SDN

Dirty fuel

An analysis of official and unofficial petroleum products in the Niger Delta

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Executive summary

This research compares differences in the standards of, and emissions from, official fuels in licensed filling stations, and unofficial fuels produced by artisanal oil refineries across Bayelsa and Rivers states.

The analysis aims to improve upon current levels of evidence and understanding around some of the impacts of consuming these fuels on air pollution, health, and damage to engines and generators. Field researchers collected 91 unofficial and official fuel samples to establish the quality of fuel produced by artisanal refiners, in comparison to fuel available at filling stations and international standards. Samples of official and unofficial fuel were obtained in Bayelsa and Rivers states, and control samples of official fuels were collected in Lagos.

The findings of this research are cause for serious concern, particularly the very high sulphur concentrations across unofficial and official fuel supplies in the Niger Delta The samples analysed suggest a low standard of fuel is on offer in the Niger Delta, likely leading to high levels of emissions, serious health impacts, and increased vehicle and generator maintenance costs to consumers. Those handling products in artisanal refineries are also potentially exposed to serious health risks.

We hope that this analysis motivates governments, commodity institutions, and the oil industry to regulate fuel content and emissions across the petroleum sector in Nigeria.

Key findings

Total Petroleum Hydrocarbons (TPH)

A hydrocarbon composition analysis provided a detailed breakdown of the relative abundance of different hydrocarbon chain lengths in the fuel samples. Chain lengths are important as they determine fuel density and viscosity, which impacts combustion and performance.

For example, diesel oil typically contains a high abundance of carbon chains between 8 and 21 carbon atoms per molecule, gasoline (petrol) between 4 and 12, and kerosene between 6 and 16. Engines are calibrated to consume a particular type and quality of fuel. If the fuel supply has an unexpected density or viscosity, or high levels of e.g. sulphur, it will adversely affect engine performance. This can cause high maintenance costs and pollutant emissions.

All fuel samples (official and unofficial) were generally found to be more viscous (thicker) than benchmark fuels. The higher viscosity hampers an engine's ability to convert fuel into droplets before combustion. This tends to be caused by refining crude without an adequate purification process (catalysts and chemicals) to remove unwanted hydrocarbons. Whilst this was expected in unofficial fuels, it was surprising to find in officially refined fuel samples. These viscous fuels will have a higher risk of causing fuel injector damage, poor engine performance, and incomplete combustion, leading to excess particulate residue in engines and higher pollutant emissions, with likely serious impacts on human health due to exposure to higher levels of pollution.

Gasoline

Official samples tended to have higher viscosities than unofficial samples from the Niger Delta. This reflects the general consumer perception that gasoline is the best product artisanal refineries produce. Official Lagos gasoline contained the highest concentrations of short carbon-chains compared to official Niger Delta gasoline, suggesting variability in the standard of official imported fuel.

Diesel

Both unofficial and official samples were found to be of a poor standard, generally containing lower concentrations of diesel-specific carbon chain lengths and high concentrations of longer carbon chain lengths that increase fuel viscosity, reduce combustion performance, and increase engine maintenance costs. However, the high viscosity of unofficial diesel is often seen as an advantage by consumers, because it burns slower and lasts longer.

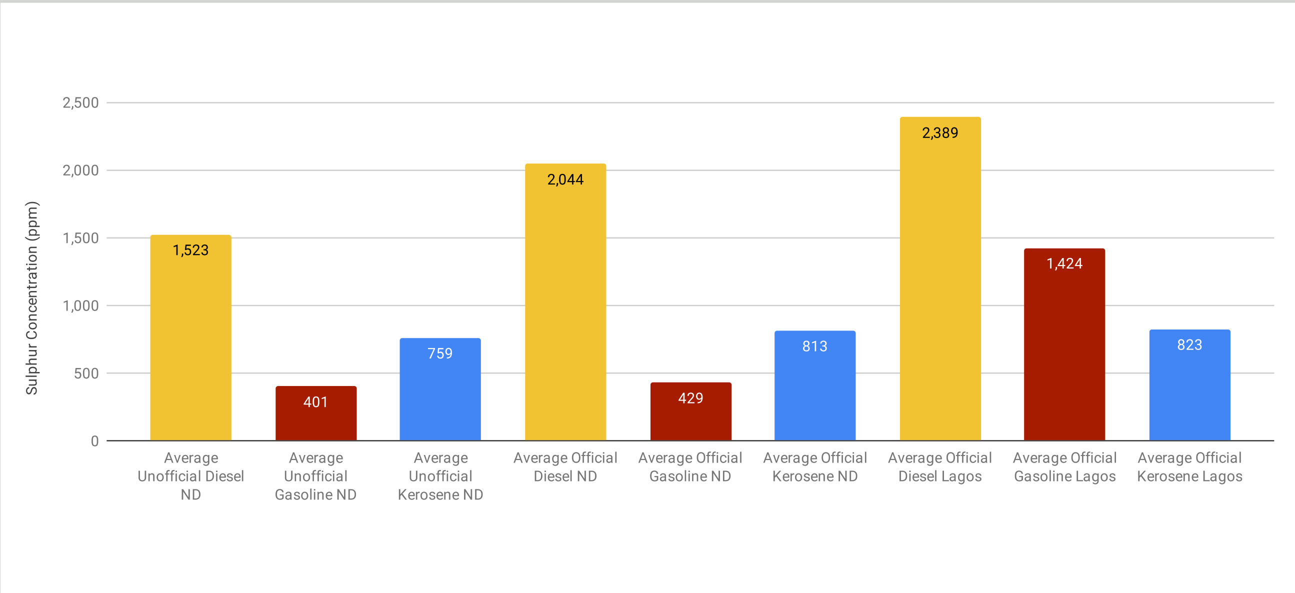
Kerosene

Official samples were of a higher standard than the unofficial samples, the latter of which contained an abundance of longer chain hydrocarbons resulting in higher viscosity fuels. This indicates artisanal camps face challenges achieving a pure kerosene product. Kerosene is a major household source of energy in the Niger Delta, especially in rural areas, but official sources often run out. Therefore, consumers can tolerate lower quality kerosene, so long as it is available, which creates demand for the artisanal refiners to fulfil. Niger Delta official samples, on average, were better than their Lagos counterparts.

Sulphur and particulate emissions

High sulphur concentrations in fuels result in high emissions of particulate matter and sulphur oxides, which are a major source of visible air pollution, 'smog' or 'soot'. Over the past four years, soot in urban areas, especially Port Harcourt city, has reached extremely hazardous levels, increasing the likelihood of serious health issues for the local population.

Average fuel sulphur concentrations for unofficial and official samples collected in the Niger Delta and Lagos



The average official diesel sample contained 204 times more than European Union (EU) fuel sulphur standards and 43 times the level for gasoline. While the average unofficial diesel sample contained 152 times more EU sulphur standards and 40 times the level for gasoline.

Therefore, all fuels had high sulphur content, particularly diesel. Official fuels collected in Lagos had the highest sulphur content, while unofficial fuels in the Niger Delta had the least. Additional research is needed to understand why official Niger Delta samples had a lower sulphur content than Lagos—it could be a result of higher quality imports, or due to blending with lower sulphur unofficial products.

Artisanal fuel refineries are supplied by pipelines carrying local 'Bonny Light' crude, which is 'light' in sulphur, compared to the 'heavy' sulphur crude oil options available to international refineries at a cheaper price. Therefore, unofficial fuels were expected to have low sulphur levels. A few anomalies with high sulphur levels in the unofficial samples suggest that some artisanal refineries may be experimenting with high sulphur performance boosting additives.

Levels recorded in official fuels are significantly above the maximum levels of sulphur that vehicle emission reduction technologies can function at. Therefore, even the latest vehicles are likely to be very high emitters of pollutants as a result of the fuel they are consuming. This finding presents a challenge for policy makers, because without enforcement of regulations, consuming official fuel will continue contributing more to air pollution than unofficial fuel.

For official fuel, this seems to substantiate allegations from a Public Eye investigation in 2016 and a Dutch Government report in 2018, that international refineries and commodity brokers are selling dirty fuel containing very high levels of sulphur into unregulated West African markets causing significant particulate pollution, infrastructure damage, and adverse health impacts for local populations. For unofficial fuel, being refined illicitly in artisanal refineries in the Niger Delta, samples with high sulphur levels potentially suggests experimentation with new techniques to produce competitive fuel, which may be putting workers and consumers at risk.

Emissions modelling and air pollution

In addition to analysing fuel samples, we modelled the potential impact of producing and consuming these fuels on emissions and air pollution in the Niger Delta—in particular to try to understand if, and how, this might be contributing to the serious soot problem that has been experienced in and around Port Harcourt city in recent years.

The heat required for the artisanal refining process is fuelled by burning crude oil and bitumen, so it was expected to contribute a significant amount of pollution. Government officials also regularly refer to it as the main source of the soot problem plaguing Port Harcourt city.

Emissions calculations using emission factors indicate that unofficial fuel production and consumption produce 40% of Port Harcourt's PM2.5 emissions, while official consumption produces an additional 10%.

Combined official consumption, unofficial consumption, and unofficial production is estimated to produce 50% of the city's PM2.5 emissions and 40% of PM10 emissions.

Calculations that estimate the production of Diesel Particulate Matter show significant particulate emission reductions can be made by enforcing sulphur standards across diesel products. Assuming similar reductions being available for gasoline, the enforcement of these standards across the Niger Delta's fuel product supply could significantly improve air quality and health of the population across the region and Nigeria as a whole.

If this modelling is accurate, then it suggests, furthermore, there are other important sources contributing towards the soot problem.

Policy recommendations:

- At a minimum, the Standards Organization of Nigeria (SON) should be vested with the powers and partners required to implement the planned Nigerian fuel sulphur standards across official supply channels to mitigate particulate emissions; 50 ppm (diesel), 150 ppm (petrol) and 150 ppm (kerosene). This level for sulphur would still undermine emission reduction technologies, and so further reductions in these limits to align with EU or similar standards should be considered.
- Commission a formal joint investigation by the Nigeria National Petroleum Corporation (NNPC), Petroleum Products Pricing Regulatory Agency (PPPRA), Federal Ministries of Petroleum Resources and Environment, and the Standards Organization of Nigeria (SON) to identify the levels of sulphur within official fuel supplies across the Niger Delta, and the rest of Nigeria. Should unacceptable levels be found, hold the relevant international and/or national companies, importers, and institutions to account.
- Commission a study into other sources of particulate emissions in the Port Harcourt area. This should be a collaboration between experts from the University of Port Harcourt, state Commissioner for Environment, Federal Ministry of Environment, international oil and gas companies, and civil society organisations. The study would need to gather data on air quality levels in different locations, and model sources and other important factors that can help policy-makers to mitigate the notorious soot.
- Request that all available data on air pollution in Port Harcourt is publicly released by international oil companies (and any others that are collecting data), and monitored to assess potential health impacts and the impact of any changes due to measures taken to improve fuel quality, the prevalence of artisanal refineries, and other sources of particulate emissions.
- Support the Rural Electrification Agency to work with private partners to develop renewable energy infrastructure across the Niger Delta to reduce demand for unofficial and official fuel, and pollutant emissions.
- The Ministry of Petroleum Resources and Petroleum Technology Development Fund should consider engaging artisanal oil refiners in plans for domestic refining, given they are often producing fuels with better characteristics than official fuel supplied to Nigeria.

Contents

Abbreviations and acronyms

BTEX	Benzene, Toluene, Ethyl Benzene, Xylenes
DPM	Diesel Particulate Matter
NNPC	Nigeria National Petroleum Corporation
PAH	Polycyclic Aromatic Hydrocarbon
PPPRA	Petroleum Products Pricing Regulatory Agency
PM	Particulate Matter
SDN	Stakeholder Democracy Network
SON	Standards Organisation of Nigeria
TPH	Total Petroleum Hydrocarbons

Glossary

Artisanal oil refineries	Locally-fabricated refineries that can refine crude oil into different petroleum products. The process is untaxed and unlicensed.
Blendstock	A product that is blended with others to produce the final fuel. This changes the characteristics of the fuel, and the desired quality specifications can be achieved by selecting the optimum combination of components.
Camp	The site where refineries are located, usually at clearings with hidden entry points in the maze of riverine mangrove forests. Also known as a dump or bunk.
Carbon chains	Carbon atoms joined in a row, linking in long chains creating complex organic compounds (e.g. hydrocarbons).
Fuel viscosity	'Thickness' of the fuel—if the viscosity is too high, it can lead to fuel injector damage in vehicles, incomplete combustion, poor engine performance, and excess particulate residue, potentially damaging the engine. Despite this, many unofficial diesel users report higher viscosity as a benefit as it burns for longer and is therefore more cost effective.
Hydrocarbon	An organic compound consisting solely of hydrogen and carbon. Can be gasses, liquids, waxes, low melting solids, or polymers. The major use of hydrocarbons is as a combustible fuel source (including diesel, gasoline, kerosene etc.).
Octane number	A standard measure of the performance of fuel. The higher the number, the more pressure the fuel can withstand before igniting.
Official fuel	Fuel available on the official market sold by licensed marketers (e.g. from filling stations).
Particulate matter	(PM) A mixture of solid particles and liquid droplets found in the air, grouped into those with diameters of 2.5 micrometres or smaller (PM2.5) and 10 micrometres and smaller.
Unofficial fuel	Fuel available on the unofficial market sold by non-licensed marketers (e.g. black market, predominantly produced by the artisanal oil industry).

1. Introduction

The amount of crude oil that is stolen from pipelines in Nigeria is difficult to measure, but various estimates place this figure in the region of 5-20% of daily production. Current official production hovers at around 2 million barrels a day at present. A significant proportion of the stolen crude is refined in artisanal refining camps in the Niger Delta, and there is widespread consumption of these fuels locally.

This research was originally undertaken with the aim of improving understanding of the potential impact of the production and consumption of unofficial fuel[1] (diesel, gasoline, and kerosene) on those living in the Niger Delta. During the research, analysis of 'control' samples for official fuel revealed worrying indications about the standard of fuel available legally. This discovery led to expansion of the original research focus, to look at the potential impact of the consumption of both unofficial and official fuel in the Niger Delta.

This research builds on a growing body of knowledge about the artisanal oil industry in the Niger Delta, including SDN's report, More Money, More Problems (2018), which researched the economic dynamics of the industry, and highlighted a gap in knowledge about the potential effects of widespread production and consumption of this fuel.

2. Objectives and methodology

2.1 Research objectives

- Interpret analysis of fuel samples to establish the standard of 'unofficial' fuel produced by artisanal refiners, compare this to 'official' fuel available at filling stations, and rank both according to international and national standards.
- Estimate the level of air pollution in Port Harcourt city to be attributed to producing and consuming official and unofficial fuels, and model the total impact based on production estimates.
- Evaluate the likely impacts that emissions have on health and the environment, with a particular focus on the contribution to particulate pollution in Port Harcourt city.

The research methodology was separated into three phases, and has been conducted in accordance with the following methods and standards:

Phase	Standards / Method	Performed by
Sample Collection	EC Petroleum Liquids Sampling Approach[1] (see appendix 1)	SDN
Sample Analysis	ASTM D3237[2] ASTM D4294-16e[3] ASTM 93[4] ASTM D2699[5] ASTM D86[6] Gas Chromatography / Flame Ionisation Detector (GC-FID) Gas Chromatography / Mass Spectrometry (GC-FID) Headspace Gas Chromatography / Mass Spectrometry (HS-GC-MS)	Laboratory (requested anonymity)
Data Analysis & Emissions Modelling	EPA WebFIRE data repository[7] (see appendix 2) and published papers	Noctis

[1] Fuel produced from stolen crude in makeshift refineries in the Niger Delta

[2] European Commission, 2020, Petroleum Liquids Sampling, viewed 1 December 2018, (http://ec.europa.eu/taxation_customs/dds2/SAMANCTA/EN/SamplingProcedure/ChemicalsPetroleumLiquids_EN.htm)

[3] ASTM D3237-17, 2017, 'Standard Test Method for Lead in Gasoline by Atomic Absorption Spectroscopy',

[4] ASTM International, West Conshohocken, PA, viewed 1 December 2018 (www.astm.org/cgi-bin/resolver.cgi?D3237)

[5] ASTM D4294-16e1, 2016, 'Standard Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry', ASTM International, West Conshohocken, PA, viewed 1 December 2018 (www.astm.org/cgi-bin/resolver.cgi?D4294)

[6] ASTM D2699-19, 2019, 'Standard Test Method for Research Octane Number of Spark-Ignition Engine Fuel', ASTM International, West Conshohocken, PA, viewed 1 December 2018 (www.astm.org/cgi-bin/resolver.cgi?D2699)

[7] ASTM D86-19, 2019, 'Standard Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure', ASTM International, West Conshohocken, PA, viewed 1 December 2018 (www.astm.org/cgi-bin/resolver.cgi?D86)

[8] United States Environmental Protection Agency, 2020, viewed 1 December 2018 (www.epa.gov/electronic-reporting-air-emissions/webfire)

The analysis is based on a total of 46 unofficial (artisanally refined) and 45 official (filling station) samples (diesel, gasoline, and kerosene) collected in three batches in December 2018, July 2019, and December 2019 across Rivers, Bayelsa, and Lagos states.

- Batch 1: 13 unofficial and 3 official fuel samples; Rivers State
- Batch 2: 9 unofficial and 18 official samples; Rivers and Bayelsa States
- Batch 3: 24 unofficial and 24 official samples; Rivers, Bayelsa and Lagos States

Official Lagos samples were collected from filling stations close to the port, on the assumption that this fuel would be most likely to be a true representation of imported refined products. This is useful, as the blending of official fuel with unofficial fuel is a known practice in the Niger Delta, and therefore it is more difficult to be certain that samples taken from official sources in Port Harcourt city only contain official fuel.

The laboratory used to test the samples has a number of industry certifications,[9] but the accuracy of the equipment used to test the samples was not verified. This would require conducting parallel tests of the same samples at a verified international laboratory, which was not feasible due to financial and logistical constraints. Independent tests of six laboratories in Port Harcourt found errors in calibration, but did not cover the laboratory used in this research. While it is expected that there will be a larger than normal margin of error, the results are generally consistent when compared against benchmarks, giving the researchers confidence in the validity of conclusions reached.

Please note that in this report, all graphical analysis is labelled according to the following nomenclature:

[Batch] number. [Sample] number, location, fuel type, fuel source.

For example, "1.1, Bille Diesel Unofficial" should be read as; Batch 1, Sample 1, a diesel sample collected from an unofficial (artisanal refining) source in Bille.

[9] A member of the British Safety Council, Standards Organisation of Nigeria ISO 9001:2008 certificate, Ministry of Environment accreditation, Permit from the Department of Petroleum Resources, and Nigerian Environmental Standards and Regulations Enforcement Agency accredited.

3. Results[10]

In order to understand the composition of each sample, the following fuel parameters were analysed:

Fuel parameters	Reason for analysis	Batch analysed
Total Petroleum Hydrocarbons	To review hydrocarbon characteristics against international benchmarks. To understand human exposure risk at artisanal refining camps[11] and soil contamination[12]	Batch 1, 2, 3
Organolead	Human and environmental toxicant[13,14]	Batch 1
Sulphur Content	Significant source of particulate emissions[15,16]	Batch 1, 2, 3
Flash Point	To understand the risks of low temperature auto-ignition and fire hazards[17]	Batch 1
Manganese	Human toxicant[18,19] and boosts octane number[20]	Batch 1, 2, 3
Octane Numbers - RON & MON	Measures fuel performance and resistance to engine knocking.	Batch 1
Benzene, Toluene, Ethyl Benzene, Xylenes (BTEX)	Carcinogens, pollutants and toxicants[21,22]	Batch 1, 2, 3
Polycyclic aromatic Hydrocarbons (PAHs)	Carcinogens, pollutants and toxicants[23]	Batch 1

Batch 1 underwent all of the lab tests listed above to explore a range of characteristics useful to compare fuel standard and emissions. It found no significant variations in Organolead, Flash Point, Octane Numbers or PAH. Both official and unofficial samples were within range of the benchmarks or expected results. Therefore, due to the high cost of these tests, the second and third batches focused on four key parameters, so that a greater sample size could be analysed in these areas.

[10] Complete datasets can be found in appendix 3
[11] Tuomi, T., Veijalainen, H. and Santonen, T., 2018, 'Managing exposure to benzene and total petroleum hydrocarbons at two oil refineries 1977–2014', International Journal of Environmental Research and Public Health, 15(2), pp. 1–15.
[12] Alinnor, I. J. and Nwachukwu, M, 2013, 'Determination of total petroleum hydrocarbon in soil and groundwater samples in some communities in', Journal of Environmental Chemistry and Ecotoxicology, 5(11), pp. 292–297
[13] Landrigan P J, 2002, 'The worldwide problem of lead in petrol', Bulletin of the World Health Organization 2002, 80 (10)
[14] National Atmospheric Emissions Inventory, 2020, 'Pollutant Information: Lead', viewed 10 January 2019, (http://naei.beis.gov.uk/overview/pollutants?pollutant_id=17)
[15] UK Government Department for Environment, Food and Rural Affairs, 2020, 'Particulate Matter in the United Kingdom', Chapter 4, viewed 10 January 2019, (uk-air.defra.gov.uk/assets/documents/reports/aqeg/ch4.pdf)
[16] Saiyasitpanich, P. et al., 2005, 'The Effect of Diesel Fuel Sulfur Content on Particulate Matter Emissions for a Nonroad Diesel Generator', Journal of the Air & Waste Management Association, 55(7), pp. 993–998
[17] Fingas, M. and Hollebone, B., 2017, 'Oil Physical Properties: Measurement and Correlation', Oil Spill Science and Technology. Gulf Professional Publishing, pp. 185–207. doi: 10.1016/B978-0-12-809413-6.00003-5
[18] US Government Agency for Toxic Substances and Disease Registry, 2020, 'Toxicological Profile for Manganese', viewed 11 January 2018, ('www.atsdr.cdc.gov/toxprofiles/tp151-c2.pdf)
[19] Neal, A. P. and Guilarte, T. R., 2013, 'Mechanisms of lead and manganese neurotoxicity', Toxicol Re(2(2)), pp. 99–114
[20] The Human Environment and Transport Inspectorate, 2018, 'Heavy fuel oil for sea-going vessels', viewed 8 December 2018, (https://english.ilent.nl/documents/reports/2018/07/04/heavy-fuel-oil-for-sea-going-vessels)
[21] World Health Organisation, 2010, 'Exposure to Benzene: A Major Public Health Concern', viewed 3 January 2019, (www.who.int/ipcs/features/benzene.pdf)
[22] US Government Agency for Toxic Substances and Disease Registry, 2020, 'Public Health Statement for Toluene', viewed 11 January 2018, (www.atsdr.cdc.gov/phs/phs.asp?id=159&tid=29)
[23] H. I. Abdel-Shafy and M. S. M. Mansour, Egypt. J. Pet., 2016, 25, 107–123.

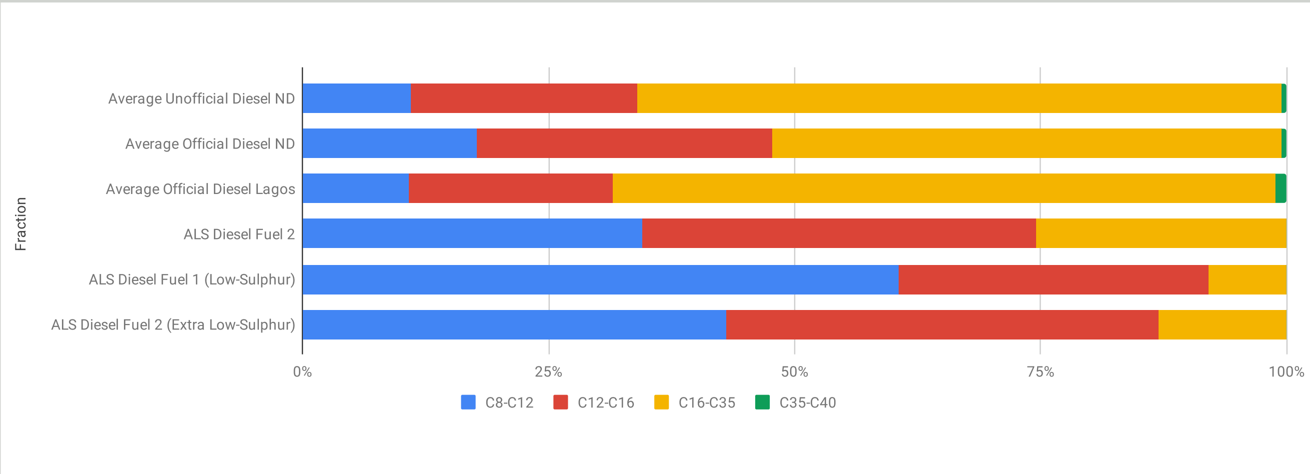
3.1 Total Petroleum Hydrocarbons (TPH)

A 'hydrocarbon composition analysis' provided a detailed breakdown and relative abundance of the fuel samples' hydrocarbon chain lengths. Chain lengths are important as they impact fuel characteristics such as fuel viscosity, combustion temperatures and completeness ('sooty' burning) which affects performance. In the context of artisanal oil refineries, these characteristics can suggest the extent of purification activity used in the camps. Average unofficial and official hydrocarbon compositions were compared against benchmarks in the Library of Petroleum Products provided by ALS Europe.[24,25]

3.2 Diesel

Diesel oil is a type of fuel containing a mixture of carbon chains that contain between 8 and 21 carbon atoms per molecule.

Figure 1: Diesel carbon-chain composition analysis compared to ALS benchmark fuel compositions



Both unofficial and official samples contained relatively low concentrations of these chain lengths compared to the benchmark ALS Diesel Fuel 2, indicating a higher viscosity. Artisanal refineries generally lack the technology to purify the final product compared to industrial refineries that purify fuel using catalysts and chemicals to remove longer carbon chain molecules and sulphur.

Fuels with higher viscosity cause atomisation issues (the process of converting fuel into droplets before combustion) which can lead to fuel injector damage, incomplete combustion, poor engine performance and excess particulate residue in the engine. Despite this, many unofficial diesel users report higher viscosity as a benefit as it burns for longer and is therefore more cost effective. An interview with a vessel captain reinforced this point, using an example of a road truck:

> ***"If you use the refinery AGO (diesel) for your truck from here to Kano, your consumption is 200 litres. If you buy artisanal refined product, you are going to use 150 litres."***

[24] ALS Environmental, 'Library of Petroleum Products and Other Organic Compounds, viewed on 5 January 2019, (www.alsglobal.eu/media-general/pdf/library-of-petroleum-products-and-other-organic-compounds.pdf)
[25] Potter, TL; Simmons, KE., 1998, 'Total petroleum hydrocarbon criteria working group series', Volume 2, p1-102

Another interviewee, when asked to compare unofficial and official diesel explained:

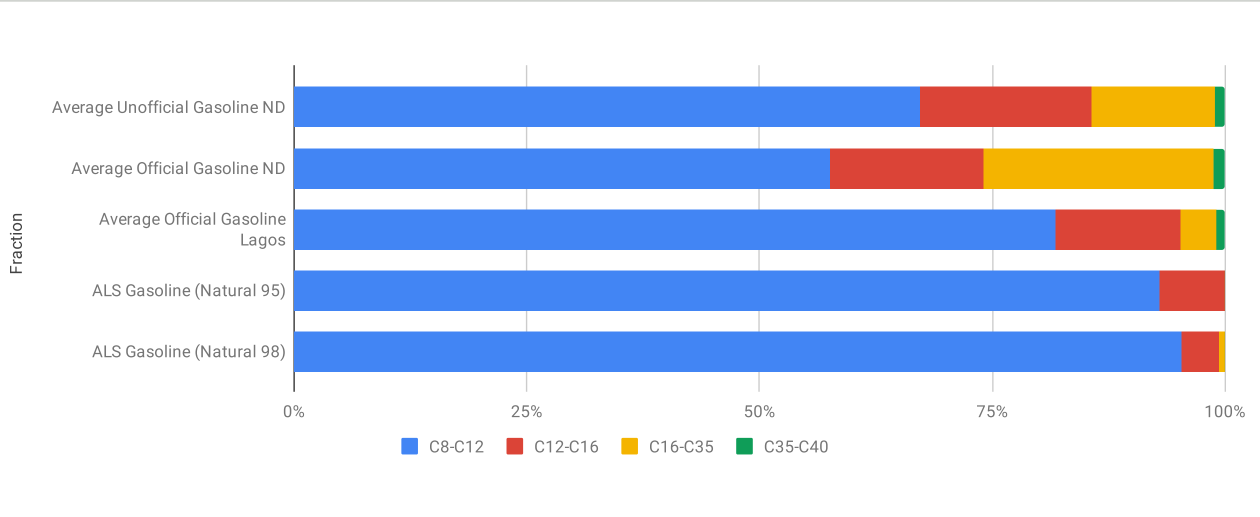
> ***"The artisanal refineries' AGO (diesel) is very thick than the one they produce in the refinery [sic]. So which one is better? Both of them are better. We are using the two to power our diesel engines, even our motors. It is not good for a NUPENG National Union of Petroleum and Natural Gas of Nigeria] man like me to be saying things like this but I will tell you."***

Although one would expect imported fuels to be aligned with benchmark compositions, both Niger Delta and Lagos official imported fuels also contained high concentrations of long carbon chain lengths.

3.3 Gasoline

Gasoline (petrol) typically contains carbon chains with between 4 and 12 carbon atoms per molecule.

Figure 2: Gasoline carbon-chain composition analysis compared to ALS benchmark fuel compositions



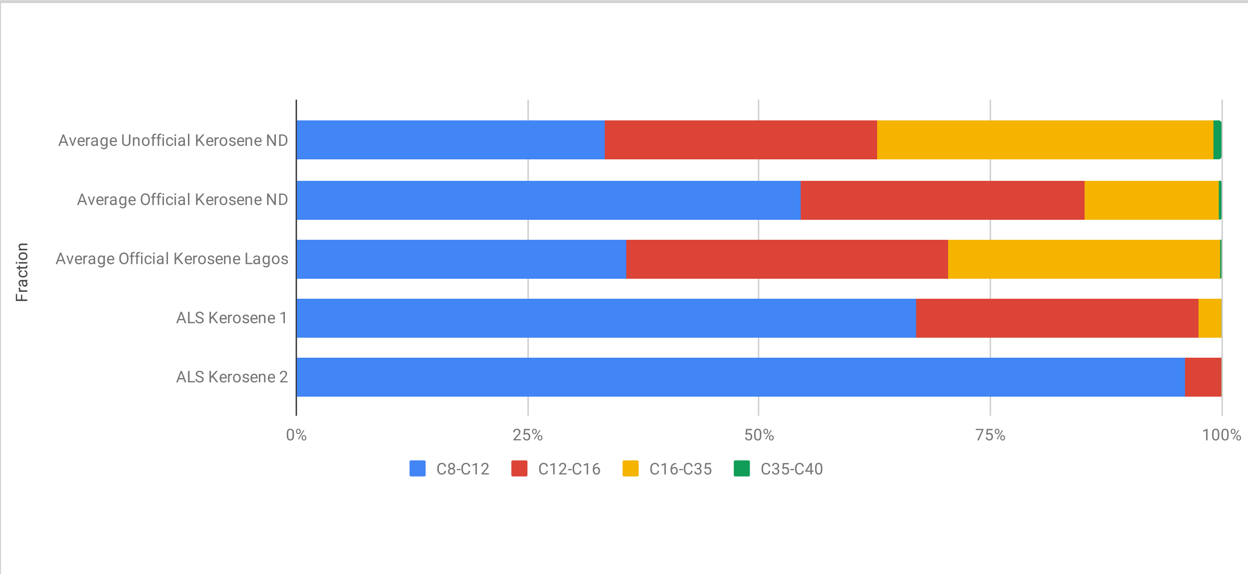
Average unofficial samples were more closely aligned to the benchmark (ALS Gasoline) compared to average Niger Delta official gasoline. Again, higher viscosity gasoline can lead to poor engine performance as mentioned above. Low quality official fuel is likely to be a factor that supports demand for alternative, artisanally refined, substitutes.

Lagos official gasoline contained the highest concentrations of short carbon-chains, likely resulting in better engine and combustion performance as a result of increased atomisation and combustion completeness.

3.4 Kerosene

Kerosene, otherwise known as paraffin oil, typically contains between 6 and 16 carbon atoms per molecule.

Figure 3: Kerosene carbon-chain composition analysis compared to ALS benchmark fuel compositions



Niger Delta official samples, on average, contained a higher abundance of shorter carbon chains compared to their Lagos counterparts and unofficial samples.

Compared to ALS Kerosene 1, the unofficial samples contain longer chain hydrocarbons, high-viscosity fuel, that indicates the challenge for artisanal camps to purify their kerosene product. Based on this, one would expect consumers to prefer official supplies. However, official kerosene sellers have recently been in short supply and so local demand has increased for, and been serviced by, artisanally refined alternatives that may be worse in terms of combustion performance and pollution.

Unofficial kerosene is generally more expensive than diesel and gasoline, so artisanal refining camps are able to generate higher profits from kerosene production despite the increased risks of fire when storing the comparatively more volatile fuel.

Kerosene is also used as an additive in unofficial fuels to reduce gelling or waxing in colder temperatures due to the presence of longer chain hydrocarbons. Note that blending with kerosene results in reduced fuel performance due to increased fuel density, decreased volatility, and reduced octane rating.[26]

[26] Obodeh O & Akhere N C, 2010, 'Experimental study on the effects of kerosene-doped gasoline on gasoline-powered engine performance characteristics, Journal of Petroleum and Gas Engineering Vol. 1(2), pp. 37-40

3.5 Environmental impact

A previous study[27] determining total petroleum hydrocarbons in soil and groundwater samples in oil-producing communities in Rivers State indicated that groundwater samples were contaminated with TPH concentrations as high as 33,076 ug/l. To put this in context, the recommended Department of Petroleum Resources (DPR) limit intervention value for groundwater is 600 ug/l[28].

Considering the crude nature of artisanal camp operations, there is a high chance of spillage and saturation into the local environment (water and soil), increasing the likelihood that artisanal refining operations contribute to local environmental degradation. Exposure to TPH compounds such as benzene and toluene can increase the risk of cancer and damage to the central nervous system. Seepage into the environment can lead to low-productivity soil and significant damage to fish stocks and animals that live off contaminated land and rivers (with livelihood implications for the many communities dependent agriculture and aquaculture).

Site of an artisanal oil refining camp in the Niger Delta

[27] Alinnor, I. J. and Nwachukwu, M. A. (2013) 'Determination of total petroleum hydrocarbon in soil and groundwater samples in some communities in', Journal of Environmental Chemistry and Ecotoxicology, 5(11), pp. 292–297
[28] Ibid.

3.6 Organolead

Tetraethyl lead (TEL) was traditionally used to improve fuel performance and reduce engine knocking. Since then, global efforts have significantly limited its use within the refining industry due to severe health and environmental consequences.

European Union (EU) regulations ban petrol with organolead, and limit the amount of sulphur in diesel fuels in order to improve air quality and reduce emissions[29]. There is an exception for older vehicles where the organolead content can be no higher than 150 ppm (0.15 g/L), and for companies marketing these products, the products are limited to a maximum of 0.03% share of total sales. In Nigeria, the DPR specifies a limit of 5 ppm (3.37 mg/L)[30] for gasoline with no standards set for diesel.

All samples tested contained low levels of organolead well below both EU and planned Nigerian standards.

3.7 Sulphur

High sulphur concentrations in on-road fuels result in high emissions of particulate matter and sulphur oxides. Nigerian crude oil is known for its relatively low-sulphur content; Bonny light contains around 0.14% (1,400 ppm)[31] sulphur by volume. To meet international standards, refineries use sulphur reduction processes to remove unwanted sulphur.

The EU standard limit for sulphur in diesel and gasoline is 10 ppm. The sulphur standard limit applicable in West African countries varies significantly; for diesel, 2,000-5,000 ppm and for gasoline 150-3,500 ppm. In 2017, the Standards Organisation of Nigeria introduced new sulphur standards for imported petroleum products limiting levels to 50 ppm for diesel (currently 3,000 ppm) , 150 ppm for gasoline (currently 1,000 ppm), and 150 ppm for kerosene (currently no limit)[32]. However, the implementation of these standards has been delayed and as a result, high-sulphur fuel continues to be imported into Nigeria contributing to significant engine maintenance costs and particulate pollution[33].

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[29] EUR-Lex, 2019, 'Quality of petrol and diesel fuels: sulphur and lead', viewed on 4 January 2019, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=legissum:l28077)

[30] Jimoda, L. A. et al., 2014, 'Atmospheric loadings of lead from refined petroleum products consumption in Southwestern Nigeria', Petroleum Science and Technology, 32(24), pp. 2921–2929

[31] Energy Insights by McKinsey, 2020, viewed on 18 January 2019, (www.mckinseyenergyinsights.com/resources/refinery-reference-desk/bonny-light-crude/)

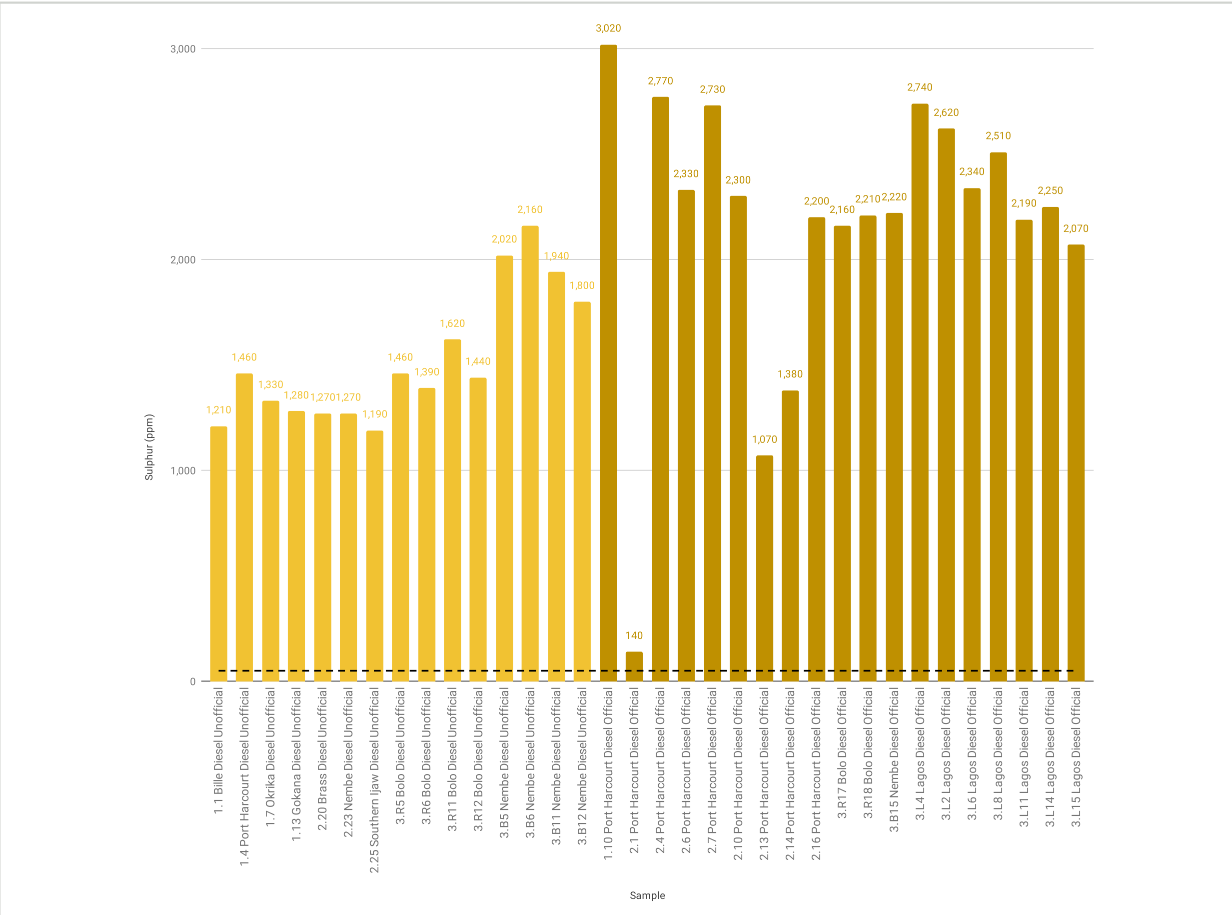
[32] The standards for the respective fuels are NIS: 949: 2017, NIS: 116:2017, and NIS: 949:2017. SON, 2017. PUBLIC NOTICE: Newly Approved Petroleum Related Standards. Viewed on 28 February 2019 (https://son.gov.ng/newly-approved-petroleum-related-standards-in-2017) Vanguard Newspaper, 2017, viewed on 17 January 2019, (www.vanguardngr.com/2017/04/fg-releases-new-standards-imported-petroleum-products/)

[33] International Centre for Investigative Reporting, 2018, viewed on 15 January 2020, (www.icirnigeria.org/investigation-how-delayed-implementation-of-dirty-fuel-ban-costs-nigerians-billions-2/)

Previous investigations into fuels blended in the Netherlands identified products that were 'keenly blended based on the sulphur standard of the country of destination; depending on the destination, often close to 3,000 ppm of sulphur for diesel and 1,000 ppm for gasoline ('Nigerian spec'). The produced diesel and gasoline blends probably comply in this way with the fuel standards of the country of destination. These sulphur concentrations are, however, very high when compared to the European sulphur standard.[35]

In addition, modern vehicles require low-sulphur fuel to contain no more than 10 ppm sulphur for the essential working of emission reduction technology[36]. High sulphur fuels damage this technology, leading to redundancy and consequently, significantly increased life-cycle emissions. This is likely to have a significant impact in cities like Port Harcourt, with large numbers of cars on the road. Public Eye's report, investigating the quality of fuels across Africa, states that 'if African countries were to adopt European standards (10 ppm) for sulphur in diesel, they would immediately cut by 50% the traffic-related air pollution from particulate matter. When combined with the introduction of existing emission control technologies these emissions would be reduced by 99%.[37]

Figure 4: Diesel sulphur content (ppm) by location, fuel type and official / unofficial source grouped by source. The planned Nigerian sulphur standard is shown as a dotted line.



[35] Heavy fuel oil for sea-going vessels". Report by the Dutch Government Human Environment and Transport Inspectorate (2018). Available at https://english.ilent.nl/documents/reports/2018/07/04/heavy-fuel-oil-for-sea-going-vessels
[36] DCCAE www.dccae.gov.ie/en-ie/environment/topics/air-quality/fuel-standards/Pages/default.aspx
[37] "Dirty Diesel: How Swiss Traders Flood Africa with Toxic Fuels". Available at: www.publiceye.ch/fileadmin/doc/Rohstoffe/2016_PublicEye_DirtyDiesel_EN_Report.pdf (accessed on 15 December 2018)

Figure 5: Gasoline sulphur content (ppm) by location, fuel type and official / unofficial source grouped by source. The planned Nigerian sulphur standard is shown as a dotted line.

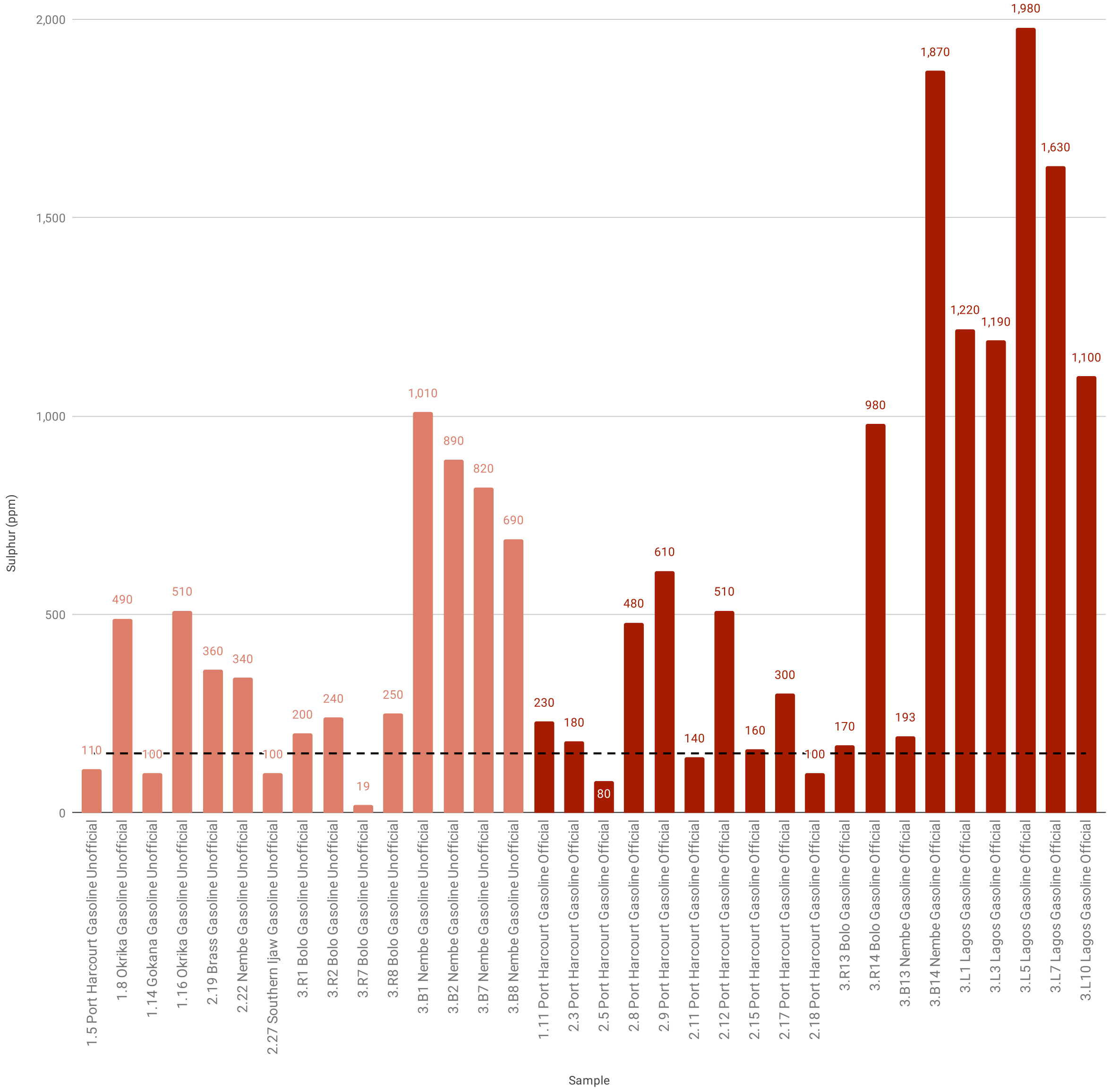
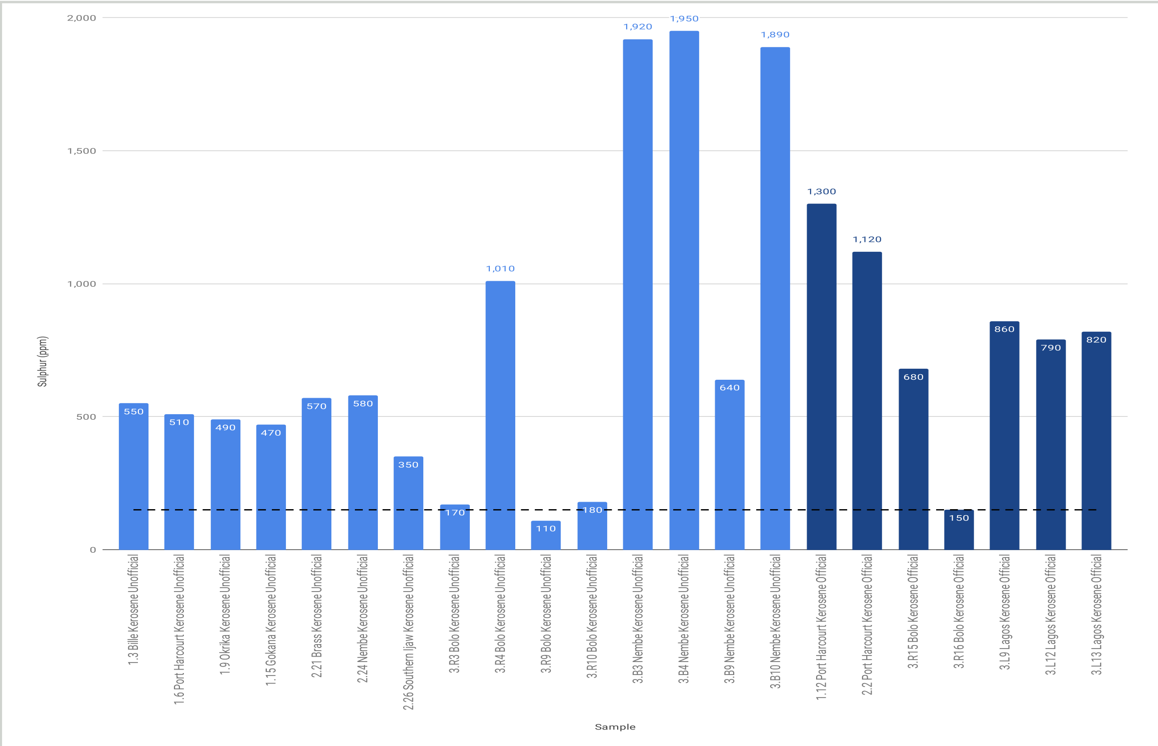


Figure 6: Kerosene sulphur content (ppm) by location, fuel type and official / unofficial source grouped by source. The planned Nigerian sulphur standard is shown as a dotted line.



The samples analysed contained very high levels of sulphur compared to EU standards. Average unofficial fuel samples contained sulphur concentrations of 1,523 ppm (diesel), 401 ppm (gasoline) and 759 ppm (kerosene). Average official samples contained 2,044 ppm (diesel), 429 ppm (gasoline) and 813 ppm (kerosene) - i.e. official fuel samples were dirtier than unofficial fuel samples.

The highest sulphur concentration analysed was 3,020 ppm found in a diesel sample from an Oando filling station in Port Harcourt city. It is striking how the majority of official samples contained high sulphur, supporting the findings of the Public Eye investigation.

Interestingly, the lowest sulphur diesel came from a Total filling station in Port Harcourt city, containing 140 ppm—still 14x over EU standards, but significantly lower than all unofficial and official samples analysed. It is encouraging to see that low-sulphur fuel can be imported by some companies. However, it should be noted that all other Total diesel and kerosene samples contained high-sulphur.

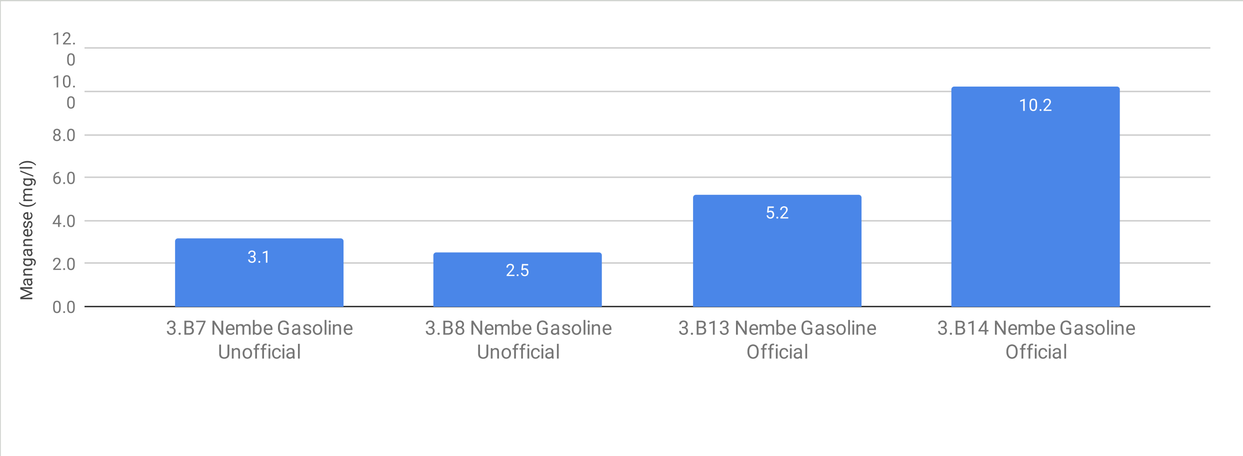
The sole NNPC diesel samples contained 1,070 ppm, considerably lower than the average official diesel fuel sample but still 107x over EU standards. NNPC, as the national oil company, could take the opportunity to lead performance in this area and to bring its products in line with the proposed standard.

Given that new emission reduction technologies require a maximum level of 10 ppm, the majority of vehicles in Port Harcourt city are likely to be very high emitters of particulate pollution, whether consuming official or unofficial fuels.

Interestingly, Lagos samples from official filling stations contained, on average, sulphur concentrations 1.5x greater than the Niger Delta samples. There could be a number of reasons for this, including the possibility that official fuel with high sulphur concentrations are being blended with lower sulphur unofficial fuel in the Niger Delta.

3.8 Manganese and Octane number

Figure 7: Samples containing > 2mg/l manganese (ppm) by location, fuel type and official / unofficial source grouped by fuel type

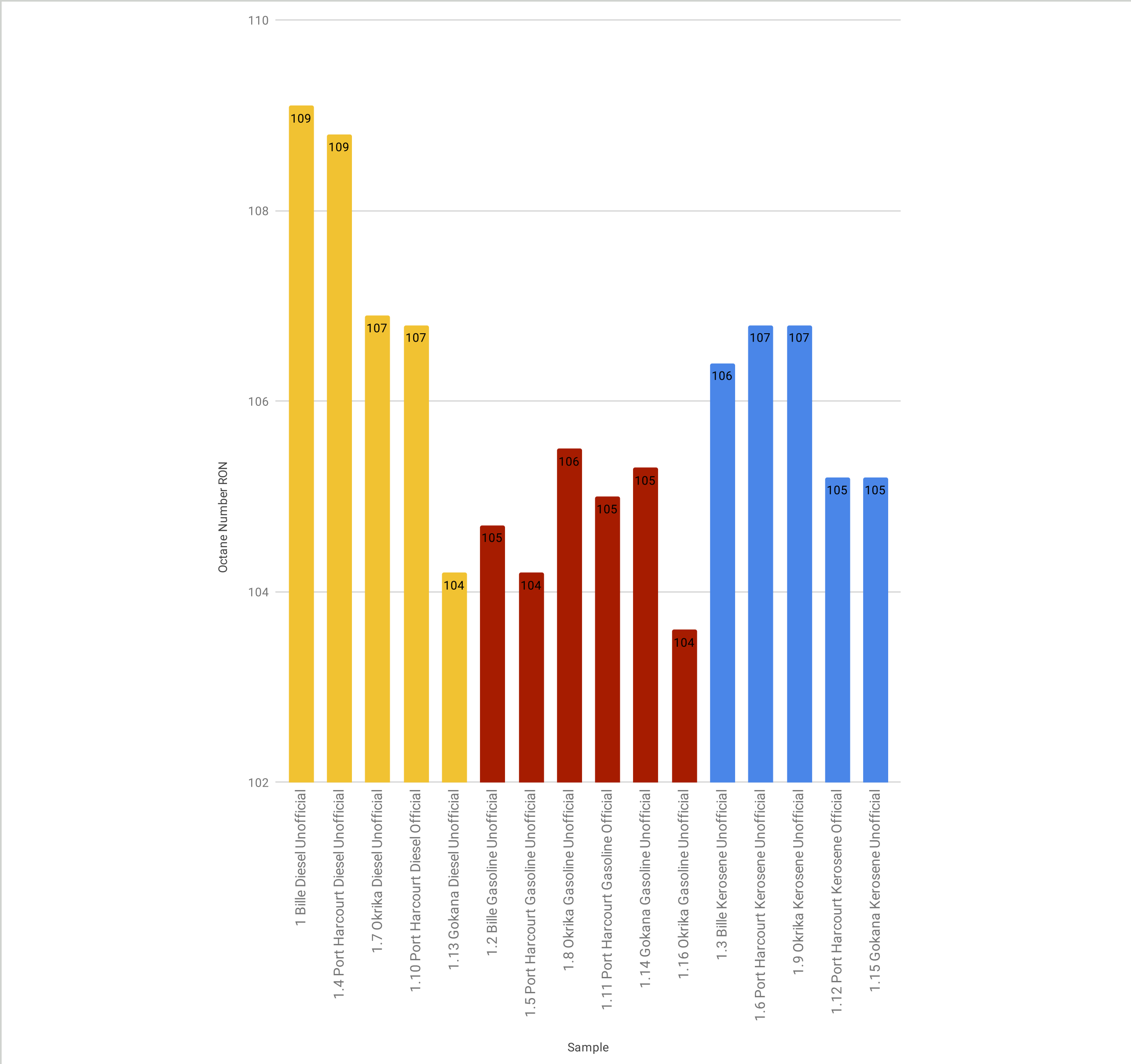


Manganese is often used as an octane booster, reducing a fuel's resistance to engine knocking and impacting engine performance. However, levels to achieve boosting effects identified by the Dutch Government Human Environment and Transport Inspectorate, are around 14-21 mg/l. Their report states that 'EU gasoline may contain no more than 2 mg/l of manganese, which in fact means that a manganese additive may not be intentionally added'.

Across the 91 samples (including Lagos), only four samples contained manganese levels greater than 2 mg/l—all from Nembe, Bayelsa State. The two unofficial Nembe samples contained 3.1 mg/l and 2.5 mg/l suggesting a crude attempt to boost performance. This could imply blending with official fuel before sale. Two official Nembe samples contained 5.2 mg/l and 10.2 mg/l, which is very high compared to international standards and worrying given that manganese is a known neurotoxin.[38]

[38] Peres, T. V. et al., 2016, 'Manganese-induced neurotoxicity: A review of its behavioral consequences and neuroprotective strategies"', BMC Pharmacology and Toxicology. BioMed Central Ltd

Figure 8: Batch 1 samples research octane number (RON) by location, fuel type and official / unofficial source grouped by fuel type



Interestingly, the octane numbers across all batch 1 samples were high, between 104-109, compared to international products that range between 91-98.

Higher octane fuels have a lower energy density and often contain alcohol compounds that are incompatible with fuel system components. They also evaporate much more easily than heavier, lower octane fuel—leading to unwanted accumulated residues in fuel systems.

3.9 Benzene

Benzene is strictly regulated in petroleum production due to its highly carcinogenic nature. Benzene concentration in fuels sold in the EU must be less than 1.0% by volume[39]. Reducing benzene in fuel not only lowers the occupational exposure levels for those working in close proximity to fuel, but also contributes significantly in decreasing the environmental benzene exposure for the general public[40]. All samples tested contained benzene concentrations within the EU limit and so are considered to be within regulatory limits for the purpose of this analysis.

Workers at an artisanal refining camp without any personal protective equipment.

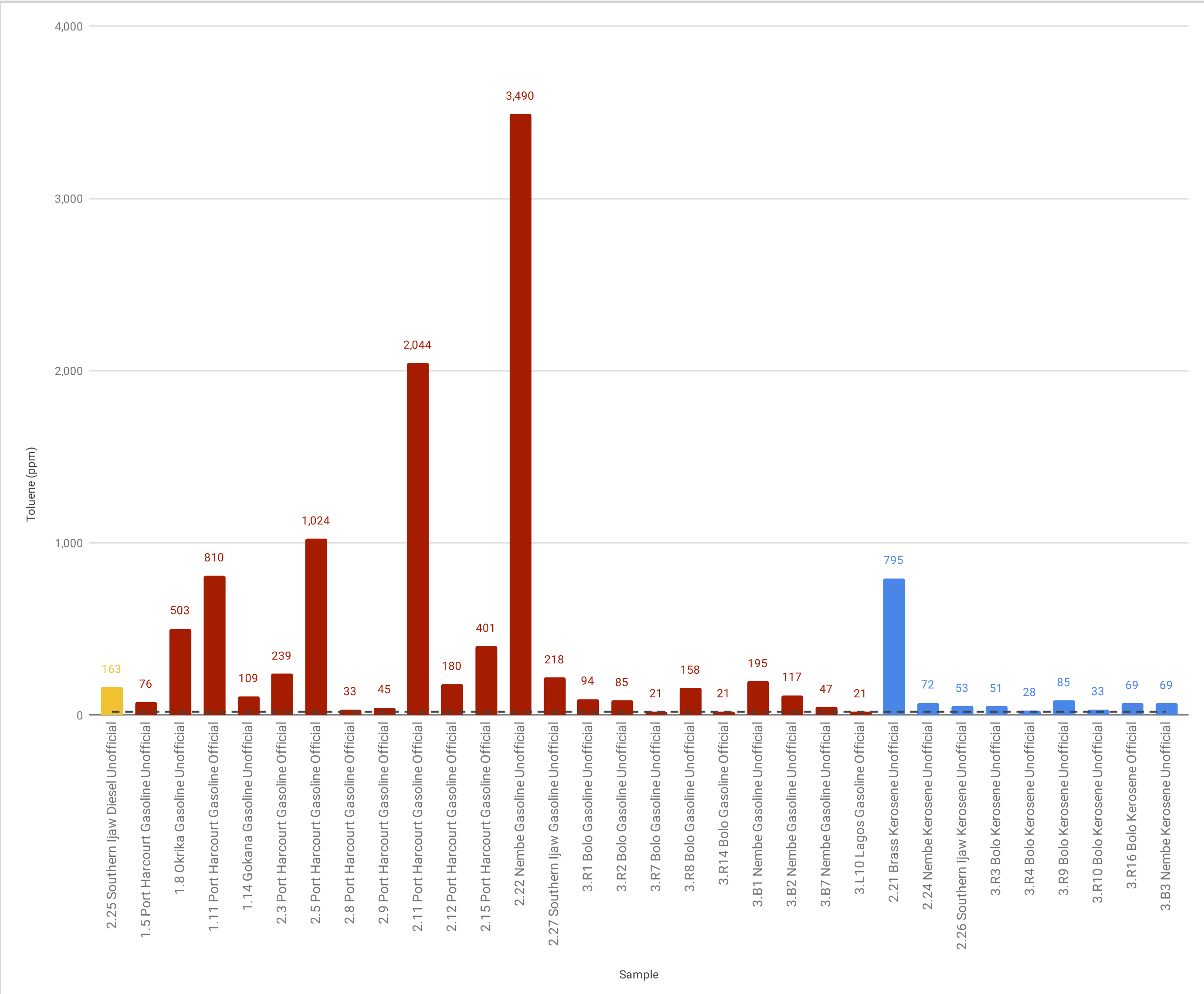
[39] World Health Organisation, 2017, 'IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Benzene, 120, p. 300. Available at: publications.iarc.fr/Book-And-Report-Series/Iarc-Monographs-On-The-Identification-Of-Carcinogenic-Hazards-To-Humans/Benzene-2018.

[40] Dave K. Verma & Karen des Tombe, 2002, 'Benzene in Gasoline and Crude Oil: Occupational and Environmental Implications', AIHA Journal, 63:2, 225-230

3.10 Toluene

Toluene is found naturally in crude oil but is also added to refined fuel to improve performance. Toluene is regulated as it may have a serious effect on nervous systems. The Association Advancing Occupational and Environmental Health recommends Threshold Limit Values (occupational exposure limits) of 20 ppm[41].

Figure 9: Samples containing > 20 ppm toluene by location, fuel type and official / unofficial source grouped by fuel type



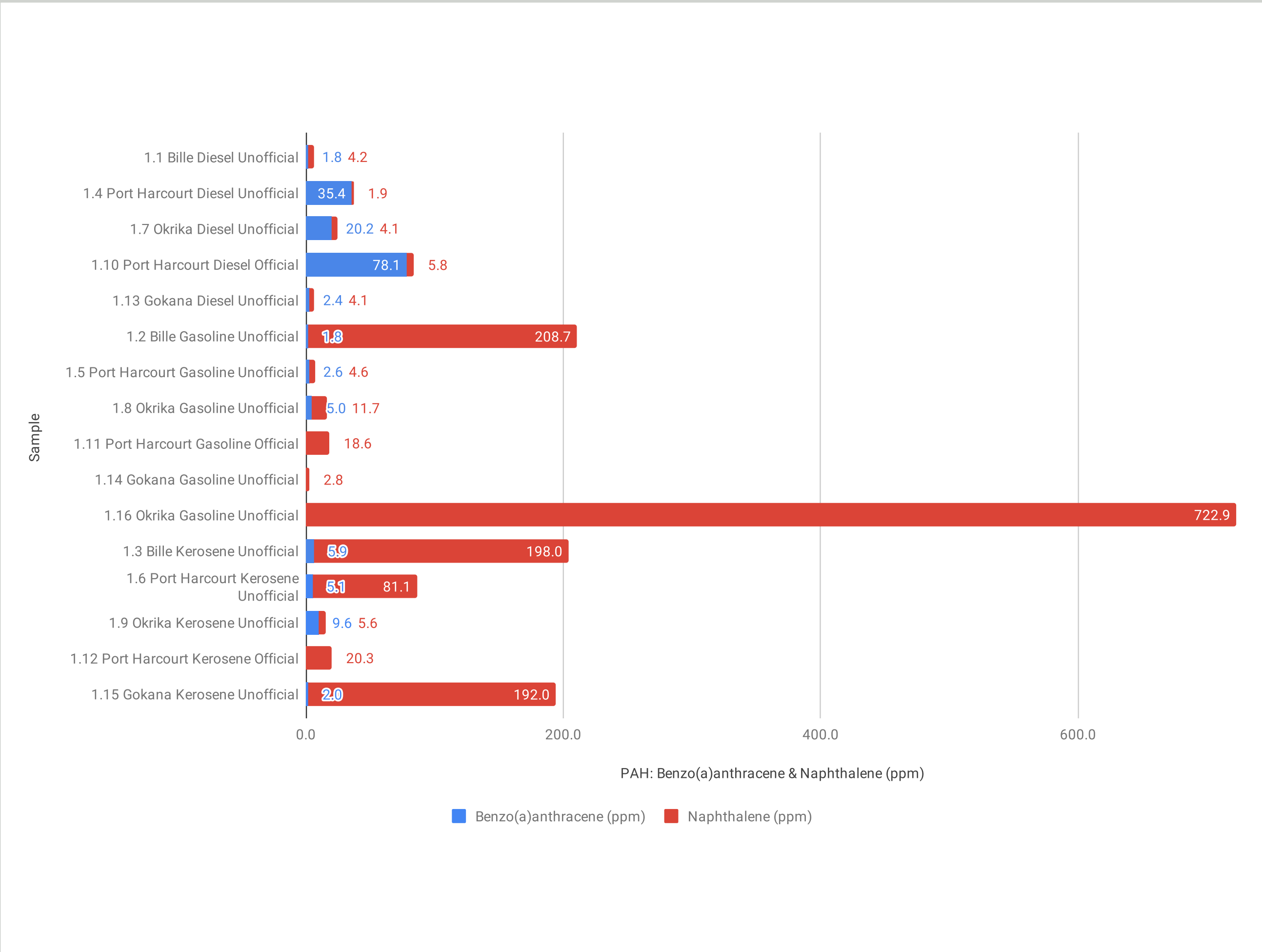
[41] Swick, D. et al., 2014, 'Gasoline risk management: A compendium of regulations, standards, and industry practices', Regulatory Toxicology and Pharmacology. Academic Press, 70(2), pp. S80–S92

Just over a third of all samples contained high concentrations of toluene compared to the occupational exposure limit recommendation. The highest concentration was found in an unofficial gasoline sample from Nembe, with two further official gasoline samples containing greater than 1,000 ppm, potentially indicating a performance boosting additive. Whilst there are no international refining limits for toluene one would expect refineries to take reasonable steps to reduce levels given toluene's toxicity in high concentrations.

In the context of camp operations, handling fuel containing high levels of toluene will likely have severe health consequences due to its toxic nature. In addition, high-toluene fuels will likely result in high concentrations of those compounds in the atmosphere, increasing the risk of toluene-related illness across the Niger Delta.

3.11 Polycyclic Aromatic Hydrocarbons—Benzo(a) anthracene and Naphthalene

Figure 10: Polyaromatic Hydrocarbons: Benzo(a)anthracene & Naphthalene (ppm) by location, fuel type, and official/unofficial source grouped by fuel type



18 Polycyclic Aromatic Hydrocarbons (PAHs) were analysed to assess levels of possible carcinogens and toxicants, particularly benzo(a)anthracene and naphthalene. Benzo(a) anthracene and Naphthalene were detected across the majority of batch 1 unofficial samples. This could be because artisanal refining lacks the technology to remove some of these harmful compounds.

The recommended exposure limit of Naphthalene is 10 ppm[42]. Samples 1.2, 1.3, and 1.15 contain 19x the exposure limit with sample 1.16 containing concentrations 72x above the exposure limit. Considering again artisanal camp operations, exposure to such high levels of naphthalene could have a serious health impact on camp workers in close proximity to the open camp ovens through inhalation and regular handling of artisanally refined fuels.

4. Emissions modelling

We used two approaches to model emissions from the production of unofficial artisanal fuel and consumption of both unofficial and official fuels based on estimated total volumes of unofficial and official fuel across Bayelsa and Rivers states, and then specifically in Port Harcourt city.

The first approach (see appendix 2 for details) uses average emissions factors across a broad range of engines (generators, vehicles etc.) to calculate total emissions, but does not take into account fuel composition.

Given the high-sulphur levels found in this research, we used a second approach to evaluate the potential emissions impact of high sulphur fuel in relation to the use of diesel generators. Saiyasitpanich[43] provides an empirical correlation for estimating diesel particulate matter (DPM) concentration when fuel sulphur content and engine loads are known. The authors found that 'the fuel sulfur [sic] reduction alone from 3,700 ppm to 500 ppm can reduce DPM emissions by >50%.' This approach is also described at appendix 2.W

Port Harcourt households and businesses use diesel fuelled generators[44] to generate power. This investigation based its model on this demonstrable reality to estimate diesel generator emissions across Bayelsa and Rivers states using average sulphur concentrations found in the samples.

Whilst we acknowledge that diesel generators represent a fraction of fuel use across Port Harcourt city, we believe this approach highlights the impact of consuming high-sulphur fuel and provides a way to evaluate the impact of enforcing low-sulphur standards.

4.1 Emissions Factor Method

4.1.1 Unofficial fuel production

Pollutant emissions from artisanal fuel production are assumed to mainly come from the camp ovens fuelled by burning crude oil and bitumen. Around 4% of crude oil stolen is used to fuel the ovens. Based on average daily theft of 175,000 barrels, of which 75% is artisanally refined (90% allocated to Bayelsa and Rivers states)[45], we calculated a range of pollutant emissions using emission factors from the WebFire database.

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[42] Centers for Disease Control and Prevention, 1988, '1988 OSHA PEL Project Documentation: Naphthalene', viewed on 10 March 2019, (www.cdc.gov/niosh/pel88/91-20.html)
[43] Saiyasitpanich, P. et al., 2005, 'The Effect of Diesel Fuel Sulfur Content on Particulate Matter Emissions for a Nonroad Diesel Generator', Journal of the Air & Waste Management Association, 55(7), pp. 993–998
[44] Gasoline generators are more widely used to fuel household power needs in the Niger Delta, however, our literature review did not identify an empirical correlation for gasoline that we could base our research upon. We hope that such a correlation will be studied and published in the future.
[45] SDN, 2018, 'More Money. More Problems - Economic Dynamics of the Artisanal Oil Industry in the Niger Delta Over Five Years', available at www.stakeholderdemocracy.org/moremoneymoreproblems

Table 3: Estimated pollutant emissions - Rivers & Bayelsa states and Port Harcourt unofficial fuel production

Pollutant Emissions	Bayelsa & Rivers Emissions (Tons / Year)	Port Harcourt Emissions (Tons / Year)	Port Harcourt Emissions (µg/day per m^3)
CO_2	253,646	49,369	1,663
CO	2,708	527	18
Total Smoke Particles	13,763	2,679	90
Soot	6,069	1,181	40

4.1.2 Unofficial and official fuel consumption (diesel, gasoline, and kerosene)

Similarly, estimated pollutant emissions from unofficial fuel consumption was calculated from total output volumes of the artisanal refining industry (estimated using operational assumptions of the artisanal refining process and scaled across total crude oil stolen for domestic refining)[46]. Emissions from official fuel consumption was calculated using fuel import statistics.[47]

To arrive at the totals below, pollutant emissions from estimated unofficial and official consumption were combined.

Table 4: Estimated pollutant emissions—Rivers & Bayelsa states and Port Harcourt city unofficial and official fuel consumption

Pollutant Emissions	Bayelsa & Rivers Emissions (Tons / Year)	Port Harcourt Emissions (Tons / Year)	Estimated Unofficial Port Harcourt Emissions (µg/day per m^3)	Estimated Official Port Harcourt Emissions (µg/day per m^3)	Estimated Port Harcourt Total Emissions (µg/day per m^3)
CO_2	8,738,228	1,700,792	37,502	19,778	57,280
CO	1,145,619	222,981	2,015	5,495	7,510
NOx	112,691	21,934	486	252	739
PM_{10} Filterable	8,299	1,615	37	17	54
$PM_{2.5}$ Filterable	7,385	1,437	34	15	48

[46] For more information on methodology and assumptions, see SDN's publication More Money, More Problems.
[47] Nigeria National Bureau of Statistics, 2017, 'Petroleum Products Imports and Consumption (Truck Out) Statistics 2017', viewed on 8 March 2019, (brandspurng.com/wp-content/uploads/2018/02/petroleumproductsimportstat2017.pdf)

The average air quality in Port Harcourt city was published in two separate papers: 1) in 2016 as part of a study into the assessment of particulate matter-based air quality index in Port Harcourt city[48] when the soot issue was recognised as a crisis, 2) in 2018 that tracked seasonal particulate pollution in Port Harcourt city.[49,50] In line with these published figures, and SDNs own informal air quality measurements, the average dry season PM2.5 and PM10 values used in this analysis are 175 µg/m³ and 350 µg/m³ respectively.

Table 5: Estimated PM10 and PM2.5 emission contributions of total fuel consumed in Port Harcourt during the dry season

Pollutant Emissions	Average Dry Season PM Concentration (µg/day per m³)	Estimated Unofficial Fuel Emissions (µg/day per m³)	Estimated Unofficial Fuel Contribution to Average PM (Dry Season)	Estimated Official Fuel Emissions (µg/day per m³)	Estimated Official Fuel Contribution to Average PM (Dry Season)
PM_{10}	350	128	36%	17	5%
$PM_{2.5}$	175	74	42%	15	8%

Production and consumption of unofficial fuel contributes an estimated 40% to average dry season PM2.5 concentration in Port Harcourt city suggesting that the unofficial industry is a strong contributor to soot and smog prevalence. Note that unofficial fuel contributes significantly more to pollutant emissions as unofficial consumption is estimated to be double that of official fuel consumption.

As the unofficial industry has grown in response to fuel demand, increased volumes produced across the refining camp network and consumed locally are likely to have resulted in a significant increase in particulate emissions across the city. The combination of unofficial (production and consumption) and official supplies (consumption only) is estimated to produce just under 50% of the city's PM2.5 emissions and 40% of PM10 emissions.

[48] Akinfolarin, O. M., Boisa, N. and Obunwo, C. C., 2017, 'Assessment of Particulate Matter-Based Air Quality Index in Port Harcourt, Nigeria', Journal of Environmental Analytical Chemistry. OMICS International, 04(04), pp. 1–4
[49] Abali, H. W., Etebu, O. M. and Leton, T. G., 2018, 'Seasonal Particulate Pollution in Port Harcourt Nigeria', Journal of Environment Pollution and Human Health, Vol. 6, 2018, Pages 20-25. Science and Education Publishing, 6(1), pp. 20–25
[50] SDN also performed informal air quality assessments in 2019 using air quality sensors which were useful to compare PM2.5 and PM10 values in our analysis.

The World Health Organisation Global Ambient Air Quality Database[51] provides average PM10 and PM2.5 for cities across the world. The table below compares Port Harcourt city's dry season with average particulate concentrations across a range of international cities (see table 6).

Table 6: Port Harcourt dry season average PM_{10} and $PM_{2.5}$ concentrations compared to the averages across international cities

Average Pollutant Emissions	Port Harcourt ($\mu g/m^3$)	Beijing ($\mu g/m^3$)	London ($\mu g/m^3$)	Accra ($\mu g/m^3$)	Delhi ($\mu g/m^3$)	New York ($\mu g/m^3$)	Rio De Janeiro ($\mu g/m^3$)
PM_{10}	350	92	23	112	292	14	42
$PM_{2.5}$	175	73	12	55	143	7	11
PM_{10} - Port Harcourt emissions multiple compared to named city		3.8x	15.2x	3.1x	1.2x	25.0x	8.3x
$PM_{2.5}$ - Port Harcourt emissions multiple compared to named city		2.4x	14.6x	3.2x	1.2x	25.0x	15.9x

Compared to other international cities particulate emissions in the dry season in Port Harcourt city are greater than Delhi, known globally as a city of widespread pollution.

[51] World Health Organisation, 2018, 'WHO Global Ambient Air Quality Database', (www.who.int/airpollution/data/cities/en/)

4.2 Sulphur Content Method

As mentioned previously, diesel generators represent a small fraction of fuel use across Port Harcourt city but we believe this approach highlights the impact of consuming high-sulphur fuel and provides a way to evaluate the corresponding impact of enforcing low-sulphur standards.

Using the method described in appendix 2, and using average sulphur concentrations found in unofficial and official fuel samples, diesel particulate matter emissions were calculated for diesel generators across Rivers State and Port Harcourt city.

Table 7: Estimated diesel particulate matter emissions as a function of sulphur concentration

Fuel Type	Average diesel sulphur content	Total Rivers State DPM emissions*	Total Rivers State DPM emissions	Total Adjusted Rivers State DPM emissions**	Total Port Harcourt DPM emissions per day
Units	**ppm**	**tons / year / generator**	**tons / year**	**tons / year**	**µg / day per m³**
Unofficial Diesel	1,523	0.0019	56.1	4.3	0.037
Official Diesel	2,044	0.0021	63.2	4.9	0.042
Total				**9.2**	**0.079**

*Across the total number of generators identified in the World Bank report (29,779 diesel generators across Rivers State)

**Adjustment to take into account the average volume of diesel used per day according to the World Bank data

Compared to the average dry season air quality in Port Harcourt city[52], household diesel generators in Port Harcourt are estimated to contribute to 0.04% of total particulate emissions in the city. Using official diesel in these generators[53] is estimated to increase particulate emissions by 13% compared to consuming unofficial diesel.

To check the accuracy of this approach, an alternative approach was used to estimate diesel fuel particulate emissions based on a World Bank report providing information on fuel consumption, emissions factors, and energy generation from diesel or gasoline gensets[53] and the total estimated power generated by these generators in Rivers State.

Table 8: $PM_{2.5}$ emissions calculated using adjusted emissions factors specifically for tier 1-3 engines in Rivers State

Pollutant	Emissions Factor (kg / MWh)	Total MWh per annum	Total Emissions (tons per year)
$PM_{2.5}$	1.46	6,001	8.8

[52] Akinfolarin, O. M., Boisa, N. and Obunwo, C. C., 2017, 'Assessment of Particulate Matter-Based Air Quality Index in Port Harcourt, Nigeria', Journal of Environmental Analytical Chemistry. OMICS International, 04(04), pp. 1–4.

[53] The World Bank, 2014, 'Diesel Power Generation Inventories and Black Carbon Emissions in Nigeria', viewed on 26 July 2019, (www.documents.worldbank.org/curated/en/853381501178909924/pdf/117772-WP-PUBLIC-52p-Report-DG-Set-Study-Nigeria.pdf).

Both methods estimate total PM2.5 emissions across Rivers State of 9 tonnes per year indicating the reliability of the sulphur content method.

DPM emissions were also calculated for a theoretical 10 ppm diesel fuel to assess unofficial and official fuel samples against EU sulphur standards (10 ppm) and planned Nigeria standards (50 ppm).

Table 9: Theoretical DPM calculation for diesel at EU and Nigeria standards

Fuel Type	Average diesel sulphur content	Total Rivers State DPM emissions [54]	Total Rivers State DPM emissions	Total Adjusted Rivers State DPM emissions[55]	Total PHC DPM emission per day
Units	ppm	tons / year / generator	tons / year	tons / year	µg / day per m^3
EU Standards	10	0.00024	7.2	0.6	0.005
Planned Nigeria Standards	50	0.00047	14.0	1.1	0.009

The impact of reducing the sulphur concentration in diesel to EU standards (10 ppm) results in a reduction of generator particulate emissions by an estimated 8x for unofficial diesel and 9x for official diesel.

The impact of reducing sulphur concentration in diesel to planned Nigeria standards (50 ppm) results in a reduction of generator particulate emissions by 4x for unofficial diesel and 5x for official diesel.

This analysis shows there are significant emissions reductions to be made by enforcing sulphur standards across diesel products. Assuming similar reductions being available for gasoline, the enforcement of these standards across the Niger Delta's fuel product supply could significantly improve air quality and citizen health across the region and Nigeria as a whole.

A more general comment on emissions concerns Nigeria's warm climate. Warmer temperatures unsurprisingly lead to greater rates of fuel evaporation. An EU report on gasoline evaporation[56] identified a link between higher atmospheric temperatures and evaporative emissions. Given much of the unofficial fuel production and distribution network is unregulated, there could be secondary pollutant emissions (non-methane volatile organic compounds) from crude oil and refined fuel stored and exposed in open containers.

[54] Across the total number of generators identified in the World Bank report (29,779 diesel generators across Rivers State).
[55] Adjustment to take into account the average volume of diesel used per day according to the World Bank data.
[56] European Environment Agency, 2009, 'EMEP/EEA air pollutant emission inventory guidebook - 2009', viewed on 22 January 2019, (www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009)

5. Discussion: impacts of unofficial and official fuel consumption

The analysis undertaken provides a useful baseline to consider the impact on air pollution, health, and equipment when consuming official fuel, and producing and consuming artisanal fuel in the Niger Delta.

5.1 Air pollution

Our analysis shows that the official and unofficial fuel currently produced and consumed in Port Harcourt produces a significant and serious contribution to the crisis levels of air pollution observed in Port Harcourt.

The unofficial supply of artisanally refined fuel developed as a market response to official fuel scarcity and reliability, filling the supply-demand gap between official petroleum supplies and consumers. Given unofficial fuel represents an estimated 65% [57,58], of total fuel available in Rivers and Bayelsa State, reducing unofficial supply should theoretically have a large impact on reducing particulate emissions. However, if all unofficial supply channels ceased to exist, the official supply would need to triple to satisfy the supply-demand gap. In this situation, and given our finding of significant levels of sulphur within official fuel samples, an expansion in the current supply of official fuel risks increasing pollutant emissions, particularly particulates, into the local environment and atmosphere.

In the short term, reducing sulphur content in unofficial and official diesel fuels to international and national standards would be a proactive step to reduce air pollution whilst ensuring that modern vehicle emission abatement technologies operate effectively. Our analysis indicates that if official diesel complied to the planned Nigerian fuel sulphur standards, particulate emissions could be reduced by an estimated 5x. If official diesel reduced fuel sulphur concentrations to EU standards particulate emissions could be reduced by an estimated 9x.

In the long term, supporting the development of renewable energy infrastructure across the Niger Delta would reduce the demand for petroleum products no matter the source and would likely reduce pollutant emissions substantially; an effective long term strategy to reduce both the artisanal refining industry and air pollution across the Niger Delta.

[57] Unofficial volume assumptions correspond with analysis in SDN's report "More Money. More Problems"
[58] Nigeria National Bureau of Statistics, 2017, 'Petroleum Products Imports and Consumption (Truck Out) Statistics 2017', viewed on 8 March 2019, (brandspurng.com/wp-content/uploads/2018/02/petroleumproductsimportstat2017.pdf)

5.2 Contributing factors to soot prevalence

5.2.1 Unofficial fuel production

By using emissions factors to calculate emissions we estimate that unofficial fuel production and consumption produces 40% of Port Harcourt's dry season PM2.5 emissions, suggesting that the unofficial industry is a strong contributor to soot and smog prevalence in Port Harcourt city. The combination of unofficial and official supplies is estimated to produce just under 50% of the city's PM2.5 emissions and 40% of PM10 emissions.

Particulate emissions often spike across the night which is also when unofficial production mainly occurs. Whilst we use average daily concentrations to base our analysis upon, in reality, the impact of artisanal production is felt across short periods of time. In addition, particulate emissions are likely to be more concentrated closer to the particulate sources and so different areas of Port Harcourt city, closer to artisanal camps, will likely be more affected than areas further away.

Construction contractors also boost demand for artisanally refined fuel in the dry season. One interviewee stated:

> ***"you see diesel; it goes with dry season... If government awards contracts, it is the dry season that they do the work. So, the actual time that we usually have higher demand for AGO is during dry season... This is the same thing in all countries, therefore, the demand and export of AGO is higher during dry season."***

A second interviewee reinforced this view:

> ***"The best time is this period, between September and March/April. This is when construction companies do more work and make more demand for AGO, both in Nigeria and other countries where these products are exported to... That was why you saw the upsurge of soot again from November 2019 till date in the State because the demand for the AGO is higher and the AOR are producing to meet the demands."***

5.2.2 Official fuel production

Despite not being part of our investigation, it is important to note the potential contributions from Nigeria's official refineries and petrochemical plants. These sources are often said to have poor emissions filters, with observers noting dark plumes from the smokestacks which may also contribute to the significant particulate levels in Port Harcourt city. This should be further investigated with air quality monitors to get an understanding of particulate concentrations in these areas and the estimated contribution to Port Harcourt city's particulate emission levels.

5.2.3 Sulphur

Our analysis and modelling focused on a published correlation between diesel fuel sulphur content and particulate emissions. High levels of sulphur concentrations were identified in both unofficial and official fuel volumes, well above both planned Nigerian and EU sulphur standards. Consequently, the high consumption of high-sulphur fuel across households and industries, due to an unreliable national power infrastructure, is likely to be a strong contributing factor to particulate emissions in Port Harcourt city. However, high levels of sulphur in Nigerian fuels is not a recent development; we consider two possible developments that may have caused the more recent smog and high levels of pollution across Port Harcourt city.

Firstly, the growth and consolidation of the artisanal oil industry over recent years[59], up to production levels of 2.4 billion litres per year (15 million barrels)[60], likely resulted in large increases of additional particulate emissions from the production process (burning crude oil and bitumen to fuel the cooking fires) and the consumption of the high sulphur fuel sold through the unofficial distribution network. In addition, the destruction of camps by security forces and burning of camp product[61] as a means of disposal are also likely to contribute to particulate emissions as the confiscated fuel is burned directly into the atmosphere rather than through engine or generator combustion where filters may reduce particulate emissions.

This also occurred in the armed conflict in northern Iraq in 2014, during which burning oil-well heads contributed to increased soot deposits on animals, land, and buildings[62]. Given that the militarised response to oil theft and artisanal refining in the Niger Delta started to escalate around 2015, this could explain the increased soot levels across the region since then. The impact of this is difficult to evaluate, however, as our emissions model is driven by estimated levels of oil stolen; the direct burning of confiscated product is likely, in part, to already be covered by our estimates.

Secondly, our analysis identified higher levels of sulphur in official supplies. Allegations of commodity brokers selling fuel containing high levels of sulphur into unregulated West African markets were previously reported by a Public Eye investigation. Whilst our sample size does not provide proof, it certainly indicates that this should be investigated further. Our analysis estimates that using official diesel increases particulate emissions by an estimated 13% compared to using unofficial products.

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[59] The crackdown on piracy off the Gulf of Guinea made it more difficult to ship crude offshore, reflected by the fact that stolen oil shipped offshore reduced from 75% to 25% in 2017. Coupled with surging local demand for refined fuel, the stolen crude found local markets via artisanal refining camps that processed the crude oil into petroleum products. Over the last few years, official fuel scarcity was often caused by official marketers withholding supply to negotiate fuel subsidy payments. During this scarcity, local consumers turned to alternative sources of refined fuel, enabling artisanal fuel marketers to gain a foothold in the industry. As high profits flowed back to unofficial camp investors, and new camps developed into very profitable enterprises across the Niger Delta, the quality, choice and availability of unofficial products grew. This provided strong competition to official products and alternative cost effective choices to consumers. In short, the artisanal industry provided consumers with a solution to their fuel problem; a reliable supply of reasonable quality fuel products at lower prices than the official alternative. Using these products, enterprises were no longer constrained by insecure fuel supplies and high costs. Small vendors and households benefited and so the unofficial supply, although illegal, was tolerated as an effective alternative to official sources.

[60] Unofficial volume assumptions correspond with analysis in SDN's report More Money. More Problems

[61] CNN, 2018, 'Port Harcourt: Why is this Nigerian city covered in a strange black soot?', viewed on 18 December 2018, (edition.cnn.com/2018/04/26/africa/nigeria-portharcourt-soot/index.html?no-st=1548844958)

[62] Pax For Peace, 2017, 'Living under a black sky: Conflict pollution and environmental health concerns in Iraq', viewed on 7 February 2019, (www.reliefweb.int/sites/reliefweb.int/files/resources/pax-report-living-under-a-black-sky.pdf)

Official supplies may also be disproportionately contributing to Port Harcourt city soot due to the higher density of official filling stations and local use of official products throughout the city, especially when requiring larger quantities of fuel for vehicles. Note that this would not be an isolated problem to Port Harcourt city, as official supplies are used throughout the country. Whilst we have analysed only samples from the Niger Delta region, it would be useful to test official supply samples in other Nigerian cities. If official supply comprised of high-sulphur fuel nationwide, the impact on particulate emissions and the associated environmental and health impacts across Nigeria would be enormous.

If further investigations prove this to be the case, international commodity institutions, brokers, and relevant Nigerian institutions must be held to account to reduce the imports of high-sulphur fuels in compliance with International and planned National fuel standards.

5.2.4 Blending

Fuel blending is often used to alter the chemical characteristics to increase the performance of a fuel. In the context of artisanal refining blending can be used as (1) a process to launder unofficial products into official distribution chains or (2) to boost the performance of unofficial products. This investigation attempted to detect blending through a comparative analysis of official samples collected from Lagos, where imported fuel enters Nigeria and unofficial and official samples from the Niger Delta.

Lagos official fuel samples, on average, contained more sulphur than the Niger Delta samples tested, however, relatively low concentrations of BTEX and manganese. Given the reasonably narrow fuel characteristics tested, high sulphur levels in unofficial Niger Delta fuels could potentially indicate blending activities. However, additional field research is required to better understand more about the types of blending activities within artisanal refining camps.

5.2.5 Health hazards

The health hazards of using these products impact all producers and consumers of fuel. Our analysis identified high levels of the carcinogen benzo(a)anthracene and the toxicants toluene and Naphthalene, particularly in the gasoline samples tested.

For artisanal camp workers mixing these chemicals as part of the refining process, the exposure to such high levels of these compounds will likely have serious adverse health effects. International regulations set % vol. limits to reduce the impact of these effects.These chemicals, especially at camp sites, are also likely to seep into the surrounding soil and water resulting in a toxic environment for the local environment and ecology. The likelihood of these compounds entering the drinking water systems, especially in rural, coastal communities is high. This vector also potentially contributes to an increased prevalence of cancers and long term health conditions.

5.2.6 Engines and generators

High sulphur concentrations are known to contribute to increased particulate residues within engines, increasing the frequency of maintenance. Therefore, the high-sulphur fuels used in the Niger Delta likely result in high vehicle and generator maintenance costs for consumers.

6. Conclusion

The findings in this investigation, particularly the extraordinarily high fuel sulphur concentrations across both unofficial and official fuel supplies in the Niger Delta, are cause for serious concern. These findings add to a growing body of evidence that unregulated fuel markets cause significant particulate pollution, infrastructure damage, and adverse health impacts. In summary:

- **Official vs. Unofficial:** in many cases, fuels sampled from official sources were actually of a poorer standard than unofficial fuels produced in local artisanal refineries.
- **Sulphur:** all official samples have worryingly high levels of sulphur—a major contributing factor to soot and particulate emissions.
- **Gasoline:** unofficial gasoline tended to be of better quality than official gasoline samples collected in the Niger Delta, supporting reports of consumer preferences and the competence of artisanal producers.
- **Diesel:** both unofficial and official diesel samples were of a poor standard and high viscosity, which is bad for engines, but reportedly preferred locally as it is perceived to last longer.
- **Kerosene:** official kerosene was found to be a much better standard than unofficial samples, but official supply generally falls short of demand, a gap bridged by unofficial supply.
- **Viscosity:** all fuel samples had higher viscosities compared to benchmarks, affecting combustion and damaging engines.
- **Lagos vs. Niger Delta:** Lagos official samples are less viscous but contain higher sulphur content, than Niger Delta official samples.
- **Air pollution:** Unofficial fuel production and consumption are estimated to produce 40% of total particulate matter (PM2.5 and 10) in the Port Harcourt city area; when official fuel consumption is added, this comes to 50%. Therefore, an estimated remaining 50% of air pollution in Port Harcourt city comes from other sources—possibly official refineries, petrochemicals and bitumen plants, and burning of organic and inorganic waste.
- **Standards:** the official fuels sampled, most of which will have been imported to Nigeria, do not comply with proposed Nigerian standards, or similar standards in place across other West African countries—and fall well below established standards required in other jurisdictions such as the EU. International commodity traders appear to be exploiting the lack of regulations and regulatory enforcement in Nigeria.

In a time when climate is firmly on the political agenda, it is crucial to understand how these regions are contributing to global climate change, environmental destruction, and citizen health. We hope that this analysis motivates governments, commodity institutions, and the oil industry to act to regulate fuel content and emissions across the petroleum sector.

6.1 Policy recommendations

Based on our research and analysis, we recommend the following policy recommendations to help reduce air pollution and instances of petroleum-related health conditions across the Niger Delta as a result of unofficial and official fuel consumption:

- At a minimum, the Standards Organization of Nigeria (SON) should be vested with the powers and partners required to implement the planned Nigerian fuel sulphur standards across official supply channels to mitigate particulate emissions; 50 ppm (diesel), 150 ppm (petrol) and 150 ppm (kerosene). This level for sulphur would still undermine emission reduction technologies, and so further reductions in these limits to align with EU or similar standards should be considered.
- Commission a formal joint investigation by the Nigeria National Petroleum Corporation (NNPC), Petroleum Products Pricing Regulatory Agency (PPPRA), Federal Ministries of Petroleum Resources and Environment, and the Standards Organization of Nigeria (SON) to identify the levels of sulphur within official fuel supplies across the Niger Delta, and the rest of Nigeria. Should unacceptable levels be found, hold the relevant international and/or national companies, importers, and institutions to account.
- Commission a study into the sources of the remaining particulate emissions in the Port Harcourt city area, working with experts from the University of Port Harcourt, state Commissioner for Environment, Federal Ministry of Environment, international oil and gas companies and civil society organisations, to gather data on air quality levels in different locations, and model sources and other important factors that can help policy-makers to mitigate the ongoing and notorious soot issue.
- Request that all available data on air pollution in Port Harcourt city is publicly released by international oil companies (and any others that are collecting data), and monitored to assess potential health impacts, and the impact of any changes due to measures taken to improve fuel quality, reduce the prevalence of artisanal refineries, and address other sources.
- Support the Rural Electrification Agency to work with private partners to develop renewable energy infrastructure across the Niger Delta to reduce demand for unofficial and official fuel.
- The Ministry of Petroleum Resources and Petroleum Technology Development Fund should consider engaging artisanal oil refiners in plans for domestic refining, given they are often producing fuels with better characteristics than official fuel supplied to Nigeria.

7. Appendices

Appendix 1: sample collection methodology

EC petroleum liquids sampling approach:

- The containers should be made of plastic, glass or metal with suitable corks or plastic stoppers (not made of rubber).
  - Plastic bottle, narrow opening, normal size, 100 to 500 ml, leak-proof closure.
  - Dark glass bottle, large size, 500 to 1,000 ml, leak-proof closure.
  - Metal can, large size, 500 to 1,000 ml, leak-proof closure. Can must be free of contaminants, such as rust and soldering flux.
- Sample containers must be clean and free from all substances which might contaminate the material being sampled (such as water, dirt, lint, washing compounds, naphtha and other solvents, soldering fluxes, acids, rust and oil).
- For gasoline—glass or metal containers only, capacity at least 1.0 litre. Leave min. 10% ullage in the container to allow for thermal expansion.
- Official commercial site fuel dispensers/filling station collection.
  - One aggregate sample of homogenous fuel is taken by means of dispensers on the filler pipes and poured directly into the sampling bottle.
  - The samples are taken by means of dispensers on the filler pipes. At least 4 litres of fuel must be discharged before sampling if there is no evidence that the tube of the fuel pump contains fresh fuel.
  - The sample container for the final samples is directly filled from the fuel dispenser using a funnel or an extension tube in order to prevent fuel evaporation.
  - The sample container should be slowly filled in order to prevent foaming.
  - The container must be filled to a maximum of 80-90% of its volume, in order to allow expansion due to heat.
- Unofficial camp collections—barrels, drums, cans, and similar small hand containers.
  - Collect one or more sample(s).
  - Sample by using a vacuum pump, various pipette-type samplers or other appropriate samplers.
  - An incremental sample is drawn from the centre of each container chosen randomly or systematically throughout the consignment.
  - If a sample is to be taken from only one container (e.g. barrel), it is poured directly from the sampler into the sample container. When a set of barrels are to be sampled and we are certain that the set represents an identical lot, incremental samples are taken from several randomly chosen barrels, which are then combined in a mixing vessel in order to create the aggregate sample.
- Complete sampling form/label.
  - Time/date/location/Sample Type (PMS, AGO, DPK)/Camp reference/Pump reference.
- Storage
  - Store in a cool, dark, dry and well-ventilated place, away from heat sources.
  - Keep the container tightly closed in order to prevent loss of light components.
  - Use a ventilated cabinet for flammables if available.
  - Appropriate warning signs should be displayed.

Appendix 2: emissions modelling methodologies and assumptions

The objectives of this investigations emissions modelling are to:

- Calculate the level of air pollution emitted from producing and consuming unofficial and official fuel, and model the total impact based on production estimates.
- Evaluate the likely impacts that these emissions have on health and the environment, with a particular focus on the contribution to the soot epidemic in Port Harcourt.

Unofficial fuel production emissions were calculated using emissions factors identified in the EPA WebFIRE database and a paper investigating particle and gas emissions from in-situ burning of crude oil on the ocean[63]. When combined, these two data sources identify a range of pollutant emissions; Carbon Dioxide, Carbon Monoxide, PM (filterable) and PM10 (filterable), Total Smoke Particles and Soot.

Unofficial and official fuel consumption emissions were calculated using emissions factors identified in the EPA WebFIRE database[64] for a range of pollutant emissions; Carbon Dioxide, Carbon Monoxide, Nitrogen Oxides, PM10 (filterable) and PM2.5 (filterable).

Emission Factors[65]

An emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per megagram of coal burned). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i.e. a population average).

The general equation for emissions estimation is:

E = A x EF x (1-ER/100)

E = emissions;

A = activity rate;

EF = emission factor, and

ER =overall emission reduction efficiency,%

WebFIRE[66]

WebFIRE is the US Environmental Protection Agency's (EPA) online emissions factor repository, retrieval, and development tool.

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[63] Ross, J. L., Ferek, R. J. and Hobbs, P. V, 1996, 'Particle and Gas Emissions from an In Situ Burn of Crude Oil on the Ocean', Journal of the Air & Waste Management Association, 46(3), pp. 251–259
[64] United States Environmental Protection Agency, 2020, 'Basic Information of Air Emissions Factors and Quantification', (www.epa.gov/air-emissions-factors-and-quantification/basic-information-air-emissions-factors-and-quantification)
[65] Ibid
[66] United States Environmental Protection Agency, 2020, viewed 1 December 2018, (www.epa.gov/electronic-reporting-air-emissions/webfire)

The WebFIRE database contains EPA recommended emissions factors for criteria and hazardous air pollutants (HAP) for industrial and non-industrial processes. In addition, WebFIRE contains the individual data values used to develop the recommended factors and other data submitted to EPA by federal, state, tribal, and local agencies; consultants; and industries. For each recommended emissions factor and individual data value, WebFIRE contains descriptive information such as industry and source category type, control device information, the pollutants emitted, and supporting documentation.

A filtered version of the latest WebFIRE dataset (090716 version) was used to identify average emission factor values across all combustion engines noting that the contribution from industries and engine type will vary. We have chosen to calculate a broad average as a starting point across Bayelsa and Rivers States. Note that emission reduction% have not been considered on the basis that, in general, unofficial refining camps do not use emission reduction technology as part of their operations.

Unofficial (Artisanal) Fuel Production

WebFire dataset (090716) filtering parameters:

Material - Asphalt (bitumen)

Pollutant - PM, filterable, PM10, filterable

Unofficial[67,68] production volumes

Table A-1: Unofficial fuel volume assumptions

Unofficial Production Assumptions	Quantity
Estimated crude oil stolen per day (NDD barrels)	175,000
Share sold in domestic black market	75%
Share available for unofficial processing per day (NDD barrels)	131,250
Estimated domestic allocation of stolen crude oil sold in Bayelsa and Rivers collectively (90% of 75%) (NDD barrels)	118,125
Processing efficiency	85%
Estimated volume of petroleum products produced in Bayelsa and Rivers collectively per day (NDD barrels)	100,406
Average Number of Monthly Production Cycles	10
Estimated annual volume produced in Rivers & Bayelsa (NDD barrels)	12,048,750
Estimated annual volume of processed petroleum products (Litres)	2,409,750,000
Estimated annual volume of processed petroleum products (US gallons)	636,588,477

[67] Unofficial volume assumptions correspond with analysis in SDN's report "More Money. More Problems"
[68] Interviews with artisanal refiners indicate that for every artisanally refined production cycle, 3 drums of stolen crude oil and 0.5 drums of bitumen (a waste product from the refining process) are used to fuel the refining "ovens".

Table A-2: Unofficial fuel “cooking” emissions assumptions

Unofficial Production - "Cooking" Assumptions	Quantity
% Stolen Crude Input Used as Cooking Fuel	3.75%
Total Daily Volume used as Cooking Fuel (NDD)	4,430
Average Number of Monthly Production Cycles	10
Total Annual Volume used as Cooking Fuel (NDD)	531,563
Total Annual Volume used as Cooking Fuel (Litres)	106,312,500
Total Annual Volume used as Cooking Fuel (US Gallons)	28,084,786
Total Annual Volume used as Cooking Fuel (kg)	90,265,330

Table A-3: Calculated emissions values based on production volume assumptions

Fuel Type	Pollutant	Average Converted Factor Value (g / kg)	Emissions (Tons / Year)
Camp Ovens			
Crude Oil			
	Carbon dioxide	2.81E+03	253,646
	Carbon monoxide	3.00E+01	2,708
	Total Smoke Particles	1.50E+02	13,540
	Soot	6.60E+01	5,958
Fuel Type	**Pollutant**	**Average Converted Factor Value (Lb / 1000 Gallons)**	**Emissions (Tons / Year)**
Camp Ovens			
Bitumen			
	PM10, filterable	1.59E+01	223
	PM, filterable	7.92E+00	111

Official[69] production volumes

Table A-4: Official fuel volume assumptions

State	Annual Production Volume (Litres)
Bayelsa	124,525,295
Rivers	1,167,284,162
Total	**1,291,809,457**

Fuel product proportions[70]

Table A-5: Estimated unofficial and official product proportions

Product Proportions	Unofficial Bayelsa & Rivers	Official Rivers 2017	Official Bayelsa 2017
Diesel	71%	26%	16%
Gasoline	12%	61%	73%
Kerosene	18%	13%	11%

[69] Nigeria National Bureau of Statistics, 2017, 'Petroleum Products Imports and Consumption (Truck Out) Statistics 2017', viewed on 8 March 2019, (www.brandspurng.com/wp-content/uploads/2018/02/petroleumproductsimportstat2017.pdf)
[70] Product proportions correspond with analysis in SDN's report "More Money. More Problems

Emissions factors: WebFire dataset filtering parameters (unofficial and official consumption)

Level 1 - Internal Combustion Engines

Level 2 - Commercial / Institutional, Electric Generation, Industrial

Level 3 - Distillate Oil (Diesel), Gasoline, Kerosene/Naphtha (Jet Fuel)

Pollutant - Carbon Dioxide, Carbon Monoxide, Nitrogen Oxides, PM10 (filterable), PM2.5 (filterable)

Table A-6: Calculated emissions values based on consumption volume assumptions

Fuel Type	Pollutant	Average Converted Factor Value (Lb / 1000 Gallons)	Emissions (Tons / Year)
Unofficial Consumption			
Distillate Oil (Diesel)			
	Carbon dioxide	2.22E+04	4,990,811
	Carbon monoxide	3.49E+01	7,846
	Nitrogen oxides (NOx)	2.04E+02	45,862
	PM10, filterable	1.79E+01	4,020
	PM2.5, filterable	2.07E+01	4,647
Gasoline			
	Carbon dioxide	1.95E+04	730,204
	Carbon monoxide	7.90E+03	295,826
	Nitrogen oxides (NOx)	2.05E+02	7,677
	PM10, filterable	1.26E+01	472
	PM2.5, filterable	1.26E+01	472
Kerosene/Naphtha (Jet Fuel)			
	Carbon dioxide	N/A	N/A
	Carbon monoxide	6.63E+01	3,721
	Nitrogen oxides (NOx)	3.68E+02	20,651
	PM10, filterable	2.18E+01	1,227
	PM2.5, filterable	5.69E-01	32
Official Consumption			
Distillate Oil (Diesel)			
	Carbon dioxide	2.22E+04	955,462
	Carbon monoxide	3.49E+01	1,502
	Nitrogen oxides (NOx)	2.04E+02	8,780
	PM10, filterable	1.79E+01	770
	PM2.5, filterable	2.07E+01	890
Gasoline			
	Carbon dioxide	1.95E+04	2,061,750
	Carbon monoxide	7.90E+03	835,273
	Nitrogen oxides (NOx)	2.05E+02	21,675
	PM10, filterable	1.26E+01	1,332
	PM2.5, filterable	1.26E+01	1,332
Kerosene/Naphtha (Jet Fuel)			
	Carbon dioxide	N/A	N/A
	Carbon monoxide	6.63E+01	1,450
	Nitrogen oxides (NOx)	3.68E+02	8,046
	PM10, filterable	2.18E+01	478
	PM2.5, filterable	5.69E-01	12

Geographical assumptions

Table A-7: Geographical areas, population and population densities

Area	Population	Area (km^2)	Density (persons / km^2)
Rivers State	7,303,924	10,575	691
Bayelsa State	2,277,961	9,059	251
Port Harcourt	1,865,000	369	5,054

Estimating diesel particulate matter from sulphur content

We evaluated and quantified DPM using a theoretical scenario modelling diesel fuelled generator use across Rivers & Bayelsa States based on research by Saiyasitpanich et al discussed in their paper, "The Effect of Diesel Fuel Sulfur Content on Particulate Matter Emissions for a Nonroad Diesel Generator"[71]. This paper describes an empirical correlation for estimating DPM concentration when fuel sulphur content and engine loads are known.

The empirical correlation described is:

$$Y = Zm(\alpha X + \beta)$$

Where:

Y is the DPM concentration mg/m3

Z is the fuel sulphur content, ppmw (limited to 500-3,700 ppmw)

X is the applied load, kW

m is the constant, 0.407

ɑ is a numerical coefficient, 0.0118 ± 0.0028 (95% confidence interval)

ß is a numerical coefficient, 0.4535 ± 0.1288 (95% confidence interval)

For the Niger Delta context we have used the following values:

Z; the average analysed diesel sulphur content; unofficial 1,320 ppm and official 3,020 ppm

[71] Saiyasitpanich, P. et al., 2005, 'The Effect of Diesel Fuel Sulfur Content on Particulate Matter Emissions for a Nonroad Diesel Generator', Journal of the Air & Waste Management Association, 55(7), pp. 993–998

X; 25 kW applied load (smallest generator tested in research)

α; 0.0118

ß; 0.4535

Data from the World Bank Report was used to estimate the volume of diesel used per day across Rivers State (table A-8). DPM emissions were calculated and then adjusted to match the total emissions estimated using emissions factors. This adjustment is important as the correlation produces DPM concentrations from exhaust emissions. Exhaust emissions at the generator source will be significantly more concentrated than when dispersed through the atmosphere. Adjusting the exhaust emissions to match the total emissions produced via the emissions factor method takes into account the activity rates used to calculate the emissions factors. We believe this is a good proxy to estimate the particulate concentration when dispersed through an atmospheric volume of air.

Table A-8: World Bank data for Rivers State household generators and diesel consumption

Rivers State	
No of generators	29,779
Energy (MWh) per annum	6,001
Diesel litres consumed unofficial per annum	4,990,472
Diesel litres consumed official per annum	1,326,581
Diesel litres consumed per generator per annum	212
Diesel litres consumed per generator per day	0.6

Daily particulate emissions concentrations

Estimated DPM concentrations (µg/m3) were calculated across Port Harcourt using an atmospheric volume that contains the surface area of Port Harcourt and a height of 200m, on the basis that the majority of particulate matter is found below this altitude[72]. This approach enables an estimation and quantification of emissions in a densely populated urban area. Calculated values were compared to average air quality readings taken in Port Harcourt in 2017[73] enabling an estimation of % contribution of household diesel generators to total particulate emissions (0.04%) and the % increase as a result of unofficial and official fuel sulphur content (13%).

Appendix 3: aggregated fuel analysis dataset (grouped by fuel type)

Table A-9: Average analysis of samples excluding Polycyclic Aromatic Hydrocarbons

	Niger Delta						Lagos		
Fuel Parameters	Average Unofficial Diesel	Average Unofficial Gasoline	Average Unofficial Kerosene	Average Official Diesel	Average Official Gasoline	Average Official Kerosene	Average Official Diesel	Average Official Gasoline	Average Official Kerosene
TPH (ppm)	11,909	7,203	9,645	20,242	6,430	15,154	7,008	5,736	4,563
Organolead (ppm)	0.005	0.008	0.006	0.004	0.001	0.006	Not tested	Not tested	Not tested
Sulphur Content (ppm)	1,523	401	759	2,044	429	813	2,389	1,424	823
Flash Point (°C)	73	64	60	80	60	51			
Boiling Point Range (°C)	244-375	Not tested	Not tested	264-368	Not tested	Not tested	Not tested	Not tested	Not tested
Manganese (mg/l)	0.04	0.51	0.04	0.02	1.13	0.06	0.26	0.18	0.11
Octane Number: RON	107	105	106	107	105	105	Not tested	Not tested	Not tested
Octane Number: MON	98	94	96	98	95	96	Not tested	Not tested	Not tested
Benzene (ppm)	77	245	25	4	955	16	13	70	21
Toluene (ppm)	16	321	81	2	345	20	5	7	3

[72] Sci Dev Net, 2016,'Air pollution declines with height', viewed on 16 June 2019, (www.scidev.net/asia-pacific/pollution/news/air-pollution-decline-with-height.html)
[73] Akinfolarin, O. M., Boisa, N. and Obunwo, C. C., 2017, 'Assessment of Particulate Matter-Based Air Quality Index in Port Harcourt, Nigeria', Journal of Environmental Analytical Chemistry. OMICS International, 04(04), pp. 1–4

Appendix 4: complete fuel analysis dataset (grouped by fuel type)

Batch 1

Sample No	1.1	1.4	1.7	1.10	1.13	1.2	1.5	1.8	1.11	1.14	1.16	1.3	1.6	1.9	1.12	1.15
Sample Time	8:00	19:00	12:00	19:00	9:00	8:00	19:00	12:00	19:00	9:00	13:00	8:00	19:00	12:00	19:00	9:00
Sample Date	17/12/18	17/12/18	18/12/18	18/12/18	19/12/18	17/12/18	17/12/18	18/12/18	18/12/18	19/12/18	18/12/18	17/12/18	17/12/18	18/12/18	18/12/18	19/12/18
Sample Location	Bille	Port Harcourt	Okrika	Port Harcourt	Gokana	Bille	Port Harcourt	Okrika	Port Harcourt	Gokana	Okrika	Bille	Port Harcourt	Okrika	Port Harcourt	Gokana
Sample Company Name	N/A	N/A	N/A	Oando	N/A	N/A	N/A	N/A	Oando	N/A	N/A	N/A	N/A	N/A	Eterna	N/A
Sample Type	Diesel	Diesel	Diesel	Diesel	Diesel	Gasoline	Gasoline	Gasoline	Gasoline	Gasoline	Gasoline	Kerosene	Kerosene	Kerosene	Kerosene	Kerosene
Official / Unofficial	Unofficial	Unofficial	Unofficial	Official	Unofficial	Unofficial	Unofficial	Unofficial	Official	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Official	Unofficial
Fuel Parameters																
TPH (ppm)	3,645	3,679	4,704	9,648	9,270	8,162	6,267	5,083	3,766	8,107	984	11,877	8,342	14,367	7,831	15,011
Lead (ppm)	0.0060	0.0070	0.0010	0.0040	0.0040	0.0110	0.0220	0.0010	0.0009	0.0070	0.0009	0.0060	0.0040	0.0080	0.0060	0.0050
Sulphur Content (wt%)	0.121	0.146	0.133	0.302	0.128	0.028	0.011	0.049	0.023	0.010	0.051	0.055	0.051	0.049	0.130	0.047
Sulphur Content (ppm)	1,210	1,460	1,330	3,020	1,280	280	110	490	230	100	510	550	510	490	1,300	470
Flash Point (°C)	82.0	66.6	67.5	80.0	77.4	80.3	63.2	63.4	60.1	62.4	51.5	55.3	55.3	67.7	50.7	63.1
Manganese (ppm)	0.011	0.010	0.004	0.004	0.006	0.044	0.027	1.618	0.114	0.006	0.343	0.005	0.004	0.005	0.005	0.007
Octane Number: RON	109.1	108.8	106.9	106.8	104.2	104.7	104.2	105.5	105.0	105.3	103.6	106.4	106.8	106.8	105.2	105.2
Octane Number: MON	99.6	99.5	97.9	97.7	93.7	94.2	93.7	95.4	94.5	95.0	93.1	96.9	93.6	97.6	96.0	96.0
Boiling Point Range (°C)	243-344	249-390	238-382	264-368	247-385											
BTEX																
Benzene (ppm)	0.09	0.10	0.14	0.18	0.01	0.10	1.44	146.29	246.71	1.77	28.77	0.08	0.20	0.05	0.04	0.09
Toluene (ppm)	1.05	0.46	2.30	0.63	0.78	7.00	76.38	503.22	810.27	109.06	1.18	1.75	0.67	13.14	0.65	4.11
Ethylbenzene (ppm)	0.36	0.18	1.14	0.34	0.10	4.69	2.80	3.59	294.11	86.41	1.05	0.79	0.68	0.69	1.59	1.45
p-xylene (ppm)	0.31	1.20	0.78	3.27	1.03	3.21	1.92	2.46	102.25	20.16	0.72	0.54	0.54	1.03	1.20	0.99
o-xylene (ppm)	1.00	1.45	2.95	6.63	1.33	33.18	31.07	90.85	203.59	40.14	11.04	21.15	6.50	20.00	14.76	21.73
	2.81	**3.39**	**7.31**	**11.05**	**3.25**	**48.18**	**113.61**	**746.41**	**1,656.93**	**257.54**	**42.76**	**24.31**	**8.59**	**34.91**	**18.24**	**28.37**

Sample No	1.1	1.4	1.7	1.10	1.13	1.2	1.5	1.8	1.11	1.14	1.16	1.3	1.6	1.9	1.12	1.15
PAH Profile																
Acenaphthene	ND	4.51	1.77	2.05	7.78	1.84	6.00	15.62	9.44	1.77	ND	4.27	21.65	3.02	10.24	2.01
Acenaphthylene	ND	2.46	5.94	1.98	19.78	3.05	2.71	1.94	14.89	1.98	4.37	2.57	1.80	19.23	1.77	1.84
Anthracene	50.16	11.18	1.98	4.48	55.09	96.56	32.25	73.27	2.15	169.11	16.21	328.60	216.04	13.29	224.57	92.26
1,2,3-trimethylbenzene	1.91	1.80	9.75	1.98	13.54	6.04	31.10	21.03	19.92	3.30	23.67	12.08	12.22	13.22	17.49	7.74
Benzo (a) pyrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (a) anthracene	1.80	35.44	20.20	78.13	2.43	1.84	2.57	4.96	ND	ND	ND	5.94	5.07	9.61	ND	1.98
Benzo (b) fluoranthene	23.88	6.87	6.18	1.77	13.47	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (g,h,i) perylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (k) fluoranthene	2.67	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chrysene	17.95	ND	ND	1.84	3.78	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibenz (a,h) anthracene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NN
Fluoranthene	8.61	32.70	15.86	29.85	2.74	18.08	62.17	76.43	ND	55.05	ND	655.47	9.86	13.29	115.97	343.01
Fluorene	ND	4.51	1.77	2.05	7.78	22.39	1.91	15.62	10.24	13.61	ND	2.08	21.35	3.02	10.24	1.94
Indeno (1,2,3-cd) pyrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-Methylnaphthalene	ND	2.46	5.94	1.98	19.78	6.18	39.26	5.00	2.19	12.95	4.37	19.23	8.92	1.87	2.15	8.19
Naphthalene	4.17	1.87	4.13	5.76	4.13	208.68	4.58	11.73	18.57	2.81	722.87	197.95	81.08	5.62	20.31	192.02
Phenanthrene	121.83	2.15	25.82	51.23	2.05	5.03	42.10	2.08	1.98	25.72	8.26	76.57	8.43	1.87	7.67	40.40
Pyrene	1.98	3.96	13.26	14.72	4.27	1.84	4.58	4.96	ND	ND	ND	10.45	2.01	5.17	ND	2.36
	234.96	**109.91**	**112.60**	**197.82**	**156.62**	**371.53**	**229.23**	**232.64**	**79.38**	**286.30**	**779.75**	**1,315.21**	**388.43**	**89.21**	**410.41**	**693.75**

Batch 2

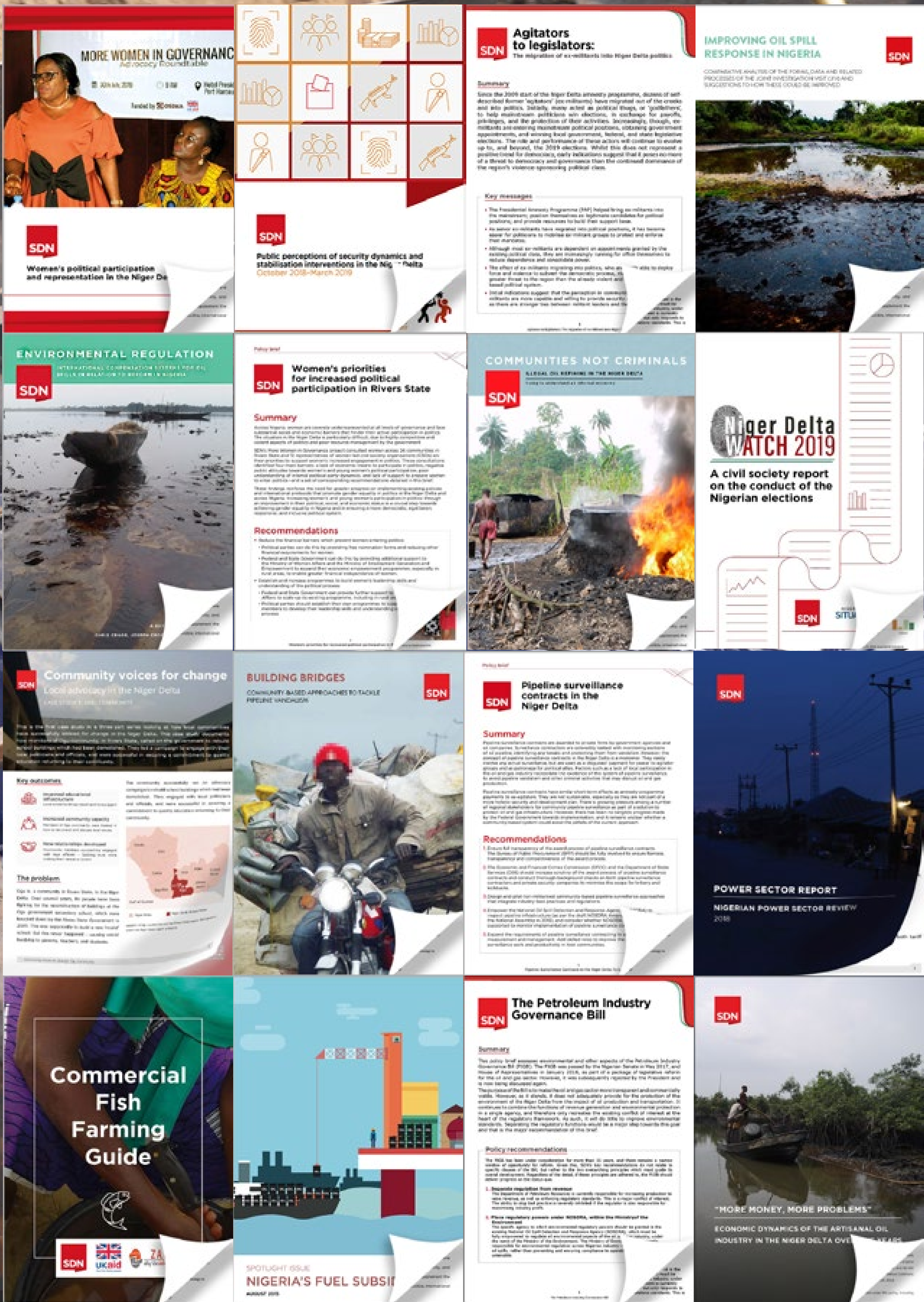
Sample No	2.1	2.4	2.6	2.7	2.10	2.13	2.14	2.16	2.20	2.23	2.25	2.3	2.5
Sample Time	13:30	12:15		14:30	10:15	13:30		13:40	10:40	17:02	15:05	13:33	12:17
Sample Date	27/5/19	27/5/19		28/5/19	28/5/19	28/5/19		28/5/19	26/5/19	25/5/19	28/5/19	27/5/19	27/5/19
Sample Location	Port Harcourt	Port Harcourt	Port Harcourt	Port Harcourt	Port Harcourt	Port Harcourt	Port Harcourt	Port Harcourt	Brass	Nembe	Southern Ijaw	Port Harcourt	Port Harcourt
Sample Company Name	Total	Eterna	Total 2	Mobil	ConOil	NNPC	Oando	Mobil 2	N/A	N/A	N/A	Total	Eterna
Sample Type	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Gasoline	Gasoline
Official / Unofficial	Official	Official	Official	Official	Official	Official	Official	Official	Unofficial	Unofficial	Unofficial	Official	Official
Fuel Parameters													
TPH (ppm)	8,064	48,447	60,634	74,271	7,477	2,582	14,687	10,286	86,813	7,615	12,027	11,177	7,747
Sulphur Content (wt%)	0.014	0.277	0.233	0.273	0.23	0.107	0.138	0.22	0.127	0.127	0.119	0.018	0.008
Sulphur Content (ppm)	140	2,770	2,330	2,730	2,300	1,070	1,380	2,200	1,270	1,270	1,190	180	80
Manganese (mg/l)	0.024	0.012	0.007	0.01	0.006	0.008	0.006	0.004	0.006	0.004	0.006	0.006	0.008
BTEX													
Benzene (ppm)	0.37	1.38	2.38	9.87	18.54	3.23	0.51	2.10	26.80	1,106.84	2.79	1,850.61	1,821.62
Toluene (ppm)	0.65	3.25	0.98	0.85	0.80	1.43	0.88	2.48	7.26	2.38	162.88	239.13	1,024.10
Ethylbenzene (ppm)	1.90	1.26	13.27	9.27	9.83	4.14	0.37	1.17	155.30	320.85	203.66	1,070.25	675.19
p-xylene (ppm)	0.70	0.78	0.56	0.69	0.32	0.44	0.22	0.86	2.24	0.66	139.52	733.17	464.20
o-xylene (ppm)	0.41	1.17	1.63	0.65	0.97	0.35	0.85	0.54	7.21	0.48	3.89	13.93	2.97

Sample No	2.8	2.9	2.11	2.12	2.15	2.17	2.18	2.19	2.22	2.27	2.2	2.21	2.24	2.26
Sample Time		14:20		10:30	13:32		13:42	10:42	17:21	6:50	14:05	10:31	17:30	15:08
Sample Date		28/5/19		28/5/19	28/5/19		28/5/19	26/5/19	25/5/19	13/5/19	27/5/19	26/5/19	25/5/19	28/5/19
Sample Location	Port Harcourt	Port Harcourt	Port Harcourt	Port Harcourt	Port Harcourt	Port Harcourt	Port Harcourt	Brass	Nembe	Southern Ijaw	Port Harcourt	Brass	Nembe	Southern Ijaw
Sample Company Name	Total 2	Mobil	Oando	ConOil	NNPC	Forte	Mobil 2	N/A	N/A	N/A	Total	N/A	N/A	N/A
Sample Type	Gasoline	Gasoline	Gasoline	Gasoline	Gasoline	Gasoline	Gasoline	Gasoline	Gasoline	Gasoline	Kerosene	Kerosene	Kerosene	Kerosene
Official / Unofficial	Official	Official	Official	Official	Official	Official	Official	Unofficial	Unofficial	Unofficial	Official	Unofficial	Unofficial	Unofficial
Fuel Parameters														
TPH (ppm)	6,023	13,173	1,159	22,491	2,938	2,594	8,638	3,708	11,404	26,912	50,618	42,809	8,329	6,643
Sulphur Content (wt%)	0.048	0.061	0.014	0.051	0.016	0.03	0.01	0.036	0.034	0.01	0.112	0.057	0.058	0.04
Sulphur Content (ppm)	480	610	140	510	160	300	100	360	340	100	1,120	570	580	350
Manganese (ppm)	0.004	0.004	0.012	0.009	0.018	0.006	0.012	0.011	0.01	0.018	0.01	0.005	0.004	0.011
BTEX														
Benzene (ppm)	1,256.01	1,198.51	1,147.63	1,222.90	1,900.29	1,428.26	195.64	19.10	1,972.79	1,738.21	0.80	40.47	5.89	306.54
Toluene (ppm)	33.12	44.61	2,044.49	179.75	401.05	9.35	2.44	4.96	3,490.40	217.80	0.99	794.77	72.42	52.59
Ethylbenzene (ppm)	566.19	490.97	423.73	1,280.75	1,334.95	149.87	225.42	405.41	2,401.43	1,314.82	60.35	505.84	43.53	935.25
p-xylene (ppm)	389.13	336.34	3.20	878.17	914.50	0.97	1.08	278.22	1,660.92	909.77	1.13	346.52	0.60	653.49
o-xylene (ppm)	1.22	1.68	2.18	1.83	99.86	2.37	0.65	1.33	7.09	9.29	2.37	3.82	10.94	9.91

Batch 3

Sample No	3.R1	3.R2	3.R3	3.R4	3.R5	3.R6	3.R7	3.R8	3.R9	3.R10	3.R11	3.R12	3.R13	3.R14	3.R15	3.R16	3.R17	3.R18
Sample Time	12:08	12:09	10:18	10:24	15:58	15:59	9:08	16:45	9:21	9:21	9:03	10:56	8:46	8:46	9:05	9:06	9:07	9:07
Sample Date	26/11/19	26/11/19	26/11/19	26/11/19	26/11/19	26/11/19	25/11/19	25/11/19	25/11/19	25/11/19	25/11/19	26/11/19	27/11/19	27/11/19	27/11/19	27/11/19	27/11/19	27/11/19
Sample Location	Bolo	Bolo	Bolo	Bolo	Bolo	Bolo	Bolo	Bolo	Bolo	Bolo	Bolo	Bolo	Bolo	Bolo	Bolo	Bolo	Bolo	Bolo
Sample Company Name													Filling Station	Filling Station	Oscare Nig Ltd	Oscare Nig Ltd	Oscare Nig Ltd	Oscare Nig Ltd
Sample Type	Gasoline	Gasoline	Kerosene	Kerosene	Diesel	Diesel	Gasoline	Gasoline	Kerosene	Kerosene	Diesel	Diesel	Gasoline	Gasoline	Kerosene	Kerosene	Diesel	Diesel
Official / Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Official	Official	Official	Official	Official	Official
Fuel Parameters																		
TPH (ppm)	1,072	876	4,599	2,402	2,075	2,734	1,950	2,094	2,104	2,218	1,787	1,055	1,332	1,127	969	1,199	1,536	1,491
Sulphur Content (wt%)	0.02	0.024	0.017	0.101	0.146	0.139	0.0019	0.025	0.011	0.018	0.162	0.144	0.017	0.098	0.068	0.015	0.216	0.221
Sulphur Content (ppm)	200	240	170	1,010	1,460	1,390	19	250	110	180	1,620	1,440	170	980	680	150	2,160	2,210
Manganese (ppm)	0.084	0.084	0.083	0.088	0.088	0.087	0.103	0.104	0.116	0.118	0.114	0.11	0.081	0.075	0.125	0.085	0.07	0.117
BTEX																		
Benzene (ppm)	3.28	0.37	0.85	1.24	3.04	9.26	7.51	0.96	8.06	9.66	0.28	0.26	24.65	481.10	40.91	23.75	7.57	6.19
Toluene (ppm)	94.40	85.36	51.43	28.14	15.13	10.04	21.31	157.74	85.49	33.05	10.80	9.80	18.86	21.49	8.84	69.13	6.19	5.60
Ethylbenzene (ppm)	119.74	130.29	81.12	42.16	19.13	78.98	39.60	66.27	90.20	78.75	129.84	47.22	46.85	19.37	40.79	56.56	8.28	79.37
p-xylene (ppm)	85.41	89.26	55.57	15.08	109.33	58.89	31.73	6.55	29.25	53.59	88.94	32.34	7.91	19.80	27.94	178.25	5.67	54.37
o-xylene (ppm)	14.70	17.60	14.73	17.97	102.59	3.99	150.04	10.23	91.13	44.09	51.64	162.08	85.63	18.91	13.50	20.56	41.59	33.78

Sample No	3.B1	3.B2	3.B3	3.B4	3.B5	3.B6	3.B7	3.B8	3.B9	3.B10	3.B11	3.B12	3.B13	3.B14	3.B15
Sample Time	16:23	18:46	16:25	18:52	16:15	18:37	14:11	14:16	17:41	19:14	17:37	19:10	7:33	19:56	19:03
Sample Date	4/12/19	4/12/19	4/12/19	4/12/19	4/12/19	4/12/19	12/12/19	4/12/19	4/12/19	4/12/19	4/12/19	4/12/19	12/12/19	12/12/19	13/12/19
Sample Location	Nembe	Nembe	Nembe	Nembe	Nembe	Nembe	Nembe	Nembe	Nembe	Nembe	Nembe	Nembe	Nembe	Nembe	Nembe
Sample Company Name													Filling Station	Filling Station	Filling Station
Sample Type	Gasoline	Gasoline	Kerosene	Kerosene	Diesel	Diesel	Gasoline	Gasoline	Kerosene	Kerosene	Diesel	Diesel	Gasoline	Gasoline	Diesel
Official / Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Unofficial	Official	Official	Official
Fuel Parameters															
TPH (ppm)	17,113	8,099	13,816	8,292	8,066	13,100	8,327	5,094	1,198	2,668	6,042	16,027	577	7,283	3,783
Sulphur Content (wt%)	0.101	0.089	0.192	0.195	0.202	0.216	0.082	0.069	0.064	0.189	0.194	0.18	0.0193	0.187	0.222
Sulphur Content (ppm)	1,010	890	1,920	1,950	2,020	2,160	820	690	640	1,890	1,940	1,800	193	1,870	2,220
Manganese (ppm)	0.003	0.004	0.033	0.003	0.004	0.001	3.141	2.521	0.019	0.065	0.08	0.009	5.198	10.203	0.009
BTEX															
Benzene (ppm)	1.07	1.33	1.31	0.43	0.36	0.23	0.54	0.73	1.18	0.50	0.47	0.77	53.11	548.74	0.75
Toluene (ppm)	195.44	116.88	69.37	5.87	1.53	1.97	47.06	4.59	2.49	1.21	4.14	3.46	1.66	1.77	1.53
Ethylbenzene (ppm)	171.15	104.18	76.54	5.09	5.45	1.29	40.19	6.27	2.13	1.76	23.02	3.42	3.45	2.94	2.21
p-xylene (ppm)	117.25	71.37	52.43	5.57	2.58	0.89	27.53	86.57	1.01	1.33	15.77	3.03	2.36	2.25	0.66
o-xylene (ppm)	2.79	2.77	2.02	2.69	0.91	2.95	2.97	3.06	1.96	1.45	1.33	6.48	4.10	0.75	0.94



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