International Meeting on Air Pollution in Asia –Inventories, Monitoring and Mitigation

Hanoi Club Hotel, Hanoi, Vietnam
02/01/2023 to 02/03/2023

Bottom-Up Emissions Inventory Analysis for a Typical Eastern Visayas City in the Philippines

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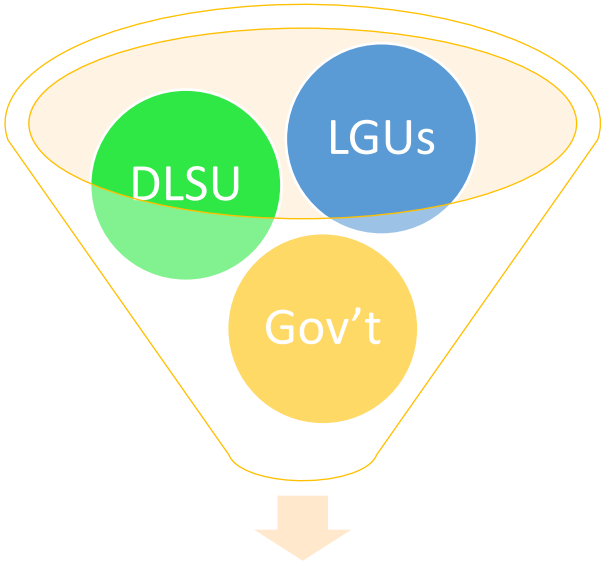


Clean Air for Future Generations

EARTH

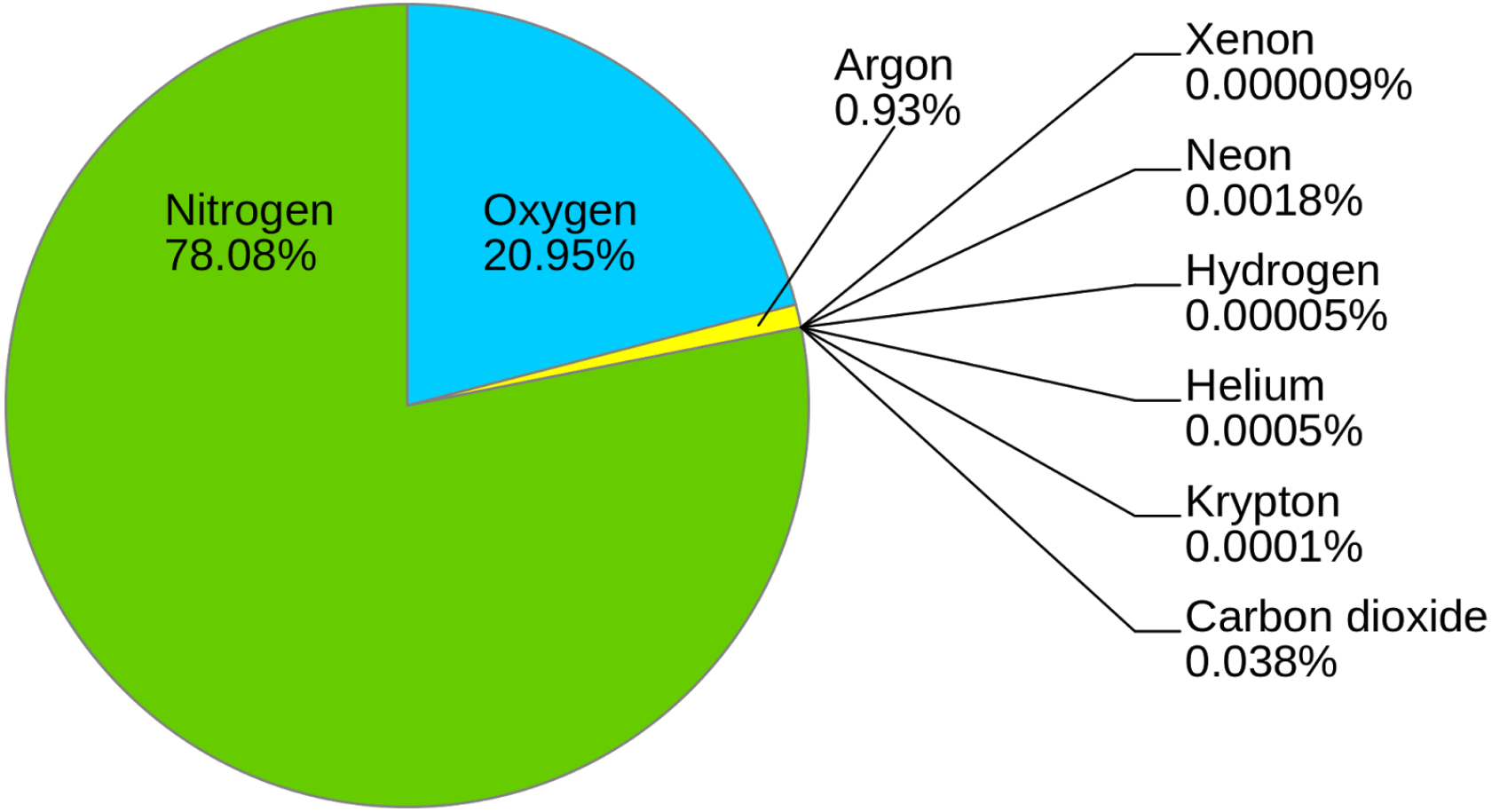
Remote Environmental Sensing Researches of the Applied Research for Community, Health and Environment Resilience and Sustainability (ARCHERS) and Environment And RemoTe sensing researcH (EARTH) Laboratory

Edgar Vallar, Ph.D.; Maria Cecilia Galvez, Ph.D.;
Ofelia Rempillo, Ph.D.; Prane Mariel Ong, Ph.D.;
Jazzie Jao, MSc

Undergraduate	Graduate	
9	MS Physics	7
	PhD Physics	2 + 1 (Chiba, Japan)

What is Clean Air?

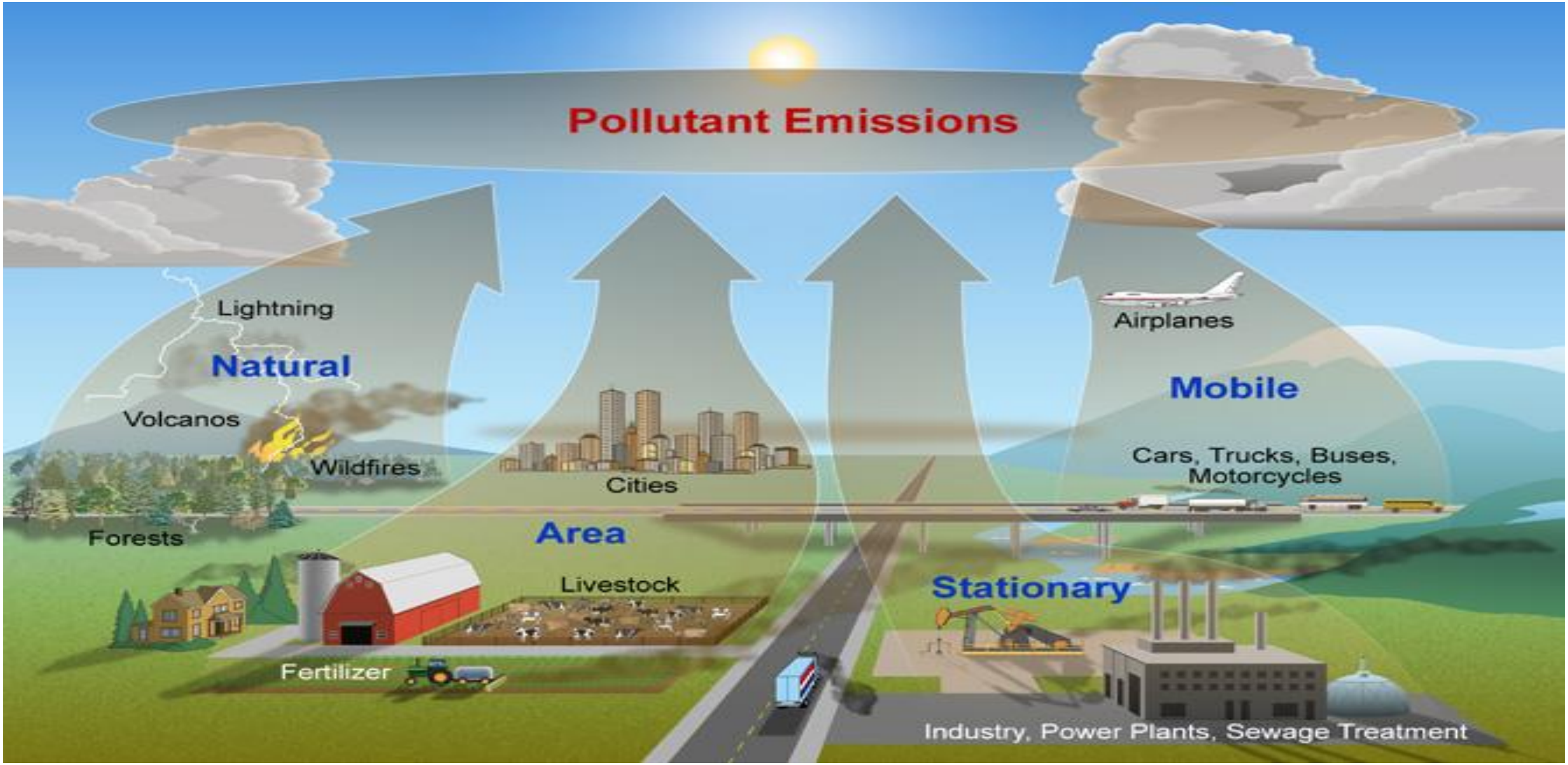
https://byjus.com/physics/air-composition-properties/



Question : What are the 2 biggest components of Clean Air?

How can we pollute the air?

https://www.nature.nps.gov/air/aqbasics/sources.cfm



Philippine National Air Quality Guideline Values (from RA8749)

Parameter	Averaging Time	NAAQGV(µg/NCM)
TSP	Annual	90
	24-hour	230
PM_{10}	Annual	60
	24-hour	150
$PM_{2.5}$	Annual	35 (Until 31 Dec, 2015), 25 (By 1 January, 2016)
	24-hour	75 (Until 31 Dec, 2015), 50 (By 1 January, 2016)
Sulfur Dioxide (SO_2)	Annual	80
	24-hour	180
Nitrogen Dioxide (NO_2)	Annual	-
	1-hour	-
	24-hour	150
Ozone (O_3)	8-hour	60
	1-hour	140
Carbon Monoxide (CO)	8-hour	10
	1-hour	35
Lead (Pb)	annual	1
	3 months	1.5

EI Development Approaches

- "Top-down" approach: typically used when local data are not available, the cost to gather local information is prohibitive
- "Bottom-up": when source specific activity or emission data are available and this approach produce more accurate estimates than a top-down approach

Emission Sources

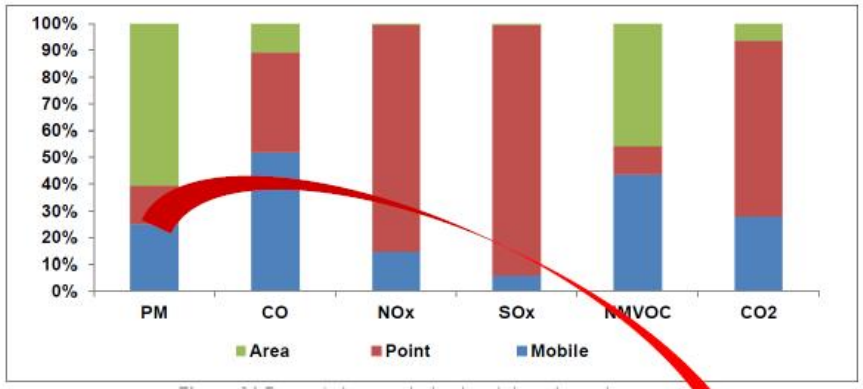
Point/Stationary Source

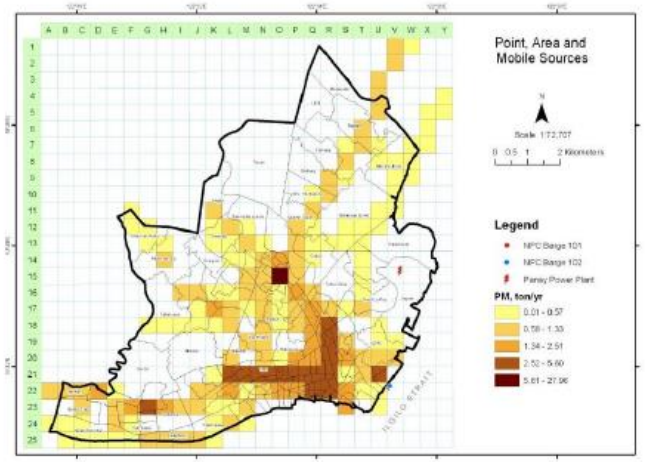
Area Source

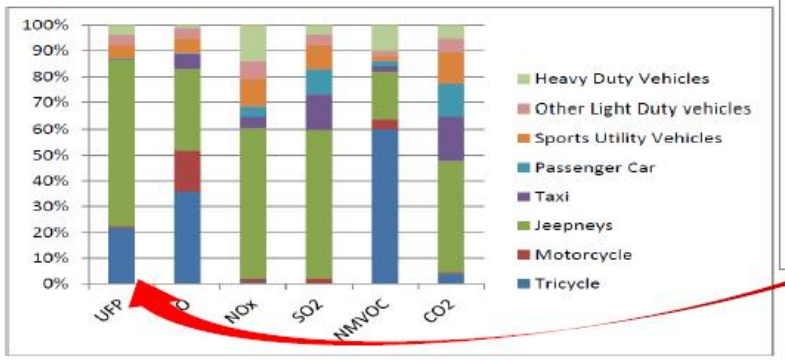
On-road Mobile Source

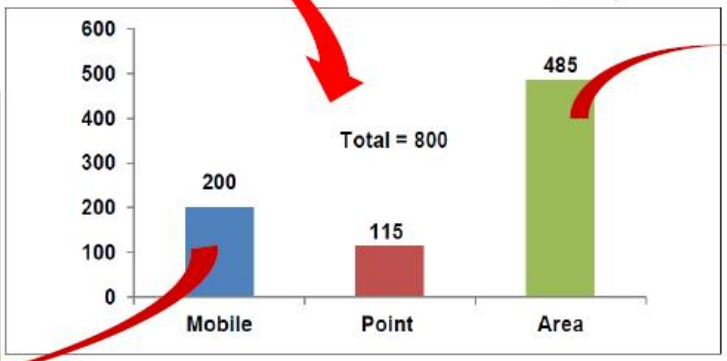
Non-road Mobile Source

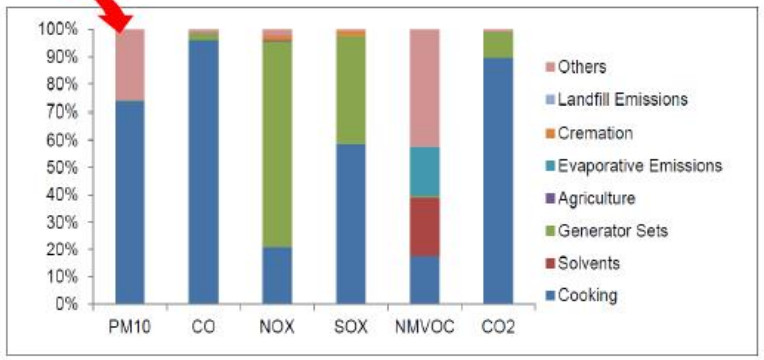
Bottom-up Emission Inventory











E= EF x AD x (100-CE)/100

E: Emission Load

EF: Emission Factor

AD: Activity Data

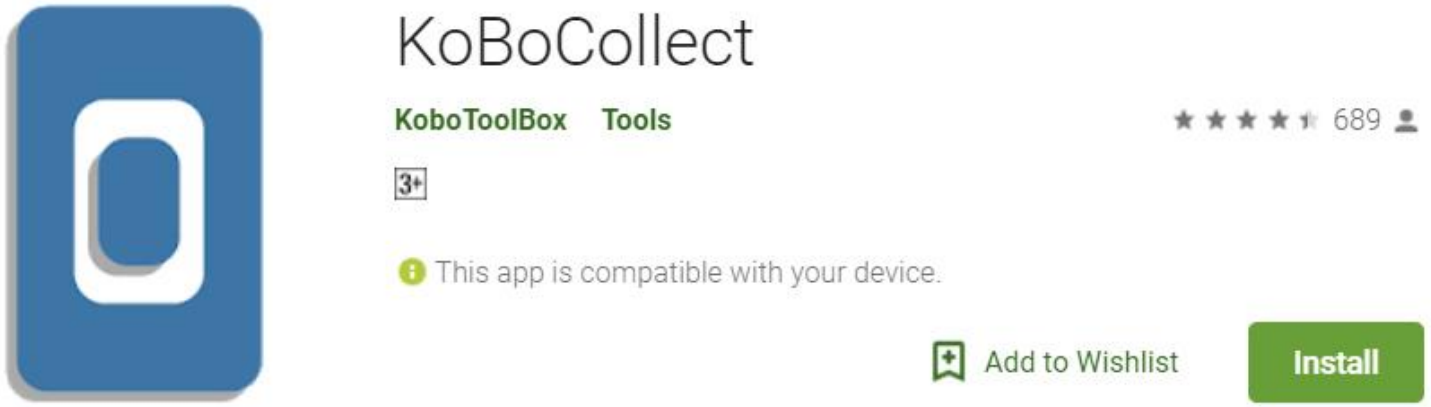
CE: Control Efficiency

For AREA Sources (Households, etc)

FOR ANDROID USERS

STEP 1:

Download KoBoCollect



Android devices:

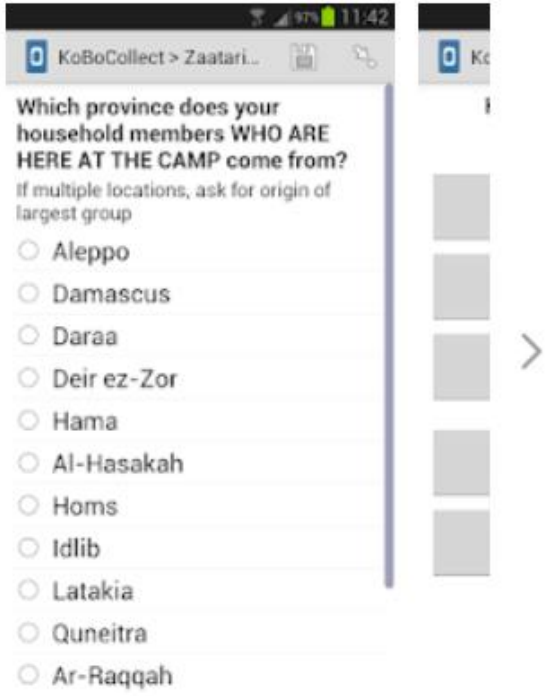
Google Play -> Search

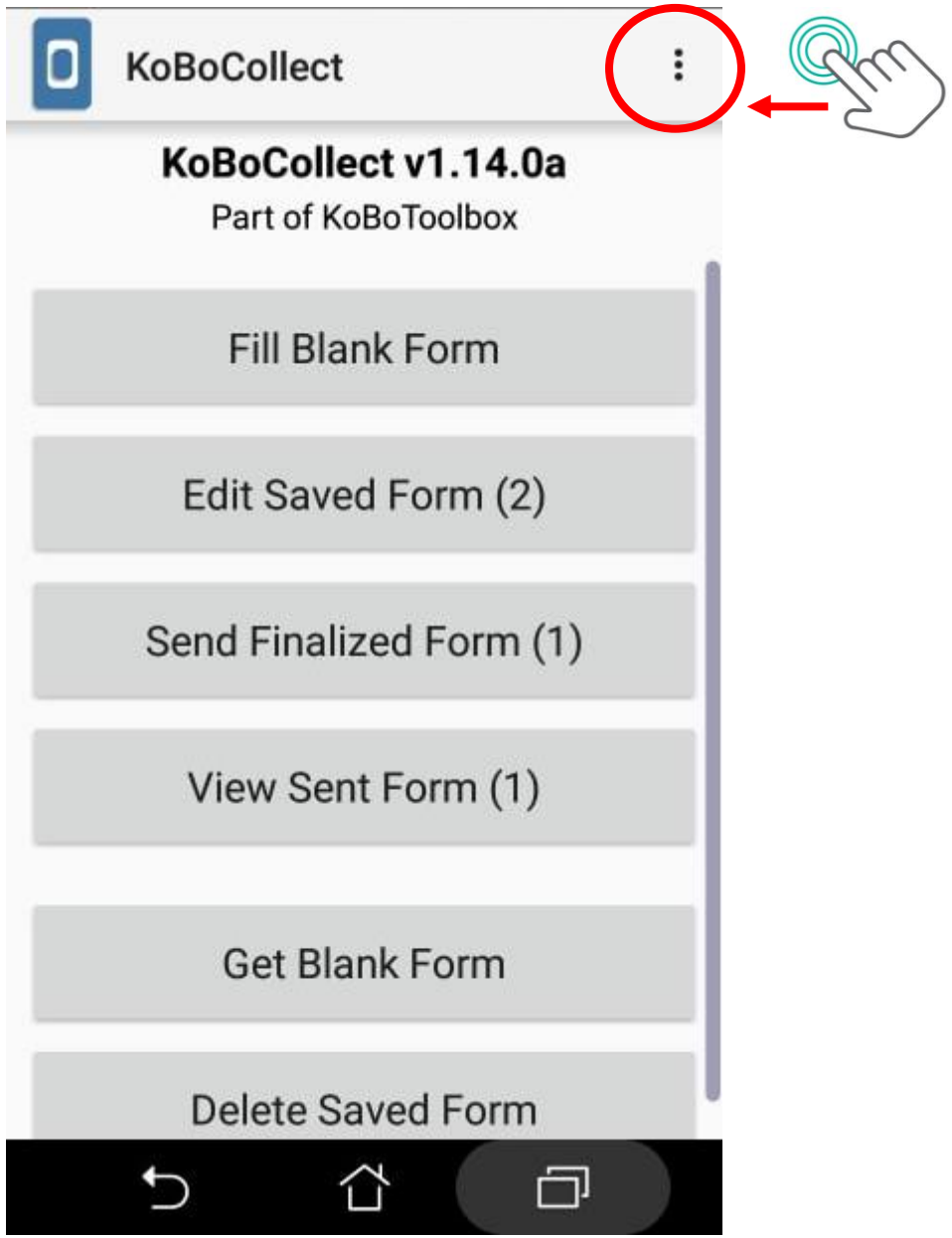
"KoBoCollect" -> download

Apple devices:

Web browser ->

bit.ly/EI_Survey




KoBoCollect
KoBoCollect v1.14.0a
Part of KoBoToolbox
Fill Blank Form
Edit Saved Form (2)
Send Finalized Form (1)
View Sent Form (1)
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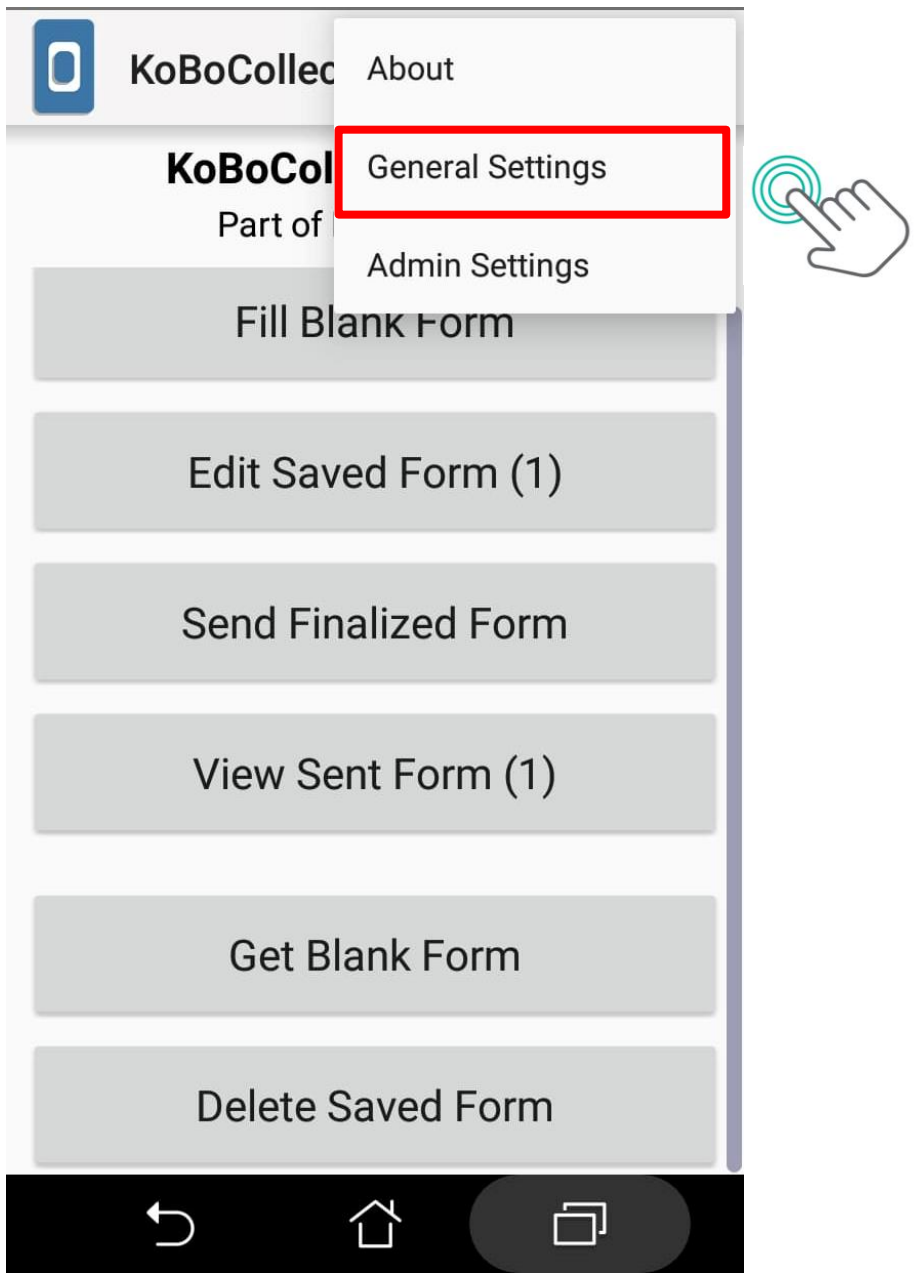
Delete Saved Form


About
General Settings
Admin Settings
Fill Blank Form
Edit Saved Form (1)
Send Finalized Form
View Sent Form (1)
Get Blank Form
Delete Saved Form

ON-Road Mobile = 24 hours on-site vehicle classification and counting

Roads selected – M, W, Sat, Sun;
2 weeks in January and 2 weeks in February; 1 Expressway; 2 of Primary; 3 of Secondary; 3 of Tertiary; 1 LGU

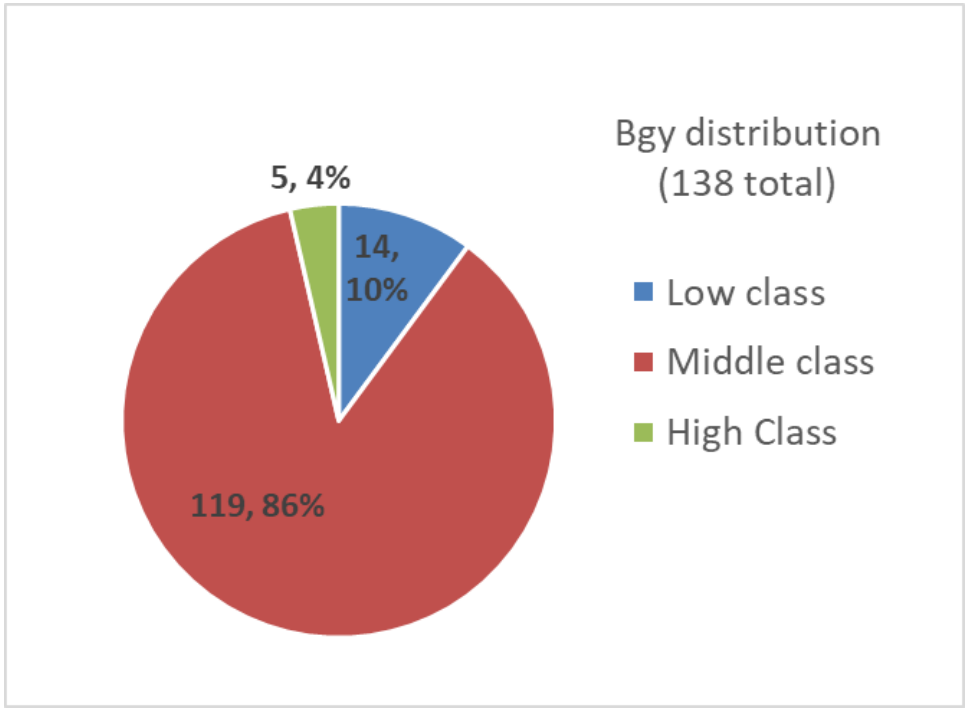
Expressway **1:**	**Primary** **1.** **2.**	**Secondary** **1.** **2.** **3.**
Tertiary 1. 2. 3.	LGU maintained 1.	

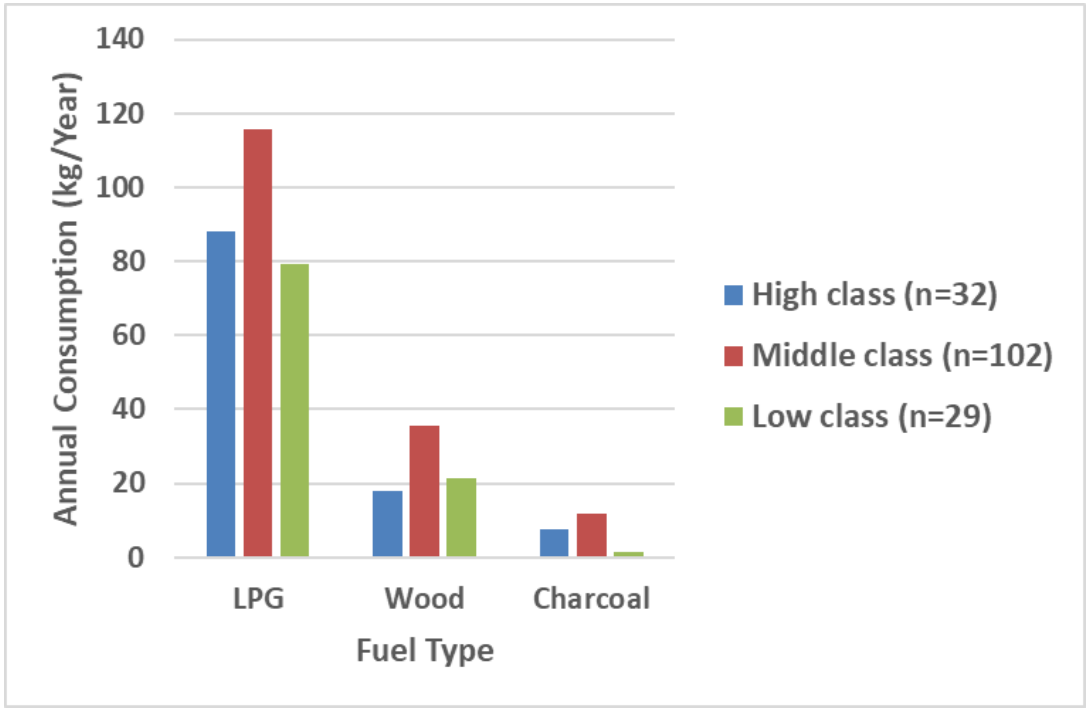
Major Roads in Tacloban City

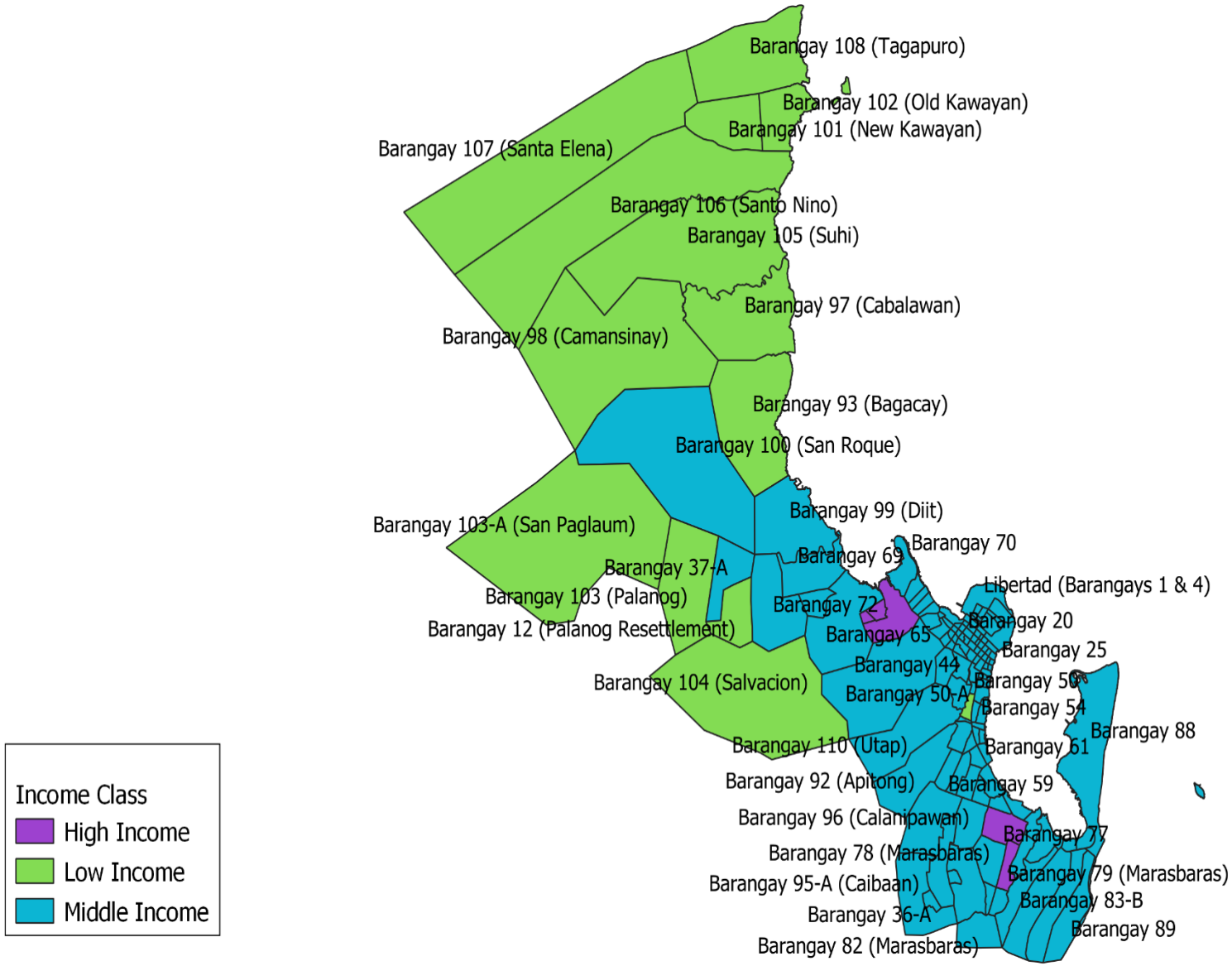
Table 3 Selected major roads by DENR-EMB Tacloban

Name	Number of Road Lanes	Number of Traffic Ways	Location	Road Length in meters
Zamora Street	2	1	Downtown	848.8569
Burgos Street	2	1	Downtown	840.1334
Avenida-Veteranos Street	2	1	Downtown	859.3735
Real Street	2	2	Downtown/PRS	3650.023
Anibong Road	2	2	AQM High	2251.112
Quezon Avenue	2	2	AQM High	1350.85
Congressman Mate Avenue	2	2	Downtown	1681.885
AH26 - Maharlika Highway	2	2	AQM High	4538.849
Pajara Road	2	2	PRS Roads	1805.511
San Jose Road	2	2	PRS Roads	4079.458
Rizal	2	1	Downtown	445.3141

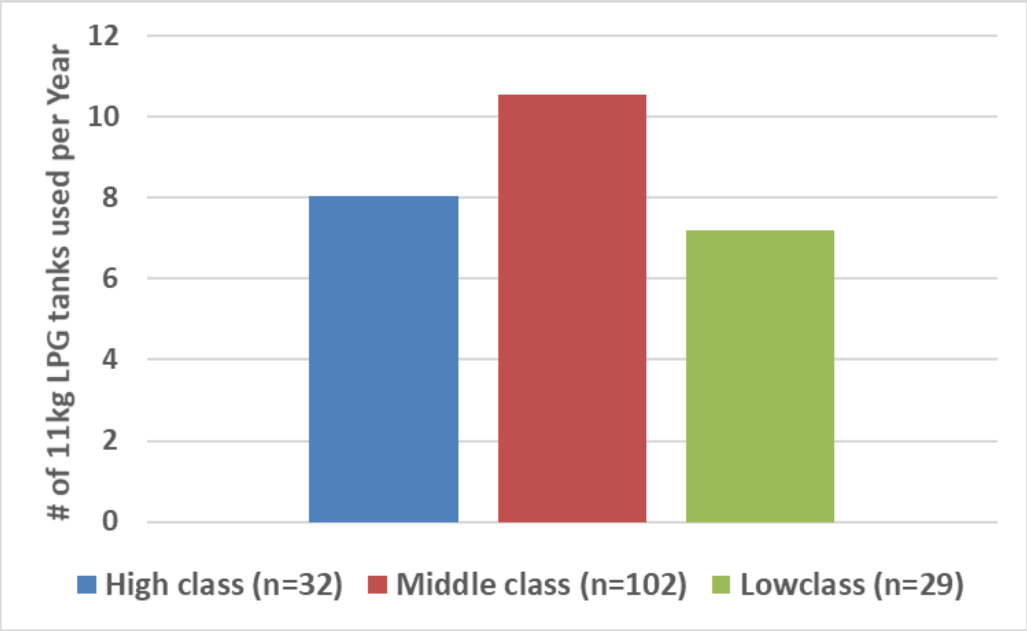
Household Emissions Results

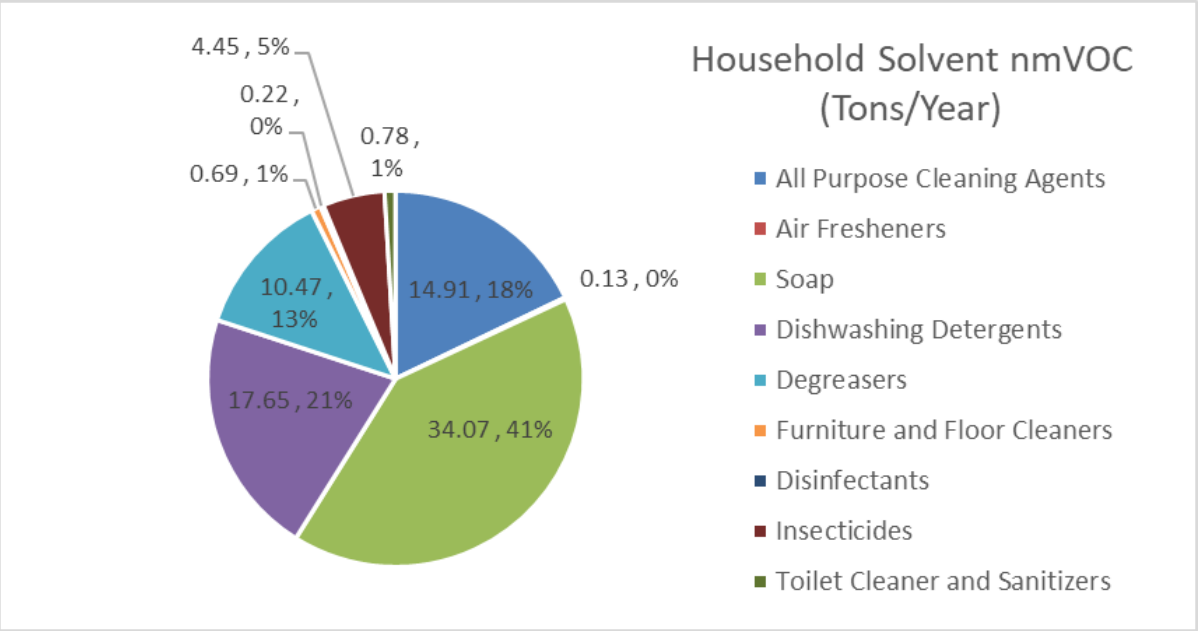




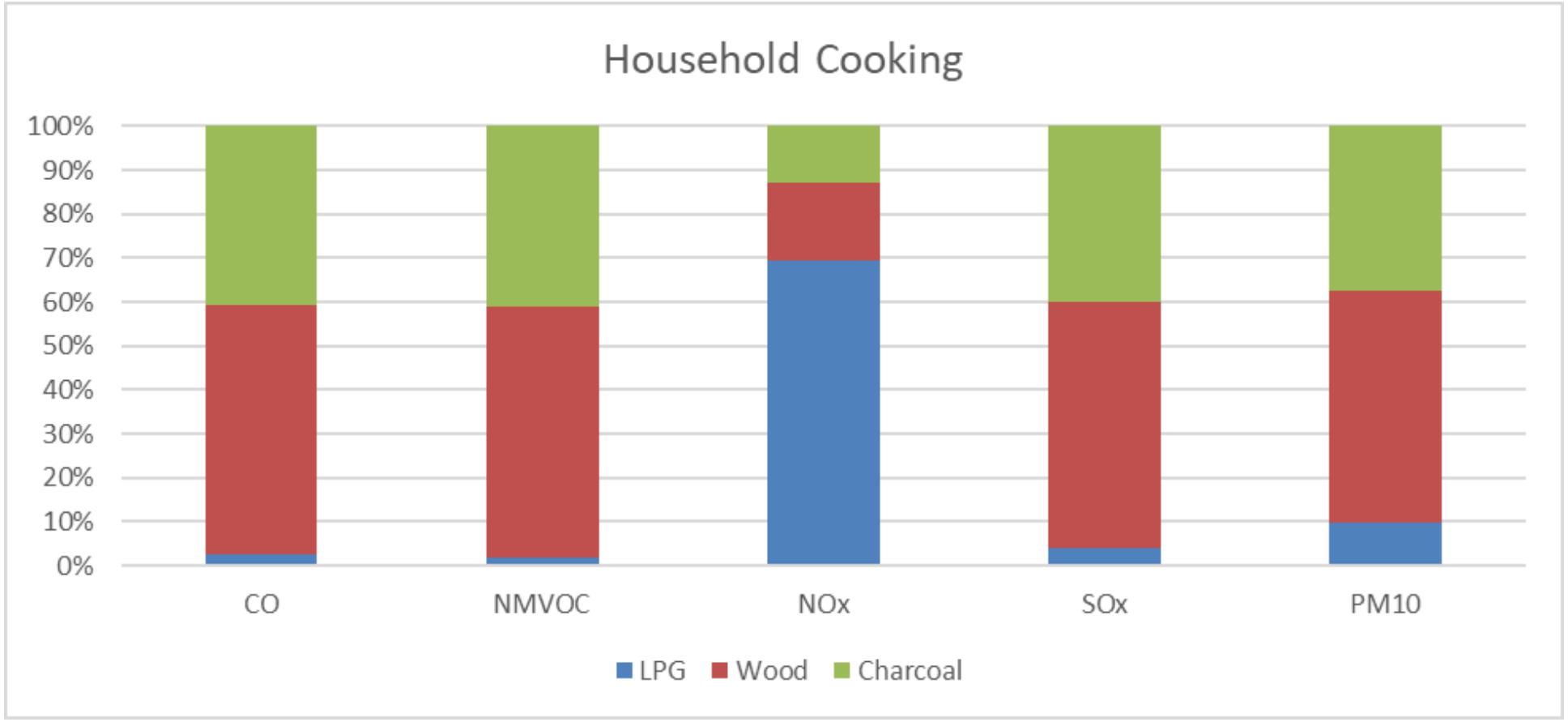

Barangay 108 (Tagapuro)
Barangay 102 (Old Kawayan)
Barangay 101 (New Kawayan)
Barangay 107 (Santa Elena)
Barangay 106 (Santo Nino)
Barangay 105 (Suhi)
Barangay 97 (Cabalawan)
Barangay 98 (Camansinay)
Barangay 93 (Bagacay)
Barangay 100 (San Roque)
Barangay 99 (Diit)
Barangay 103-A (San Paglaum)
Barangay 69
Barangay 70
Barangay 37-A
Libertad (Barangays 1 & 4)
Barangay 103 (Palanog)
Barangay 72
Barangay 20
Barangay 12 (Palanog Resettlement)
Barangay 65
Barangay 25
Barangay 44
Barangay 104 (Salvacion)
Barangay 50
Barangay 50-A
Barangay 54
Barangay 88
Barangay 110 (Utap)
Barangay 61
Barangay 92 (Apitong)
Barangay 59
Barangay 96 (Calanipawan)
Barangay 77
Barangay 78 (Marasbaras)
Barangay 95-A (Caibaan)
Barangay 79 (Marasbaras)
Barangay 83-B
Barangay 36-A
Barangay 89
Barangay 82 (Marasbaras)
Income Class
High Income
Low Income
Middle Income

Household Emissions Results





Household Emissions Results



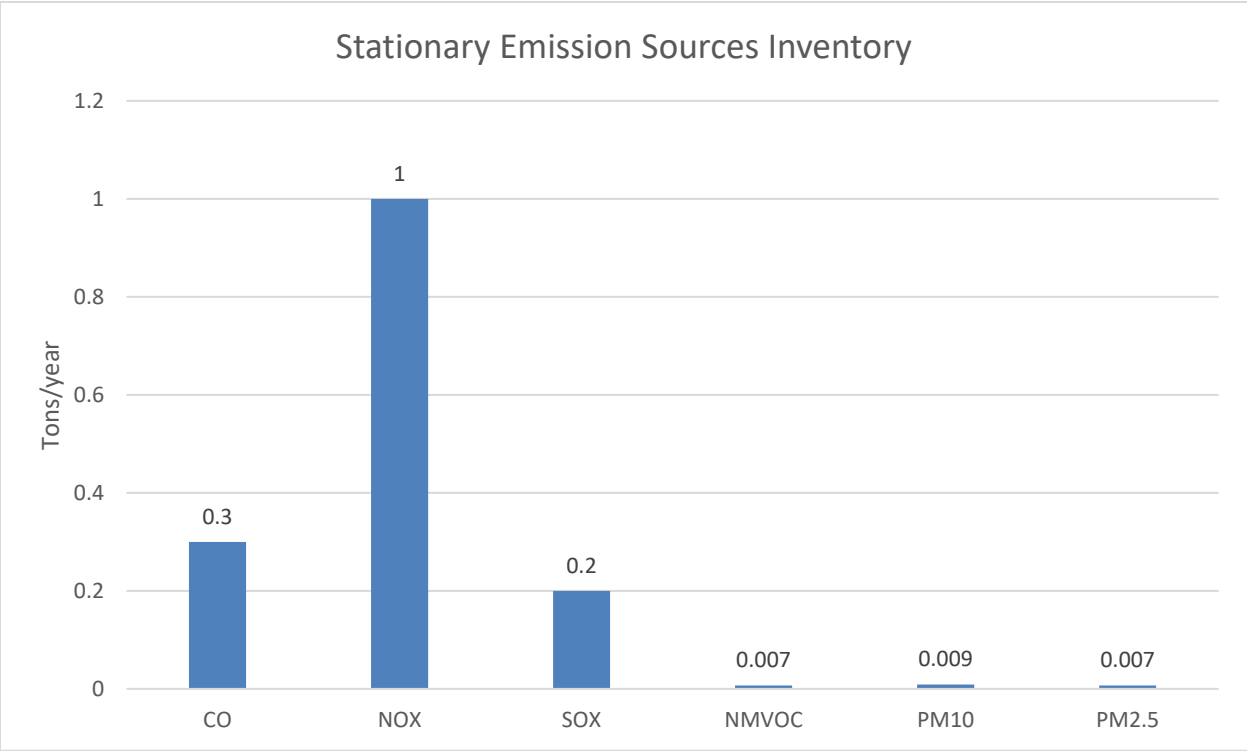
The attached EI Report provides the plots needed for the 2019 Emission Inventory. Below are the geographical distribution of these emissions. Please note that all the data presented is for the Tacloban Airshed only.

I. STATIONARY SOURCE

a. Total Mass Emission Expressed in Tons/year

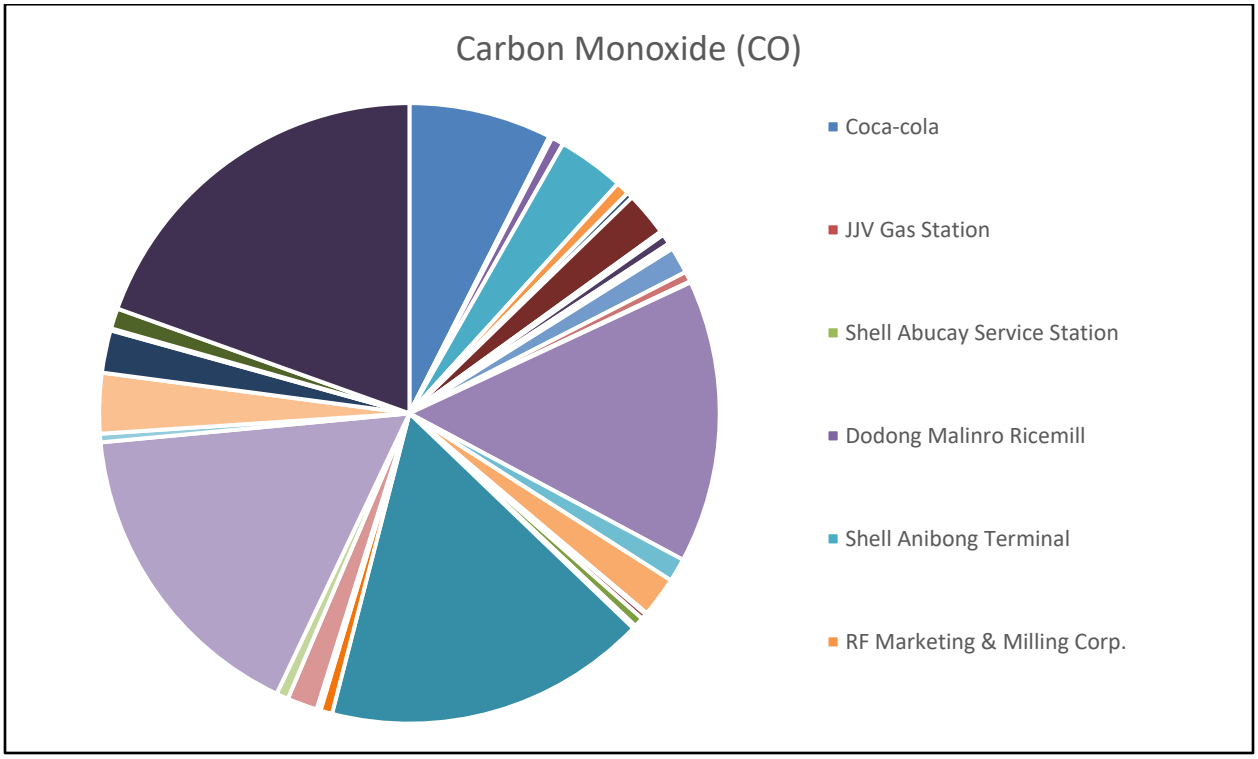
CO	NOx	SOx	NMVOC	PM10	PM2.5
0.3	1	0.2	0.007	0.009	0.007

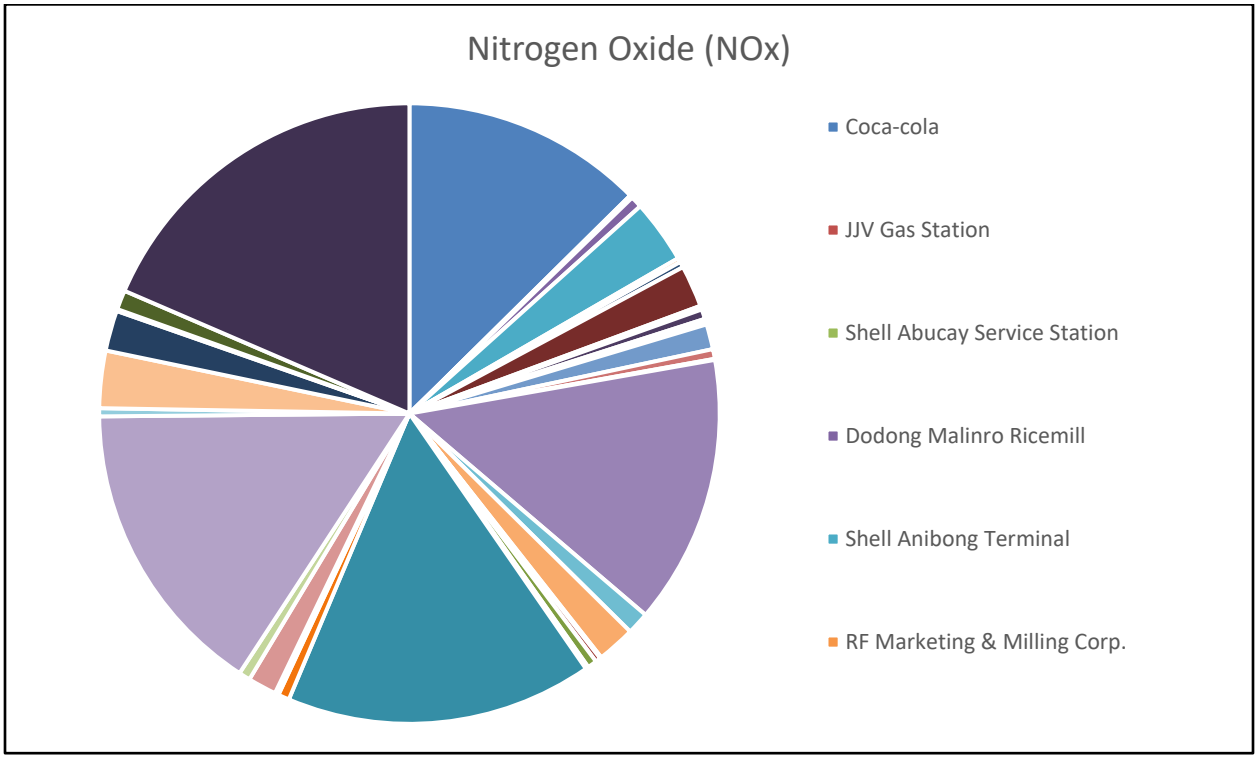
b. Graphical presentation of the Total Emission (Tons/year) in Bar Chart

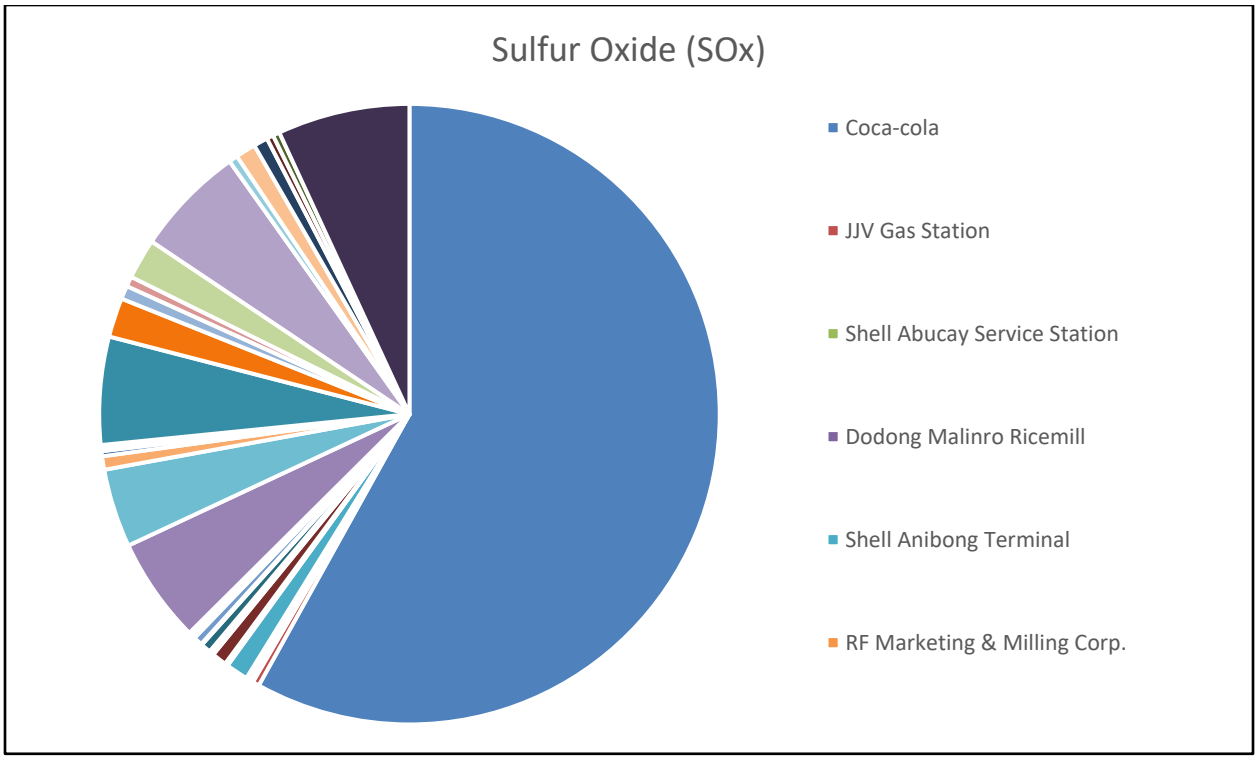


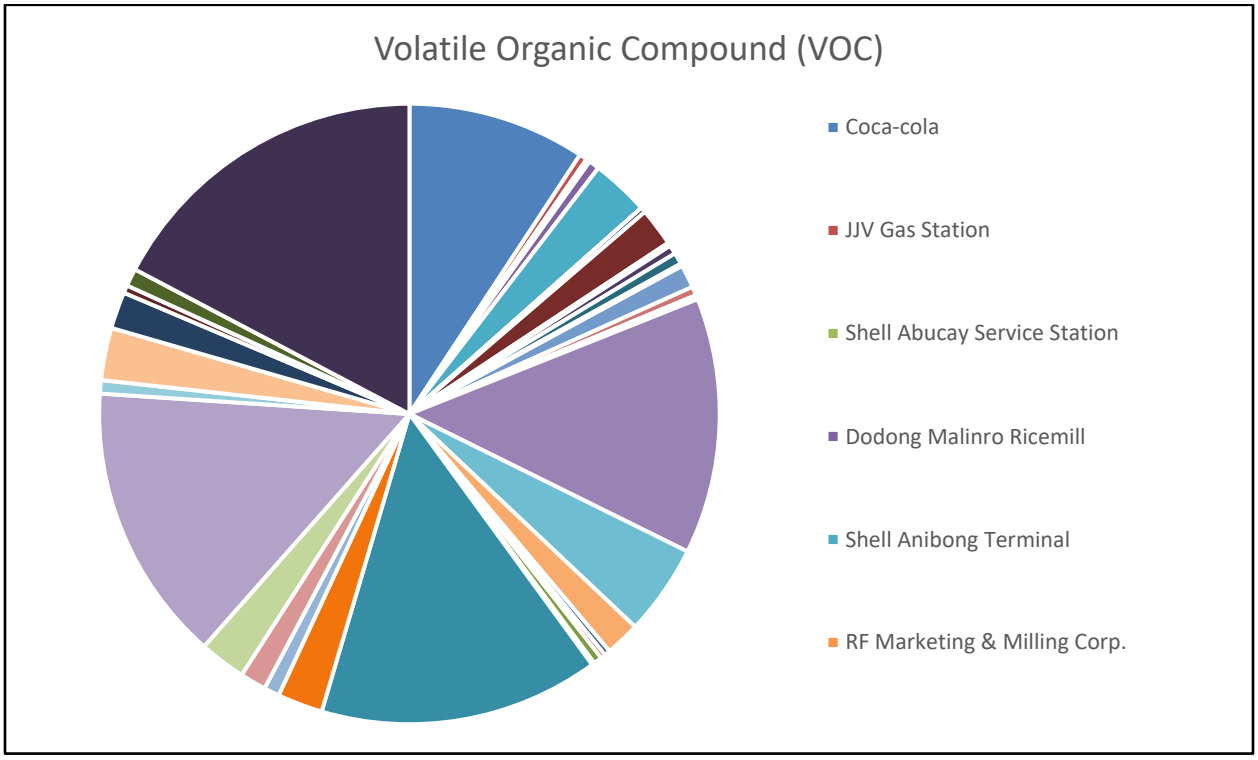
c. Classification of Stationary Sources in Pie Chart according to the following:

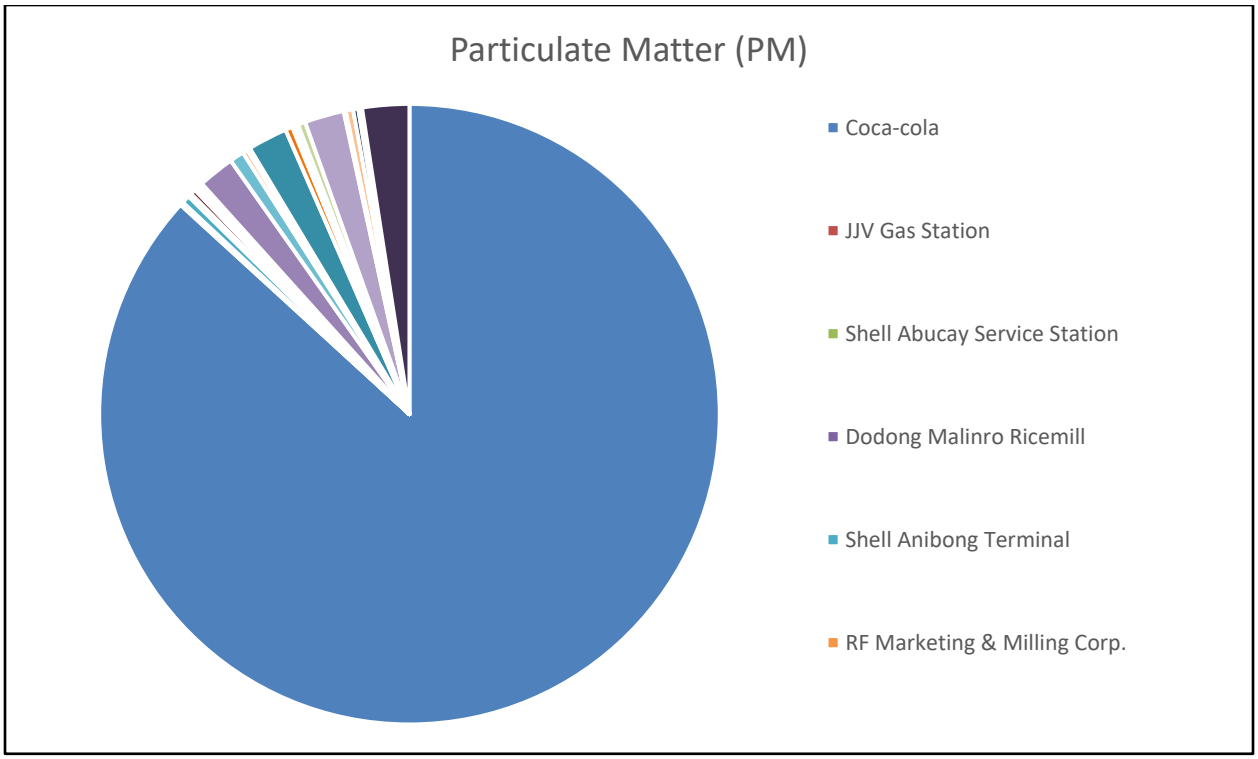
i. According to criteria pollutant (PM, CO, NO_x, SO_x, and VOC)



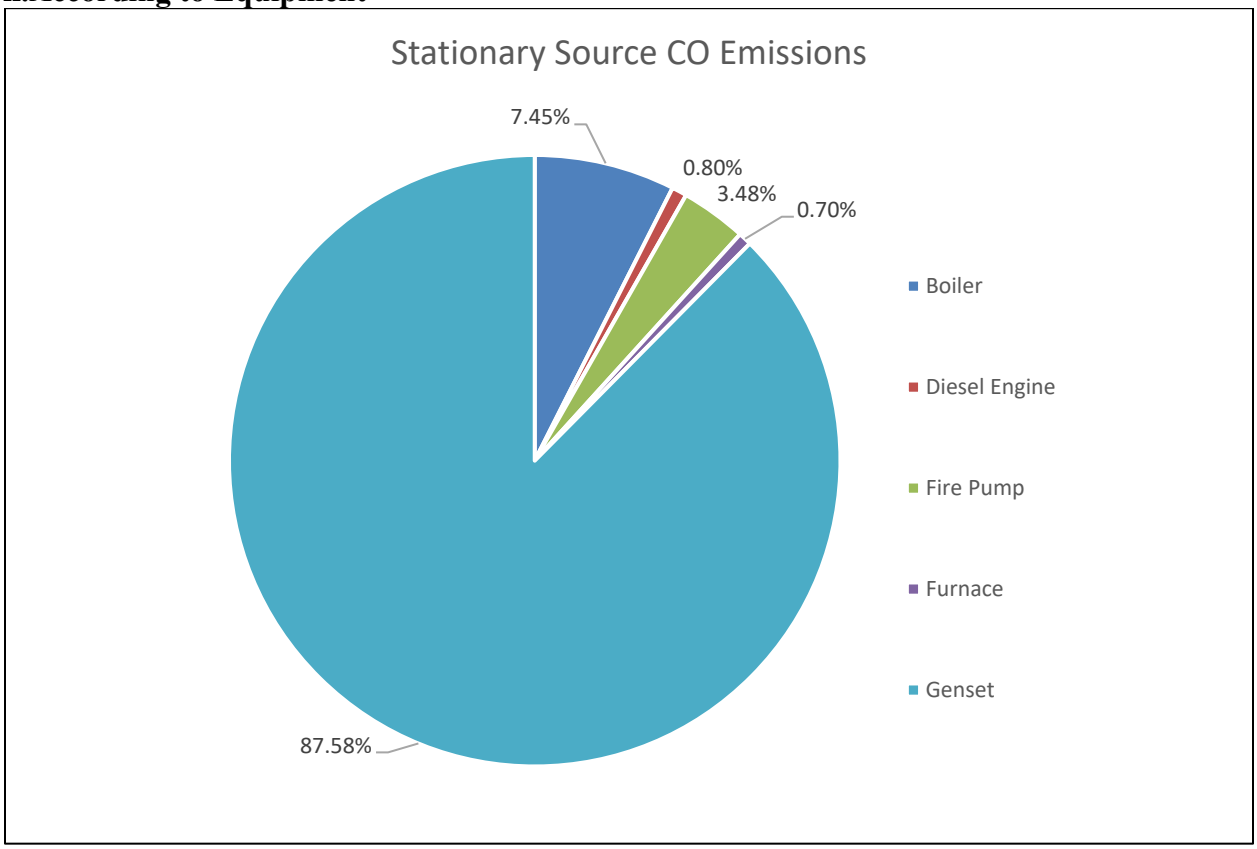


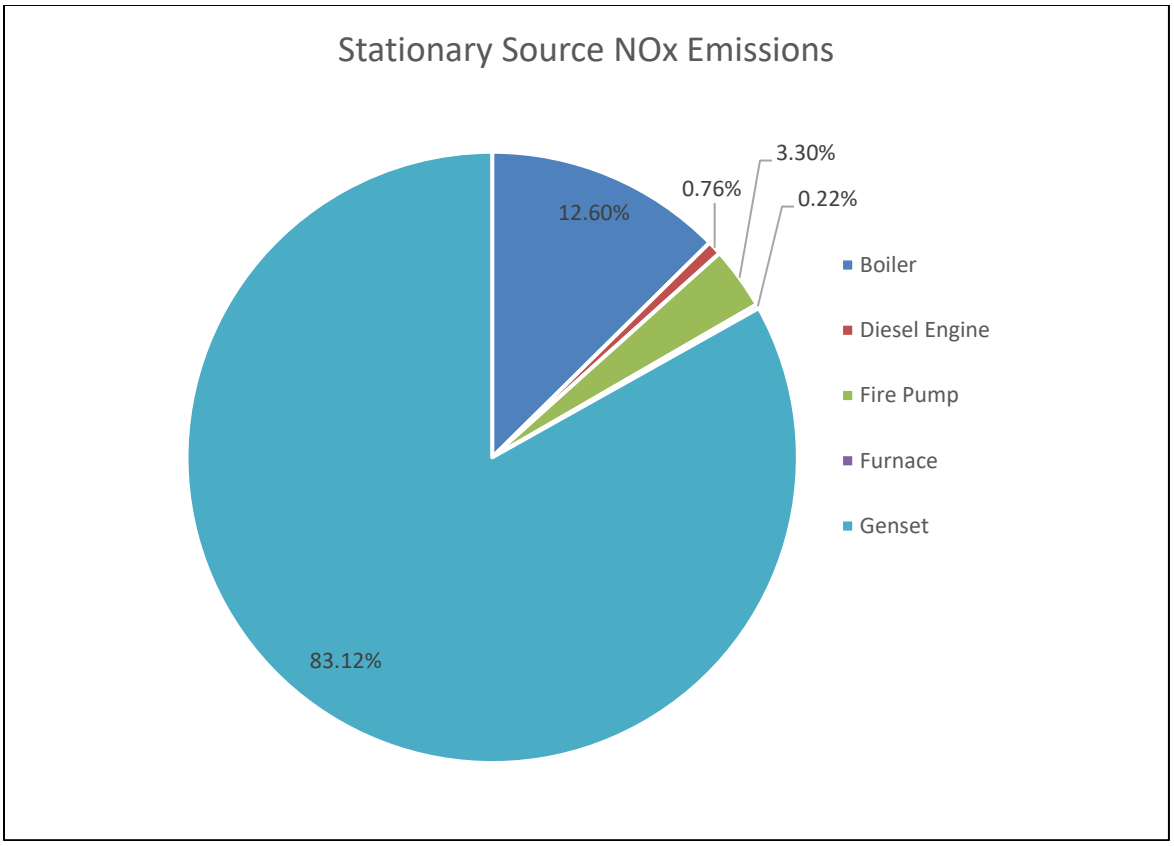

Sulfur Oxide (SOx)
Coca-cola
JJV Gas Station
Shell Abucay Service Station
Dodong Malinro Ricemill
Shell Anibong Terminal
RF Marketing & Milling Corp.

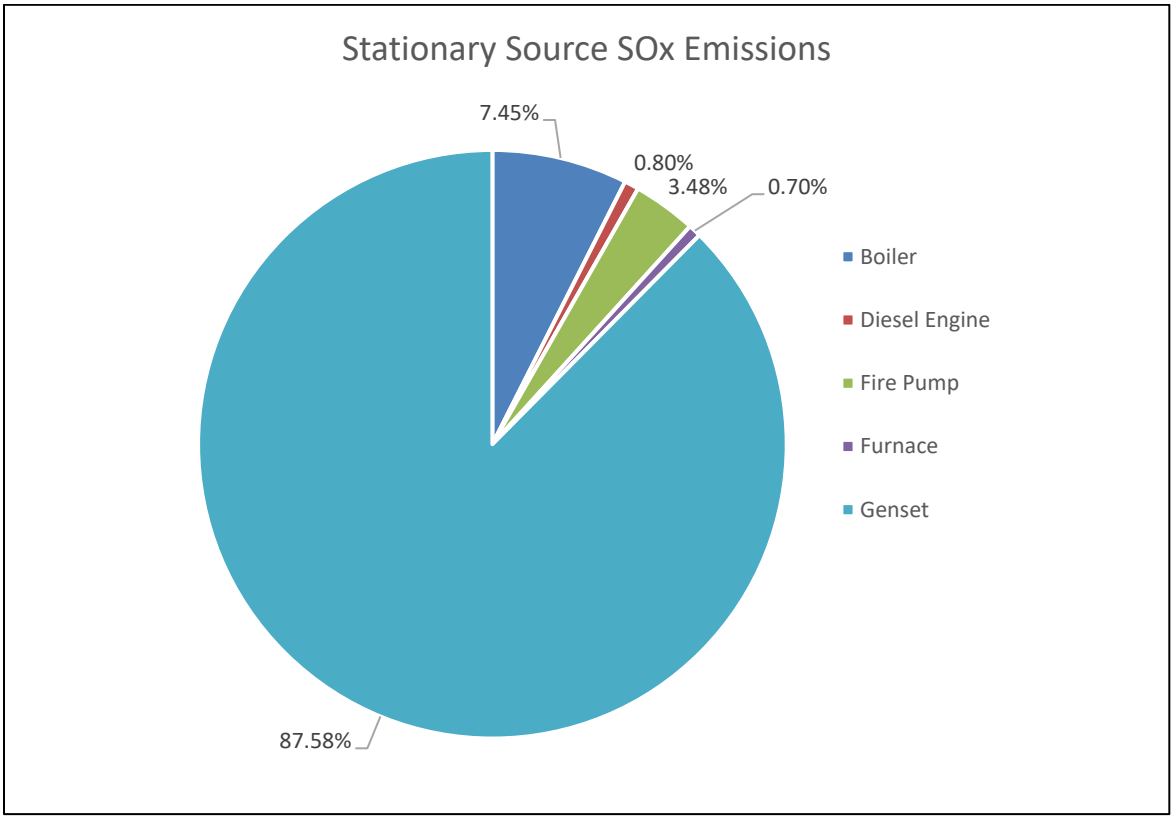

Volatile Organic Compound (VOC)
Coca-cola
JJV Gas Station
Shell Abucay Service Station
Dodong Malinro Ricemill
Shell Anibong Terminal
RF Marketing & Milling Corp.

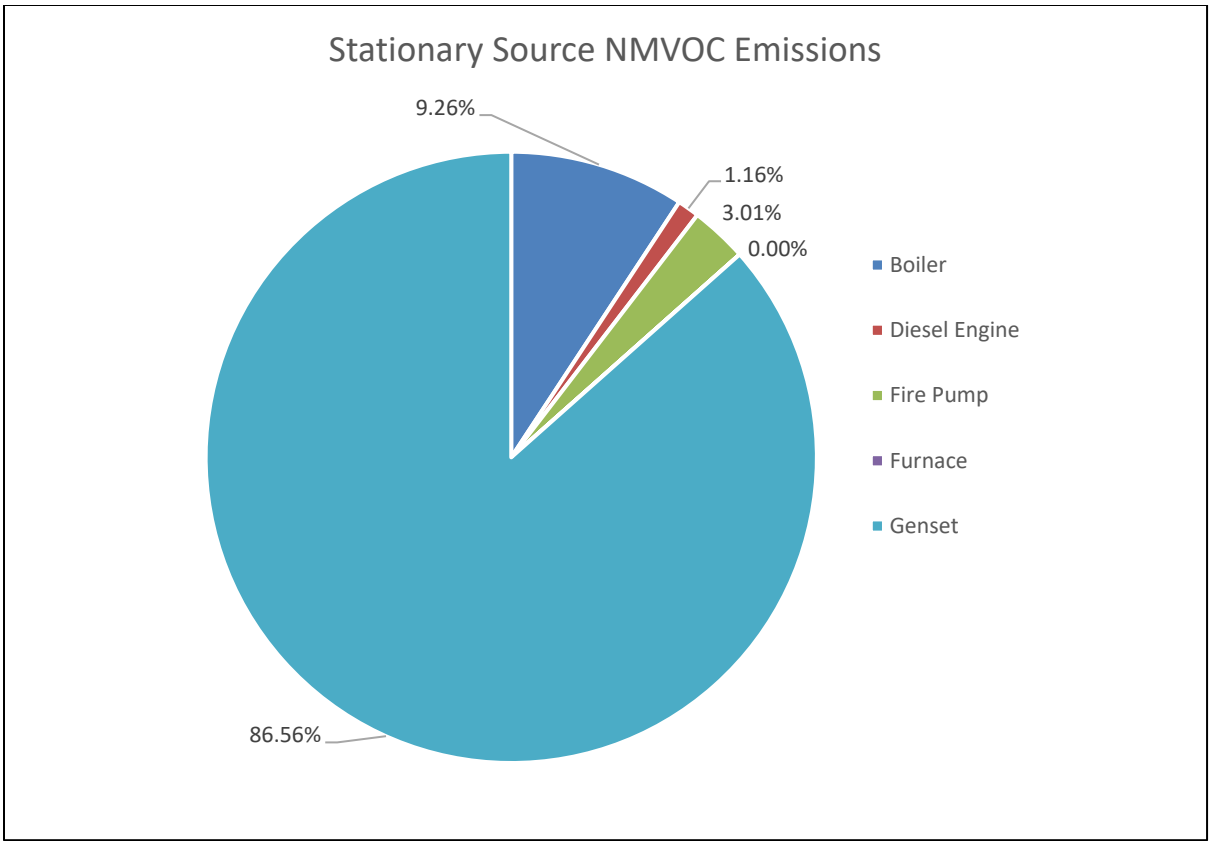


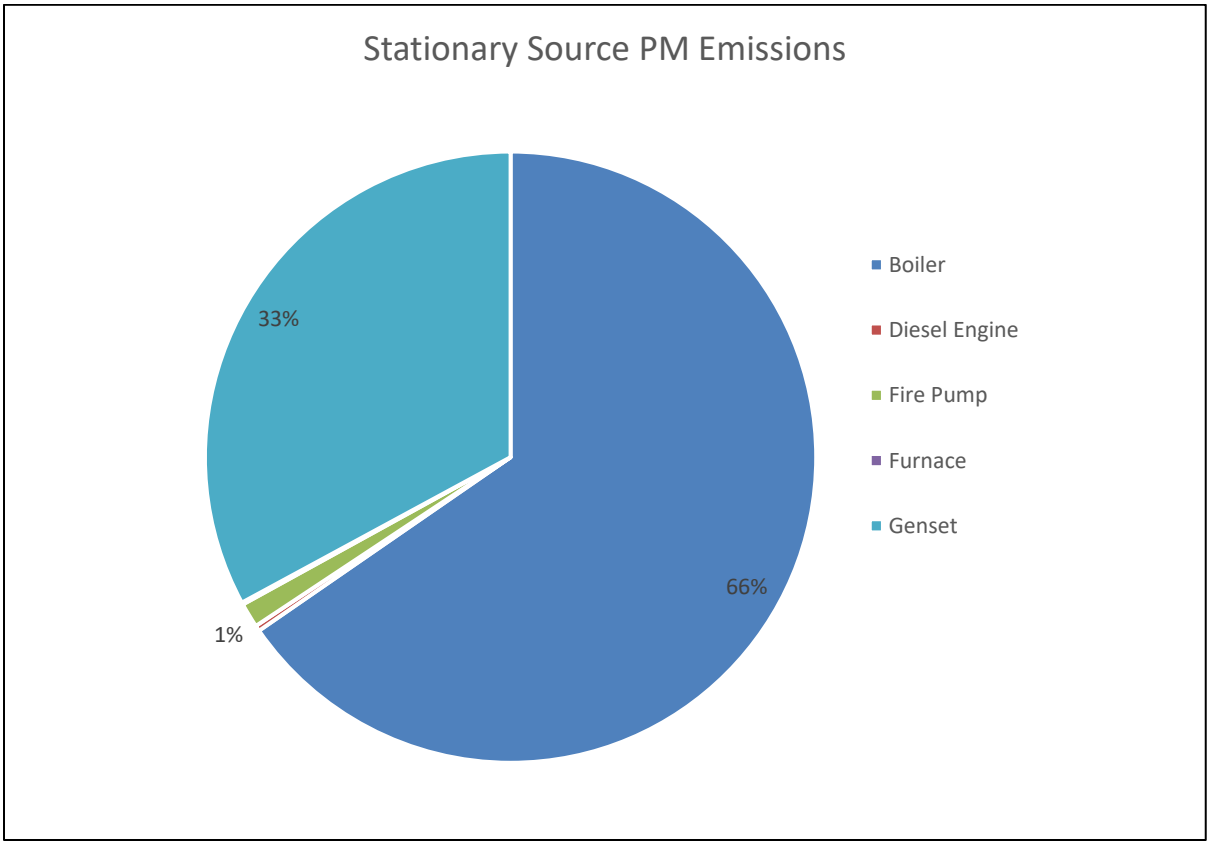
ii.According to Equipment



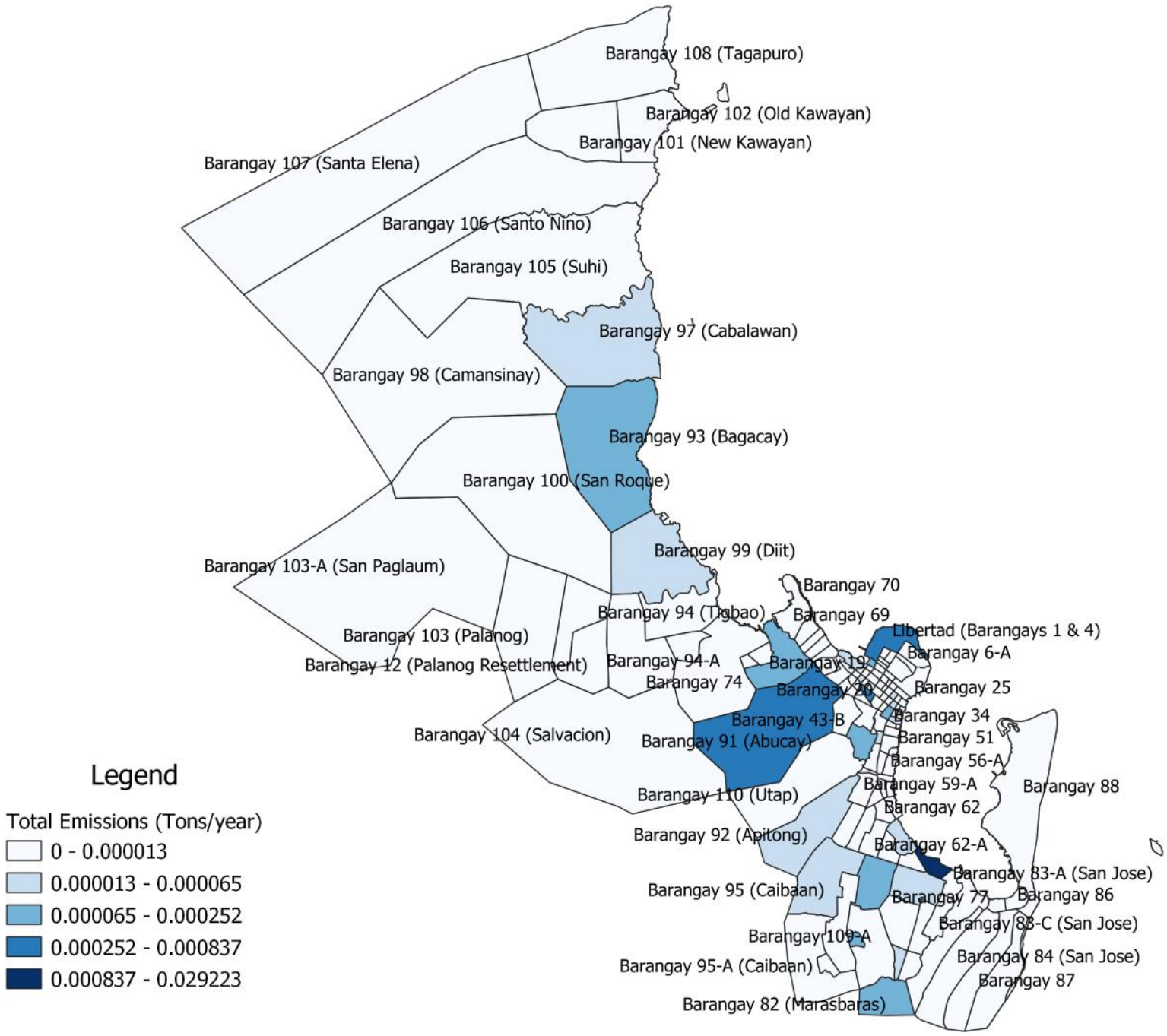

Stationary Source NOx Emissions
12.60%
0.76%
3.30%
0.22%
83.12%
Boiler
Diesel Engine
Fire Pump
Furnace
Genset


Stationary Source SOx Emissions
7.45%
0.80%
3.48%
0.70%
87.58%
Boiler
Diesel Engine
Fire Pump
Furnace
Genset

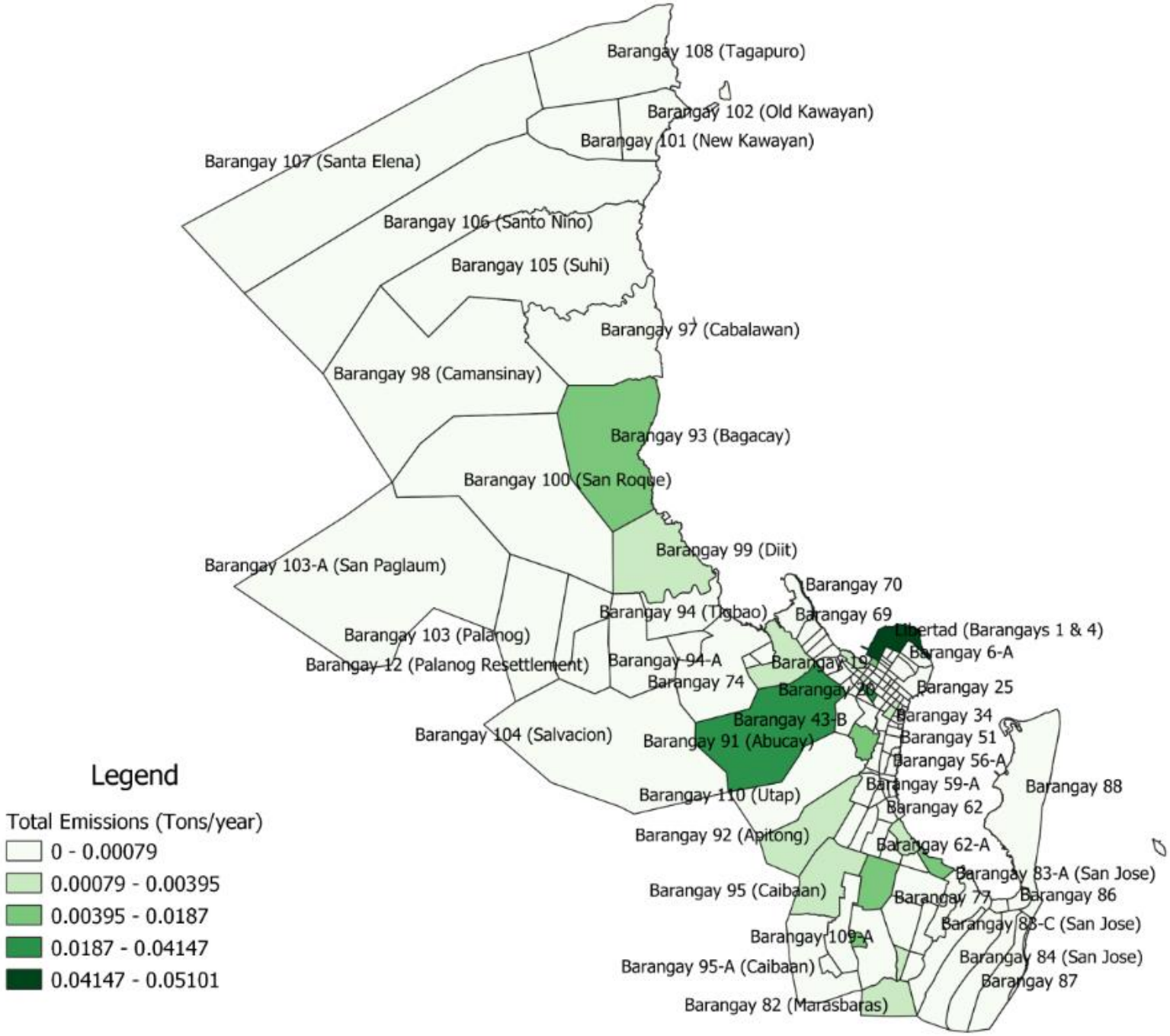

Stationary Source NMVOC Emissions
9.26%
1.16%
3.01%
0.00%
86.56%
Boiler
Diesel Engine
Fire Pump
Furnace
Genset


Stationary Source PM Emissions
33%
66%
1%
Boiler
Diesel Engine
Fire Pump
Furnace
Genset

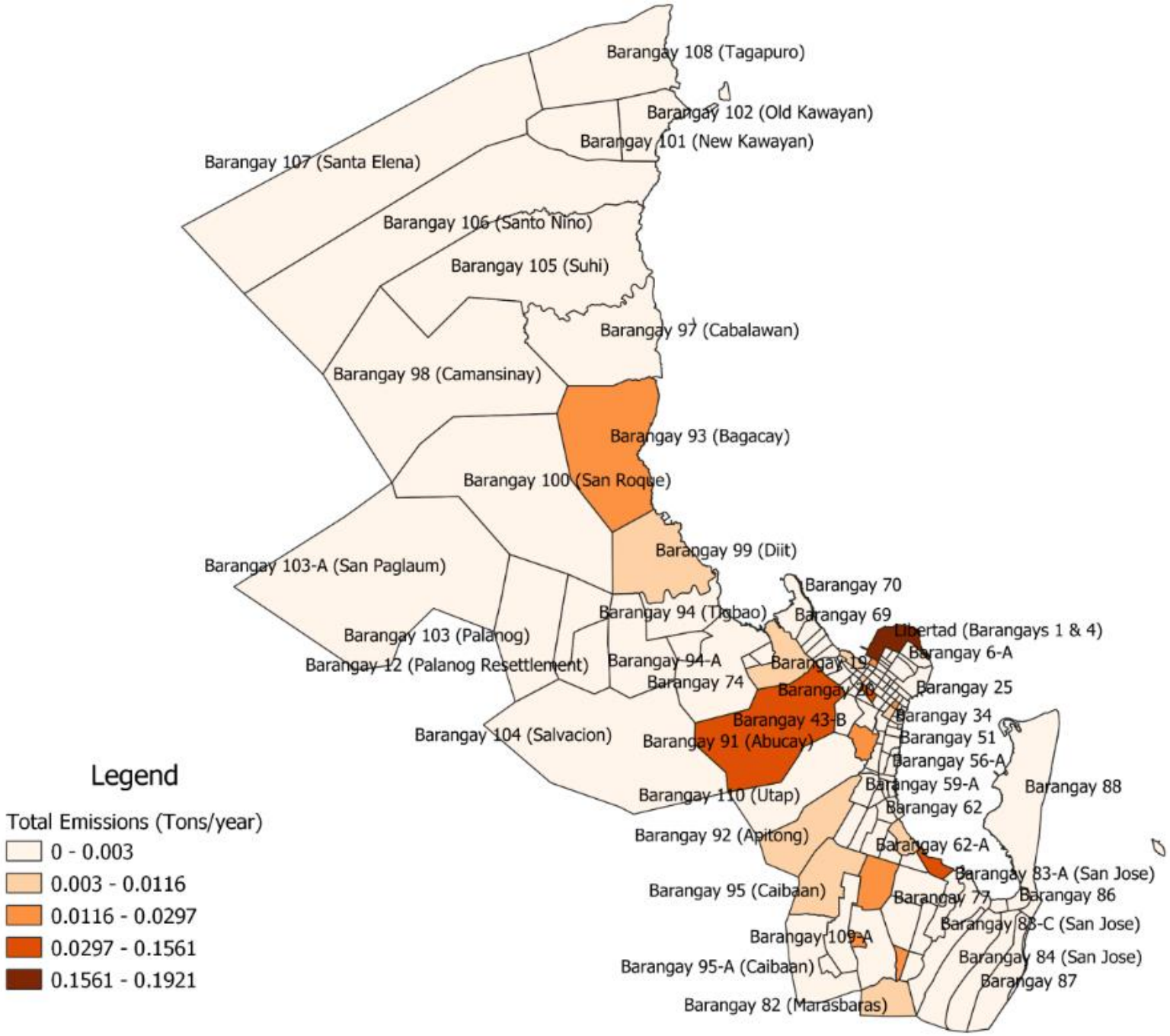
Spatial Distribution of Particulate Matter (PM) for Stationary Sources



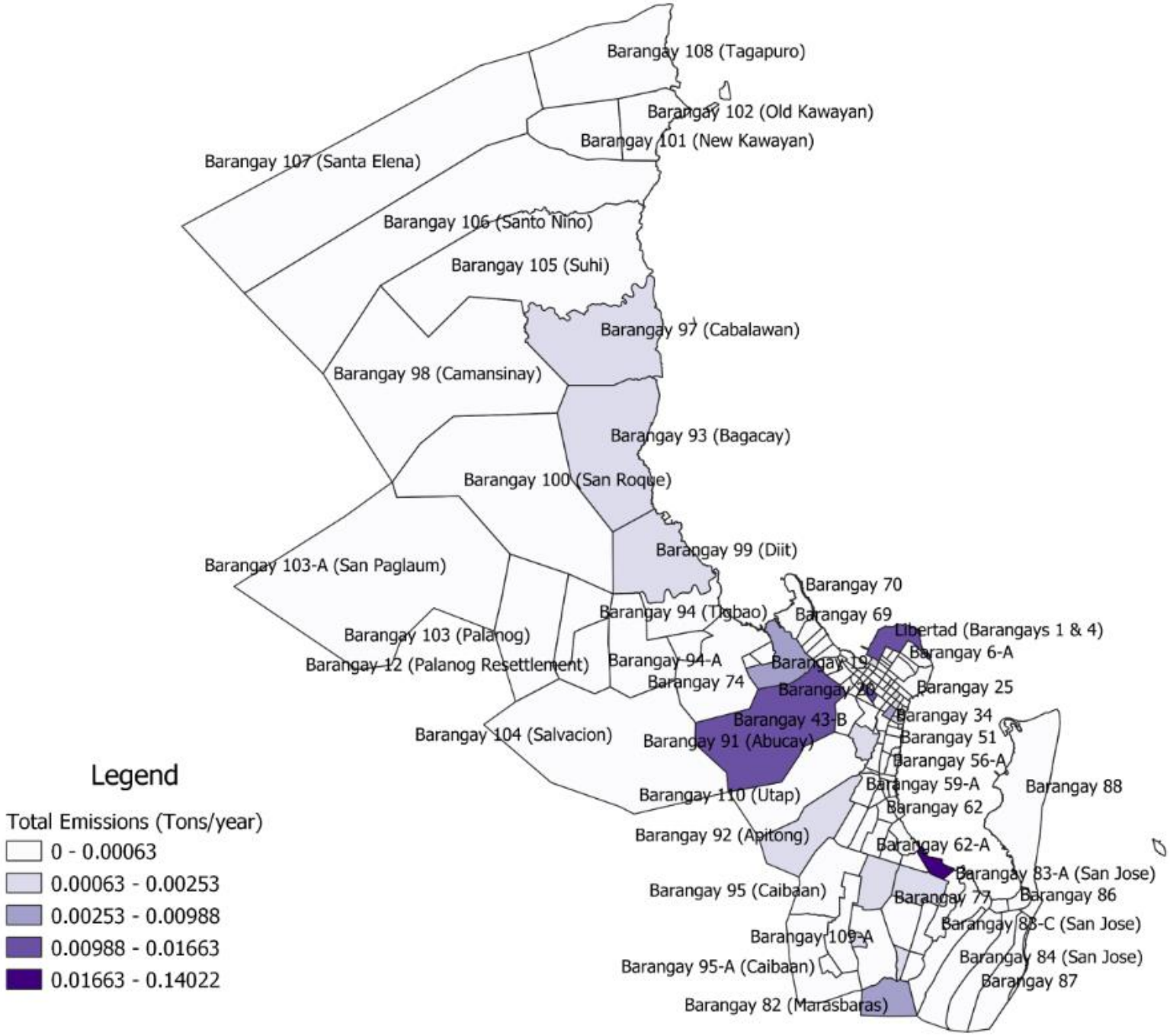
Spatial Distribution of Carbon Monoxide (CO) for Stationary Sources



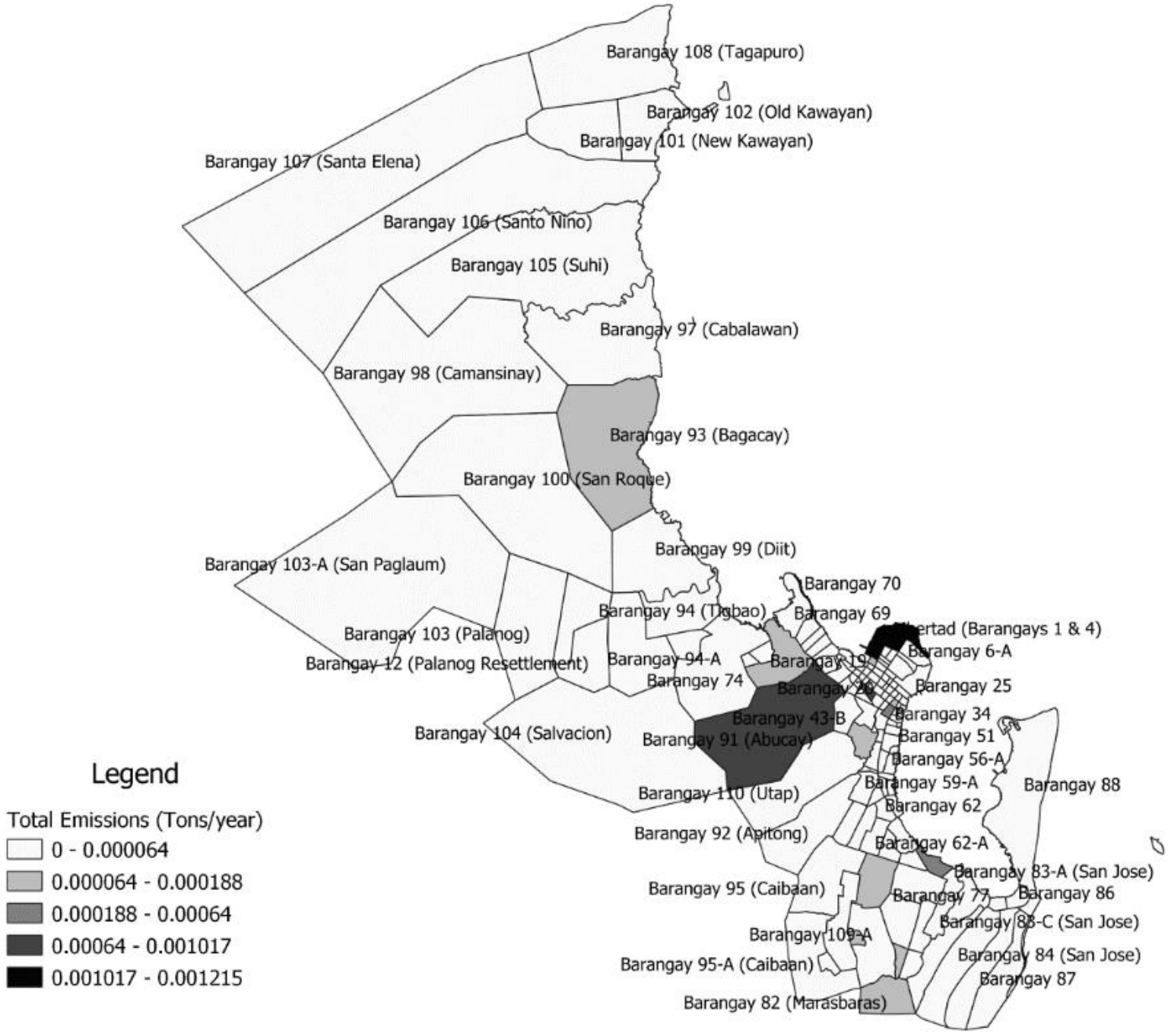
Spatial Distribution of Nitrogen oxide (NOx) for Stationary Sources



Spatial Distribution of Sulfur Oxide (SOx) for Stationary Sources



Spatial Distribution of Volatile Organic Compounds (VOC) for Stationary Sources

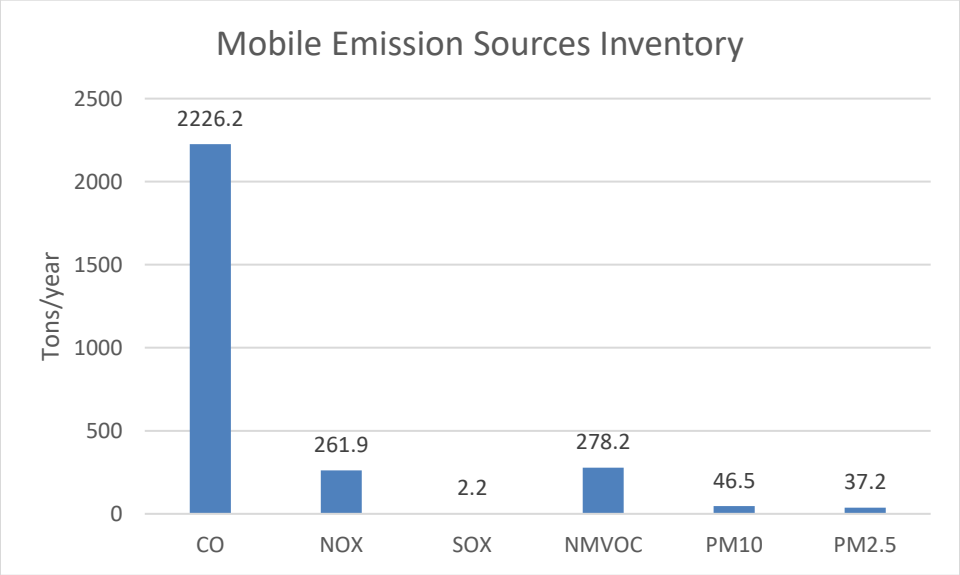


II. MOBILE SOURCE

a. Total Mass Emission Expressed in Tons/year

CO	NOx	SOx	NMVOC	PM10	PM2.5
2226.2	261.9	2.2	278.2	46.5	37.2

b. Graphical presentation of the Total Mobile Source Emission (Tons/year) in Bar Chart

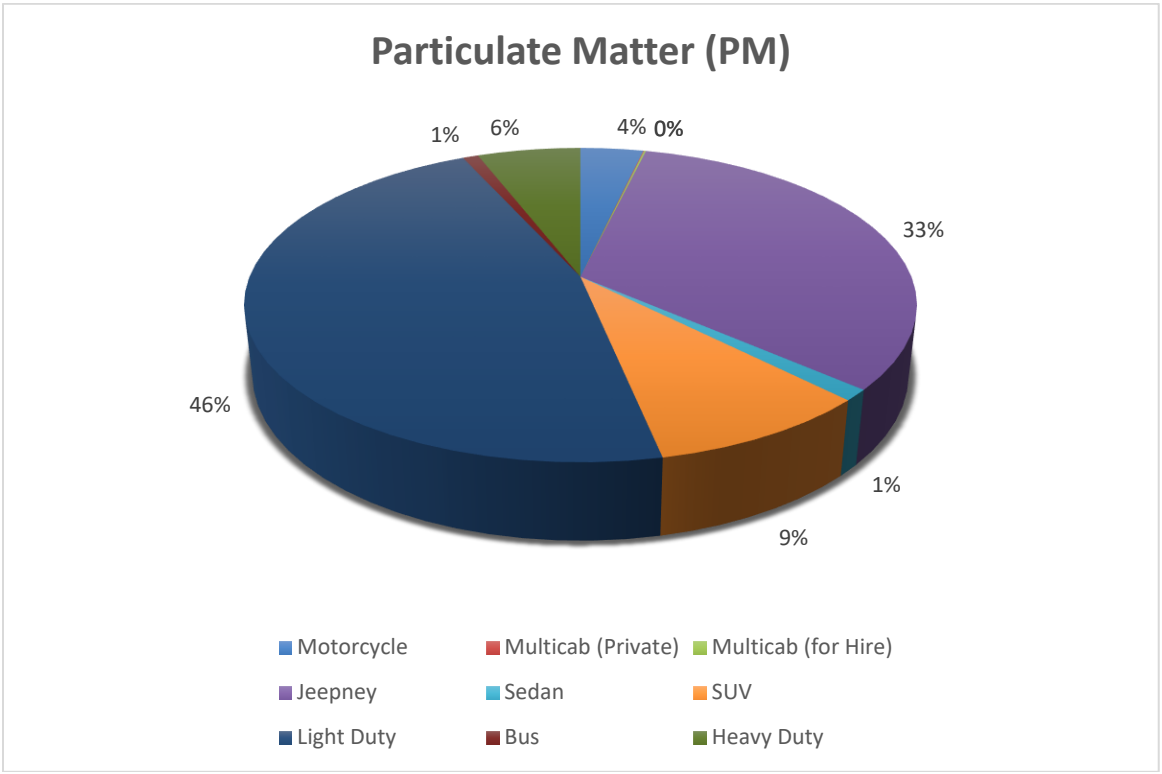


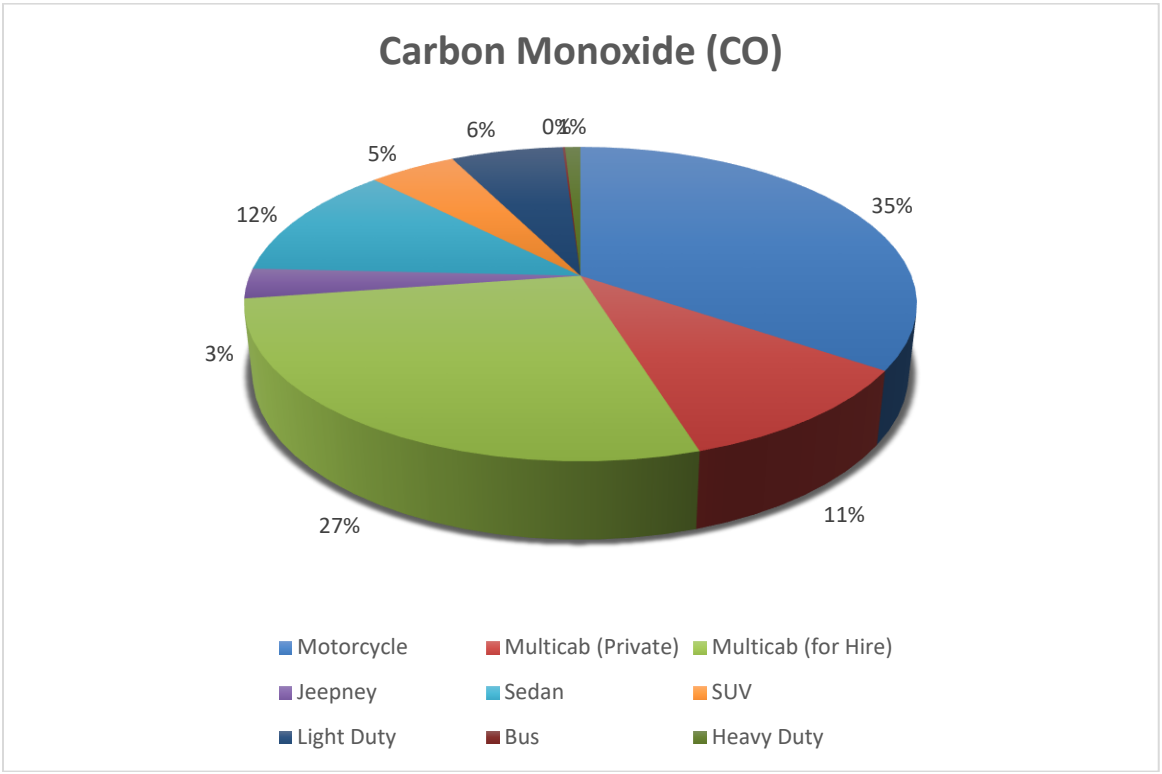
Motor Vehicle Total Emissions in Tons/year by Vehicle Type

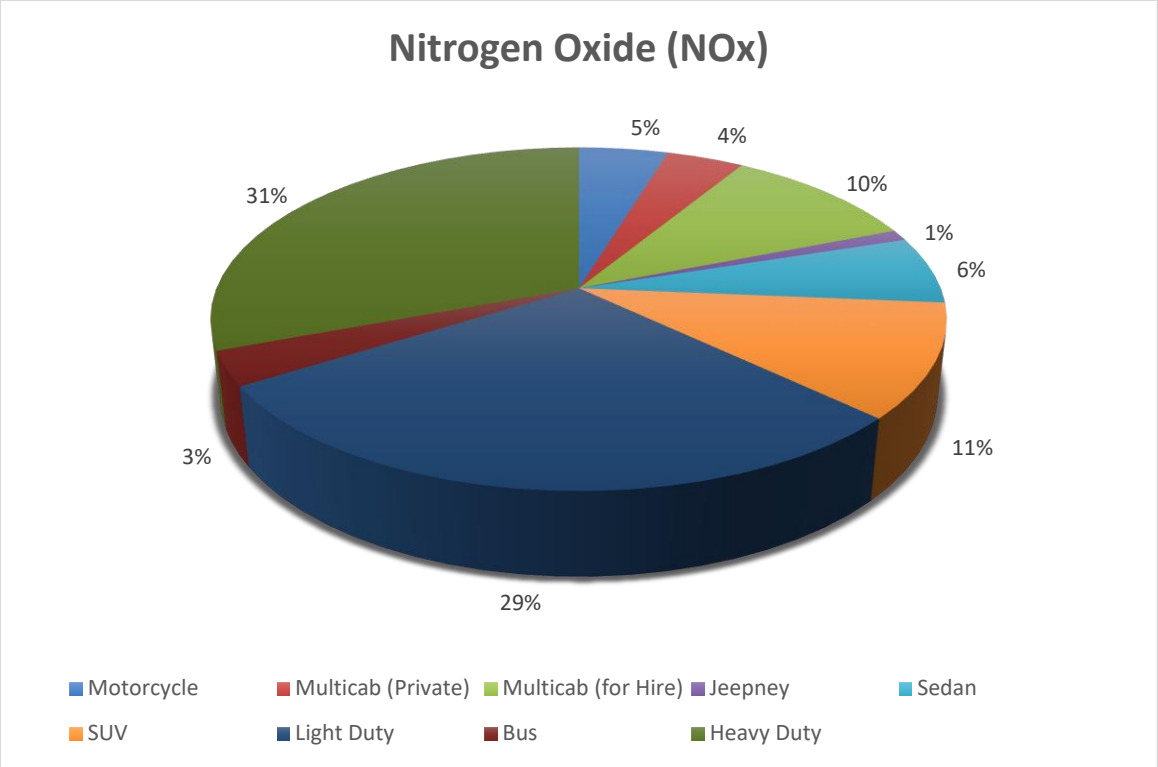
	NMVOC	CO	NOx	PM10	PM2.5	SOx	CH4	CO2
Tricycle	78.79	515.88	6.13	1.38	1.10	0.07	78.79	1349.92
Motorcycle	104.23	601.99	12.05	1.62	1.29	0.11	104.23	1907.45
Multicab (Private)	14.27	186.38	10.43	0.02	0.02	0.05	14.27	2330.69
Multicab (for Hire)	36.81	479.78	26.60	0.05	0.04	0.13	36.81	5545.20
Jeepney	3.97	53.75	2.65	14.72	11.77	0.37	3.97	13659.05
Sedan	16.77	206.42	16.36	0.52	0.42	0.21	16.77	6117.61
SUV	9.83	87.00	27.66	4.14	3.31	0.27	9.83	4850.01
Light Duty	9.84	111.95	74.83	20.97	16.76	0.76	9.84	16911.72
Bus	0.68	2.34	8.38	0.40	0.32	0.02	0.68	345.42
Heavy Duty	4.04	15.34	79.41	2.66	2.13	0.21	4.04	2830.87

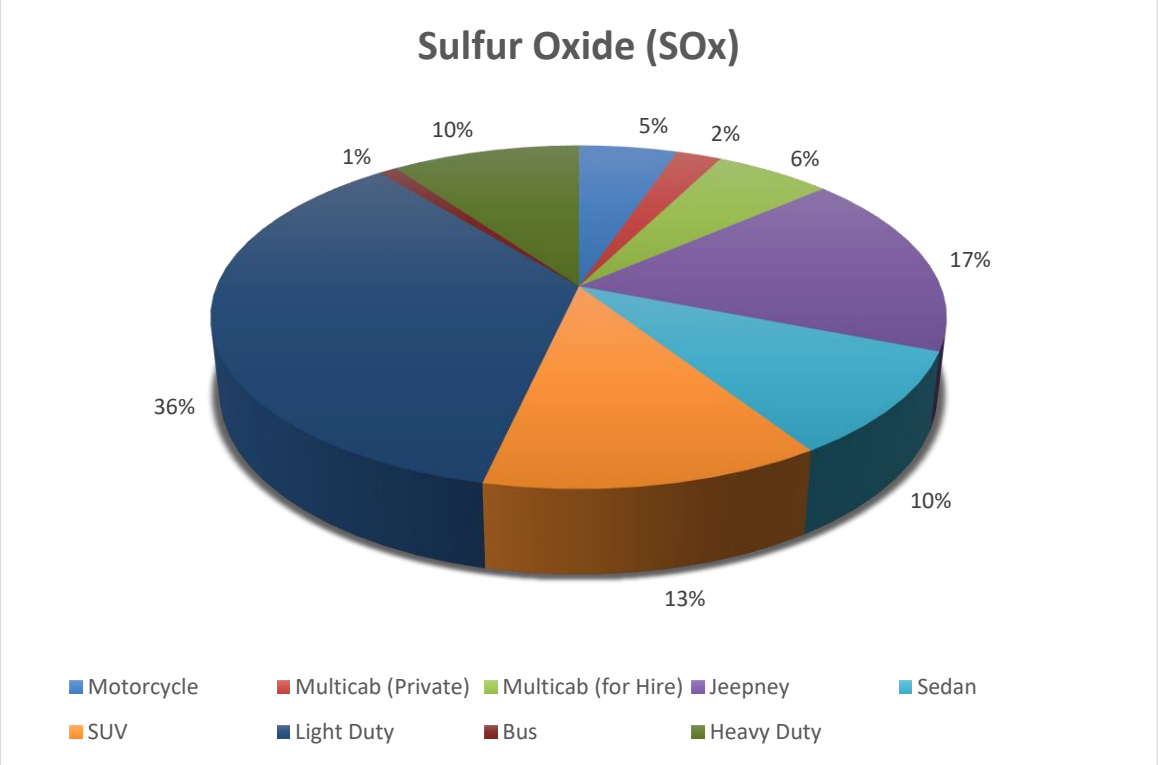
c. Classification of Mobile Sources in Pie Chart according to the following:

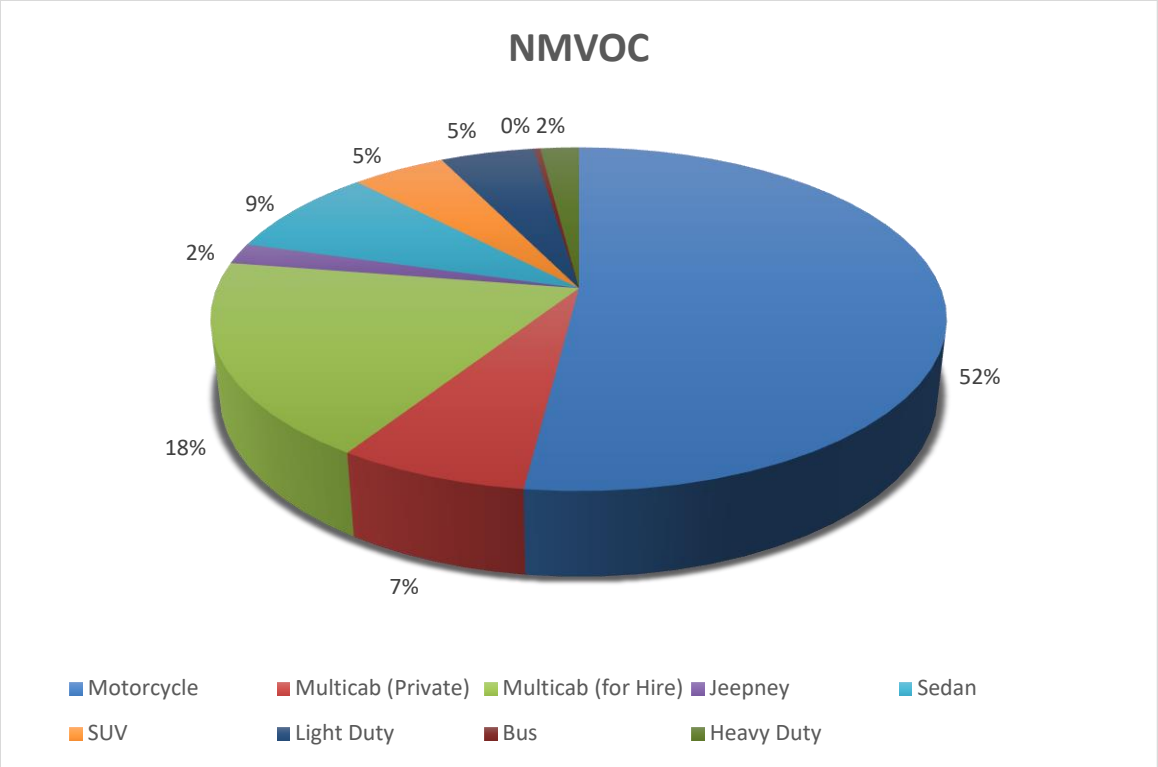
i. According to criteria pollutant (PM, CO, NO_x, SO_x, and VOC)


Particulate Matter (PM)
1%
6%
4%
0%
33%
46%
1%
9%
Motorcycle
Multicab (Private)
Multicab (for Hire)
Jeepney
Sedan
SUV
Light Duty
Bus
Heavy Duty

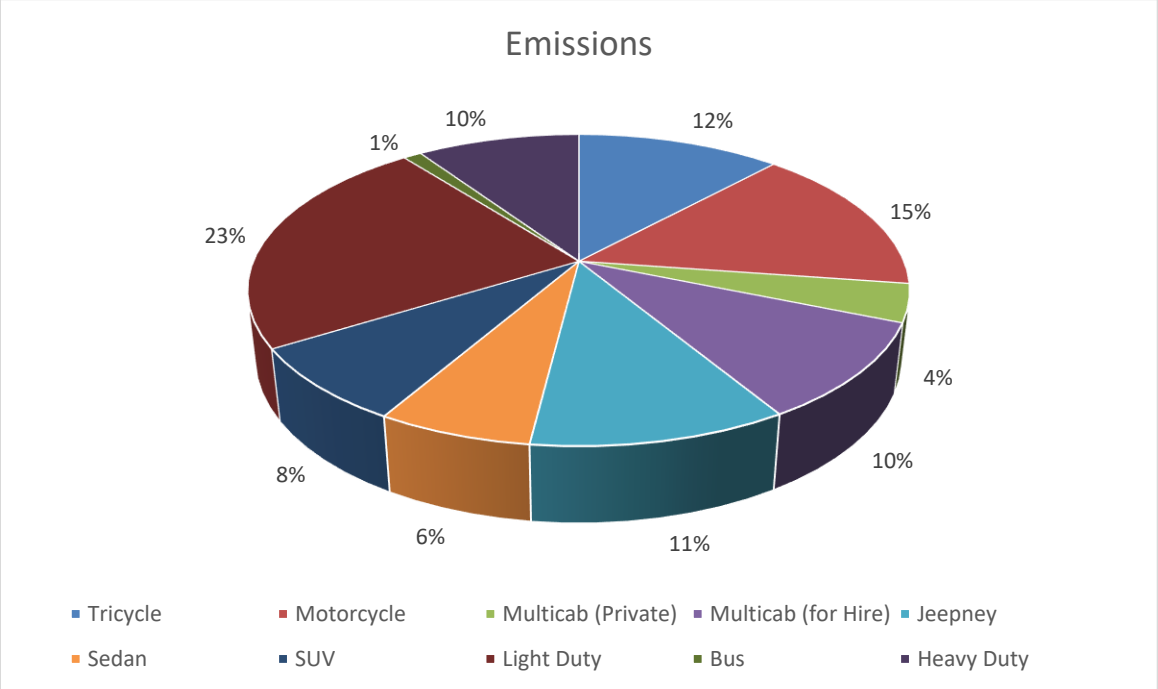

Carbon Monoxide (CO)
6%
0%
5%
12%
35%
3%
27%
11%
Motorcycle
Multicab (Private)
Multicab (for Hire)
Jeepney
Sedan
SUV
Light Duty
Bus
Heavy Duty


Nitrogen Oxide (NOx)
5%
4%
10%
1%
6%
11%
29%
3%
31%
Motorcycle
Multicab (Private)
Multicab (for Hire)
Jeepney
Sedan
SUV
Light Duty
Bus
Heavy Duty

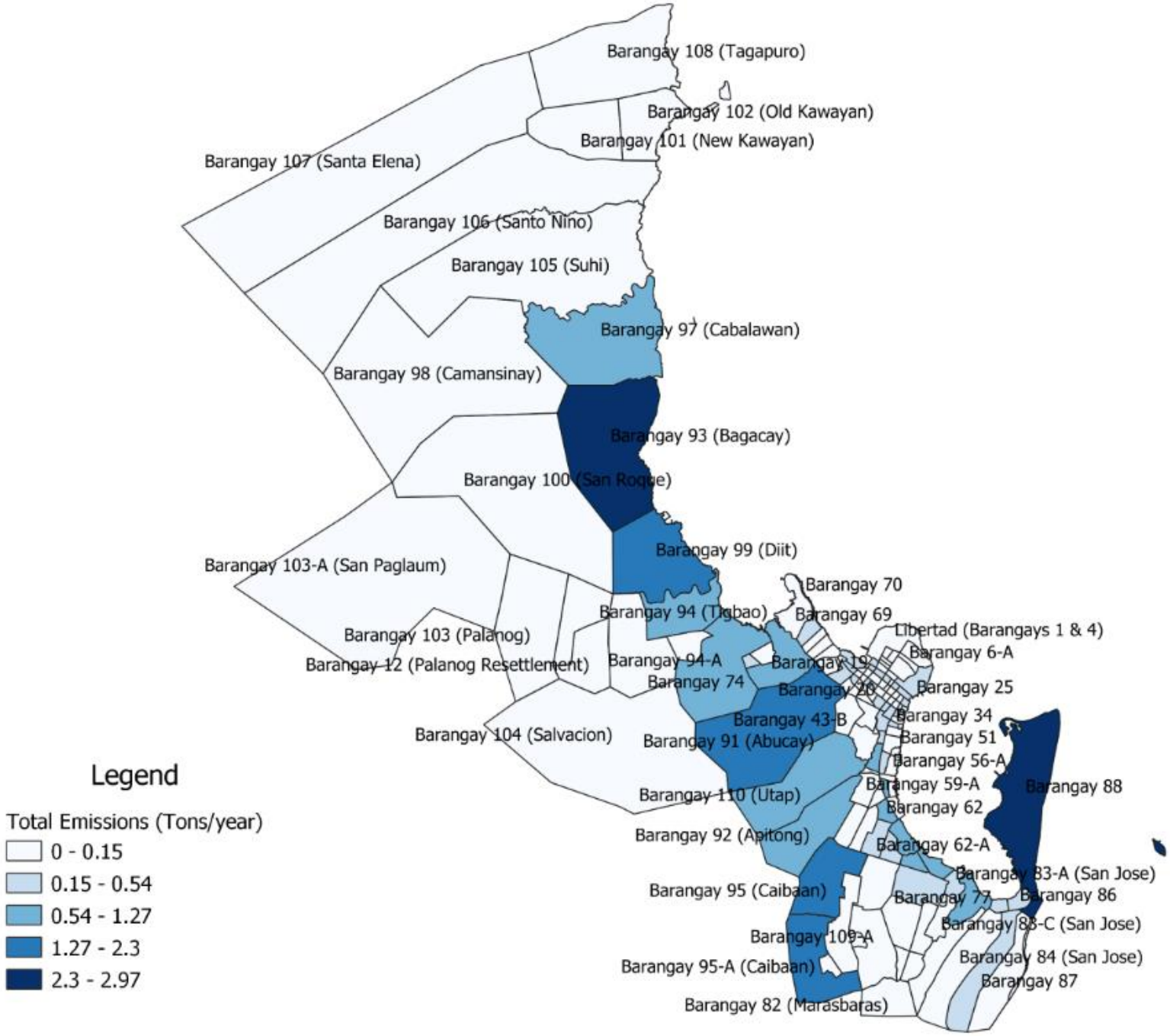

Sulfur Oxide (SOx)
5%
2%
6%
17%
10%
13%
36%
1%
10%
Motorcycle
Multicab (Private)
Multicab (for Hire)
Jeepney
Sedan
SUV
Light Duty
Bus
Heavy Duty



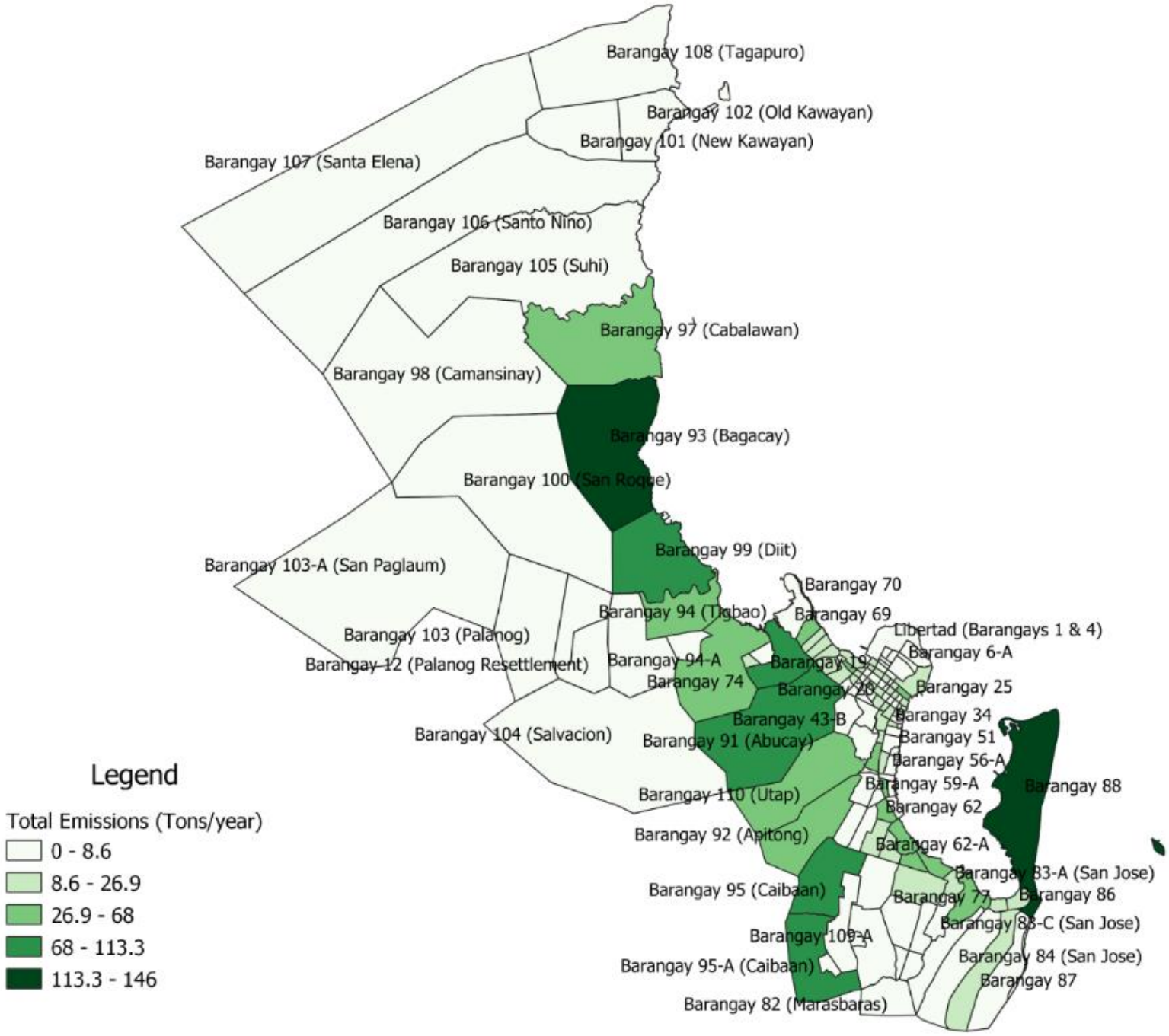
ii. According to Vehicle Type



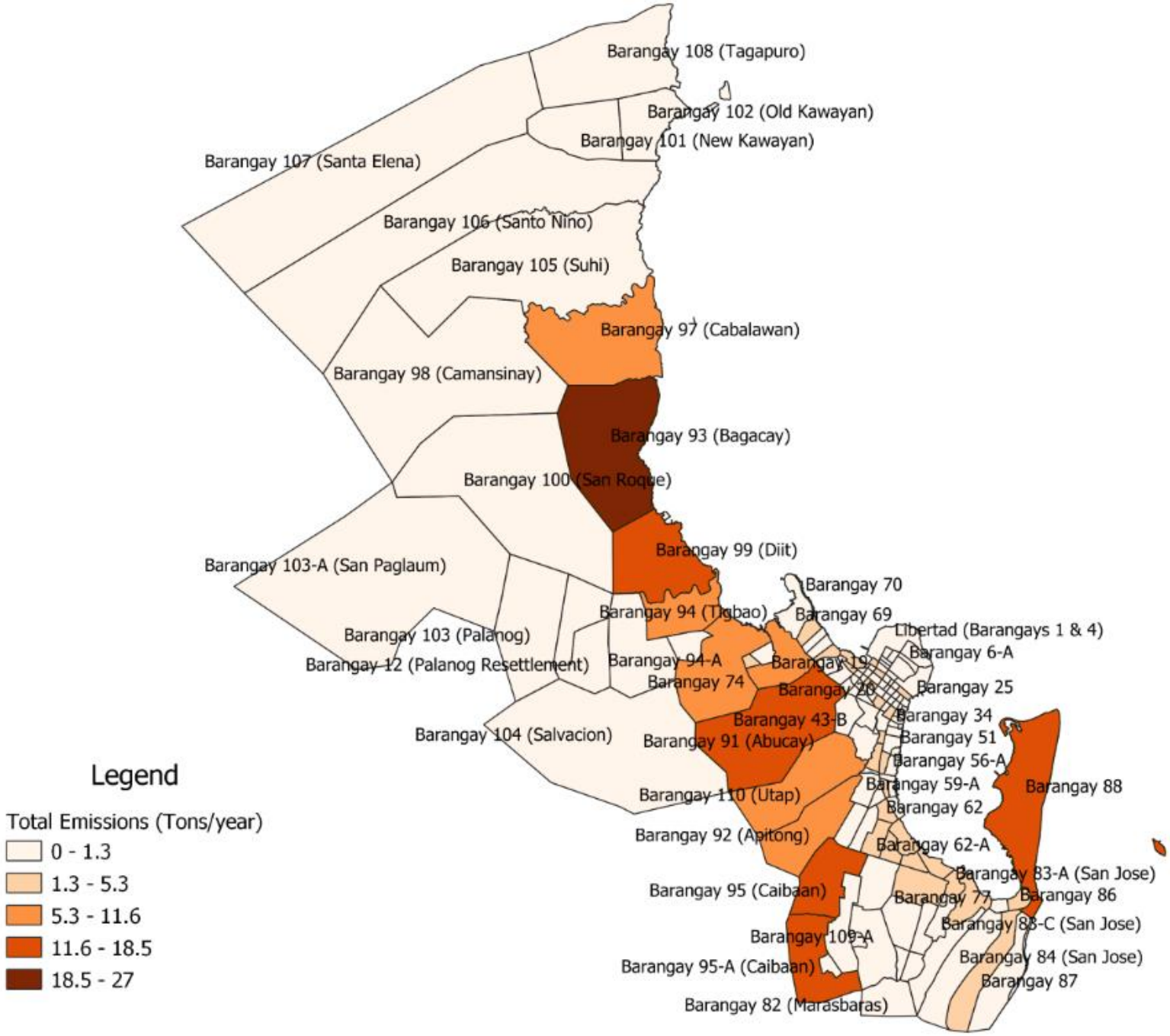
Spatial Distribution of Particulate Matter (PM) for Mobile Sources



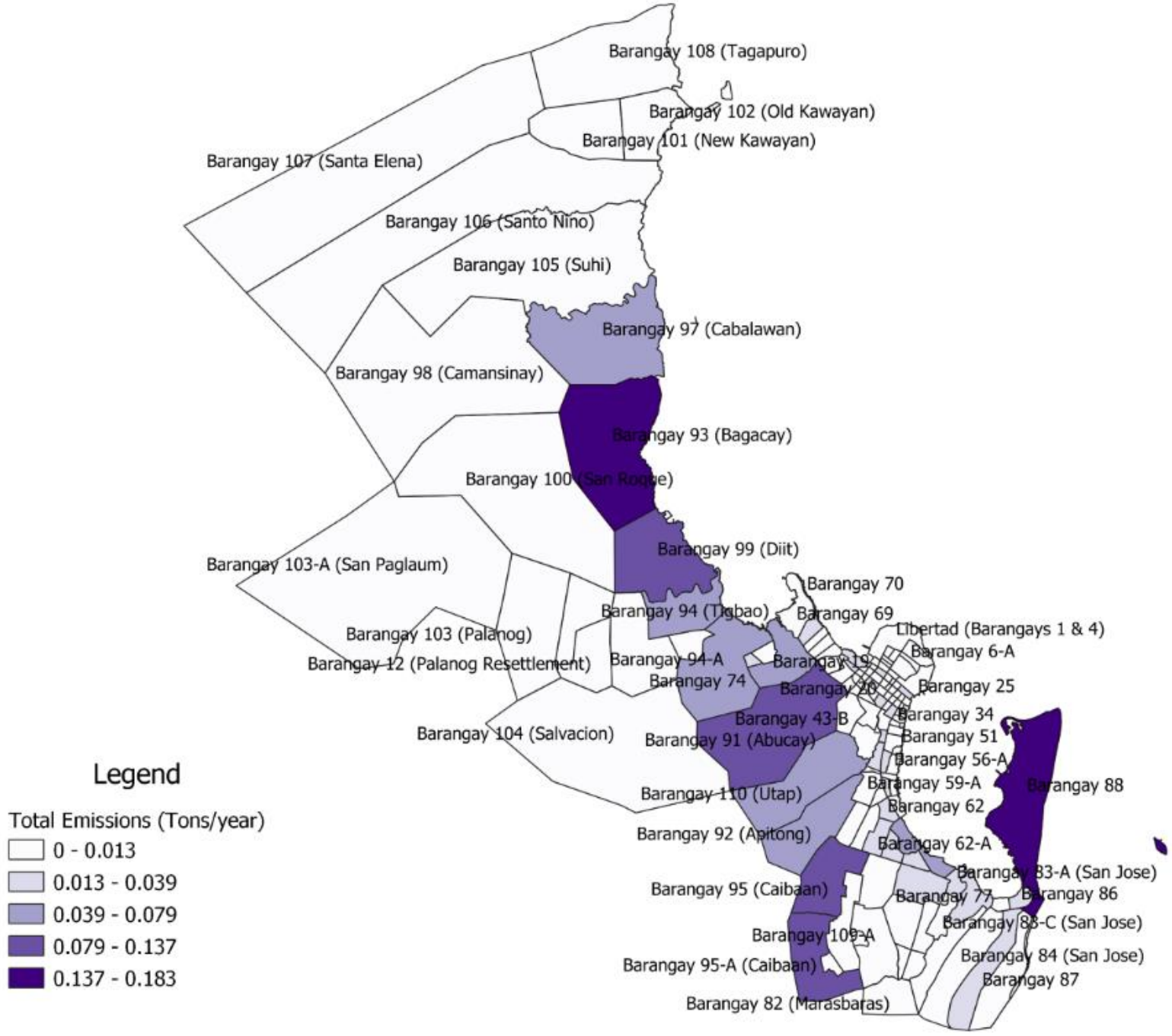
Spatial Distribution of Carbon Monoxide (CO) for Mobile Sources



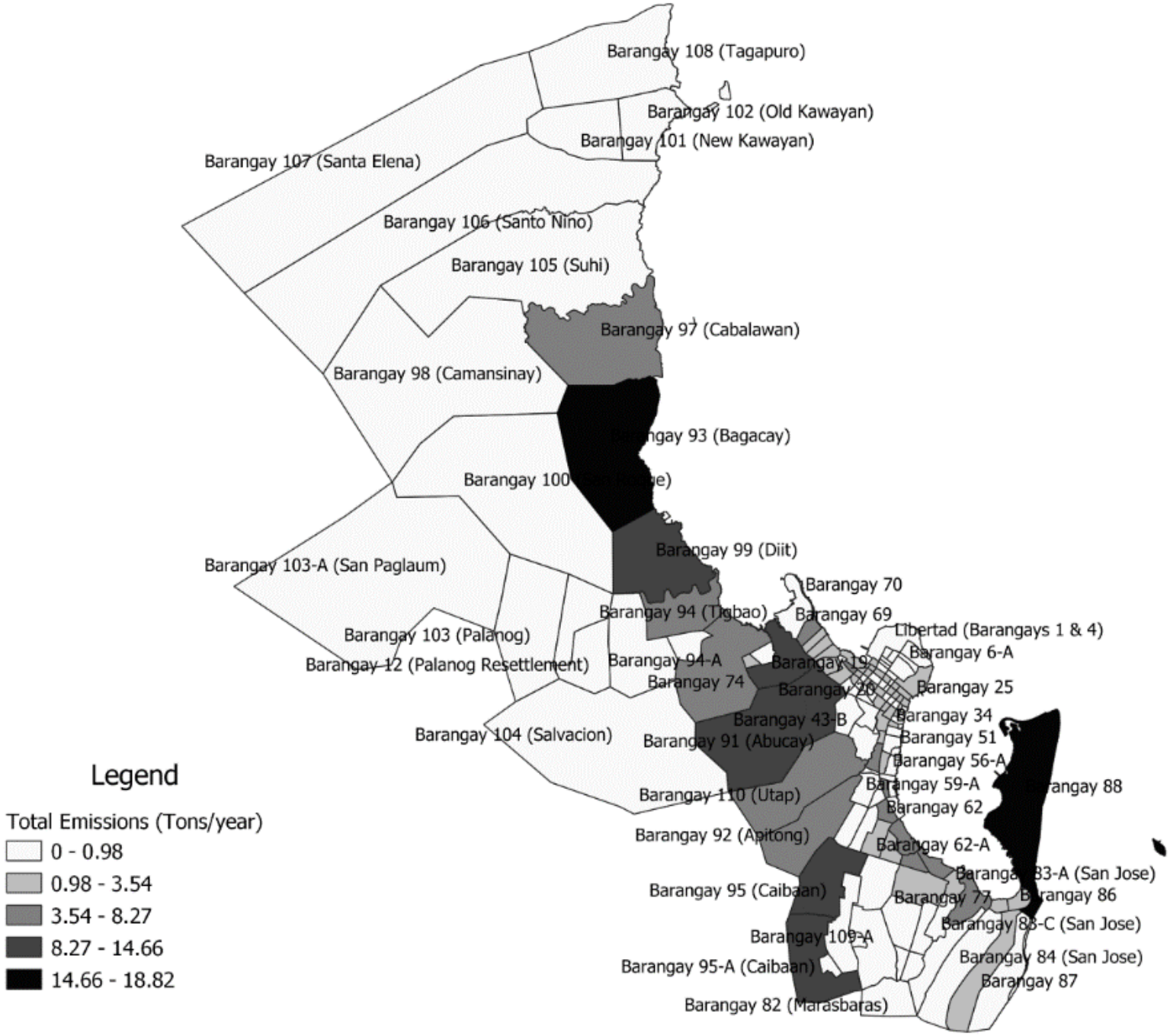
Spatial Distribution of Nitrogen Oxides (NOx) for Mobile Sources



Spatial Distribution of Sulfur Oxides (SOx) for Mobile Sources



Spatial Distribution of NMVOC for Mobile Sources

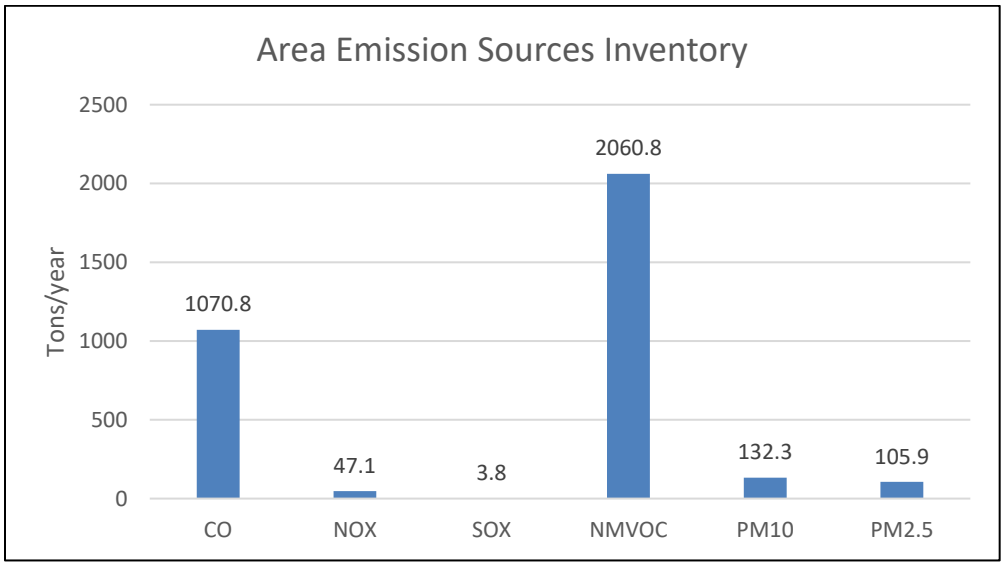


III. AREA SOURCES

a. Total Mass Emission Expressed in Tons/year (Using AP 42 emission factor)

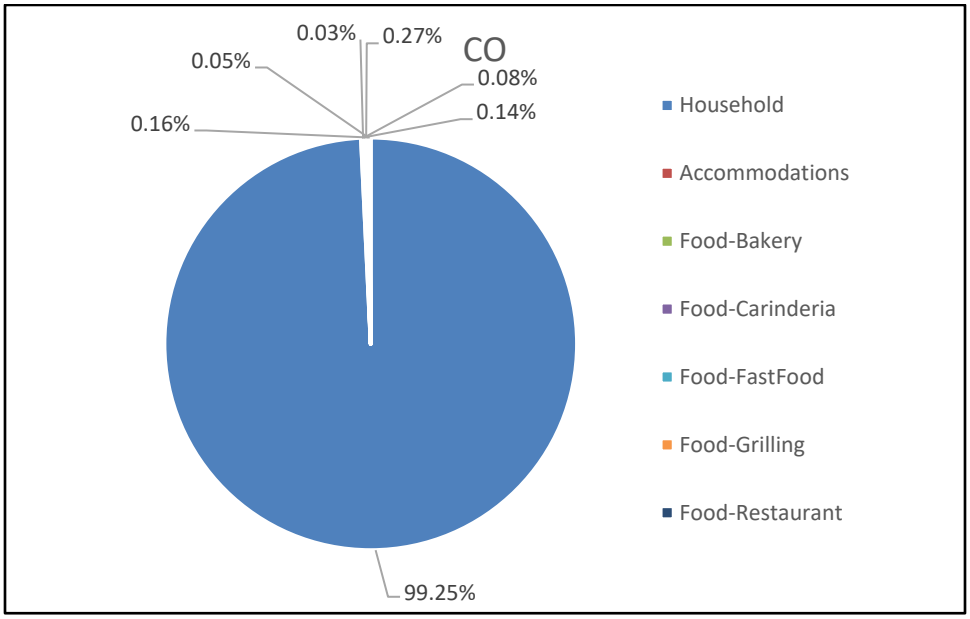
CO	NOX	SOX	NMVOC	PM10	PM2.5
1070.8	47.1	3.8	2060.8	132.3	105.9

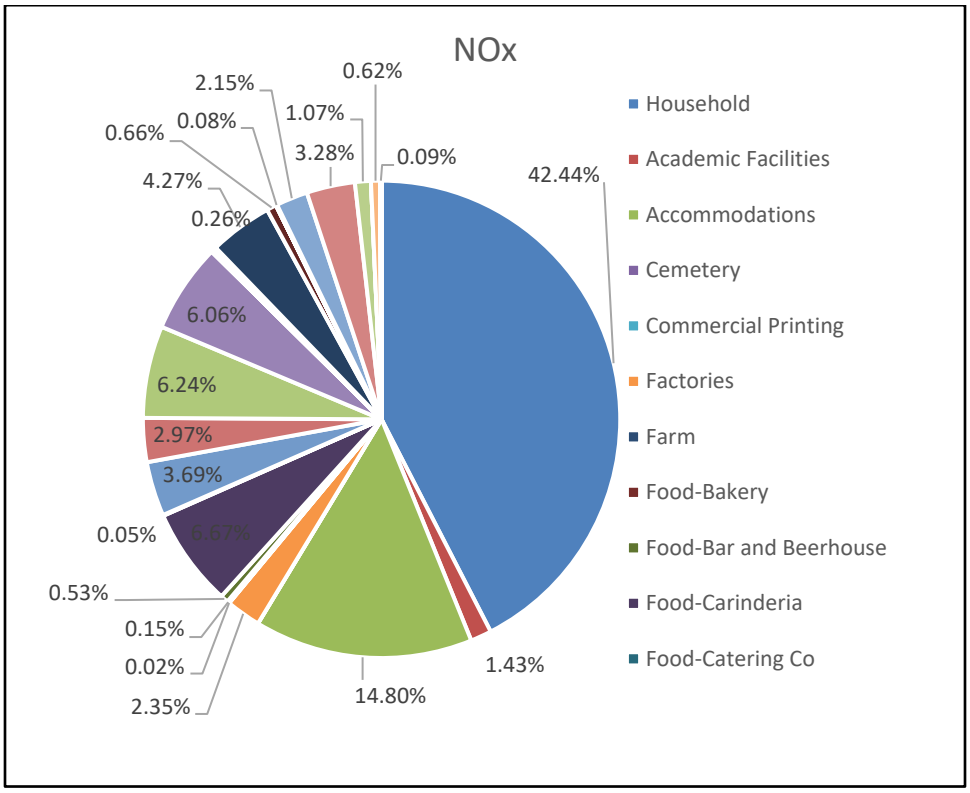
b. Graphical presentation of the Total Emission (Tons/year) in Bar Chart

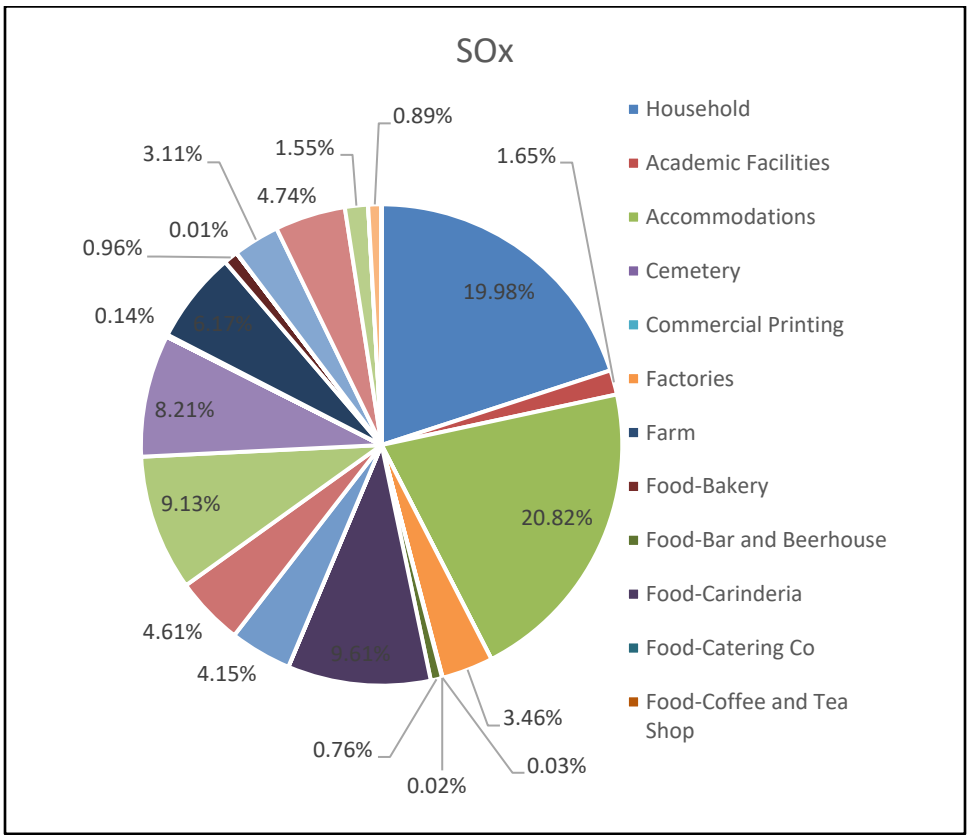


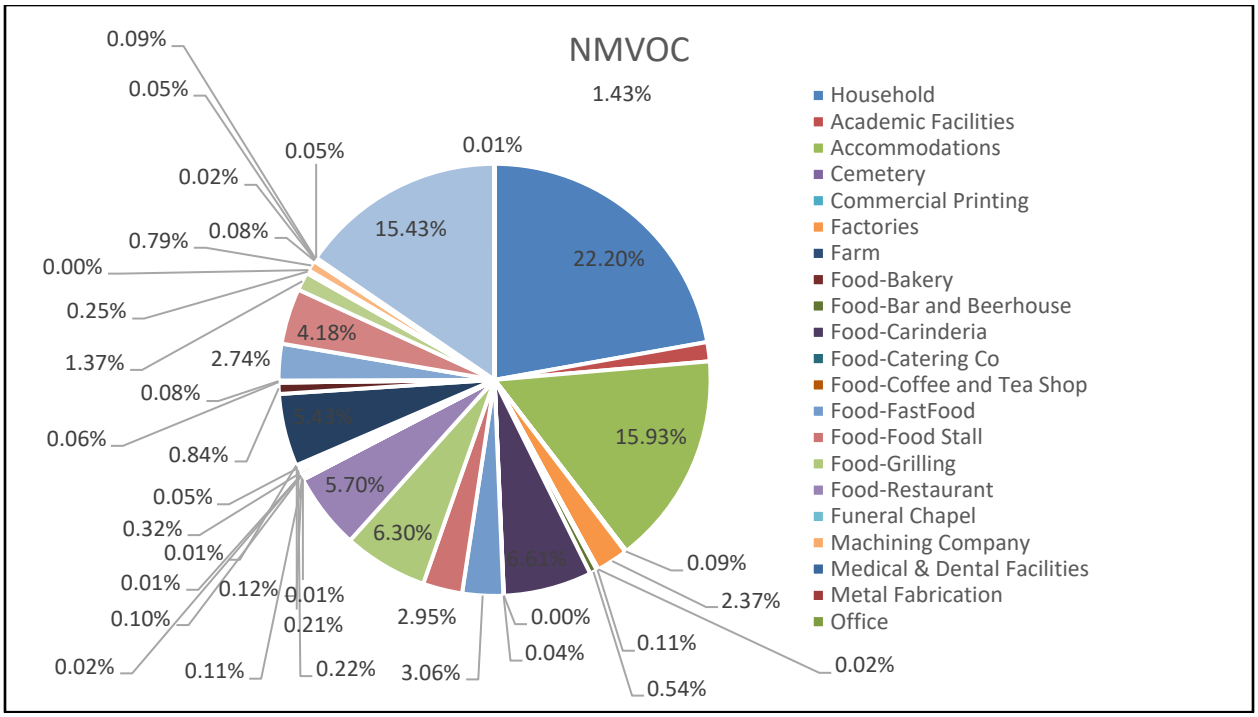
c. Classification of Stationary Sources in Pie Chart according to the following:

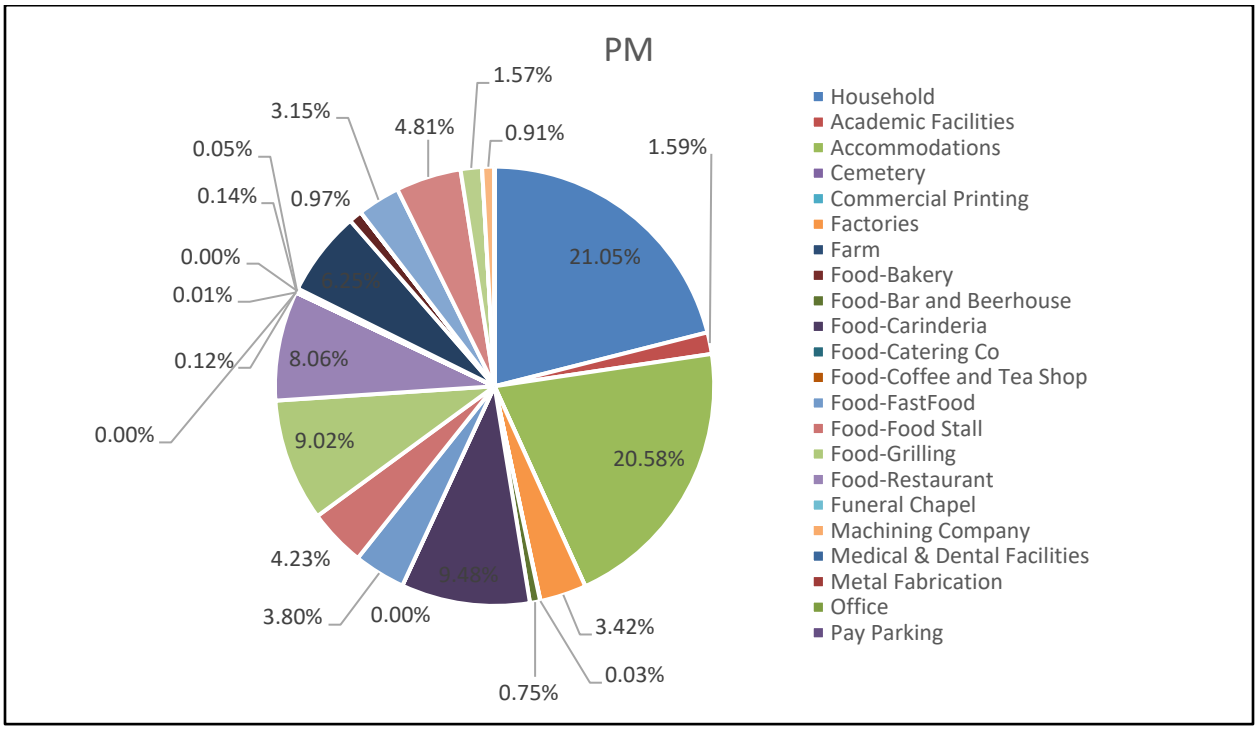
i. According to criteria pollutant (PM, CO, NO_x, SO_x, and VOC)



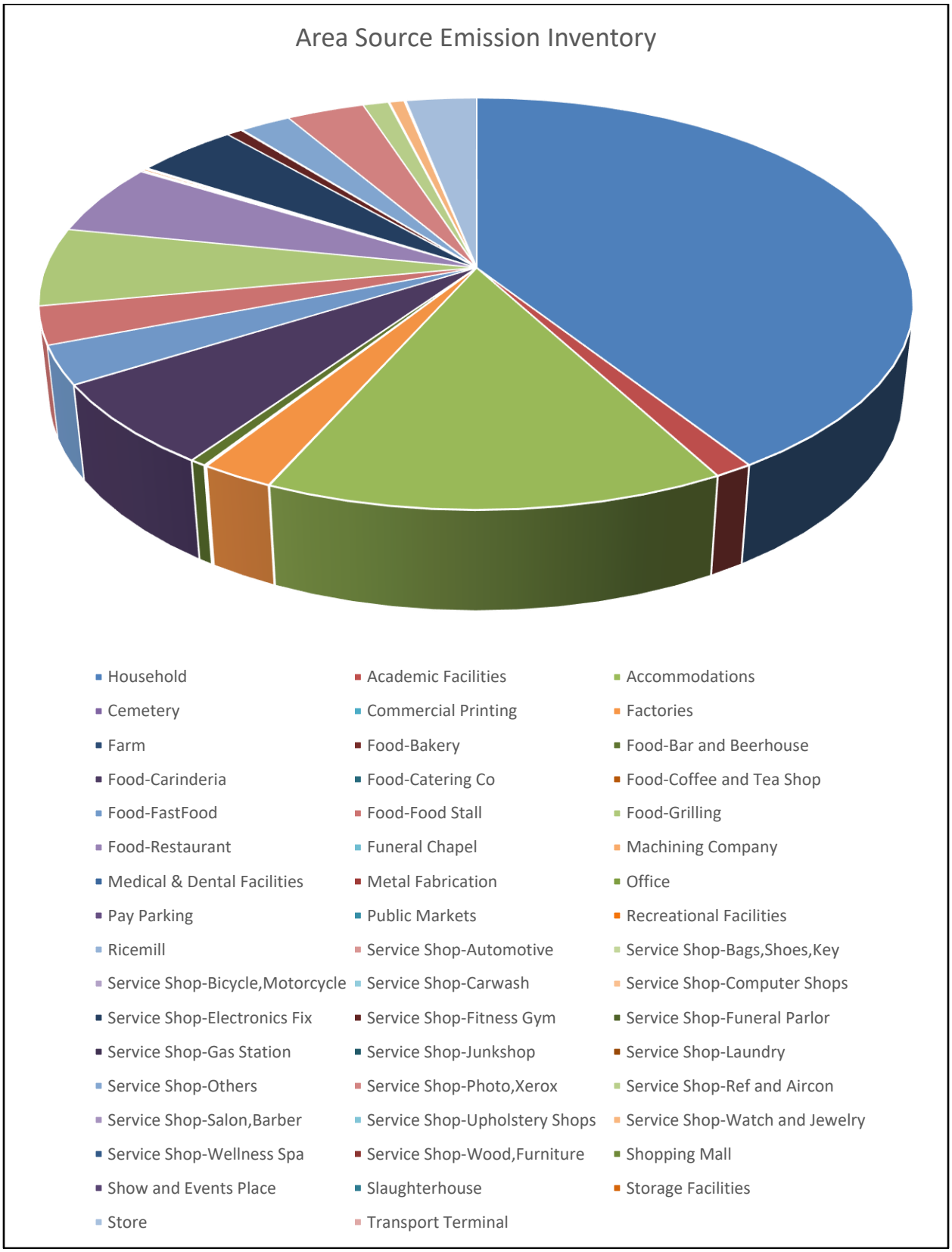

NOx
0.62%
2.15%
1.07%
0.08%
0.66%
3.28%
0.09%
4.27%
42.44%
0.26%
6.06%
6.24%
2.97%
3.69%
0.05%
6.67%
0.53%
0.15%
0.02%
2.35%
14.80%
1.43%
Household
Academic Facilities
Accommodations
Cemetery
Commercial Printing
Factories
Farm
Food-Bakery
Food-Bar and Beerhouse
Food-Carinderia
Food-Catering Co


SOx
0.89%
3.11%
1.55%
1.65%
4.74%
0.01%
0.96%
19.98%
0.14%
6.17%
8.21%
9.13%
20.82%
4.61%
4.15%
9.61%
3.46%
0.76%
0.03%
0.02%
Household
Academic Facilities
Accommodations
Cemetery
Commercial Printing
Factories
Farm
Food-Bakery
Food-Bar and Beerhouse
Food-Carinderia
Food-Catering Co
Food-Coffee and Tea Shop

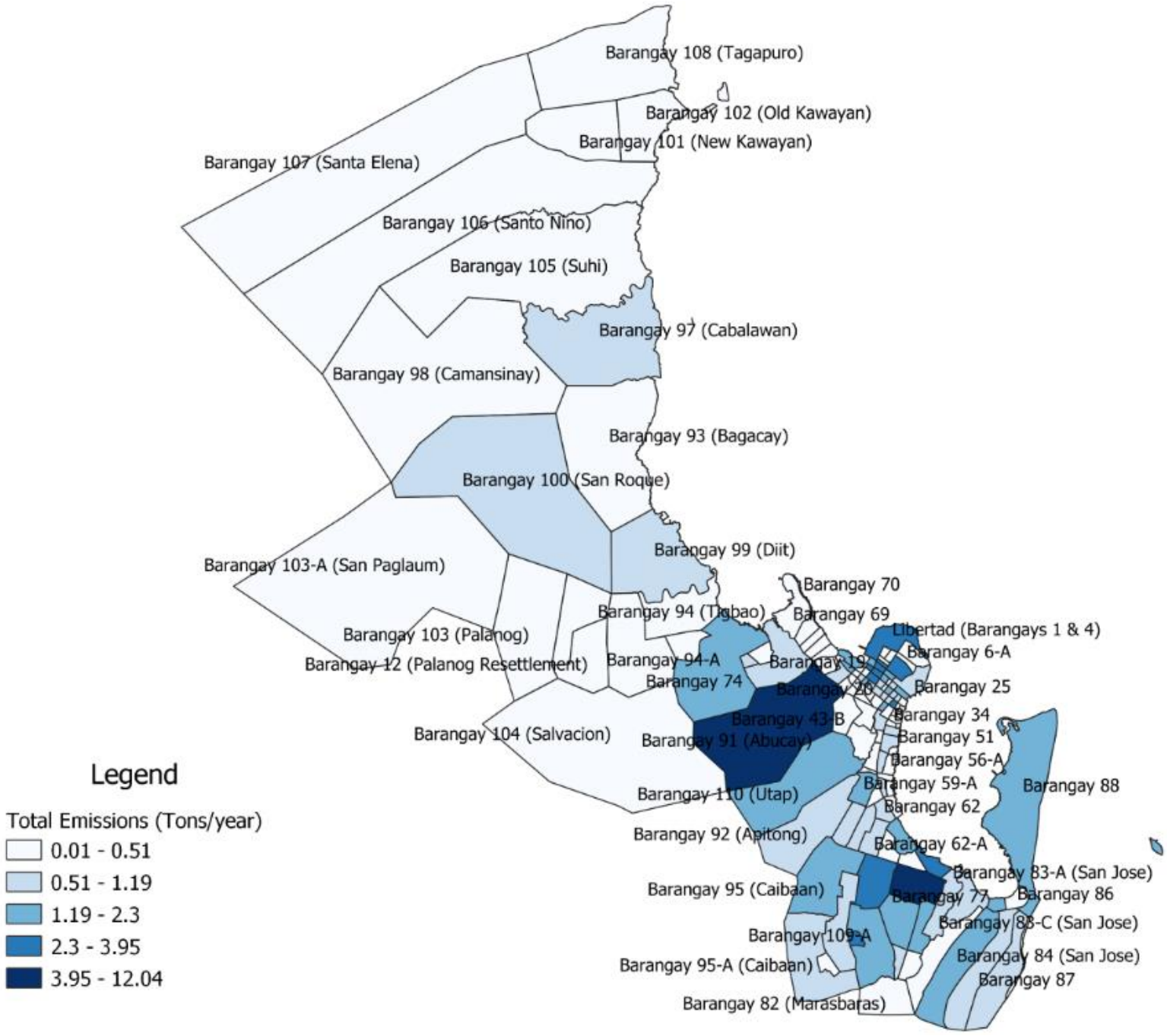

NMVOC
0.09%
0.05%
0.05%
0.01%
1.43%
0.02%
0.08%
15.43%
22.20%
0.79%
0.00%
0.25%
4.18%
1.37%
2.74%
0.08%
5.43%
15.93%
0.06%
0.84%
5.70%
0.05%
6.30%
0.32%
0.01%
6.61%
0.09%
0.01%
0.12%
0.01%
2.37%
0.10%
0.21%
2.95%
0.00%
0.11%
0.04%
0.02%
0.11%
0.22%
3.06%
0.54%
0.02%
Household
Academic Facilities
Accommodations
Cemetery
Commercial Printing
Factories
Farm
Food-Bakery
Food-Bar and Beerhouse
Food-Carinderia
Food-Catering Co
Food-Coffee and Tea Shop
Food-FastFood
Food-Food Stall
Food-Grilling
Food-Restaurant
Funeral Chapel
Machining Company
Medical & Dental Facilities
Metal Fabrication
Office


PM
1.57%
3.15%
4.81%
0.91%
0.05%
1.59%
0.14%
0.97%
21.05%
0.00%
0.01%
8.06%
0.12%
0.00%
9.02%
20.58%
4.23%
9.48%
3.80%
0.00%
3.42%
0.03%
0.75%
Household
Academic Facilities
Accommodations
Cemetery
Commercial Printing
Factories
Farm
Food-Bakery
Food-Bar and Beerhouse
Food-Carinderia
Food-Catering Co
Food-Coffee and Tea Shop
Food-FastFood
Food-Food Stall
Food-Grilling
Food-Restaurant
Funeral Chapel
Machining Company
Medical & Dental Facilities
Metal Fabrication
Office
Pay Parking

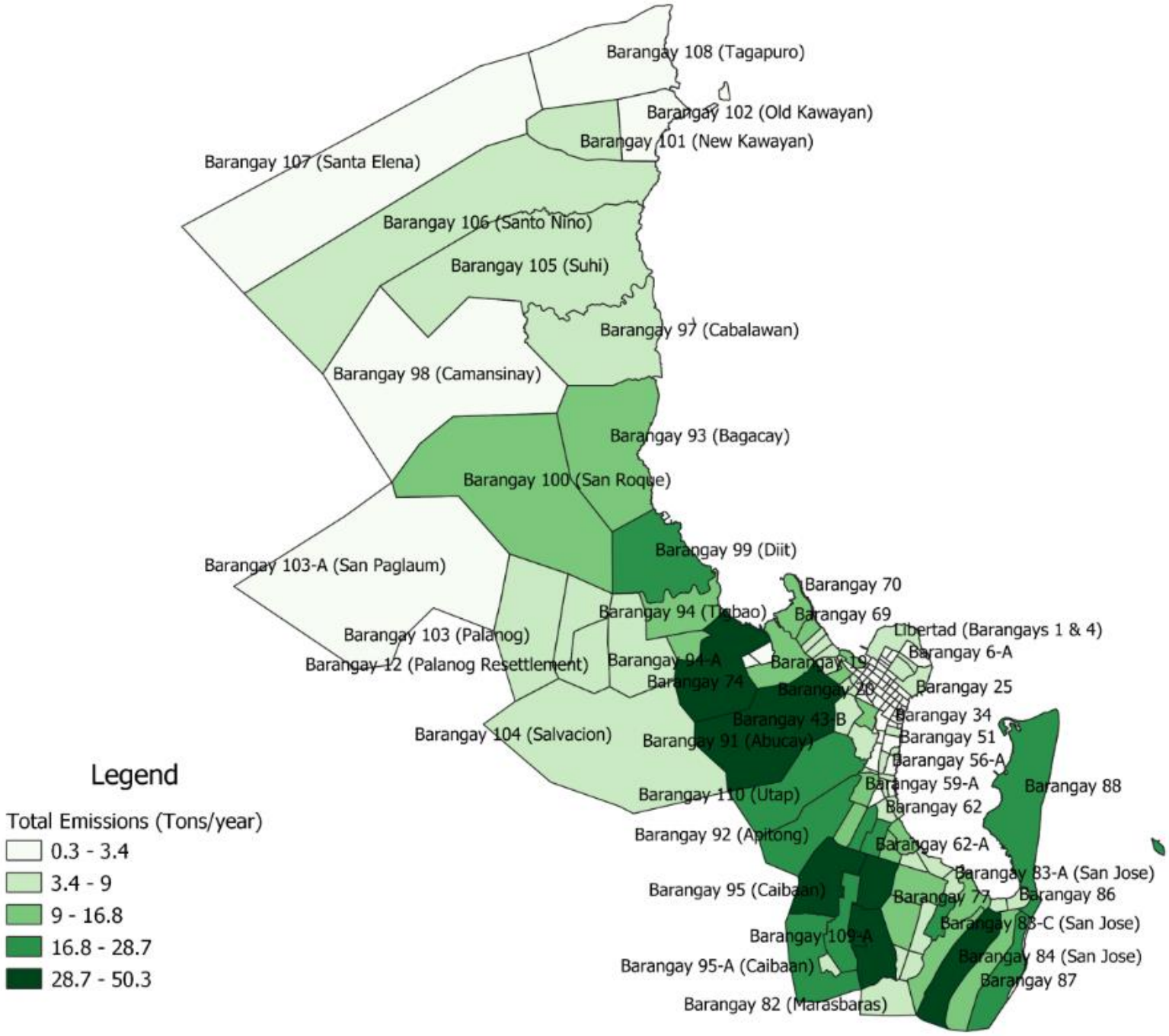
ii.According to Area Sources



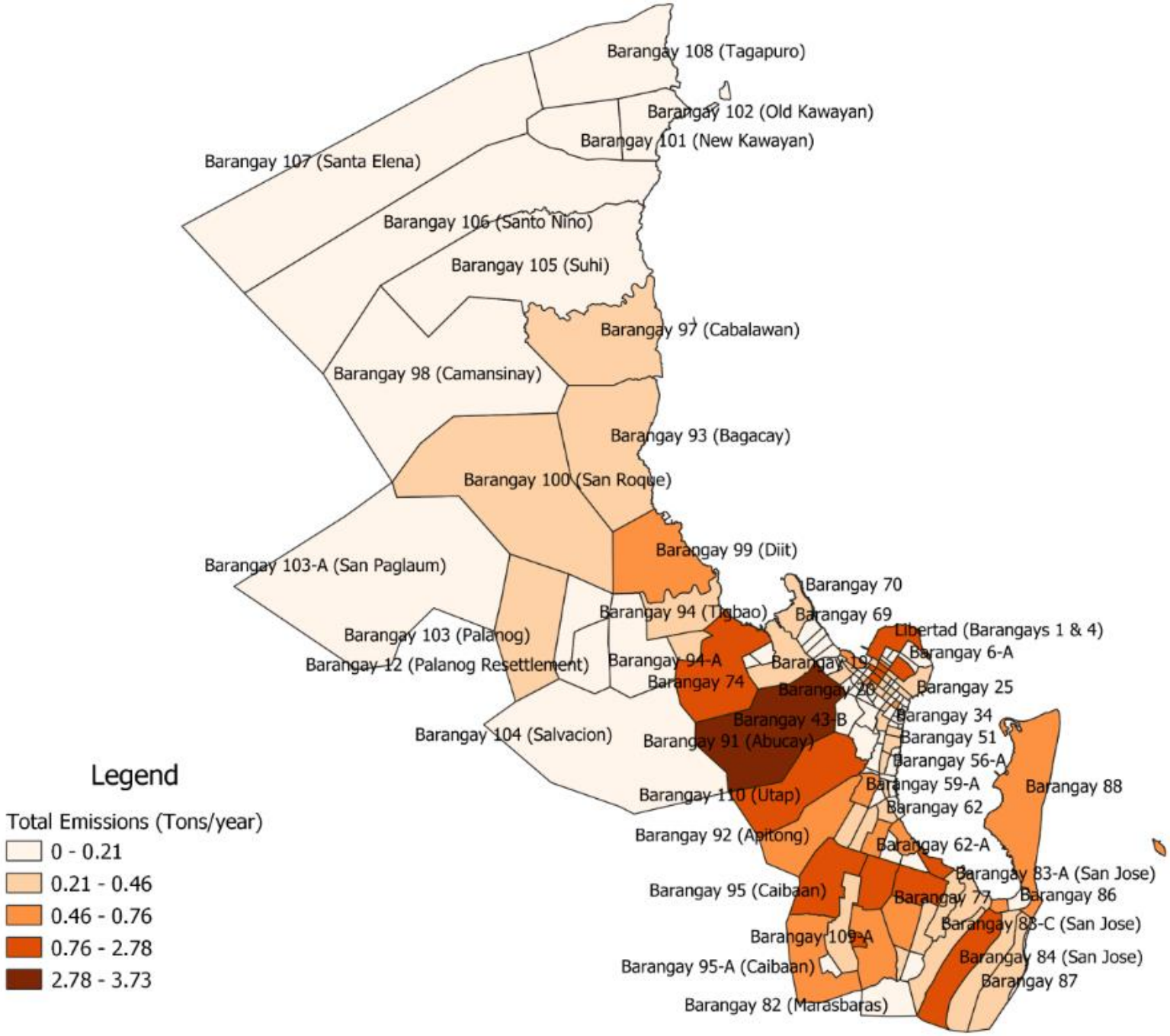
SPATIAL DISTRIBUTION OF PARTICULATE MATTER (PM) FOR AREA SOURCES



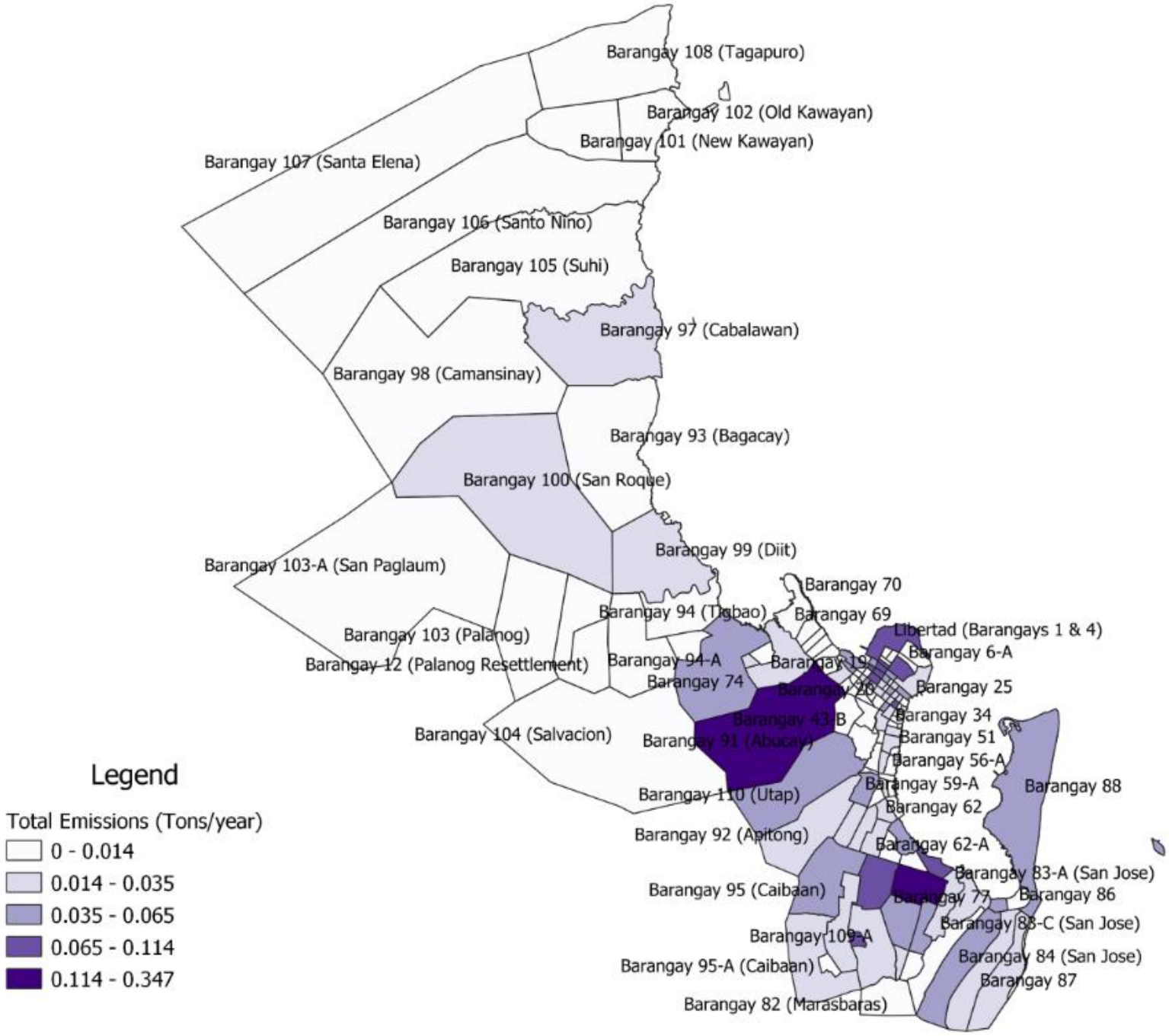
SPATIAL DISTRIBUTION OF CARBON MONOXIDE (CO) FOR AREA SOURCES



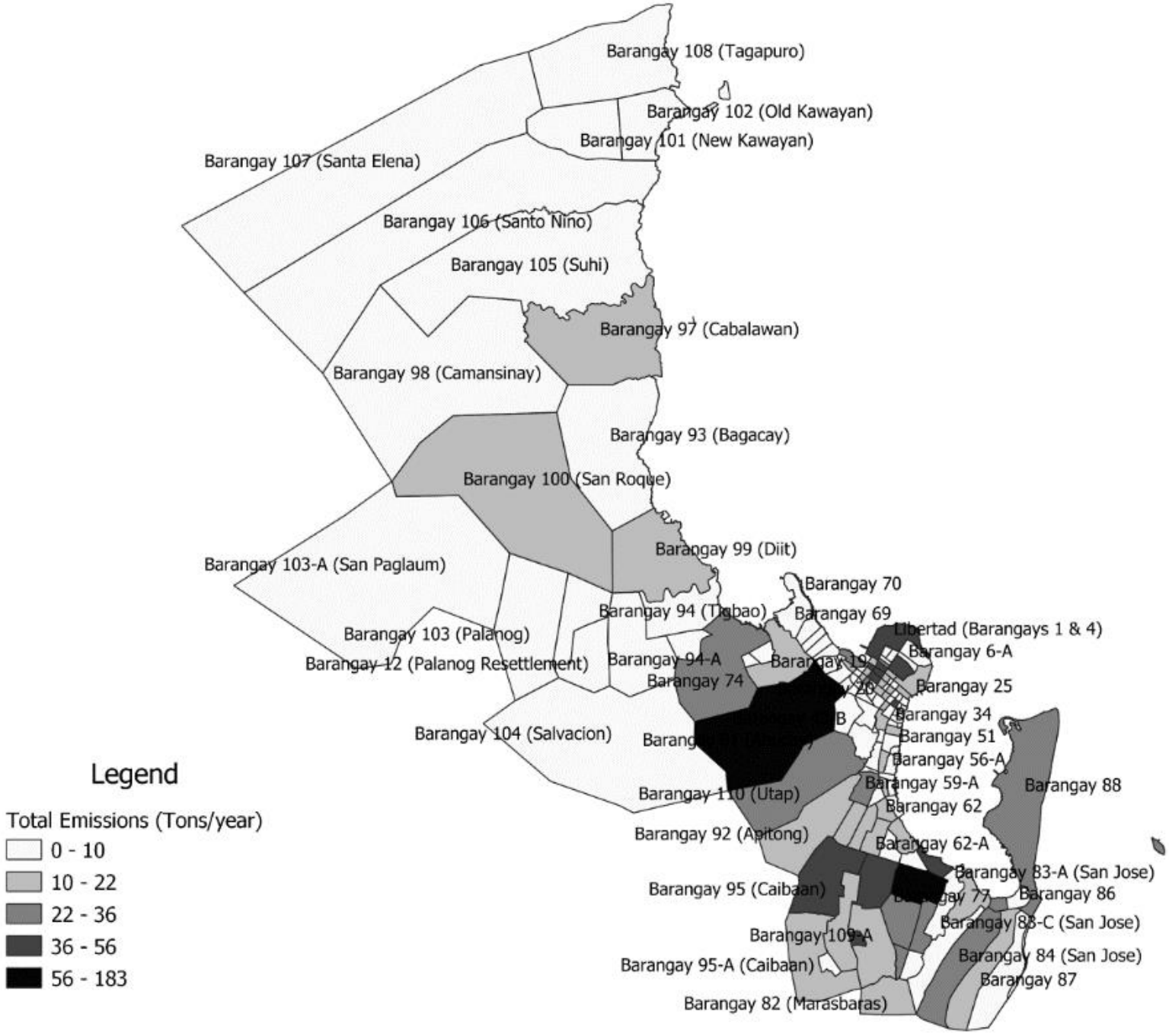
SPATIAL DISTRIBUTION OF NITROGEN OXIDES (NOx) FOR AREA SOURCES



SPATIAL DISTRIBUTION OF SULFUR OXIDES (SOx) FOR AREA SOURCES



SPATIAL DISTRIBUTION OF VOLATILE ORGANIC COMPOUND (VOC) FOR AREA SOURCES



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IV. SOME USEFUL FIGURES

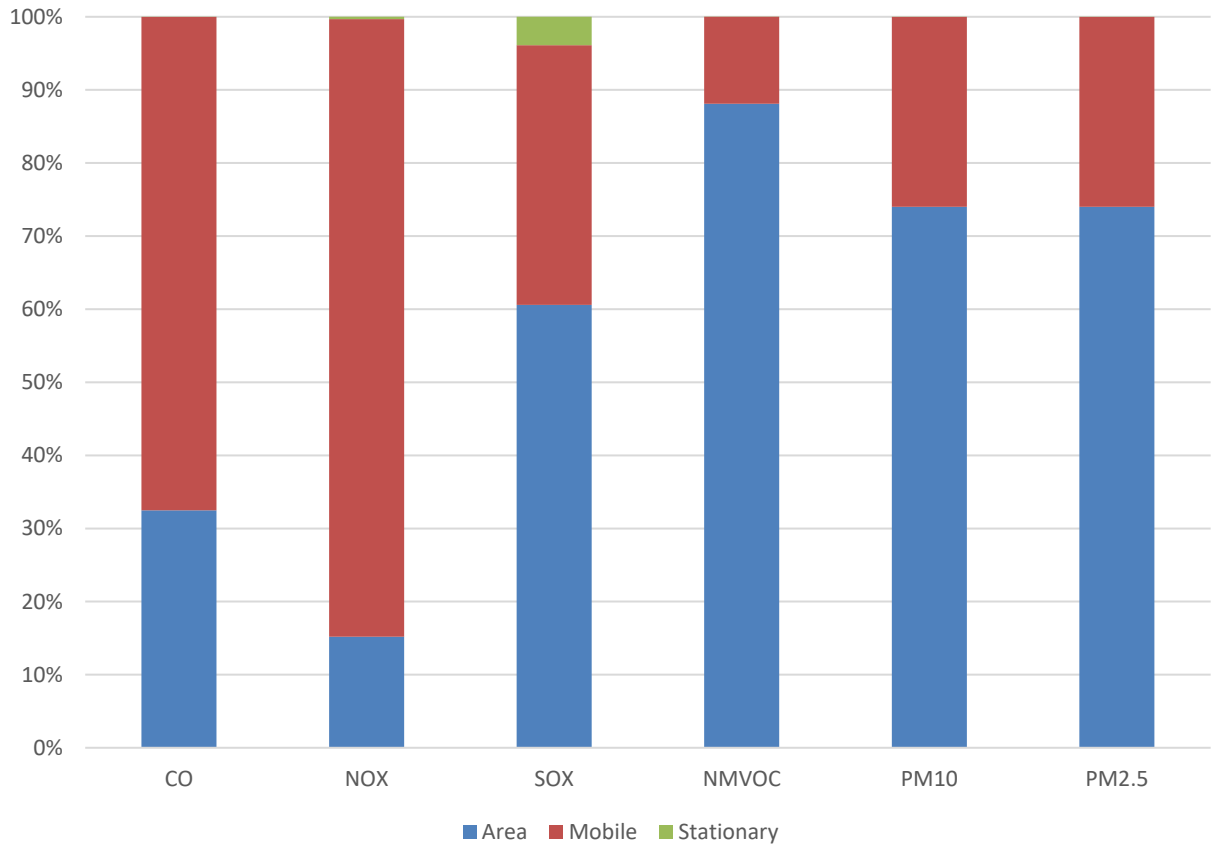


Figure IV.1 Mobile sources dominate CO and NOx emissions while area sources contribute most of the SOx, NMVOC, PM10 and PM2.5 emissions in Tacloban.

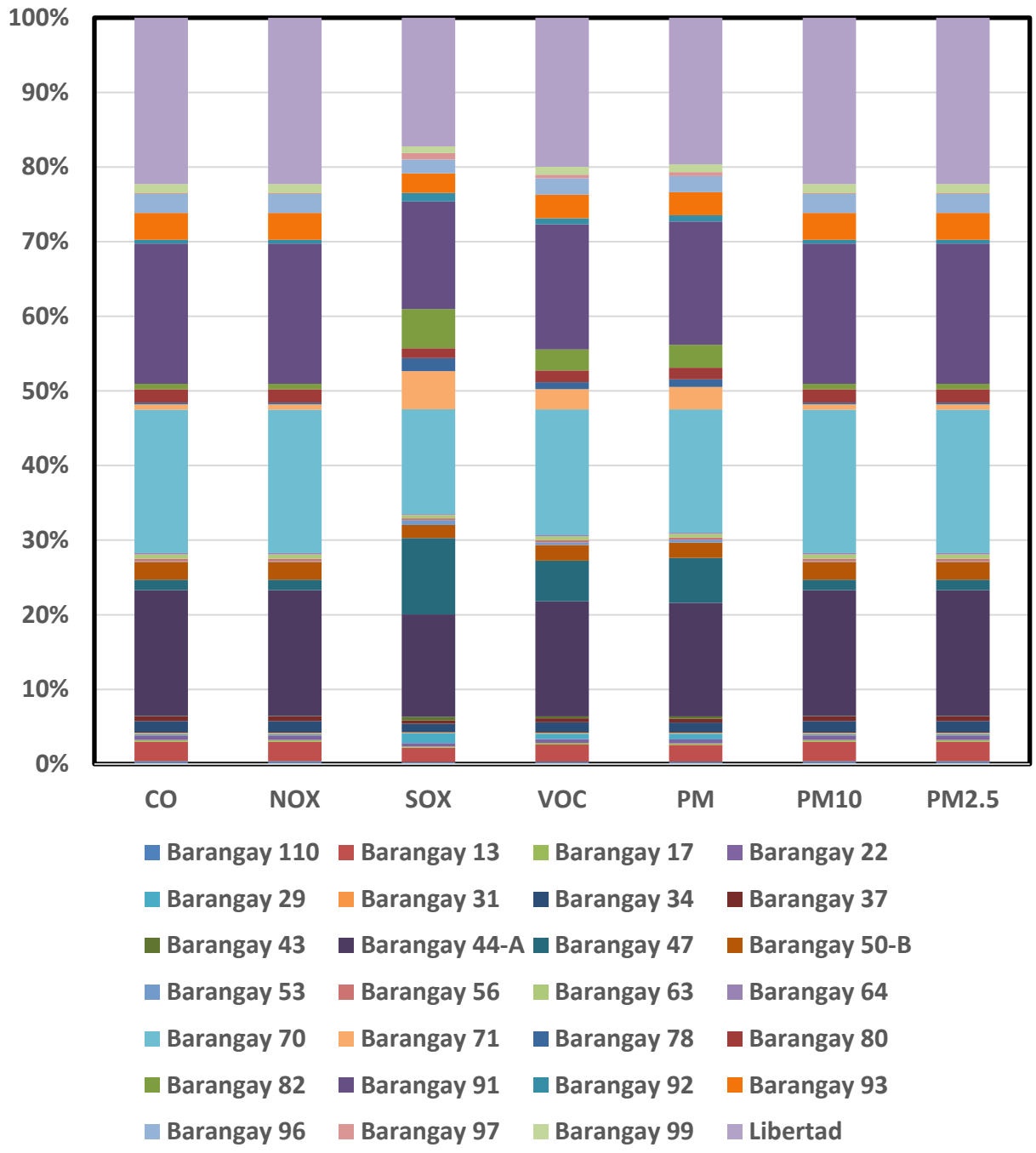


Figure IV.2 Genset Emissions

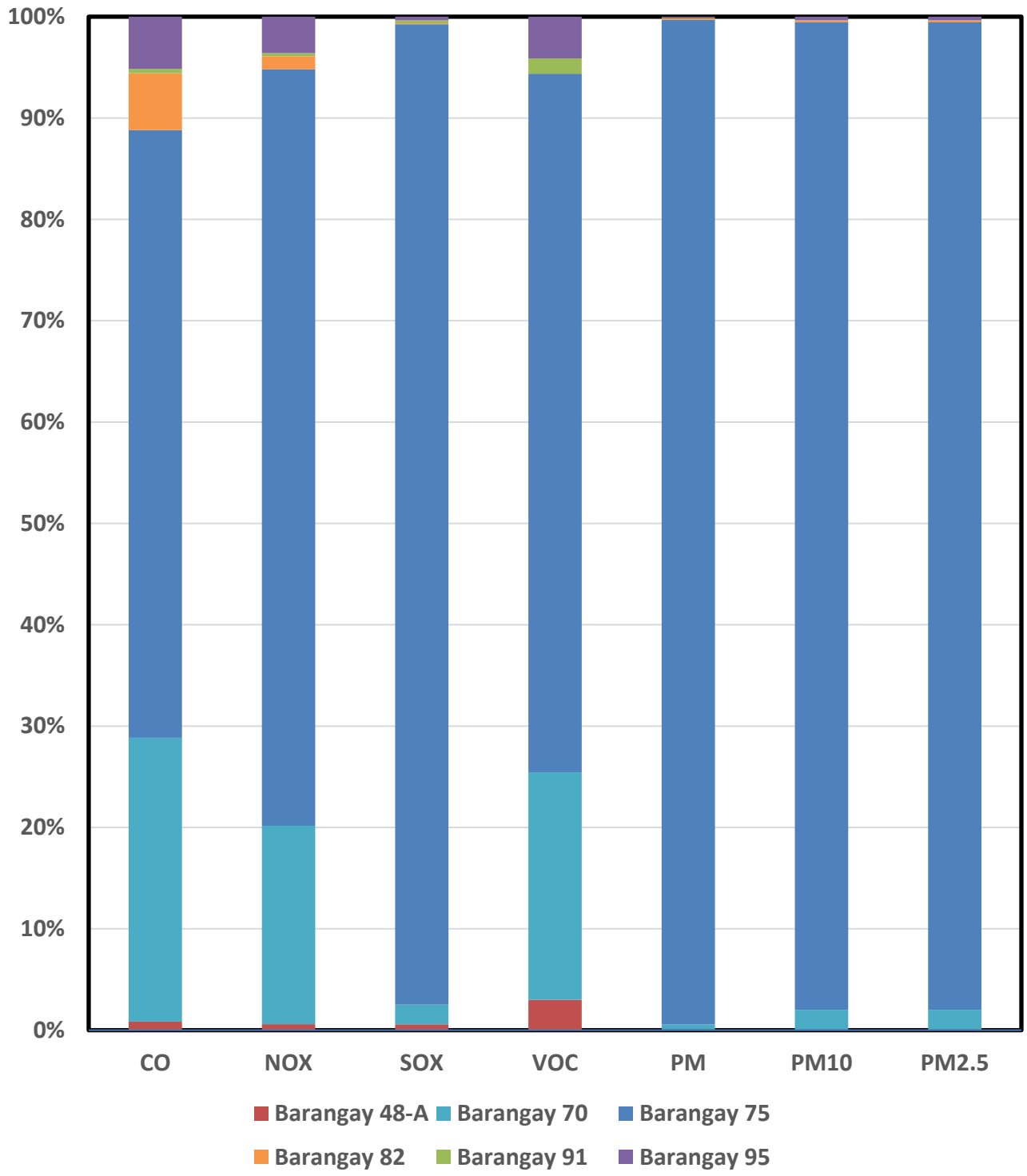


Figure IV.3 Boiler and other Point Source Emissions

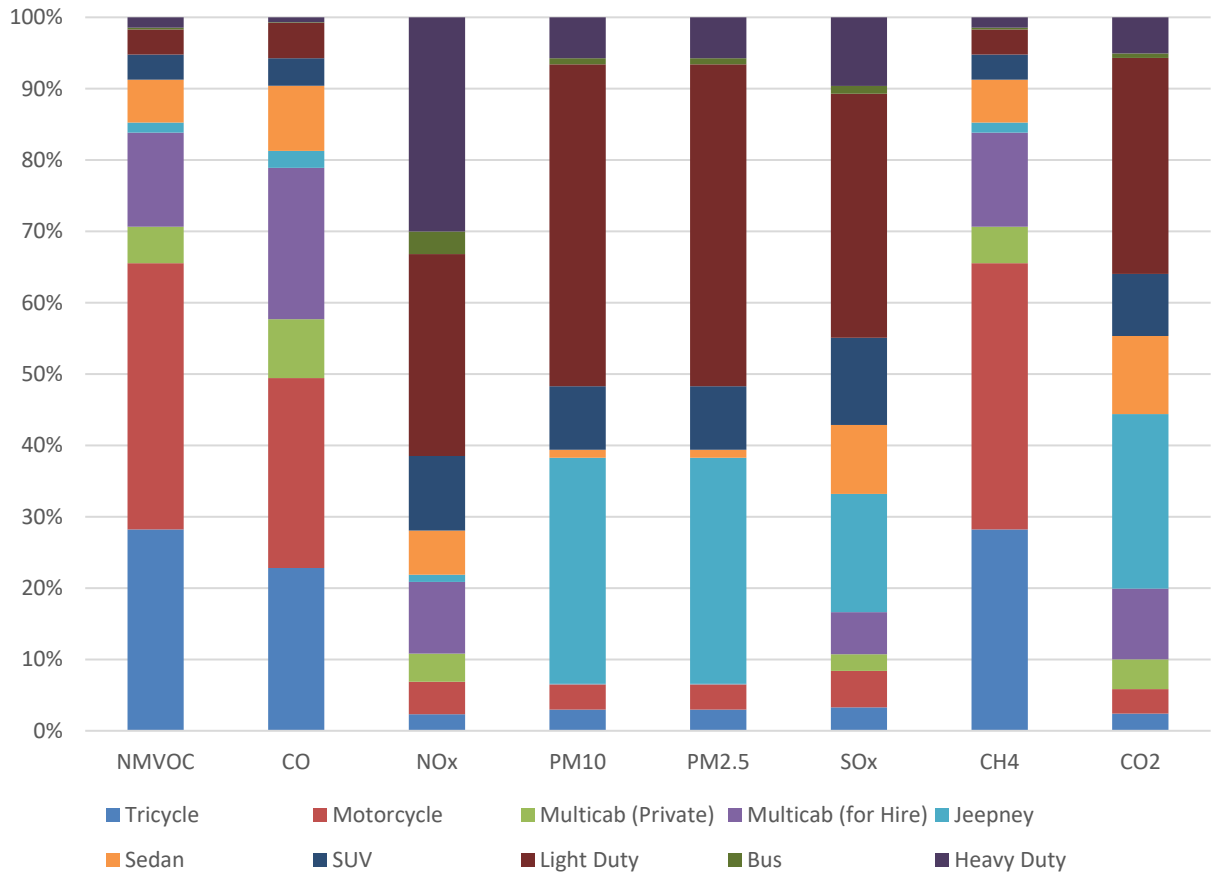


Figure IV.4 Mobile Emissions Share per Vehicle

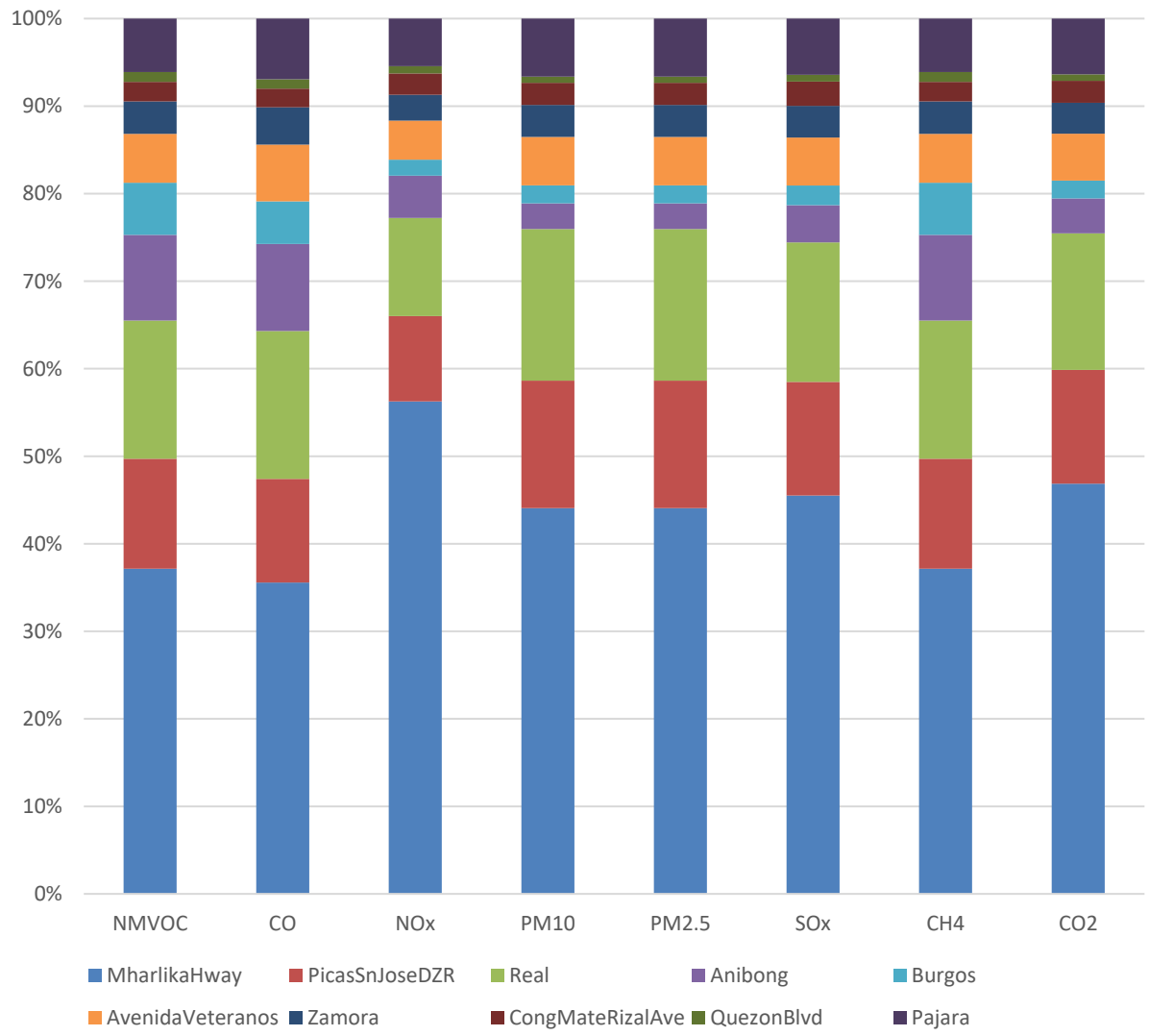


Figure IV.5 Mobile Emissions Share by Major Road

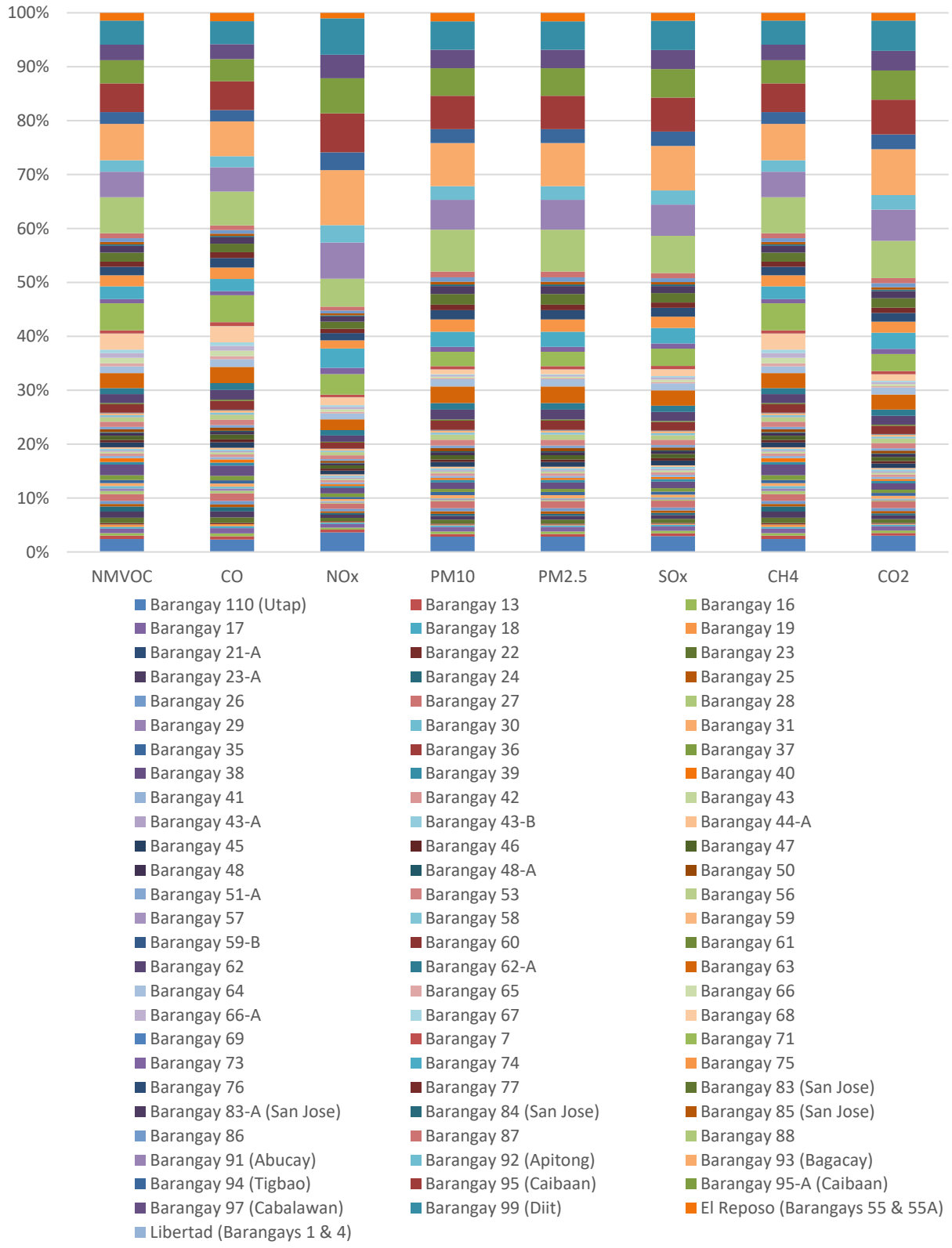
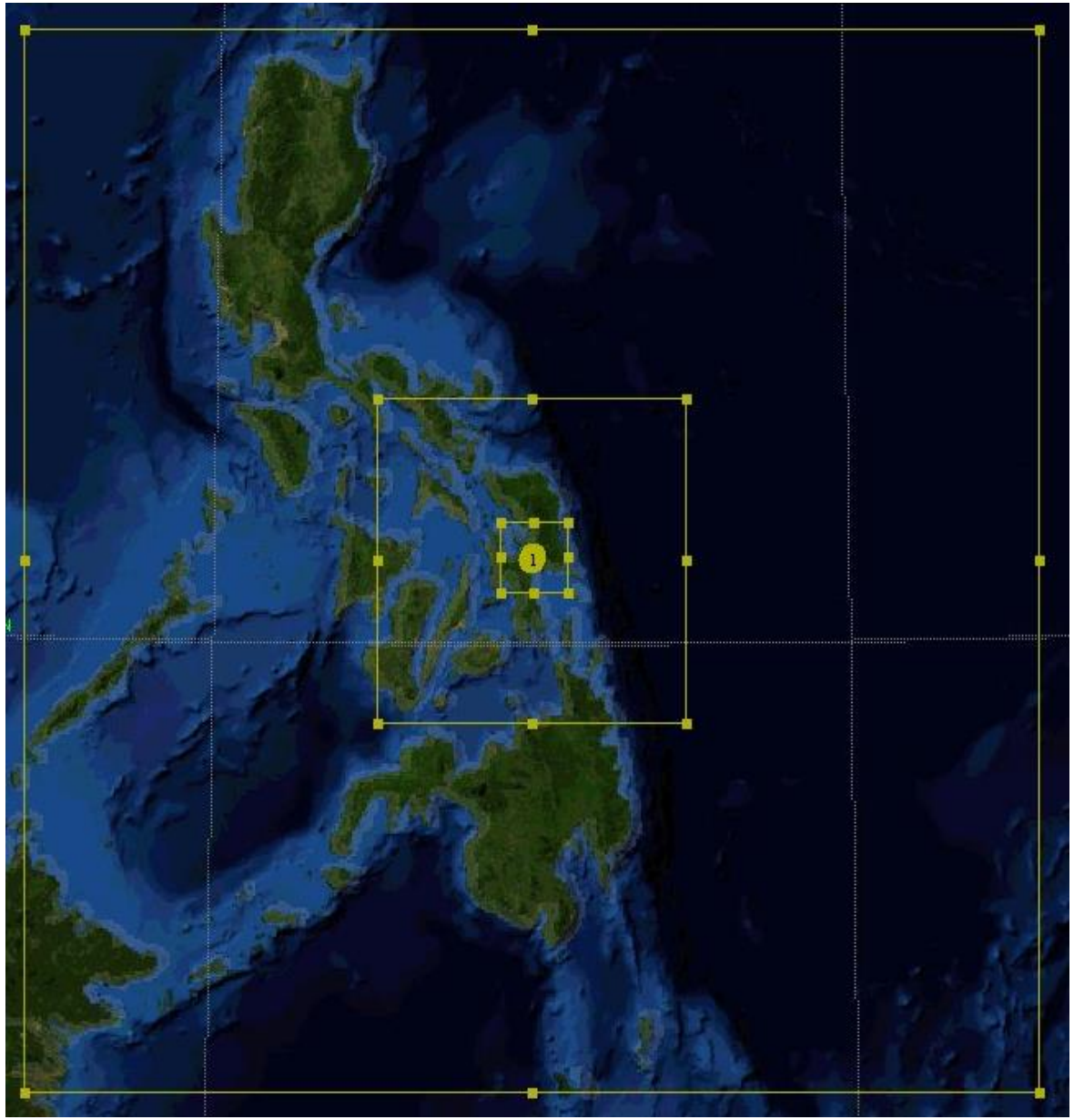


Figure IV.6 Mobile Emissions per Barangay

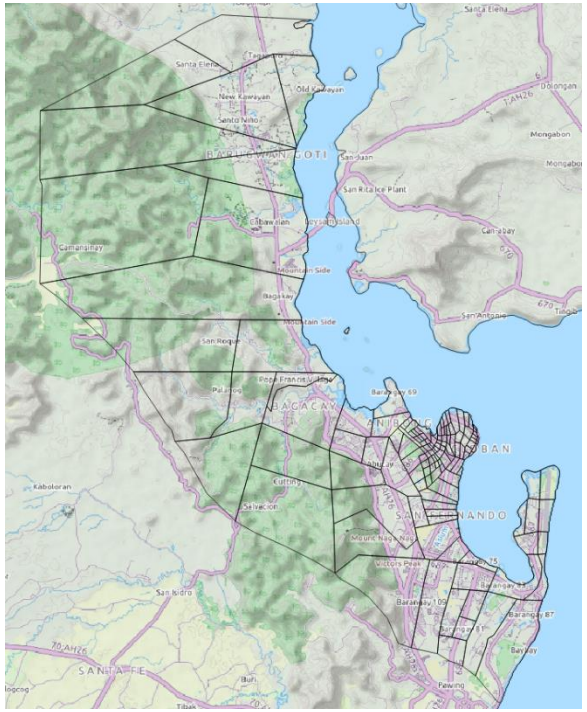
Pollution Dispersion Modeling (WRF-Chem)

Domains	Domain 1	Domain 2	Domain 3
Horizontal Resolution	25 km	5 km	1 km
Vertical Resolution	51 levels	51 levels	51 levels
Grid Points West-East	70	106	116
Grid Points South-North	70	106	116
Center Latitude	11.254°N		
Center Longitude	124.962°E		

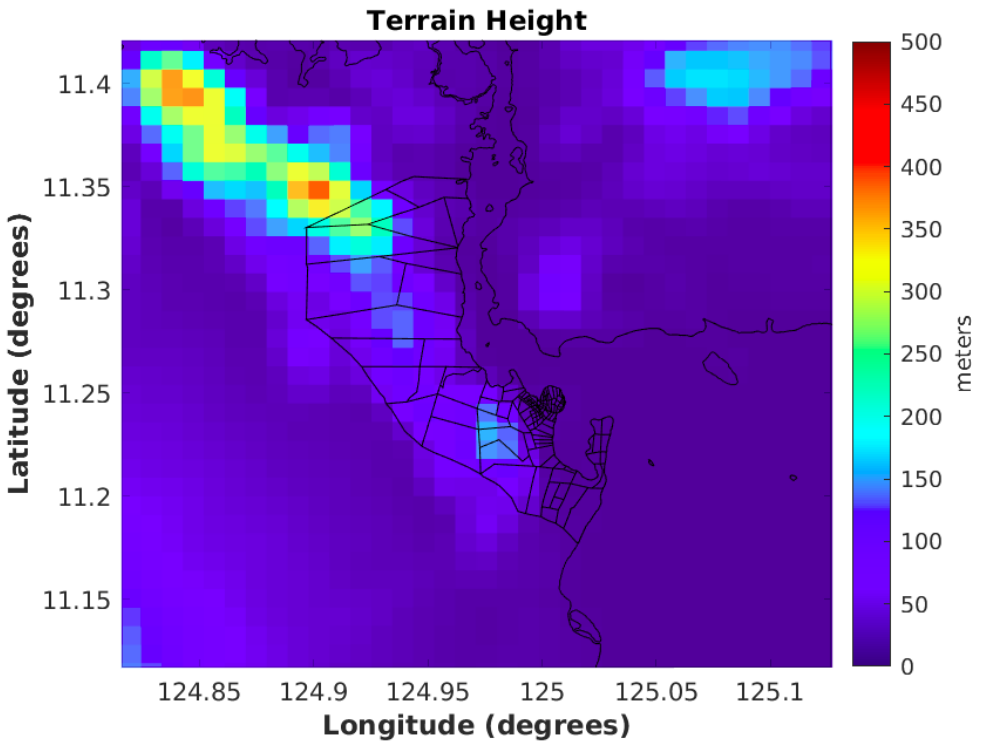


Pollution Dispersion Modeling

(a)



(b)

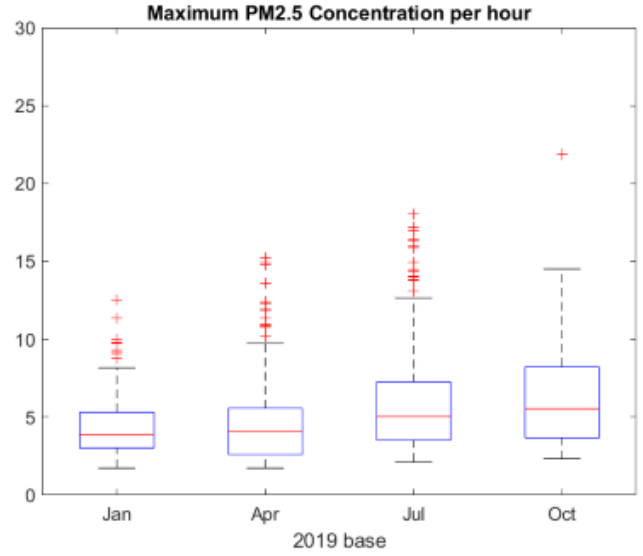


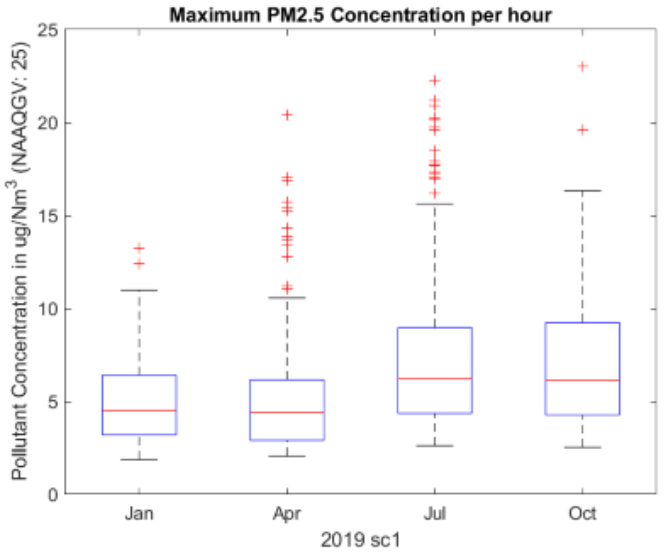
(c)

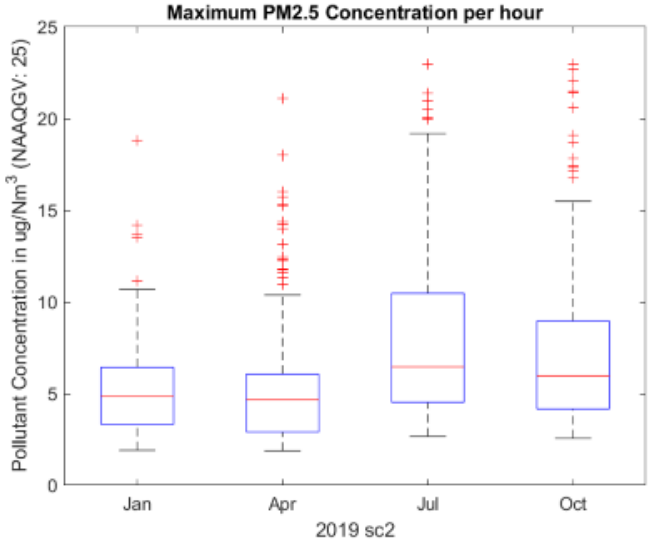
Figure 2 (a) Shapefile of Tacloban Airshed, (b) Topography, and (c) Elevation Map

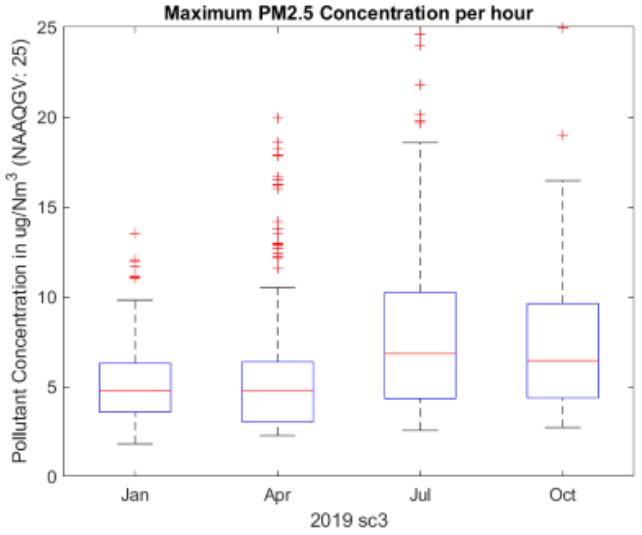
ADM Results using the obtained Emissions Inventory

Baseline and Scenario for Maximum PM2.5

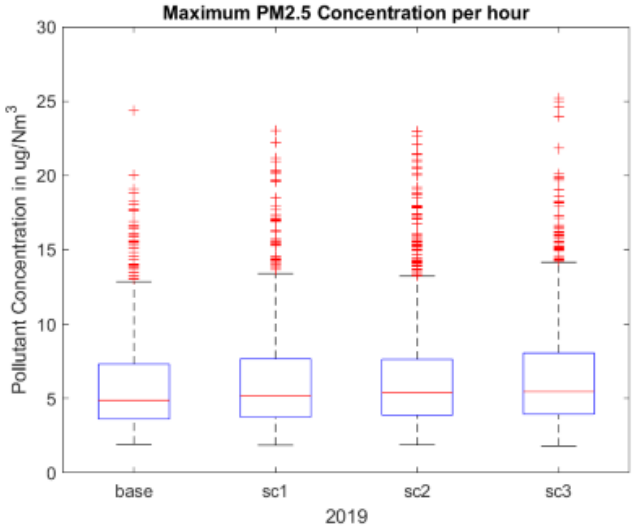


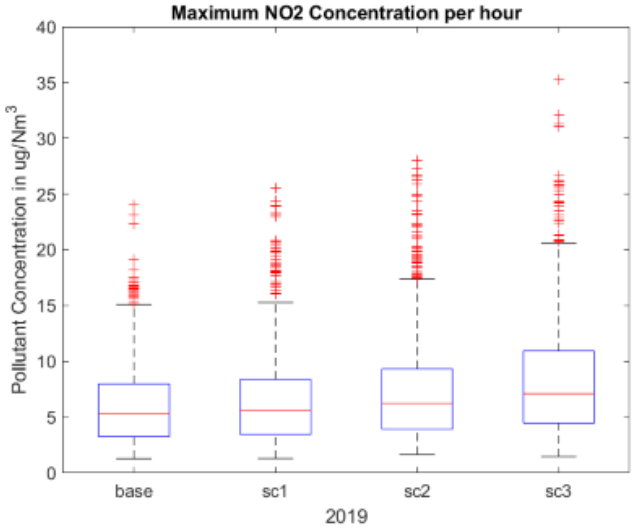


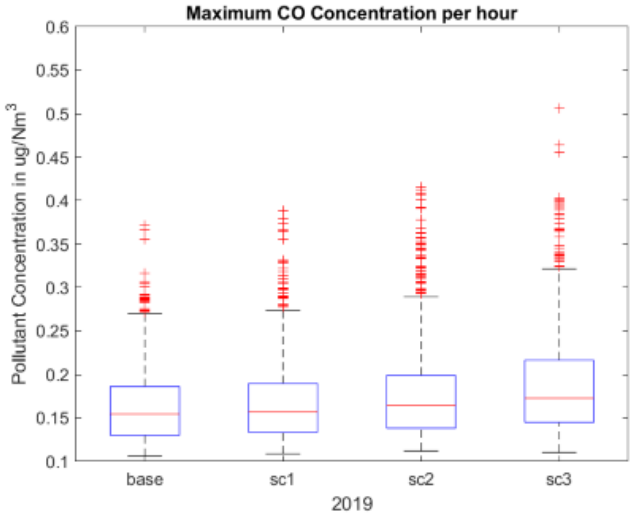


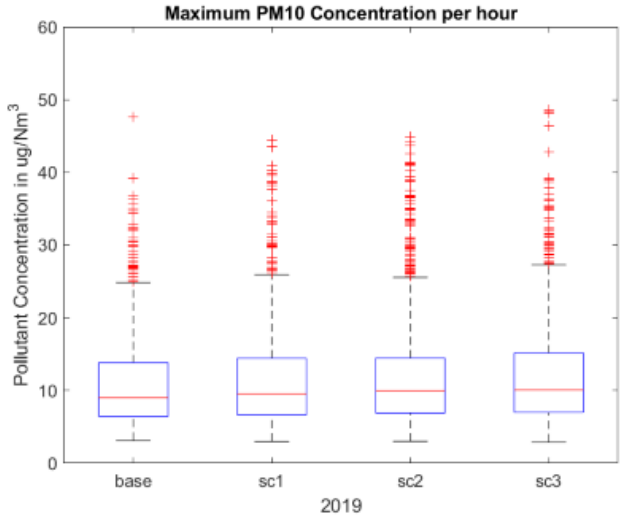


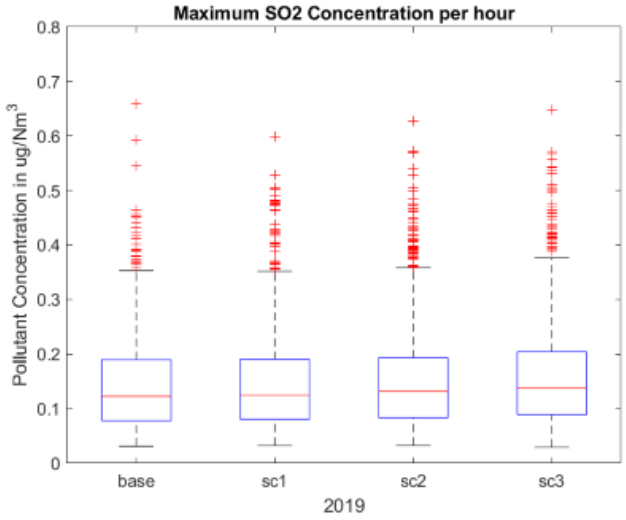
Ambient Pollutant Concentrations in Tacloban City for Different Scenarios (**Annual Average**)











Baseline PM2.5

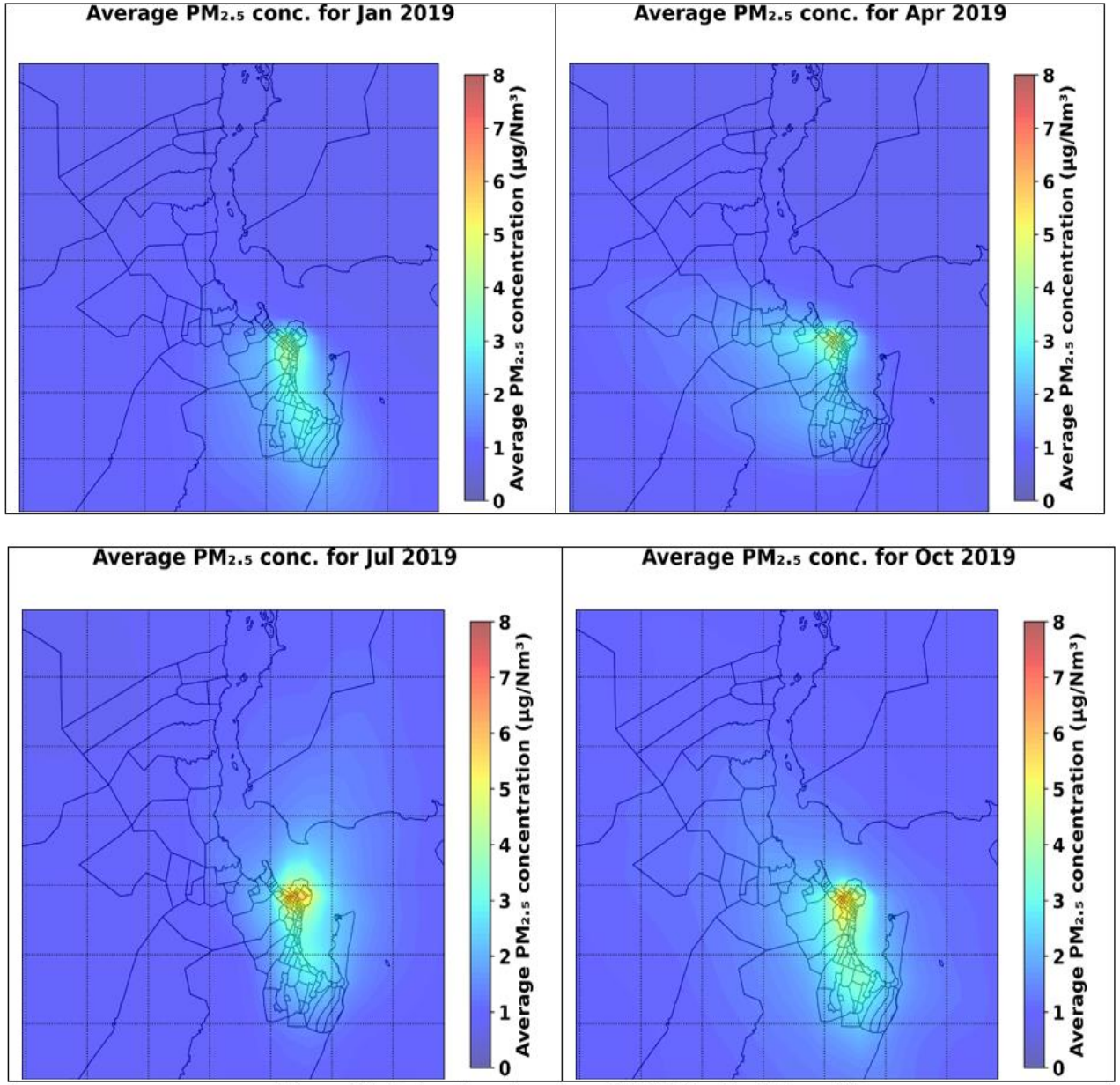


Figure IV.6 Baseline Average PM2.5 for Tacloban City

PM2.5 Sc3 (50% inc. vehicles)

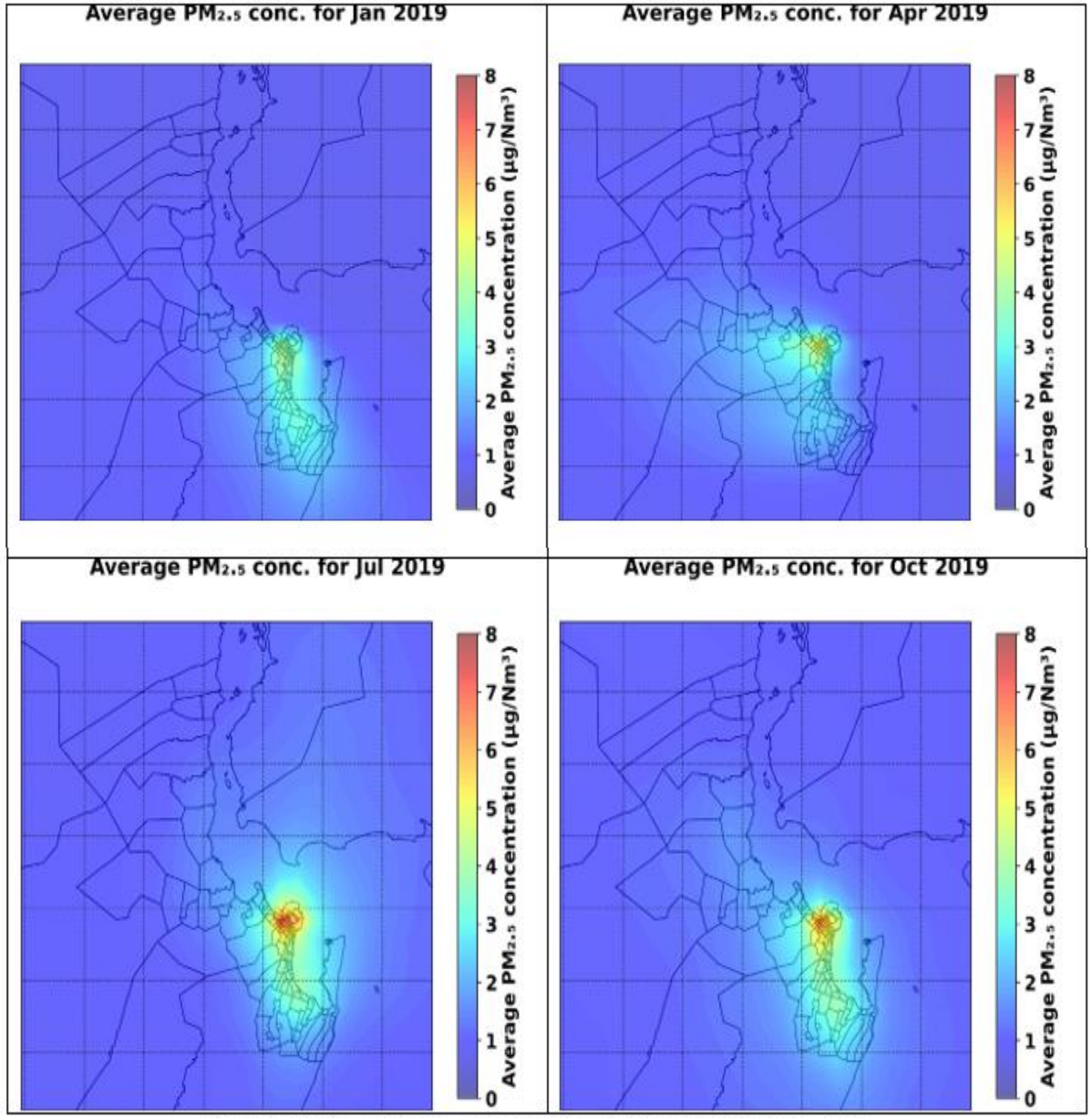


Figure IV.9 Scenario 3 – 50% increase in mobile: Average $PM_{2.5}$

Carrying Capacity of Tacloban Airshed

Pollutant	Area	Stationary	Mobile (Baseline)
CO	32.48%	0.01%	67.52%
NO_x	15.19%	0.32%	84.48%
SO_x	61.29%	3.23%	35.48%
NMVOC	88.11%	0.00%	11.89%
PM_{10}	73.99%	0.01%	26.01%
$PM_{2.5}$	74.00%	0.00%	25.99%