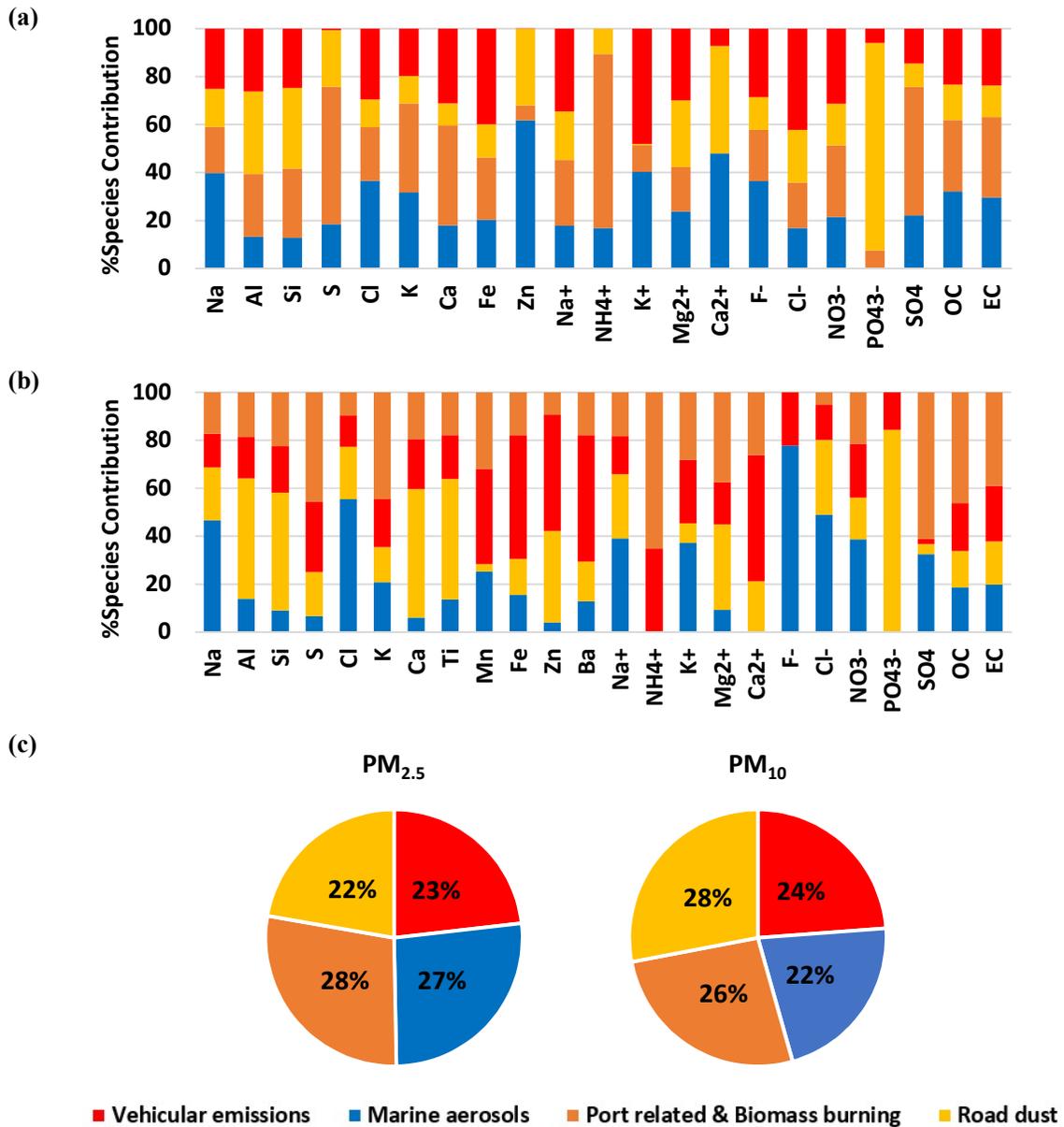


Figure 4.2: Factor Fingerprints for Goldsmith House for a) PM<sub>2.5</sub>, b) PM<sub>10</sub>, c) Percentage Contribution of Sources

### 4.3.3 MPT Guest House(MPT) (S3):

The study was carried out for both PM<sub>10</sub> and PM<sub>2.5</sub> samples at the MPT Guest House (MPT) sampling location. After the EPA PMF run analysis, 4 factors were identified in the study location for both the cases. The Factor finger prints are shown in Figure 4.3(a & b). Based on factor finger prints and source profiles Factor 1 was indicated by Zn, Fe, Ca<sup>2+</sup>, Mg<sup>2+</sup> (contributions ~ 7%, 8%, 17%, 7 %), as major elements with some minor indicators like EC, OC and Mn which are indicators of Vehicular emission. Factor 2 was identified with indicator elements such as Na, Cl, Na<sup>+</sup> and Cl<sup>-</sup> (~9%, 9%, 8%, 8%) as major species markers along with F<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-</sup> as minor markers which indicated the source to be Marine aerosols.

Factor 3 was identified with marker such as EC, Ca, S, SO<sub>4</sub><sup>2-</sup> & NH<sub>4</sub> (~8%, 8%, 9%, 8%, 12%) and minor markers like Fe, Ca, K & K<sup>+</sup> (3%, 4%, 5%, 6%) which are indicators of Port related activities and Biomass burning. Factor 4 was identified as Road dust with major markers such as Al, Si, Ti, Ca and PO<sub>4</sub><sup>3-</sup> (~ 8%, 8%, 7%, 8%, 15%) along with minor contributions from Na, Ga, Fe, Cr and Zn. Road dust is resuspended due to vehicular activities such as movement of heavy-duty trucks.

The road dust analysis also showed the major elements such as Fe, Ca, Ca<sup>2+</sup>, Si, Al (~45%, 12%, 7%, 11%, 4%) in the samples which were found in road dust profiles from PMF Analysis. The dust profiles indicated more amount of Fe which indicates the iron ore handling as a major port activity over past years and limestone handling over the sampling duration as shown in Figure 3.4 and Figure 3.5 respectively.

The major contributor for both PM<sub>10</sub> & PM<sub>2.5</sub> samples is Port related activities & biomass burning which is followed by Marine aerosols, Road dust and vehicular emission source as seen in Figure 4.3 (c). The MPT Guest house is within ~1Km of the vicinity of nearby port as shown in Figure 2.1. The major activity at the port area are Coal and limestone handling. Biomass open burning and ship idling was also observed during the sampling duration influencing this factor as indicated in Table 4.4.

Table 0.4: Percentage Source Contribution for MPT Guest House

	Most likely source(s)	%Contribution	
		PM <sub>2.5</sub>	PM <sub>10</sub>
Factor 1	Vehicular emission	24.2	19.2
Factor 2	Marine aerosols	26.3	27.3
Factor 3	Port related activities and Biomass burning	27.9	28.3
Factor 4	Road dust	21.6	25.2

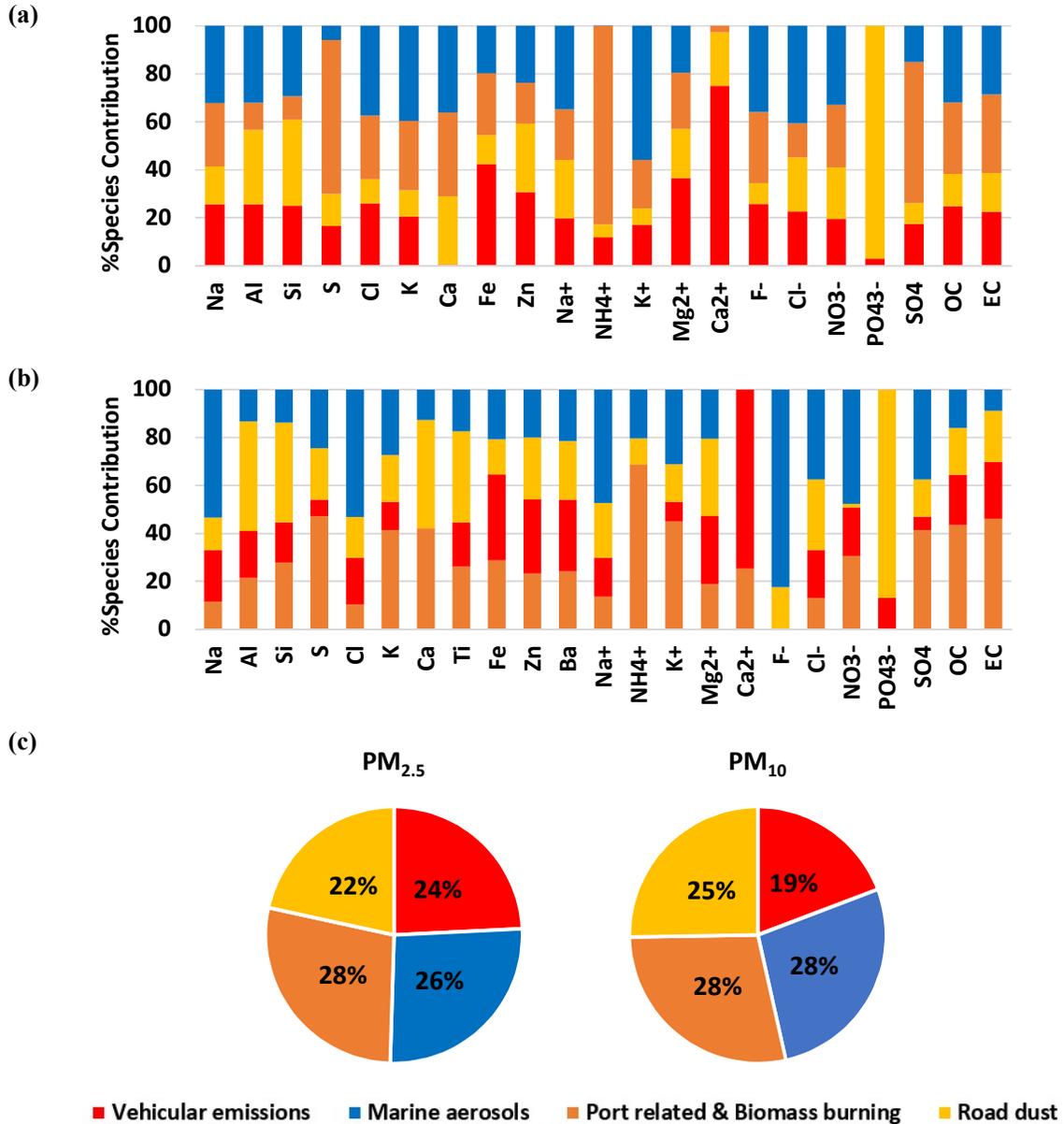


Figure 4.3: Factor Fingerprints for MPT for a) PM<sub>2.5</sub>, b) PM<sub>10</sub>, c) Percentage Contribution of Sources

#### 4.3.4 Fire Brigade Station(FBS) (S4) :

The study was carried out for both PM<sub>10</sub> and PM<sub>2.5</sub> samples at the Fire Brigade Station(FBS) sampling location. After the EPA PMF run analysis, 4 factors were identified in the study location for both the cases. The Factor finger prints are shown in Figure 4.4(a & b). Based on factor finger prints and source profiles Factor 1 was indicated by Zn, Fe, Ca<sup>2+</sup>, Mg<sup>2+</sup> (contributions ~ 14%, 5%, 14%, 7%), as major elements with some minor indicators like EC, OC and Mn which are indicators of Vehicular emission. Factor 2 was identified with indicator elements such as Na, Cl, Na<sup>+</sup> and Cl<sup>-</sup> (~9%, 10%, 7%, 8%) as major species markers along with F<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-</sup> as minor markers which indicated the source to be Marine aerosols.

Factor 3 was identified with marker such as EC, S, SO<sub>4</sub><sup>2-</sup> & NH<sub>4</sub><sup>+</sup> (~7%, 6%, 12%, 8%) and minor markers like Fe, Ca, OC, K & K<sup>+</sup> (~6%, 5%, 4%, 5%, 6%) which are indicators of Port related activities and Biomass burning. Factor 4 was identified as Road dust with major markers such as Al, Si, Mg<sup>2+</sup>, Ca<sup>2+</sup> and PO<sub>4</sub><sup>3-</sup> (~ 7%, 4%, 7%, 8%, 14%) along with minor contributions from Na, Ga, Fe, Cr and Zn. Road dust is resuspended due to vehicular activities such as movement of heavy-duty trucks.

The road dust analysis also showed the major elements such as Fe, Ca, Ca<sup>2+</sup>, Si, Al (~54%, 10%, 9%, 8%, 4%) in the samples which were found in road dust profile from PMF Analysis. This profile also showed trace elements such as K (~6%) which can be considered as minor indicator of biomass burning respectively (Gupta *et al.*, 2012; Sharma *et al.*, 2016; Siddiqui *et al.*, 2020). The dust profiles indicated more amount of Fe which indicates the iron ore handling as a major port activity over past years and limestone handling over the sampling duration as shown in Figure 3.4 and Figure 3.5 respectively.

The source contribution of all four sources for both studies is comparable as shown in Table 4.5 . The major contributor for both studies for both PM<sub>10</sub> & PM<sub>2.5</sub> samples is by Port activities followed by Road Dust, Marine and Vehicular emission as shown in Figure 4.4(c). Fire Brigade Station is located on the port area itself so it will be impacted by the activities occurring on the port which includes coal, limestone and iron ore handling. Biomass open burning and ship idling was also observed during the sampling duration influencing this factor. Also, as cargo is being loaded and unloaded on the port and transportation by heavy duty trucks is contributing to road dust and vehicular emissions.

Table 0.5: Percentage Source Contribution for Fire Brigade Station

	Most likely source(s)	%Contribution	
		PM <sub>2.5</sub>	PM <sub>10</sub>
Factor 1	Vehicular emission	20.5	16.6
Factor 2	Marine aerosols	27.4	23.4
Factor 3	Port related activities and Biomass burning	28.6	28.1
Factor 4	Road dust	23.5	27.7

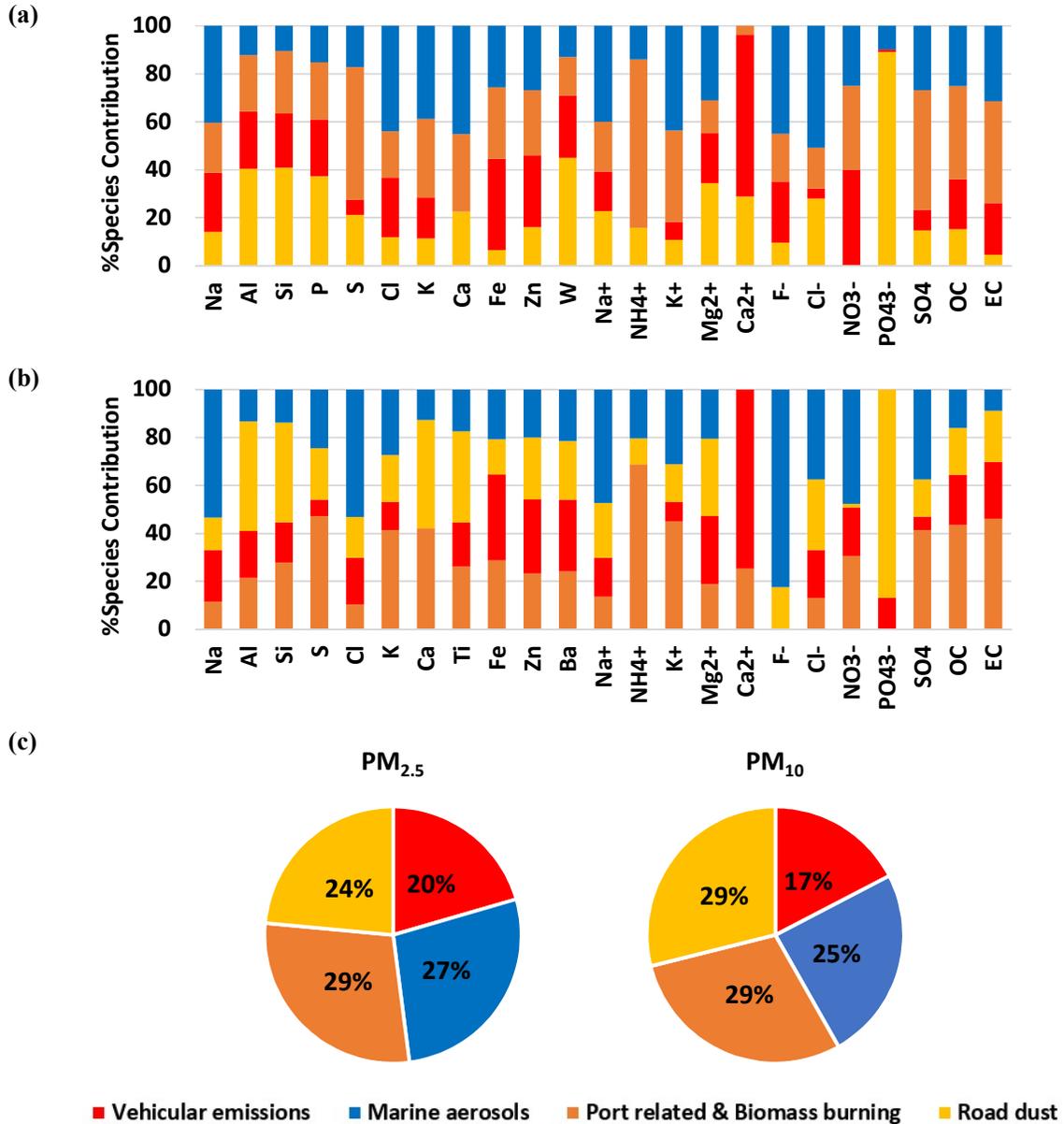


Figure 4.4: Factor Fingerprints for FBS for a) PM<sub>2.5</sub>, b) PM<sub>10</sub>, c) Percentage Contribution of Sources

#### 4.3.5 Khariwada (S5) :

The study was carried out for both PM<sub>10</sub> and PM<sub>2.5</sub> samples at the Khariwada sampling location. After the EPA PMF run analysis, 4 factors were identified in the study location for both the cases. The Factor finger prints are shown in Figure 4.5(a & b). Based on factor finger prints and source profiles Factor 1 was indicated by Zn, Mn, Fe, Cr (contributions ~ 11%, 8%, 7%, 7 %) as major elements with some minor indicators like EC, OC and Mn which are indicators of Vehicular emission. Factor 2 was identified with indicator elements such as Na, Cl, Na<sup>+</sup> and Cl<sup>-</sup> (~7%, 8%, 6%, 6%) as major species markers along with F<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-</sup> as minor markers which indicated the source to be Marine aerosols.

Factor 3 was identified with marker such as EC, OC, S, SO<sub>4</sub><sup>2-</sup> & NH<sub>4</sub><sup>+</sup> (~10%, 5%, 12%, 15%, 17%) and minor markers like Fe, Ca, K & K<sup>+</sup> (3%, 6%, 6%, 6%) which are indicators of Port related activities and Biomass burning. Factor 4 was identified as Road dust with major markers such as Al, Si, P, Ca and PO<sub>4</sub><sup>3-</sup> (~ 8%, 7%, 8%, 14%, 17%) along with minor contributions from Na, Ga, Fe, Cr and Zn. Road dust is resuspended due to vehicular activities such as movement of heavy-duty trucks.

The road dust analysis also showed the major elements such as Fe, Ca, Ca<sup>2+</sup>, Si, Al (~29%, 11%, 14%, 15%, 7%) in the samples which were in comparable percentage as found in road dust profiles from PMF Analysis. This profiles also showed trace elements such K (~4%) can be considered as minor indicator of Biomass burning (Gupta *et al.*, 2012; Sharma *et al.*, 2016; Siddiqui *et al.*, 2020). This dust profile of Khariwada showed more contribution of Crustal elements like Si, Al and Ti and marine elements like Na<sup>+</sup> and Cl<sup>-</sup> as compared to other locations which also validates that this can be considered as background source.

The major contributor for both studies for both PM<sub>10</sub> & PM<sub>2.5</sub> samples is Marine aerosols followed by Port related activities & biomass burning, Road dust and Vehicular emission as shown in Figure 4.5 (c). Khariwada is located on the Sea side so marine factor being highest is justified. Also, since this location is further away (~2Km) from the port there is less impact of Port related activities on this sampling location as shown in Table 4.6.

Table 0.6: Percentage Source Contribution for Khariwada

	Most likely source(s)	%Contribution	
		PM <sub>2.5</sub>	PM <sub>10</sub>
Factor 1	Vehicular emission	27.5	22.9
Factor 2	Marine aerosols	29.4	28.6
Factor 3	Port related activities and Biomass burning	18.2	21.5
Factor 4	Road dust	24.9	27

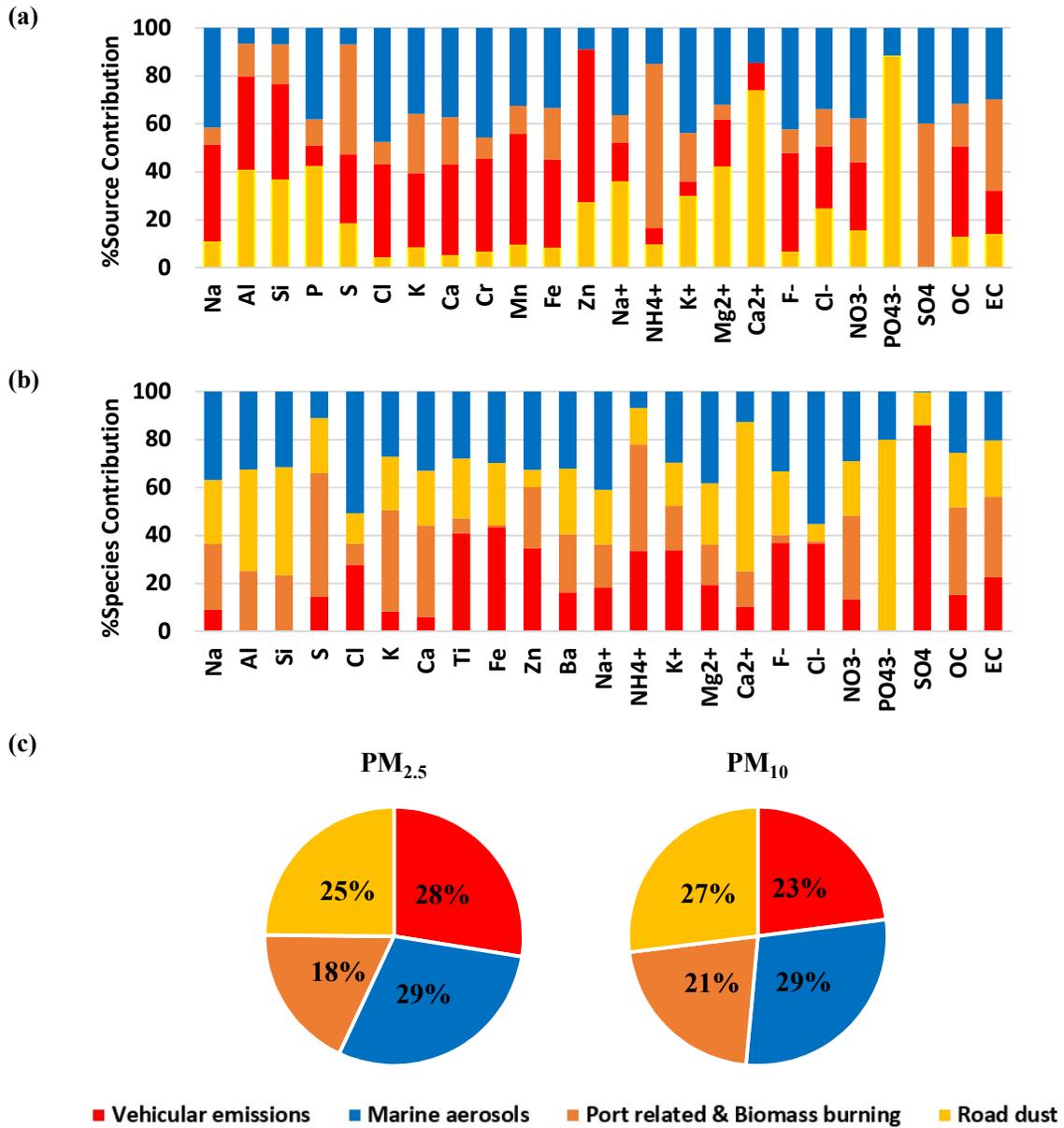


Figure 4.5: Factor Fingerprints for Khariwada for a) PM<sub>2.5</sub>, b) PM<sub>10</sub>, c) Percentage Contribution of Sources

### 4.3.6 Cluster Studies

The Gold smith house and MPT Guest House are within ~1Km of the vicinity of nearby Murmagaon Port whereas Fire Brigade Station is on the port area itself. So, port activities are most likely to influence these locations to a large extent. Hence, two Combined studies were undertaken to get a clear idea:

- a. Goldsmith House (S2) + MPT Guest House (S3) + Fire Brigade Station (S4)
- b. Goldsmith House (S2) + MPT Guest House (S3)

Also, as the cargo is being loaded and unloaded on the port and transportation was taking place in heavy duty trucks, thereby contributing to road dust resuspension and exhaust emissions. The meteorology and geography of these sampling locations also has some influence on the pollution sources impacting ambient air quality.

#### 4.3.6.1 Cluster of Goldsmith House, MPT Guest House and Fire Brigade station (S2+S3+S4)

A combined study was carried out for 3 sampling locations: Goldsmith House, MPT Guest house and Fire Brigade Station for both PM<sub>10</sub> and PM<sub>2.5</sub> samples. After the EPA PMF run analysis, 4 factors were identified in the study location for both the cases. The Factor finger prints are shown in Figure 4.6(a & b).

Factor 1 was indicated by Zn, Fe, Ca<sup>2+</sup>, Mg<sup>2+</sup> (contributions ~ 10%, 9%, 15%, 5%) as major elements with some minor indicators like EC, OC and Mn which are indicators of Vehicular emission. Factor 2 was identified with indicator elements such as Na, Cl, Na<sup>+</sup> and Cl<sup>-</sup> (~9%, 9%, 8%, 9%) as major species markers along with F<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-</sup> as minor markers which indicated the source to be Marine aerosols. Factor 3 was identified with marker such as EC, OC, S, SO<sub>4</sub><sup>2-</sup> & NH<sub>4</sub><sup>+</sup> (~8%, 8%, 10%, 8%, 13%). and minor markers like Fe, Ca, K & K<sup>+</sup> (5%, 5%, 6%, 6%) which are indicators of Port related activities and Biomass burning. Factor 4 was identified as Road dust with major markers such as Al, Si, Mg<sup>2+</sup>, Ca and PO<sub>4</sub><sup>3-</sup> (~ 9%, 8%, 8%, 8%, 18%) along with minor contributions from Na, Ga, Fe, Cr and Zn.

The source contribution for both studies is shown in **Table 4.7**. The major contributor for both studies for both PM<sub>10</sub> & PM<sub>2.5</sub> samples is Port related activities and Biomass burning, followed by Marine aerosols, Road dust and Vehicular emission as shown in **Figure 4.6(c)**. So, this validates that port activities influences these locations to a large extent.

Table 0.7: Source Contribution for Goldsmith House, MPT and FBS

	Most likely source(s)	%Contribution	
		PM <sub>2.5</sub>	PM <sub>10</sub>
Factor 1	Vehicular emission	23.4	21.5
Factor 2	Marine aerosols	25	25.2
Factor 3	Port related activities and Biomass burning	27.3	27.7
Factor 4	Road dust	24.3	25.6

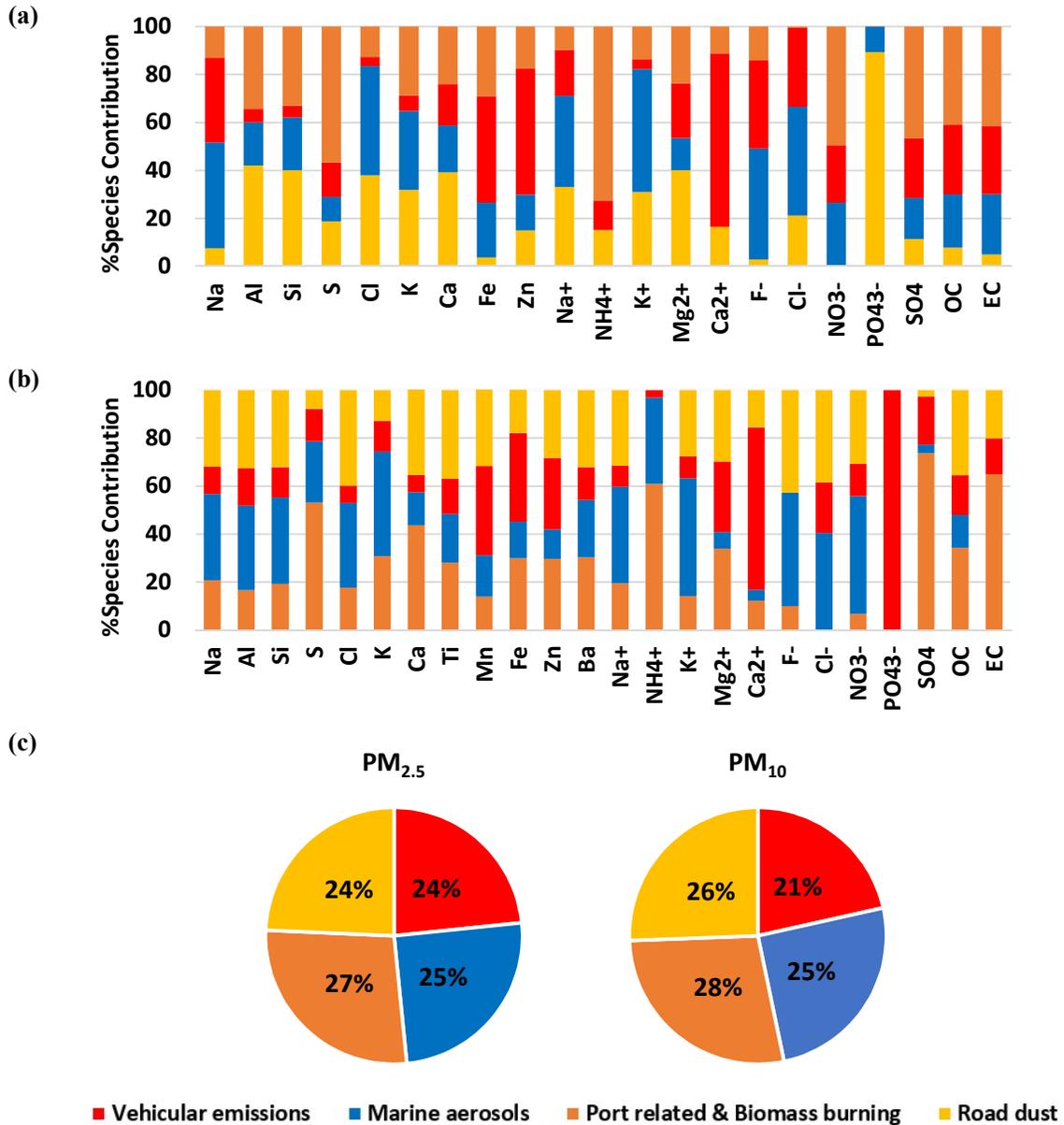


Figure 4.6: Factor Fingerprints for Goldsmith House, MPT and FBS for a) PM<sub>2.5</sub>, b) PM<sub>10</sub>, c) Percentage Contribution of Sources

#### 4.3.6.2 Cluster of Goldsmith House and MPT Guest House (S2+S3)

A combined study was carried out for 2 sampling locations: Goldsmith House and MPT Guest house for both PM<sub>10</sub> and PM<sub>2.5</sub> samples. After the EPA PMF run analysis, 4 factors were identified in the study location for both the cases. The Factor finger prints are shown in Figure 4.7(a & b).

Factor 1 was indicated by Zn, Mn, Fe, Ba (contributions ~ 7%, 12%, 14%, 7%), as major elements with some minor indicators like EC, OC and Mn which are indicators of Vehicular emission. Factor 2 was identified with indicator elements such as Na, Cl, Na<sup>+</sup> and Cl<sup>-</sup> (~7%, 8%, 7%, 8%) as major species markers along with F<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-</sup> as minor markers which indicated the source to be Marine aerosols. Factor 3 was identified with marker such as EC, S, SO<sub>4</sub><sup>2-</sup> & NH<sub>4</sub><sup>+</sup> (~6%, 10%, 9%, 12%) and minor markers like Fe, Ca, K & K<sup>+</sup> (4%, 5%, 6%, 6%) which are indicators of Port related activities and Biomass burning. Factor 4 was identified as Road dust with major markers such as Al, Si, Mg<sup>2+</sup>, Ca and PO<sub>4</sub><sup>3-</sup> (~ 6%, 6%, 6%, 7%, 18%) along with minor contributions from Na, Ga, Fe, Cr and Zn.

The source contribution for both studies is shown in Table 4.8. The major contributor for s for PM<sub>10</sub> Samples was from Port related activities and Biomass burning whereas for PM<sub>2.5</sub> samples was from Vehicular emission as shown in Figure 4.7 (c). Since the Gold smith house and MPT Guest House are within ~1Km of the vicinity of nearby Murmagaon Port as shown in Figure 2.1, port related activities influence these locations in large extent. Also, as this cargo handling and transportation is contributing to road dust and vehicular emissions. The metrology and geography of these sampling locations also has some influence on air pollution levels.

Table 0.8: Source Contribution for Goldsmith House and MPT Guest house

	Most likely source(s)	%Contribution	
		PM <sub>2.5</sub>	PM <sub>10</sub>
Factor 1	Vehicular emission	27	22.7
Factor 2	Marine aerosols	25.9	24.7
Factor 3	Port related activities and Biomass burning	26.3	28.7
Factor 4	Road dust	20.7	23.8

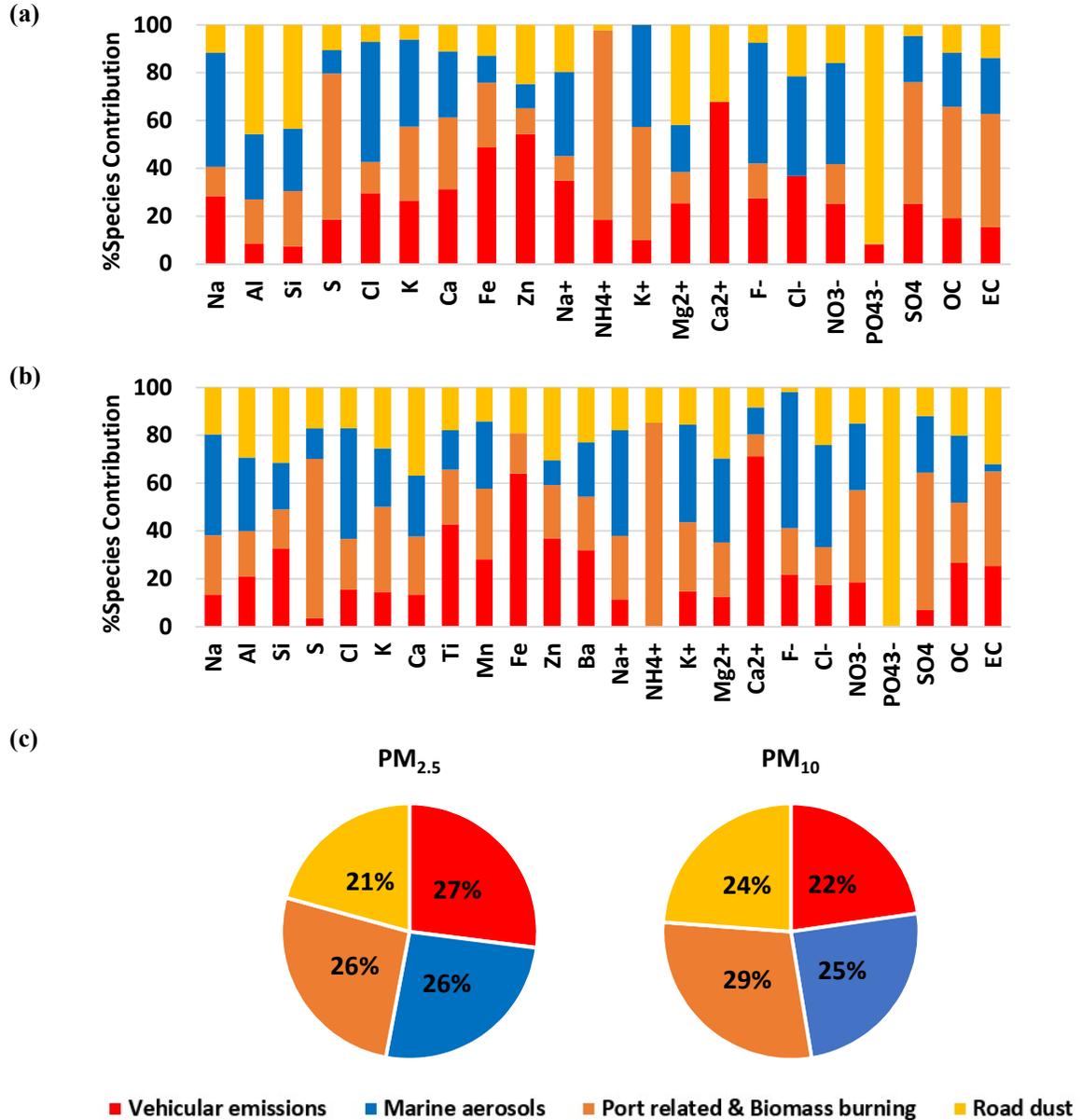


Figure 4.7: Factor Fingerprints for Goldsmith House, and MPT for a) PM<sub>2.5</sub>, b) PM<sub>10</sub>, c) Percentage Contribution of Sources

#### 4.3.6.3 Cluster of all Locations (S1+S2+S3+S4+S5) :

A combined study was carried out for 5 sampling locations: Fuse off call office, Goldsmith House, MPT Guest house, Fire Brigade Station and Khariwada for both PM<sub>10</sub> and PM<sub>2.5</sub> samples. After the EPA PMF run analysis, 4 factors were identified in the study location for both the cases. The Factor finger prints are shown in Figure 4.8(a & b).

Factor 1 was indicated by Zn, Fe, Mn, Ca<sup>2+</sup>, Mg<sup>2+</sup> (contributions ~ 8%, 10%, 11%, 16%, 8%), as major elements with some minor indicators like EC, OC and Mn which are indicators of Vehicular emission. Factor 2 was identified with indicator elements such as Na, Cl, Na<sup>+</sup> and Cl<sup>-</sup> (~7%, 8%, 7%, 8%) as major species markers along with F<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-</sup> as minor markers which indicated the source to be Marine aerosols. Factor 3 was identified with marker such as EC, Ca, S, SO<sub>4</sub><sup>2-</sup> & NH<sub>4</sub><sup>+</sup> (~9%, 8%, 14%, 15%, 19%) and minor markers like Fe, Ca, K & K<sup>+</sup> (4%, 5%, 6%, 6%) which are indicators of Port related activities and Biomass burning. Factor 4 was identified as Road dust with major markers such as Al, Si, Mg<sup>2+</sup>, Ca and PO<sub>4</sub><sup>3-</sup> (~ 8%, 8%, 8%, 15%) along with minor contributions from Na, Ga, Fe, Cr and Zn.

The source contribution for both studies is shown in Table 4.9. The major contributor for s for PM<sub>10</sub> Samples was from Port related activities and Biomass burning whereas for PM<sub>2.5</sub> samples was from marine aerosols as shown in Figure 4.8 (c).

Table 0.9: Source Contribution for All locations

	Most likely source(s)	%Contribution	
		PM <sub>2.5</sub>	PM <sub>10</sub>
Factor 1	Vehicular emission	20.5	21.4
Factor 2	Marine aerosols	29.6	23.3
Factor 3	Port related activities and Biomass burning	23.1	29
Factor 4	Road dust	26.8	26.3

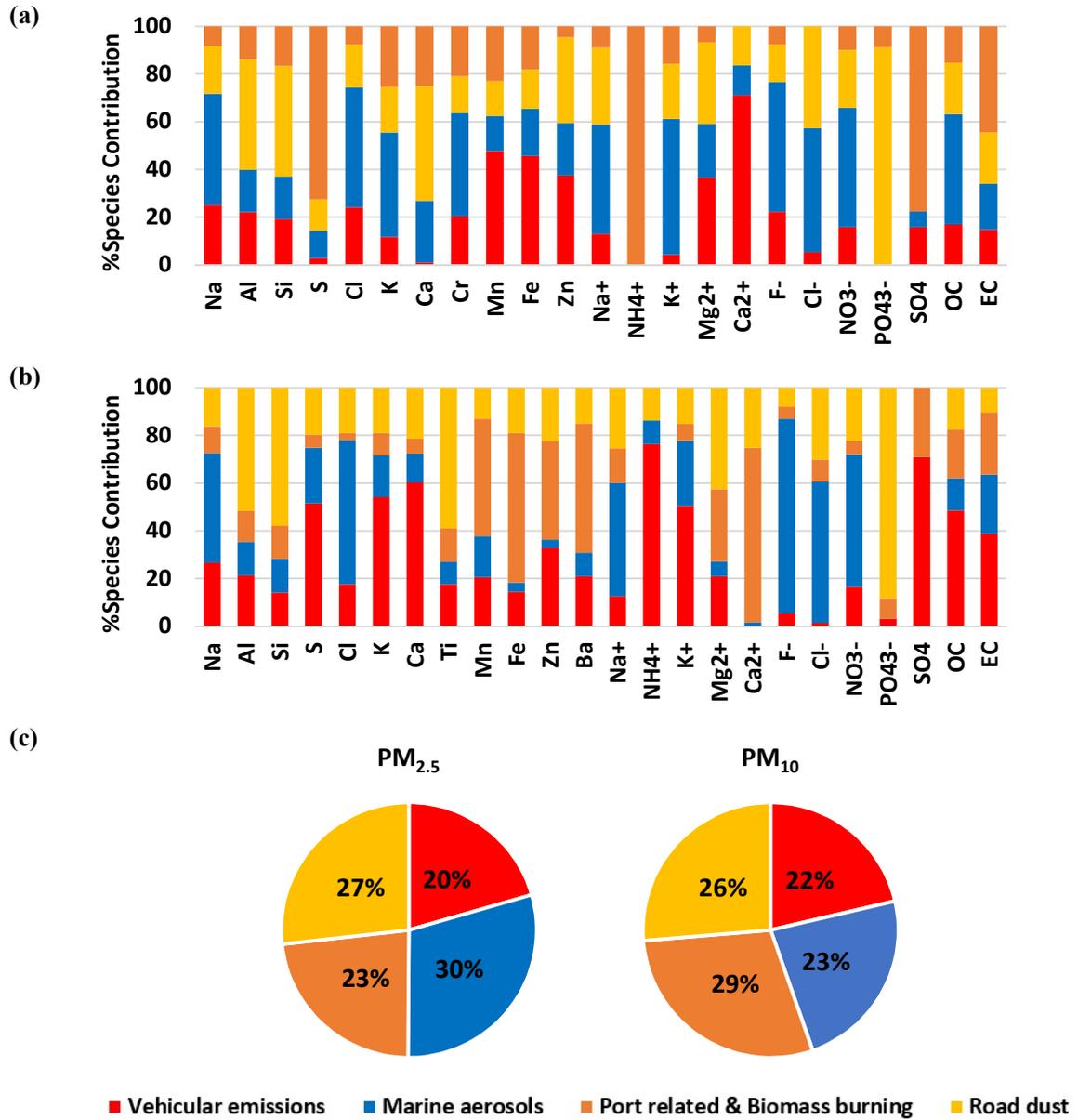


Figure 4.8: Factor Fingerprints for all locations for a) PM<sub>2.5</sub>, b) PM<sub>10</sub>, c) Percentage Contribution of Sources

#### 4.4 Summary and Conclusions for Chapter 4

Source apportionment study was carried out for representative samples collected at five locations during the sampling campaign. For source identification, 100 trial runs were carried out for all cases and best possible convergent solution from 3-7 factors was determined. These sources were also optimised based on  $Q_{\text{robust}}/Q_{\text{true}}$  ratio, Factor mapping, Correlation check, Rotational Ambiguity from Fpeak analysis and Bootstrapping error estimation methods. The factor fingerprints then obtained for most optimum runs were compared with standard factor profiles and previous studies to identify the sources (Maykut *et al.*, 2003; Zhang, 2008; Kothai, 2011; Gupta *et al.*, 2012; Goix *et al.*, 2014; Banerjee *et al.*, 2015; Habil *et al.*, 2016; Sharma *et al.*, 2016; Zhong *et al.*, 2016; Landis *et al.*, 2017; Taghvaei *et al.*, 2018, Ashrafi *et al.*, 2018).

The four factors identified from the study were Vehicular emissions, Road Dust, Port related activities and Biomass burning, and Marine aerosols. From the result of source apportionment study, it was observed that the contribution of vehicular pollution to  $PM_{2.5}$  were found to be higher than  $PM_{10}$  at all locations and it ranged from 23 – 28 %, whereas for  $PM_{10}$  it was in the range of 16 – 25%. The contribution of Marine aerosols to  $PM_{2.5}$  were also found to be higher than  $PM_{10}$  at all locations and ranged from 26 – 30 %, whereas for  $PM_{10}$  it was in the range of 22 – 29%. The contribution of Port related and Biomass burning to  $PM_{2.5}$  and  $PM_{10}$  were almost similar at all locations and ranged from 18 – 28 %. Road dust contributions were dominated by  $PM_{10}$  as compared to  $PM_{2.5}$  at all locations with the range of 25 – 28% ( $PM_{10}$ ) and 20 – 25% ( $PM_{2.5}$ ). The comparative graph for percentage of source contribution for all cases is shown in Figure 4.9.

The major source influencing air quality at Khariwada is marine aerosols as least impact of port related activities and biomass burning is observed at this site. Fuse Off Call Office is located in city center where Vehicular emissions and Road dust are major sources impacting air pollution and Port activities and Biomass burning seem to impact at a lesser extent. Goldsmith house, MPT Guest House and Fire Brigade station showed Port related activities and Biomass burning as major sources which was also further validated by cluster studies which indicated that there is larger influence of activities occurring on these locations as shown in Figure 4.10 (a & b). Also, coastal area influence is validated by Marine aerosol source can be distinctly observed at all locations along with road dust source impacting the ambient air pollution of entire study area.

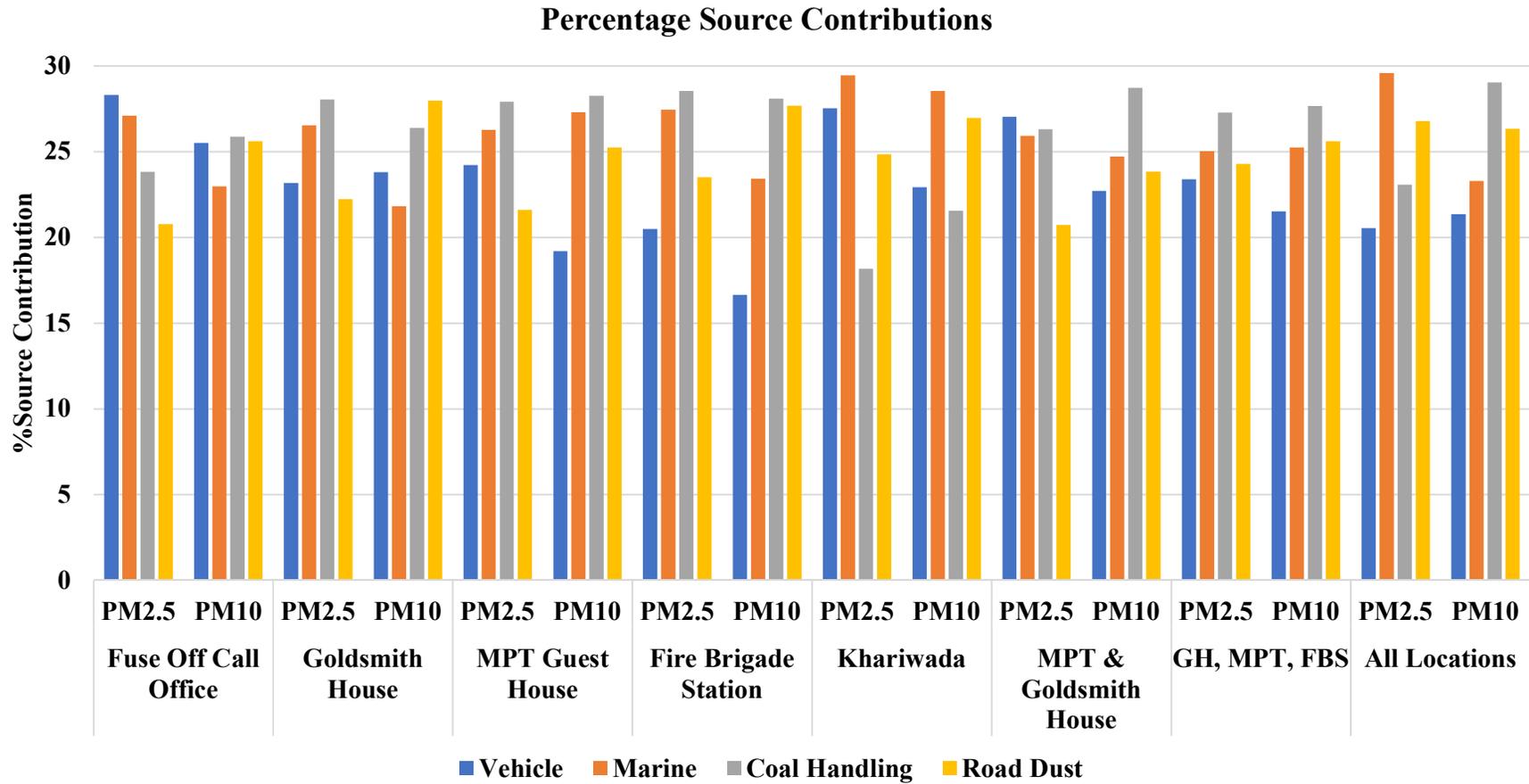
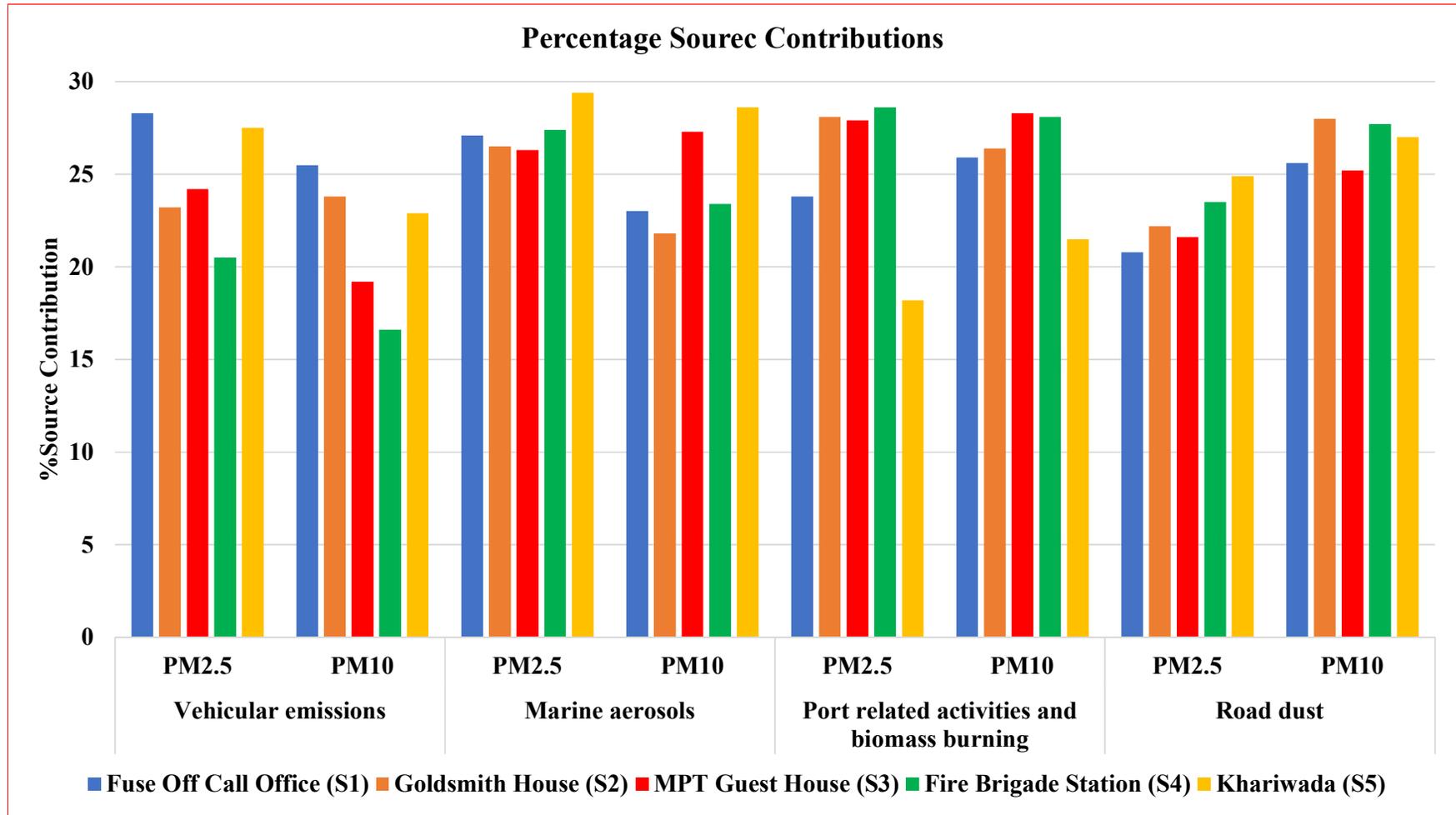


Figure 4.9: Percentage contribution of different sources for all locations

(a)



(b)

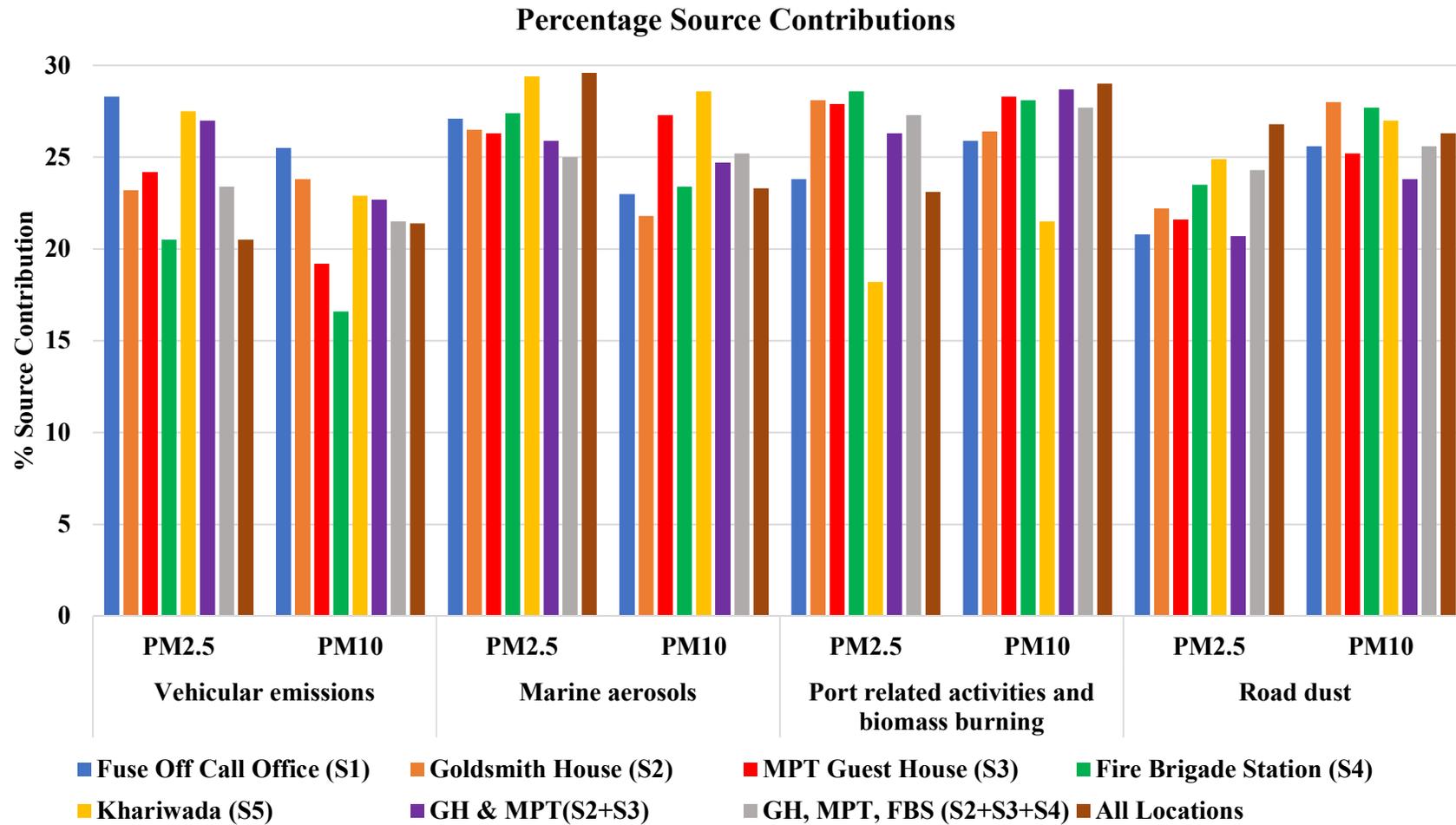


Figure 4.10: Percentage contribution of different sources a) 5 locations, b) all cases

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**URL**

URL 1: EPA PMF v5.0 Software link: <https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses>

URL 2: DRI EC-OC Manual : [https://www.epa.gov/sites/production/files/2018-10/documents/csn\\_improvea\\_model2015\\_2-231r0\\_053118\\_508comp-dri.pdf](https://www.epa.gov/sites/production/files/2018-10/documents/csn_improvea_model2015_2-231r0_053118_508comp-dri.pdf)

URL 3 : US EPA Speciates : <https://www.epa.gov/air-emissions-modeling/speciate-0>

## Chapter 5

### Summary and Conclusions

This chapter summarizes the study and presents conclusions. The focus of the work has been on gravimetric measurements for comparison of levels of particulate matter (PM<sub>10</sub>, PM<sub>2.5</sub> and TSP) relative to the proximity of the port activities (Chapter 2). The PM samples collected during the sampling campaign, were analyzed for elements, ions and EC-OC for source apportionment using PMF receptor model (Chapter 4). Influence of meteorology on the dispersion of PM from port activities was studied, based on the level of activity in the port during the sampling period, using AERMOD (Chapter 2).

The following conclusions are made from the results of the study:

1. GSPCB has been monitoring air quality in 18 locations in Goa as RSPM. Historical NAMP data from 2003-2019 for the stations in Goa indicate that the status of PM levels has been in compliance consistently with the 24-hour standard of 100 µg/m<sup>3</sup>, but not with the annual standard of 60 µg/m<sup>3</sup>(Figure 2.10(a)). The year 2011-12 is an exception to this. Further, 2015-18 the PM levels have been higher than previous years, with the Fire Brigade Station in the MPT port, Vasco da Gama (Figure 2.10(b)), indicating higher levels of RSPM compared to the other sampling locations.
2. The Fire Brigade Station has been used as a NAMP station, but is more representative of a source dominated measuring station. The PM concentration here have been consistently high. It is suggested that the station may continue to be operated as already done historically, to be able to compare the benefits of any mitigation measures undertaken for control of PM in the port area.
3. Measurements and reporting of Suspended Particulate Matter (SPM) has been discontinued as a regulatory requirement by CPCB in the NAMP efforts. PM<sub>10</sub> and PM<sub>2.5</sub> are now regulated and reported. However, given the nature of issues in and around areas where dusty materials are handled (mines, railway sidings, cargo at ports), Total Suspended Particulate (TSP) may need to be routinely monitored, and reported at a suitable frequency designed to

capture the influence of port activities. This would help build up a database to understand the influence of handling dusty cargo in the port area, and to make any appropriate recommendations for control if needed.

4. During the present study, sampling was carried out at five locations for  $PM_{10}$  and  $PM_{2.5}$  (each with Quartz and Teflon filters), five locations for TSP (Quartz and Teflon filters) and two locations using GSPCB High Volume samplers. The purpose of the gravimetric measurements was for source apportionment studies and for the relative levels of  $PM_{10}$ ,  $PM_{2.5}$  and TSP:
  - a. The  $PM_{10}$  levels both with quartz and Teflon filter samplers are higher in the Fire Brigade Station, Goldsmith House, Fuse-Off Call Office and Khariwada compared with the MPT Guest house location. A comparison of all stations was made with MPT Guest House as the baseline, and indicates that Chicalim and Mangor Hill locations are much lower in  $PM_{10}$  even when compared with MPT Guest house location (Figures 2.4 (a and b)). This indicates a level of activity in the locations with higher  $PM_{10}$  compared to the low activities areas (Chicalim and Mangor Hill).
  - b. The  $PM_{2.5}$  levels are used as a representation of combustion activities (vehicles, industries, biomass burning and solid fuel cook stoves). Vicinity to the sea can lead to significant contribution of marine salt aerosols to this fraction. A comparison was made for the  $PM_{2.5}$  measurements for all the locations, once again with MPT Guest House location as the baseline, but this time, the  $PM_{2.5}$  levels were found to be more or less independent of the location (Figures 2.5 (a and b)). This points to a background level of  $PM_{2.5}$  levels in the area based on sources such as vehicles, industries, biomass burning and solid fuel cook stoves, and not activities that are related to resuspension of dust-like fugitives. Fuse-off Call Office and Goldsmith House location indicate higher  $PM_{2.5}$  than other locations, and is likely to be contributed from the vehicular and other activities in the dense commercial activity area of the Fuse-Off Call Office, and proximity to the road for the Goldsmith House location.
  - c. The ratio of  $PM_{2.5}$  to  $PM_{10}$  is routinely used as an indicator of level of contribution of human activity (transport, cooking, industry) compared with the background crustal dust-like materials. These ratios are summarized as Figure (Figure 2.9) with MPT Guest house data as the baseline. All the locations have lower  $PM_{2.5} / PM_{10}$  ratio compared with MPT Guest house,

again, pointing to possibility of MPT Guest house receiving most of the marine salt aerosol consistently. Khariwada has as high a ratio on certain days as the MPT Guest House, but seems to be affected by other activities that lower the ratio on other days. Goldsmith House, Fuse-Off Call Office, and the Fire Brigade Station locations, all have lower ratios.

5. Elemental Carbon and Organic Carbon (EC-OC) content of PM are used routinely to differentiate between sources of air pollution especially for vehicular emissions in urban settings. In the present study, since coal handling was expected in the port activities, the EC-OC content in PM would be influenced by the proximity of the location to the port activities. Thus, EC-OC analyses were carried out for the samples at CSIR-NEERI, Nagpur.

The PM<sub>10</sub> levels at the Fire Brigade Station, Goldsmith House and the Fuse-off Call Office were already known to be higher, however, the EC-OC analyses showed that the EC content in Fire Brigades station was highest (Figure 2.11(a)). Such a location dependence was not observed for PM<sub>2.5</sub>, which indicates as common background level of PM<sub>2.5</sub> from multiple sources not specific to a location in the Vasco area.

Further, Organic Carbon (OC) is expected to be higher than EC in vehicular emissions as the fuel is petrol/diesel. However, coal has higher EC. Thus a ratio of EC to OC analysis was carried out as shown in Figures 2.11(f and g). Clearly, the EC content at the Fire Brigade Station is higher than at other locations on most days. The Goldsmith house and MPT Guest house locations are close to the port activity area, and the EC/OC ratio is observed to be higher than Khariwada and Fuse-off Call Office locations. This indicates more contribution from port activities to the location in closer proximity to the port.

The particle size influence on the EC/OC ratio is also evident when comparing EC/OC ratios for PM<sub>10</sub> and PM<sub>2.5</sub> (Figure 2.11(g)). The PM<sub>2.5</sub> samples seem to have more or less the same EC/OC ratio throughout the 21 days of sampling, at all the locations. The Fire Brigade Station and Goldsmith House locations, still show a higher ratio compared to the other three locations based on proximity.

A comparison of the EC/OC ratios for PM<sub>10</sub> and PM<sub>2.5</sub> with Fire Brigade station as the baseline show that the EC/OC ratios are highest for the Fire Brigade station, with little correlation with

the other four sites for both the size fractions (Figures 2.12 (a) and (b)). A similar exercise for the EC/OC ratio for TSP with the data at Goldsmith House as the baseline, indicates higher ratios in the Upper Jetty and Lower Jetty when compared with the distant Chicalim and Mangor Hill locations.

An attempt was made to correlate the EC/OC ratio for the different size fractions with the level of coal activities for the days of the sampling period. Figure 2.13(a) indicated the level of coal and limestone handled per day. For PM<sub>10</sub>, Fire Brigade Station has inconsistently high EC/OC ratios. The TSP levels at Upper and Lower Jetty locations are observed to increase with the level of coal activities. Chicalim and Mangor Hill locations have a weak relationship with the coal handling activities in the port. The EC/OC ratio in PM<sub>2.5</sub> has weak or no relationship with increase in coal handling activities in the port.

6. Dispersion model AERMOD was utilized to assessing the influence of meteorology, terrain and the pollution source strengths (port activities) on the ground level PM concentrations in the neighborhood of the port. The terrain of the MPT port area is complex as there is steep rise in the terrain from the sea-side as a hill. The validity of application of AERMOD to complex terrains was verified using studies reported in literature where real time data was used. AERMOD software includes the terrain data in the programme.

The source strengths for the model input was developed using emission factors from USEPA AP42 document for a) Batch operations: Clam-shell, b) Continuous operations: silos; and c) resuspension from stock piles. The sources were adapted as volume sources (area with a given height) for three distinct square shaped location of the berths. Emission factors are highly variable, and change from location to location, and characteristics of the dusty cargo (particle size, moisture content, height of release, wind conditions etc.) Thus, activity levels were estimated as a best approximation from the data provided for the 21 days of sampling duration.

Meteorology inputs for the model were taken from the MPT weather station and a portable weather station (courtesy NEERI, Nagpur) used in the present study at Khariwada location. These were compared with the MM5 meteorological dataset that was procured commercially for the Vasco region. The average of wind speeds, directions and frequency were comparable, but affected by the locations and altitudes of the weather stations. However, the present location

of the MPT weather station may not be suitable to represent the wind conditions in the port area as it is located on top of the plateau (~70 m above MSL). The local terrain is such that the influence of a hill would greatly affect the local micro-meteorology. Thus, any decisions to shut down operations in the port due to high wind conditions, requires installation of a network of weather stations at a height and vicinity that represents the conditions in the area of port operations.

Simulation were run for each month of the year (Figures 3.12 to 3.23) with a fixed highest level of activity during the 21 days of sampling period. The purpose of the simulation was to investigate the changing influence of the wind patterns on the impact on the inhabited areas in the neighborhood of the MPT port in Vasco. The monthly patterns indicated a broader seasonal variation and the months were thus clubbed as three seasons based on months of similarity of the wind conditions as a) February to May; b) June to September; and c) October to January (Figure 3.25). For a) the influence is largely toward South-East of the port, while for c) it is more South-West. During b), that also are the months of the monsoon season, the winds are away from the Vasco area.

It is to be emphasized that the sources at the port berths were the only sources considered in the simulations to understand the extent of influence of port activities.

The contribution from the port activities would increase if the quantity of cargo handled is increased. The present data is for a coal and limestone handling level of 1,17,075 MT and limestone handling of 40,431 MT respectively, and the resuspension from stockpiles in the total berth area or coal. The contribution follows an exponential decay pattern as in diffusional Gaussian plume model, further affected by the terrain. A simulation was carried out again for the two seasons of a) and c) with the source strengths doubled to those previously shown. These are shown in Figure 3.26, where the concentration scales are similar to Figure 3.25, and therefore the extent is visualized as affected over a greater distance. This indicates that as the port coal activities increase, the fractional contribution to PM concentrations would increase spatially.

7. Samples collected during the study were analyzed for the chemistry using EDXRF for elemental analyses, ion chromatography for anions and cations, and DRI method for EC-OC. These results were used as inputs for the source apportionment exercise using positive matrix

factorization (UESEPA PMF 5.0) (Chapter 4). This model predicts the factors (source profiles or fingerprints of sources), relative contributions, and uncertainties for identification of sources of ambient air pollution.

The model was run for seven cases based on sampling locations (Table 2.1) and clustering of receptors that were likely to have similar source activities. All cases indicate 4 key factors : Factor 1 (Vehicular emissions), Factor 2 (Marine aerosols), Factor 3 (Port related activities and Biomass burning), and Factor 4 (Road dust). The sources were identified based on the best possible match with known source chemical profiles as reported in literature (Chapter 4).

The results of source apportionment point to a 20-30% range of contributions from each of these four key sources. The EC-OC analyses (Chapter 2) points to the contribution of coal handling activities is seen in the form of. All other activities, whether it is the port area or the city area, are affected by vehicles, resuspended dust, biomass and solid-waste burning, and road sweeping. Further, the road dust profiles for dust collected at 15 locations in Vasco showed similarity, indicating that over decades of operations, the road dust has acquired characteristics that cannot be differentiated based on the locations (i.e. port versus other locations). Since the sources are common and distributed, source apportionment could resolve 4 key sources based on individual locations as well as clustered-location analyses. Thus, Khariwada or Fuse-off Call Office, while at a significant distant from the port area, still indicate contribution to by Factor 3 ("Port related" activities and Biomass burning). The dispersion model analysis does not support this as influence from the port activities by wind dispersion. The key contribution from the port activities was however visible in the exclusive signatures of the EC/OC ratio in the port area and the other locations based on proximity.

8. The results indicate that control measures need to be taken for port activities, open burning of biomass and solid-wastes, vehicular emissions, and road dust resuspension by vehicles and sweeping, across the Vasco da Gama area. Marine aerosols cannot be controlled as Vasco da Gama is a coastal city.
9. The influence of coal activities in the neighborhood locations of the port was observed by the characteristic high EC/OC ratio. While  $PM_{10}$  and  $PM_{2.5}$  are also higher at the locations close to the port, what distinguishes the contribution from coal specifically is the higher EC/OC ratio.

Some measures may need to be taken for preventing entrainment of fugitives from dusty cargo handling, and thereby affecting the areas in the vicinity of the source activities. These could be best practices available in the industry such as the water sprays to maintain moisture content in the stock piles (~12%), which is already in place. Screens may be designed with varying levels of pore opening, height and distance, and utilized upstream of the stockpiles to prevent the entrainment of dusty cargo as fugitive dust.

Ongoing monitoring using a network of sampling locations is essential for assessing the effectiveness of control measures at the port. In the absence of these, there is no way to establish the effectiveness or the need for additional controls. At present, only one sampling location is available at Fire Brigade Station, which is not adequate to monitor the impact of port activities in the neighborhood. The development of network of the sampling sites would necessarily requires inputs from the meteorological influence in the area (Chapter 3). As suggested earlier in this chapter, in addition to PM<sub>10</sub> and PM<sub>2.5</sub>, measurement of TSP is essential in the port area to monitor the influence of dusty cargo on air quality. Norms for fugitives by MoEFCC for coal mines may be adapted as guidelines for this effort. Monsoon season measurements may be used as the baseline for comparison with dry seasons.

10. Historical relationship of annual loads of dusty cargo were related with the annual PM pollution levels. The cargo load data were provided by MPT and the PM level data were provided by GSPCB. PM observations as a time series show that the ambient PM levels increased after the year 2012 (Figure 5.1). Thus, the period before 2012 and after 2012 were assessed separately as a correlation of (i) amount of just coal and (ii) Non-coal other dusty cargo for the periods of 2003 to 2011 and 2012 to 2018.

Since data were available for Fire Brigade Station location and Fuse-Off Call Office Locations, these were plotted as 5.2(a) and (b) respectively. In Figure 5.2(a), it becomes evident that the correlation of cargo handling activity with the PM<sub>10</sub> data at the Fire Brigade Station site is high, and indicates that the PM<sub>10</sub> levels are more sensitive to the level of coal cargo. However, the correlation with non-coal other dusty cargo is comparatively poor. This indicates that the contribution of cargo handling activity to the ambient particulate concentration is more sensitive to coal, and therefore, has a bearing on the type of dusty cargo.

Further, since the historical data for Fuse-Off Call Office location were also available, such a correlation between coal or non-coal activities at the port was attempted (Figure 5.2(b)). As per the modelling exercise in the present study, the influence of port activities at the Fuse-Off Call Office location was expected to be low. This was confirmed by a lack of any significant correlation between the PM levels and the activities (coal or non-coal other) at the port. The PM levels are much lower in this location compared to the Fire Brigade Station location, and likely to be contributed by road dust, vehicles and other such sources that are indicated in the analyses for source apportionment.

11. A comprehensive Environmental Management Plan (EMP) is recommended to re-evaluate the monitoring and control measures for the influence of duty cargo in the vicinity of the port area. The scope of this would be beyond EIA to include additional monitoring locations for TSP and PM10, real-time weather stations for fore-warning of unfavorable wind conditions, and measures to control the dust emissions. This may be carried out under the direction of GSPCB as also suggested by the Project Review Experts. Local academic agencies may be invited to collaborate in this effort for ongoing monitoring, modelling and sustained efforts to maintain air quality. Please see Appendix D at the end of Chapter 5 for suggestions towards the development of an EMP.

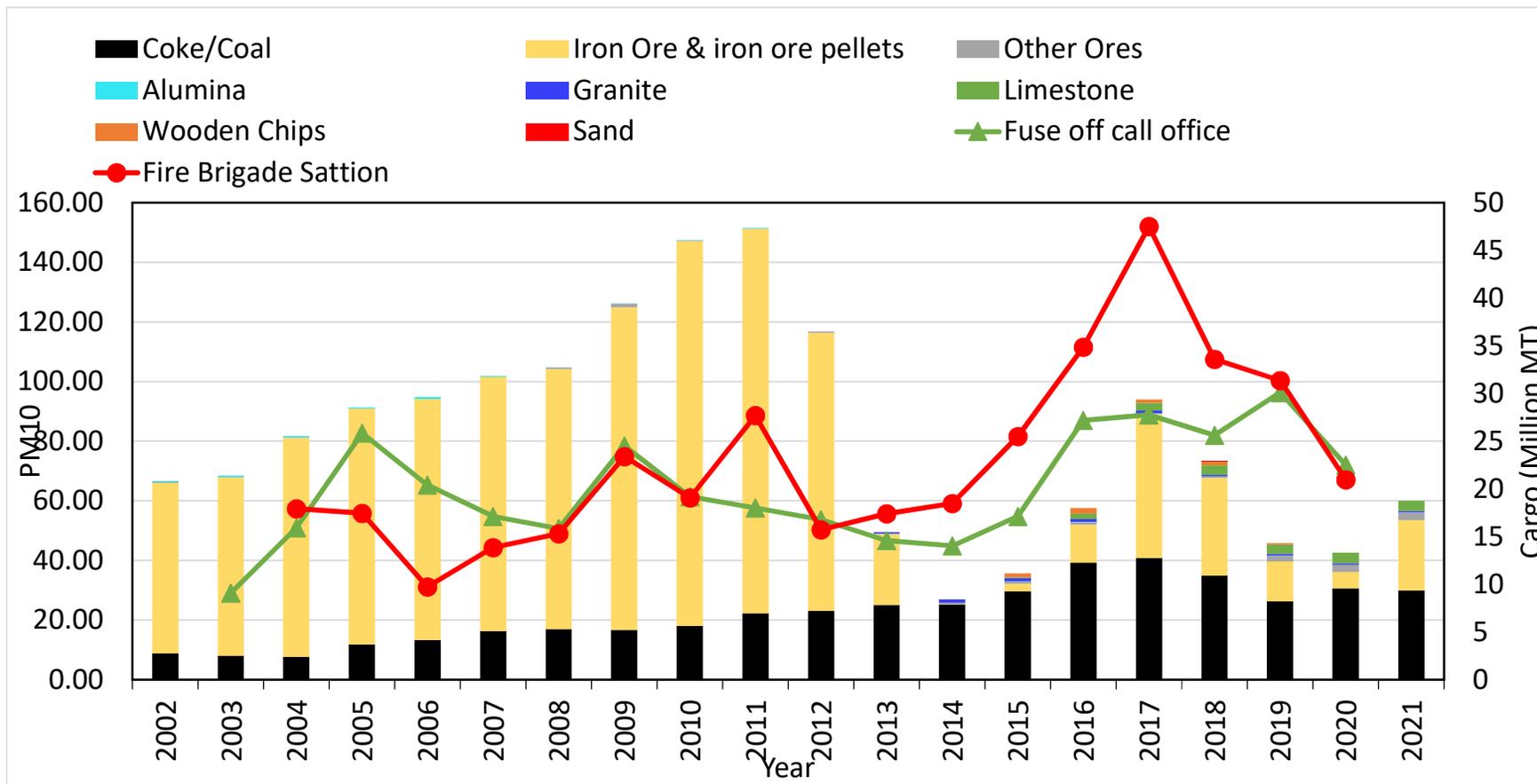
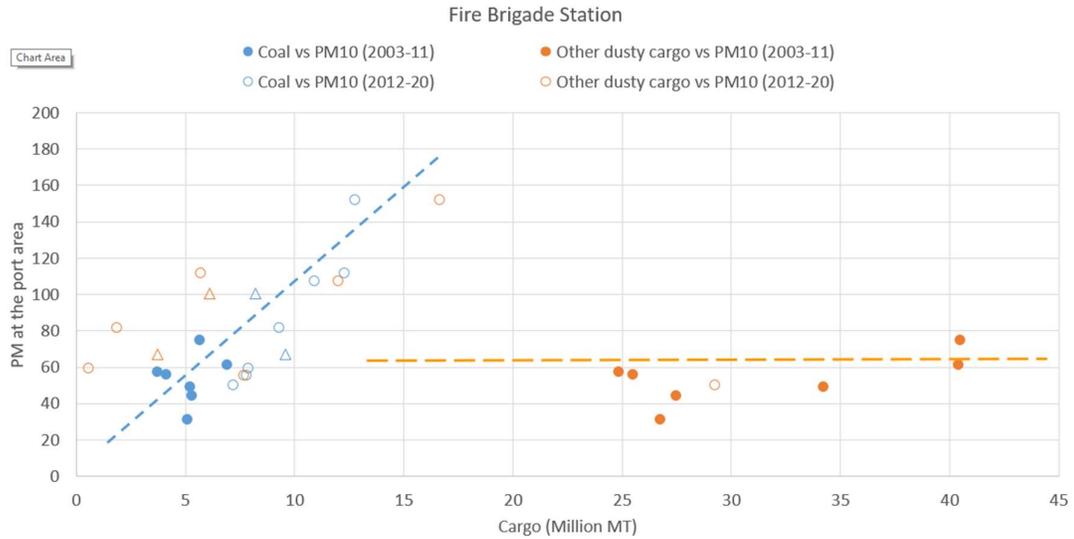


Figure 5.1 Historical data for cargo loads at MPT versus the pollution levels as PM10/RSPM

(a)



(b)

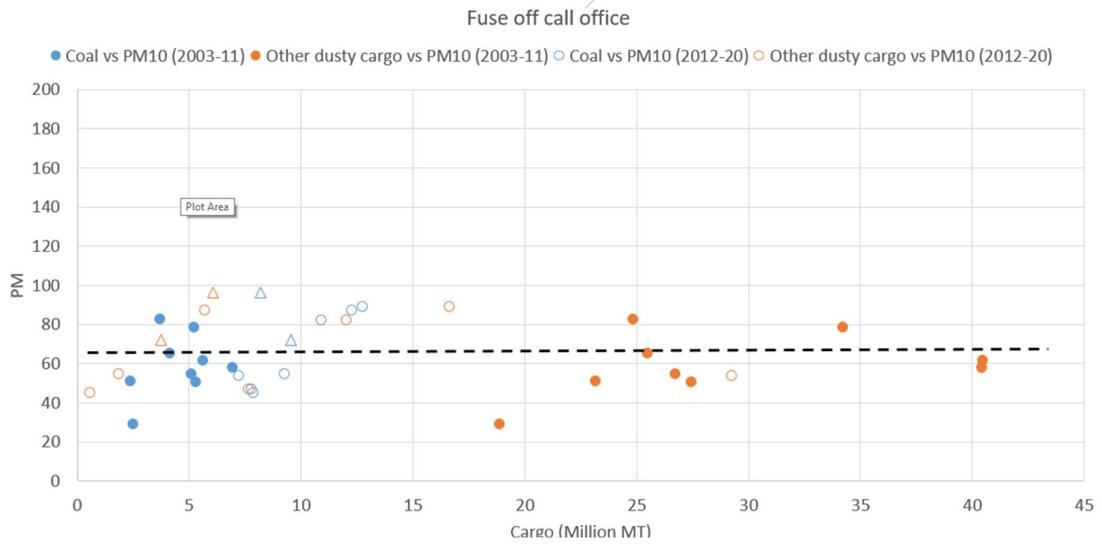


Figure 5.2 Historical data for cargo loads at MPT versus the pollution levels as PM10/RSPM at (a) Fire Brigade Station and (b) Fuse-Off Call Office locations.

## APPENDIX D

*(Based on the advice of the experts, based on the insights and findings of the present project, a set of key points are included here for consideration in the development of an Environmental Management Plan).*

### **Suggestions for Development of Environmental Management Plan (EMP) Based on insights from the present study**

#### **A. Mitigation**

1. Current practices of water sprays and covering of stock piles with impervious sheets is desirable and may require routine revisits for effective planning and revisions as needed.
2. Possible use of Wind Screens and shadow effect  
AP42 emission factor indicate that the resuspension from stock piles is higher than those due to batch or continuous drop activities for the present study area. Thus, adequate attention is also required to prevent wind erosion from stock piles. Use of wind screens has been tested and reported as a potential and effective mitigation measure (Zimmer et al., 1986).

Further, there are studies where geometry and placement of stock piles has been shown to utilise shadow effect judiciously for reduction of resuspension by wind (Cong et al., 2011).

#### **B. Management**

1. Need for monitoring wind speed and direction  
Particulate resuspension is directly proportional to the wind speed (USEPA AP 42, 2006) and direction for suspension for all operations when the wind conditions exceed a certain wind speed, are already in place by GSPCB.  
Thus, local monitoring of wind conditions is essential. The placement of the weather stations, therefore, should represent the conditions in the berth areas where the cargo handling takes place.
2. Regular monitoring and recording of cargo specifications:  
Cargo type, cargo particle size (and distribution) need to be monitored and recorded as an operational practice. This data would be useful to for deciding any cargo specific threshold wind speeds, and to study the emission characteristics for the port. The application could then be more universally shared with other ports in India.  
The plan, in addition to the water spray operations should attempt to include practices to estimate the moisture content such that the requirements for adequate suppression optimally.
3. Particulate monitoring:  
Particulate monitoring at a suitable temporal resolution is recommended. Since the influence was observed more in TSP and PM<sub>10</sub> compared to PM<sub>2.5</sub>, focus on larger particles may be appropriate. Routine QA/QC and calibration are desirable as a part of

good practices. The monitors need to be placed strategically based on seasonal wind patterns and estimate of zones of influence using a dispersion modelling exercise (Some of which has been initiated in the present work). Such data from locations outside the port area are also required to fulfil public health interests.

Record of such data could be used as a resource for future planning of expansion of activities.

#### 4. Strategic operational approach

Strong seasonal (February-May, June-September and October-January) dispersion patterns have been observed by the modelling effort for the study area. Judicious use of berth versus mooring dolphin options may be considered in the EMP.

The EMP may look more rigorously into the operations (spatial and temporal) to propose environmentally sound operational details using detailed data with dispersion modelling tools.

5. While TSP is not a regulatory requirement for ambient air quality, it was suggested that the port activities may be considered as a subset of 'industrial activities' and therefore the regulations effective for mining/railway sidings/equivalent may be considered by GSPCB (in consultation with CPCB as appropriate) towards development of the EMP.
6. Resuspended dust from vehicular movement, especially in the trucks parking areas has a significant influence on the ambient air quality. While it may appear as trivial, a simple effort towards well swept paved roads and parking area, and paving (possibly compaction as an interim measure) of open grounds can prove to be a significant effective measure. Spray of water over such areas may be considered, but only as a temporary/interim measure.
7. Attempts for green belts in and around the port area have been planned by MPT and need to be acknowledged. The EMP may consider enhancing the same but also ensure measures to prevent resuspension of particulate matter at the source. Further, expertise in the choice of tree species/grass/other vegetation may be useful.
8. The concept of an AIR QUALITY/Environmental CELL and Lab is suggested in the EMP, where, meteorological data, cargo data, movement of vessels, dispersion modelling, PM monitoring are routinely recorded and analysed to monitor the performance of the EMP. In addition, wet chemistry work for runoff water from stock piles and other open water sources may also be considered as a part of comprehensive environmental protection effort.

Internal efforts towards ambient air quality measurements as per NAAQS may be included so as to allow comparison of NAAQS data between the port area and the measurements made by GSPCB in the rest of Vasco. This is highly desirable especially if the spectrum of the types of cargo may in future expand from the presently considered dusty cargo to other kinds of cargo.

## References

1. Cong, X.C., Cao, S.Q., Chen, Z.L., Peng, S.T. and Yang, S.L., 2011. Impact of the installation scenario of porous fences on wind-blown particle emission in open coal yards. *Atmospheric Environment*, 45(30), pp.5247-5253.
2. USEPA AP 42 (2006), Fifth Edition, Volume I Chapter 13: Miscellaneous Sources, Section 13.2.5. [https://www.epa.gov/sites/default/files/2020-10/documents/13.2.5\\_industrial\\_wind\\_erosion.pdf](https://www.epa.gov/sites/default/files/2020-10/documents/13.2.5_industrial_wind_erosion.pdf)
3. Zimmer, R.A., Axetell, K. and Ponder, T.C., 1986. *Field evaluation of windscreens as a fugitive-dust control measure for material storage piles. Final report, April 1985-June 1986* (No. PB-86-231289/XAB). PEI Associates, Inc., Golden, CO (USA).

**Annexure I**

Background History of the Proposal for this Study :

- A. The proposal was originally submitted on invitation by Goa State Pollution Control Board (GSPCB). The approval was received via letter dated 25/7/2017
- B. Subsequently, based on discussions between GSPCB and MPT, copy of a letter addressed to the Chief Engineer, MPT, dated 12/10/2017 was received
- C. Letter from MPT dated 26/10/2017 was received request for invoice to carry out the study

## GOA STATE POLLUTION CONTROL BOARD

गोंय राज्य प्रदूषण नियंत्रण मंडळ

(An ISO 9001-2008 Certified Board)

Phone Nos : 91-832-2438567, 2438528  
2438563, 2438550

Tel / Fax No. : 0832-2438528



Email id's :

Member Secretary, GSPCB - ms-gspcb.goa@nic.in  
Environment Engineer, GSPCB - ee-gspcb.goa@nic.in  
Scientist, GSPCB - scientist-gspcb.goa@nic.in  
Asst. Env Engineer, GSPCB - aee-gspcb.goa@nic.in  
Asst. Law Officer, GSPCB - alo-gspcb.goa@nic.in

No. GSPCB / Job Form 7 / 1591

Dated: 23/07/2017

To,

Dr. Virendra Sethi  
MPCB Chair Professor  
Centre for Environmental Science and Engineering  
BT Hornby  
Powai, Mumbai 400 076

Sub: Source apportionment study in MPT  
Ref: Your email dated 17/05/2017

Sir,

With reference to the above cited subject this is to inform that your proposal has been accepted by the Board with additional requirements as cited by the CPCB as informed to you.

You are to revert back with your final revised proposal, your final date of initiation of the project at the earliest.

Thanking you,

Yours faithfully

  
Levison J Martins  
(Member Secretary)

c. c. to

- 1) The Chief Engineer, M/s Mormugao Port Trust, (Ministry of shipping, Government of India Administrative office, Headland Sada, Vasco-da-Gama
- 2) Office file
- 3) Guard file

**GOA STATE POLLUTION CONTROL BOARD**  
**गोंय राज्य प्रदूशन नियंत्रण मंडळ**  
 (An ISO 9001-2008 Certified Board)

Phone Nos : 91-832-2438567, 2438528  
 2438563, 2438560  
 Tel / Fax No. : 0832-2438526



Email Id's :  
 Member Secretary, GSPCB - ms-gspcb.goa@nic.in  
 Environment Engineer, GSPCB - ee-gspcb.goa@nic.in  
 Scientist, GSPCB - scientist-gspcb.goa@nic.in  
 Asst. Env. Engineer, GSPCB - aee-gspcb.goa@nic.in  
 Asst. Law Officer, GSPCB - alo-gspcb.goa@nic.in

No. GSPCB/2017/lab/13139.

12/10/2017

To,  
 The Chief Engineer,  
 The Mormugao Port Trust  
 HeadLand, Sada, Goa - 403 804

Sub: Conducting Source Apportionment Study through Indian Institute of Technology,  
 Bombay, (IITB)

Ref: 1) This office letter GSPCB/2017/lab/9776 dated 28/082017.  
 2) Your office letter No.CE/WKS-404/Source Apportionment) 2017/4380 dtd  
 05/10/2017.

Sir,

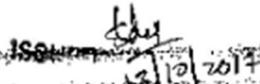
This has reference to your letter cited above, wherein you have stated that you would like Indian Institute of Technology, Bombay, (IITB) to suggest Mitigation measures in addition to the Source Study Apportionment at MPT and that you would request IITB to quote for Mitigation Measures.

In view of the above and as requested by you, you may deposit at the earliest, an amount of Rs.94.00lakhs-plus tax towards the Source Apportionment Study with IITB with additional amount for Mitigation Measures (if required).

Yours faithfully,

  
 Levison J. Martins  
 Member Secretary

C.C.TO:  
 Dr. Virendra Sethi, MPCB Chair Professor, Centre for Environmental Science and  
 Engineering, IIT Bombay, Powai, Mumbai - 400 076.

  
 12/10/2017

Dempe Towers, 1st Floor, EDC Pinto Plaza, Panaji, Goa 403 001



An ISO 9001-2008 Port  
ISPS CODE Compliant

## मुरगांव पत्तन न्यास

प्रशासनिक कार्यालय, हेडलॅण्ड, सडा, गोंय-४०३ ८०४

### MORMUGAO PORT TRUST

ADMINISTRATIVE OFFICE: HEADLAND, SADA, GOA-403 804  
Mail:mptgoa@mptgoa.com, Website: www.mptgoa.com

CE/WKS-404 (Source Apportionment)/2017/4750

26.10.2017

To,  
✓ The Professor,  
Centre for Environmental Science and Engineering,  
Indian Institute of Technology Bombay,  
Mumbai. Powai 400 076

**SPEED POST**

Kind Attention: Dr. Virendra Sethi, Professor

Sub: Conducting Source Apportionment Study for Mormugao Port Trust

- Ref: 1. Proposal on Conducting Source Apportionment Study GSPCB's letter No. GSPCB/2017/Lab/9776 dtd. 28/08/2017  
2. E.mail received from IITB dtd. 21.09.2017  
3. This office letter No. CE/WKS-404 (Source Apportionment) /2017/4380 dtd.5.10.2017  
4. GSPCB's letter No. GSPCB/2017/Lab/13139 dtd. 12/10/2017

Sir,

This is to inform you that Mormugao Port is confirming to carry out Source Apportionment Study through Indian Institute of Technology, Bombay (IITB).

As per the proposal you have submitted to Goa State Pollution Control Board (GSPCB) first instalment will be 100% on Capital Expenditure on equipment and 70% of the remaining expenditure, which amounts to Rs.69,75,000/-. It was also mentioned in the proposal that the prices stated above were excluding any taxes.

You are therefore requested to submit the invoice including rate of taxation, so as to release amount at the earliest. The rate of taxation is necessary for preparation of Work Order/Purchase Order.

Yours faithfully

(D. D. Ambe)

Executive Engineer (P&C)

c.c. : Goa State Pollution Control Board.

डेम्पो टावर्स, 1<sup>st</sup> तल.

Dempo Towers, 1<sup>st</sup> Floor,

EDC प्लाजा Patto, वजळी, गोंय. 403 001

कृपया आपले सगळे पत्राचार में हमारी फईल संदर्भ लिखे | Please quote our file reference in all your correspondence

Code: 0832	Chairman	Dy. Chairman	CVO	Secretary	CME	CE	FA & CAO	TM	DC	CMO	CISF
BSNL	2521100	2521110	2521820	2521120	2521170	2521180	2521130	2521140	2521150	2521377	2521210
EPABX	2594000	2594003	2594161	2594101	2594201	2594601	2594401	2594701	2594801	2594901	2594471
FAX	2521105	2521115	2521127	2521125	2521175	2521180	2521135	2521145	2521155	2521777	2521210

## Acknowledgements

Gratitude is expressed to MPT and GSPCB for the committed discussions and for making historical data available to be included in the assessment for this report.

Funding from MPT for this important work towards public health protection and their commitment to environmental stewardship.

All GSPCB Personnel for their kind support and assistance in making this study possible.

The homeowners at Goldsmith House, Khariwada, Upper Jetty, Lower Jetty and Mangor Hill for making their homes available to us for the sampling.

Analytical assistance from Department of Chemical Engineering for TGA, and NEERI Nagpur for EC-OC is gratefully acknowledged. The EDXRF and IC analyses were carried out at ARAI in an External Services mode.

### **Project Team**

Ms. Rasma K., PhD Student

Ms. Umangi H. Mehta, PhD Student

Ms. Swetha Pendyala, MS Graduate

Ms. Renuka Makwana, Staff

Ms. Pranalee More, Staff

Ms. Sonali Borse, Staff

Mr. Sarveshkumar Sharma, Staff

Ms. Megha Kulkarni, Staff

Mr. Vinod Bansode, Staff

Dr. Nitin Goyal

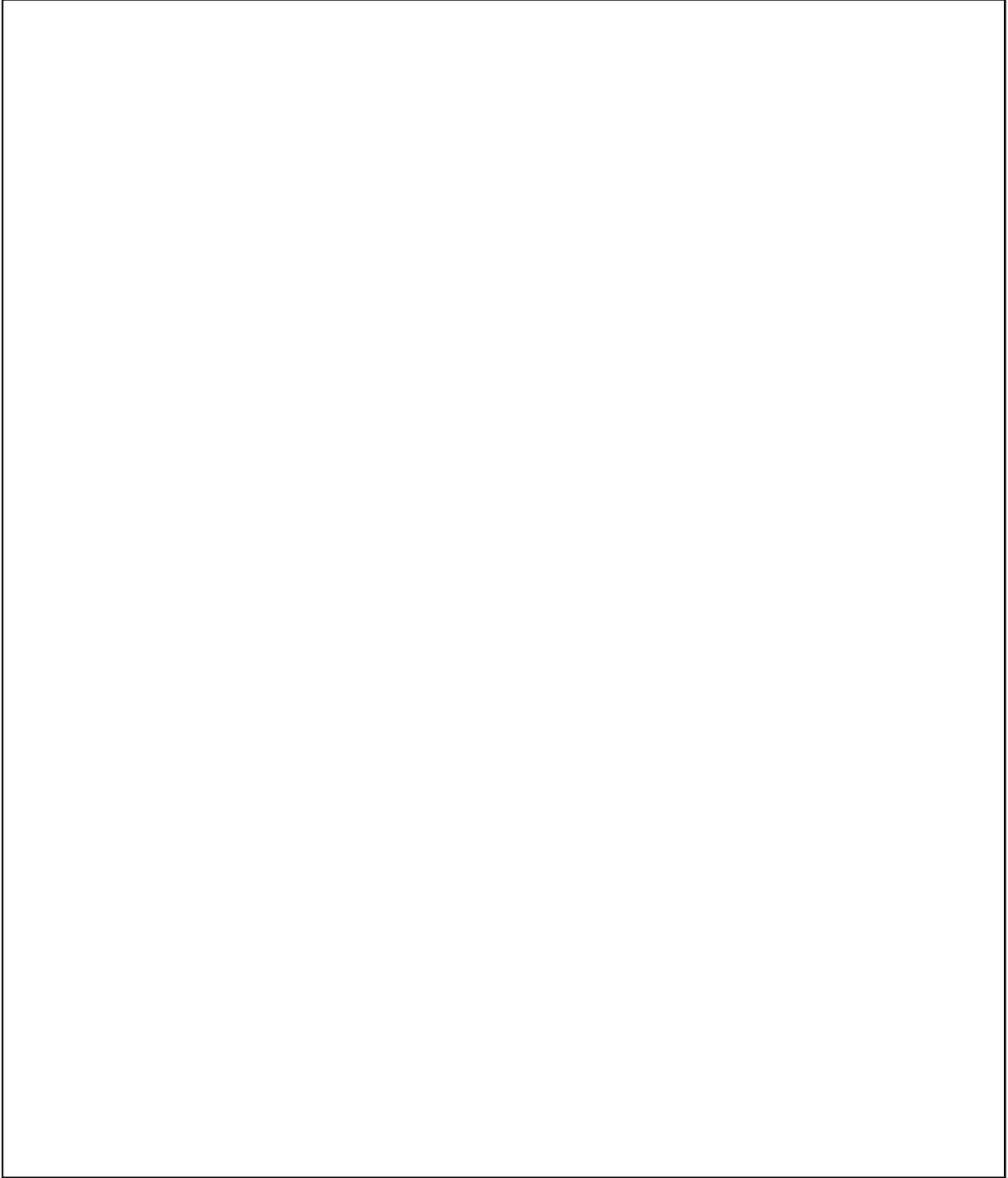
Professor Virendra Sethi

The progress of the study has been severely affected by the COVID-19 pandemic related lockdowns, and the work by staff and all personnel in the face of such hardships are gratefully acknowledged.

It is also requested, that in the light of these unprecedented circumstances, the delay in completion of the project may kindly be forgiven.

**\*\*\* END OF THE REPORT \*\*\***

**THANK YOU !**





आईएसओ 9001-2015 पत्तन  
AN ISO 9001-2015 PORT

मुरगांव पत्तन प्राधिकरण

**MORMUGAO PORT AUTHORITY**

(पत्तन, पोत परिवहन और जलमार्ग मंत्रालय, भारत सरकार)

(MINISTRY OF PORTS, SHIPPING & WATERWAYS, GOVT. OF INDIA)

प्रशासनिक कार्यालय, हेडलेण्ड . सडा, मुरगांव, गोवा. ४०३ ८०४

ADMINISTRATIVE OFFICE, HEADLAND-SADA, MORMUGAO, GOA - 4 3 804

Tel. No.: 0832-2521160 \*\*\* Email: ce@mptgoa.gov.in \*\*\* Website: www.mptgoa.gov.in

SAGARMALA

CE/Wks-404/2023/00987

Date 15/06/2023

The Member Secretary  
Goa State Pollution Control Board,  
Near Pilerne Industrial Estate,  
Opp. Saligao Seminary,  
Saligao, Bardez, Goa. 403 511

Madam,

**Sub: Environmental Management Plan (EMP) of Mormugao Port Authority**

Secretary (Environment) Govt. of Goa had directed MPA to submit Environmental Management Plan of MPA to GSPCB, during the meeting held on 18/11/2022.

Accordingly, Environmental Management Plan (EMP) for Mormugao Port has been prepared and is enclosed h/w for your perusal.

Yours Faithfully,

(Sudin Prabhudessai)

Dy. Chief Engineer

## ENVIRONMENT MANAGEMENT PLAN FOR MORMUGAO PORT AUTHORITY

### EMP FOR OPERATIONS:

1. To carry out emission monitoring from the stacks once in a year from a laboratory recognized by Ministry of Environment and Forest under the Environment Protection Act, 1986 and the result shall be submitted to this Board.
2. To take adequate measures for control of noise levels from its own sources within the premises in respect of noise.
3. To take adequate mitigation measures shall be taken to control emissions of SO<sub>2</sub>, NO<sub>x</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> within the permissible limit.
4. To ensure that the online CAAQMS system is operated continuously and always remains connected to Boards server.
5. To maintain wind breaking walls/barriers.
6. To maintain dust containment cum suppression system.
7. To maintain metallized road within the premises.
8. To carry out regular cleaning and wetting of ground within the plots to suppress dust pollution.
9. To plant fast growing trees along the periphery/compound wall of the plot to arrest dust pollution.
10. As per IIT Recommendations, to carry out dispersion modelling subject to confirmation from IIT, Mumbai.
11. As per IIT Recommendations, to install CAAQMS one in up-wind and two in down-wind direction subject to confirmation from IIT, Mumbai.
12. Continuous water sprinkling on coal/coke stacks to be carried out on the top of the heap at regular intervals to prevent dusting, fire & smoke.
13. To ensure regular sweeping of the bulk material from internal and main road and also ensure that there is space for free movement of vehicles at the surrounded area.
14. Fixed pipeline should be installed for sprinkling of water to ensure that total plot area is covered with adequate water tank of compatible storage.
15. Proper drainage system should be provided in all bulk material storage area so that water drained from sprinkling is collected at a common tank.
16. Should install flow meter to maintain record of water consumption per day.
17. Should take into consideration Best Available Technology (BAT) or Good International Industry Practices (GIIP).w.r.t Dust Management when determining air quality management techniques, generally and in specific cases, including during expansion or upgradation.
18. Coal/coke handling Units should use enclosures (detachable if required) on conveyors or chutes and telescoping arm loaders, hoppers to reduce spillage and dust; also,

minimize the distance between the working area and trucks/trains being loaded to reduce the area exposed to fugitive dust generation and area that has to be swept/cleaned free fall of material should be avoided.

19. Coal/coke handling Units should cover the cargo stock pile with an impervious tarpaulin, adequately anchored, as soon as possible after loading/unloading and adjusting the cover as material is removed from the pile thereby ensuring maximum closure of the pile and minimum exposure to existing weather conditions.
20. Coal/coke handling Units should install ship unloader hopper with fogging sprays.
21. Should periodically clean the drainage channels and properly dispose of the sediment as per applicable regulations.
22. Should use dust suppression system, vacuum collecting mobile equipment wherever practical in the handling and further prevention of dispersion of fine, granular or powdery material.
23. Should ensure the cargo dispatched by wagons should be properly covered by Tarpaulin & tied neatly in order to avoid spillage during transport.
24. The bulk material stockpile should be covered and sprinkling should be carried out when loading/unloading activity of coal is in progress.
25. Normal bulk cargo operations permitted up to a wind-speed of 28 km/hr, Precautionary measures should be in place with proportionate scaling-down Operations when the wind speed exceeds 28 km/hr and all operations should stop at a wind-speed of 30 km/hr (except June to September).
26. Each Unit shall install a strong network of weather station within the port area that represent the condition in the area of port operation.
27. Each Unit shall concretize the internal road within the port and as an immediate measures stop movement of vehicles on unpaved road.
28. Each Unit in addition to the water spray operation should attempt to include practices to estimate the moisture content such that the requirements for adequate suppression optimally.
29. Each Unit should consider enhancing the green cover and also ensure measure to prevent resuspension of particulates matter of the source. Further, expertise in the choice of tree species/grass/other vegetation's may be useful.
30. Each Unit shall segregate solid/wet waste and treat through authorized Solid Waste disposal plant.
31. Sewage generated shall be treated in Sewage Treatment Plant.

**BEST PRACTICES ADOPTED AT PPP TERMINALS AND PORT**  
**OPERATIONAL AREAS**

The Environmental protection measures taken up to maintain Ambient Air Quality in the Port operational areas , surrounding villages , Port town and Vasco city by Mormugao Port and Private terminals operated are detailed below:-

- Hopper with Dry Fog System, Fine Water Droplets in the form of mist is sprayed during unloading of coal/ coke cargo in hopper. Aquadyne system water sprinklers for dust suppression has been provided in the hoppers, yard conveyor system at all discharging/transfer points.
- The coal is being transported through covered conveyor galleries from jetty to stock yard/silo wherever feasible . Most of the conveyor galleries are closed;
- Conveyor receiving and discharge Chutes are with dry Fog System, Fine Water Droplets in the form of mist is sprayed at every transfer points;
- Cargo covered with HDPE Tarpaulin sheets in stack yard, Water sprinklers are used during Stacking & Reclaiming;
- Wagons are covered with Tarpaulin;
- Closed loop Pipe Conveyor and In-motion wagon Loading system for rake loading.
- Road Sweeping Machine deployed for removing dust in the yard, operational areas and city Roads.
- Automatic Water Sprinklers and manual sprinklers have been provided in Plots longitudinally. Water sprinklers are also used during wagon loading at SILO;
- Wind Shields/Screens are provided at the periphery made of HDPE fabric of 12 meters height, are installed.
- Green belt with suitable native species has been developed, The landscape around Port area has been planted with various types of useful trees.
- Reduction in fugitive emission by laying paved/concrete roads and retaining wall to prevent sliding of coal.
- Mist canon is provided on water tanker.
- Operational areas are concreted/paved
- Ambient Air Quality parameter monitoring through Continuous Ambient Air Quality Monitoring System (CAAQMS) installed at Bogda , Jetty and near Port Institute , Vasco .
- Automatic Truck Wheel Washing System before leaving premises

- . water tanker with 10,000 Lts capacity is utilized for sprinkling water on the roads which covers road length of 20 to 30 kms.
- Wind Speed Annemometer is installed at Berth No. 6, 7 and 10/11 with alarms signal to stop operation during wind speed above 30 Km/Hr.