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Experimental Investigation of Exhaust Gas Emission Status in Tanzania: A Case Study of National Institute of Transport Vehicle Inspection Center – Dar es Salaam

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Abstract
Exhaust gas emission is a by-product of air and fuel combustion in vehicle engines. It is a crucial contributing factor to air and environmental pollution that authorities emphasize controlling to mitigate the health and environmental hazards to communities. This was an experimental investigation to ascertain the emission status of used vehicles used for transport in Tanzania, some on the verge of surpassing their allowable emission levels. An experimental research design was opted for in this study and data were collected experimentally and through observations. Gas analyzers and emission detectors were used to obtain emission data for the study, where cluster sampling was preferred and 403 gasoline and diesel-powered vehicles were investigated for general inspection. The study found that engine size, year of manufacture, and kilometers of travel affected vehicle emission levels. The results were analyzed and compared with the allowable emission values in the Tanzanian standards.

Keywords: Transport, Road Worthiness, Air Pollution, Exhaust Gas Emission, Green House Gases.

Introduction

The rapid increase of socio-economic development in developing countries like Tanzania has led to a rapid rise in vehicle ownership, thus increasing vehicle traffic in the country. The transport sector utilizes fossil fuels, especially diesel, petrol, and natural gases to power internal combustion engines. The burned fuels release energy and emit products as a result of the incomplete combustion process, which is the primary source of Green House gases (GHG) that pollute the atmosphere (Réquia et al., 2015; Siskos & Moysoglou, 2019). The emission consists primarily of the technically known as 'criteria air pollutants` such as Carbon Monoxide (CO), Hydrocarbons (HC) in the particulate form such as soot or in gaseous form, Nitric Oxide (NO) and other forms of oxides of Nitrogen (NOx) and Sulphur (SOx) (Qin & Gao, 2022). These include Carbon Dioxide (CO2), Water Vapour, and other Volatile Organic Compounds (VOC). When a vehicle burns fuel in an internal combustion engine, the fuel results in heat energy. Some combustion by-products react negatively and harm our health when inhaled while others harm the environment. Cognizant of this, authorities worldwide impose emission testing standards for vehicles to ascertain the levels of emitted harmful gases. In Tanzania, the emission tests are compared with the revised Tanzania Bureau of Standards (TBS) regulation No (TZS 698:2013) named the "Road Vehicles-Code of Practice for Inspection and Testing of Used Motor Vehicles for Road Worthiness" where the allowable emission levels should not exceed 4.5% by volume CO, 1200 PPM of HC and 2.5 per meter of opacity (soot) for diesel engines.

Fuel + Air = Heat Energy + Carbon Dioxide + Carbon Monoxide + Water + Oxygen + Nitrogen Oxides + Hydrocarbons + Particulate matters

The emissions have severe effects on the environment and human health (Adeyanju et al., 2003) (Franco et al., 2013; Zhong & Bushell, 2017; Du et al., 2019; Chen et al., 2022; Xu et al., 2023). Therefore, some countries such as the United Kingdom (U.K), France, and others in European Union Block have imposed harsh regulations aiming at limiting allowable levels of vehicle emissions. Other countries offer incentives to customers who abide by the zero-emission concept (Kontou et al., 2017). In developed countries like the United States of America (U.S.A) and U.K, authorities promote an Ultra-Low Emission Vehicle (ULEV) Standard that describes vehicles that emit less than 75 grams of CO2 per kilometer of travel measured from the vehicle tailpipe (Smmt 2023). Of course, these are mostly either electric or plug-in hybrid vehicles. An example of this is given in a study by (Kontou et al., 2017). The researchers quote, "Electric vehicles are promoted by policymakers through tax credits and other incentives partly because of their potential to reduce tailpipe emissions." In another study by (Wu 2022), it was reported that monetary incentives such as rebates tend to reduce an electric vehicle's capital cost and investments, resulting in lower operating costs and driver savings. The United Nations Emission Gap Report of 2022 stresses that the world is not on track to abide by the Paris Agreement goals and must cut emissions by 45% to avoid catastrophic consequences of global warming caused by greenhouse gases (UNEP 2022).

In developing countries like Tanzania, almost all vehicles are powered by either diesel or gasoline internal combustion engines, which exhaust much more petroleum-based emissions due to partial combustion. Besides, most of these vehicles are imported as used vehicles having significant depreciation rates. Regardless of the efforts made by the government to curb the importation of cars more than ten years after manufacturing, there are still old vehicles on Tanzania roads. Vehicles with obsolete emission-limiting technology and using contaminated or poorly handled fuel can guarantee increasing levels of harmful environmental emissions. Therefore, this study investigated the extent of the tailpipe emission levels in Dar es Salaam City using data from vehicles inspected at the National Institute's Vehicle Centre to represent the various types of vehicles in the country. The vehicles were tested using modern emission-detecting devices. The study, ultimately, proposes measures to help attenuate the harmful emissions.

Research Problem

Air pollution caused by vehicular emissions contributes to the deterioration of human health by being one of the causes of respiratory and cardiovascular diseases. Therefore, researchers should conduct studies on smart road transport equipment that pollute less to improve air quality and prevent people and the environment from being at risk of harmful emissions. One of the measures for limiting these harmful emissions from vehicles is through lessening their levels from vehicles after identifying the emission status of the existing vehicles in the city of Dar es Salaam. It is against this backdrop that this study investigated this phenomenon to make suggestions for policymakers on the matter at hand based on the outcome of the study.

Literature Review

Because vehicular emissions negatively affect our environment and health (Grahame & Schlesinger, 2010), studies have been conducted to show their effects on various aspects. Some studies propose using electric vehicles for urban transport and restricting means of transport that rely solely on fossil fuels. Other studies have extensively investigated the effects of emissions on the ozone layer and global warming. In a study by (Kjellstrom et al., 2007), the researchers found that as much as 29% of deaths from cardiovascular diseases in Bangkok are likely caused by air pollution. A study by (Currie et al., 2005) found that criteria air pollution is known to be hazardous to health.

A report by WHO (2004) suggests an association exists between ambient air pollutants and various health effects such as respiratory symptoms or illness, impaired cardiopulmonary function, reduction of lung function, and premature mortality. Particulate matter, one of the vehicular emissions, has been linked to causing severe health problems of shortening life expectancy and premature deaths.

A recent study by Schraufnagel et al., (2020) investigated the health effects of ultrafine particles, where they found that ultrafine particles ($PM_{0.1}$) cause more pulmonary inflammation, induce cough, worsen asthma, and are retained longer in the lungs. The study further reiterated that ultrafine particles, which among other ways, are dispersed atmospherically through vehicular emissions, can cause cerebral and autonomic dysfunction. In another study by Heusser et al., (2019), exposure to Ultrafine Carbon Particles (UFP) combined with Ozone (O_3) was found to increase sympathetic nervous systems activity in healthy older individuals. In a United Nations environmental report of 2021 on emissions, however, it is reported that, due to COVID-19 Pandemic, global CO_2 emissions have dropped by 5.4%.

A study by Ayetor et al., (2021) investigated the state of road vehicle emission in African dwellings in Ghana and Rwanda, where emission tests conducted on 400 vehicles indicated that even some new vehicles failed the test while almost all diesel cars failed the international standard. They also noted that only five African countries have emission standards that are hardly implemented and that about 70% of all greenhouse emissions in Africa are contributed by only seven countries. This study tried to investigate the emission levels of some sampled vehicles in Dar es Salaam and compare the data with other studies conducted so far.

Materials and Methods

Vehicle emission tests can be measured under two scenarios: 1) controlled conditions in workshops or laboratories and 2) real-time application or on-road tests. This study was based on a controlled condition whereby 403 vehicles were subjected to the tests at the National Institute of Transport Vehicle Inspection Centre (NIT-VIC). The vehicles tested were from manufacturers such as SCANIA, Leyland DAF, Iveco, Fiat, TOYOTA, and Nissan and were powered by petrol and diesel engines. The tests were conducted using modern petrol engine gas analyzers and diesel engine smoke meter machines. The emission standards were from the TBS regulation No TZS 698:2012 & TZS 239:2013.

The experimental set

During the investigation of vehicular emissions, the study embarked on making proper use of the machines used at the (NIT-VIC). The devices available at the Centre include a gas analyzer and smoke tester used for emission testing. The German-made MAHA brand model MGT 5 V 1.10/0.00.GB machine was used to analyze exhaust gas for petrol engines and model MD02-LON 15801version (AU V 6.00/1.29.GB) to test smoke (soot) emitted from diesel engines. The software employed to analyze the parameter was MAHA V7.5.102, whereas the machine-embedded Epson brand printer was used to print the test results. The experimental setup is shown in Fig 1.

Figure 1: Experimental set up used in the study

Vehicular emission testing

According to Collins English Dictionary, vehicle emissions are substances emitted from a vehicle due to internal combustion. Therefore, emission testing is carried out to determine the contents and levels of the substances (pollutants) emitted into the air.

During testing, the vehicle was brought into the testing bay, and parked while its engine was idling at a speed between 400 and 1200 rpm at a temperature range of 70◦C to 80◦C. Wheel chocks (stoppers) were then applied to secure the vehicle for safety. The emission testing machine (Gas analyzer or smoke meter) and computer were turned on based on the engine fuel type to be tested. Then the details of the vehicle were uploaded into the computer. The probe of the emission machine was inserted and well-secured into the vehicle exhaust pipe as shown in Fig 2. The vehicle was then accelerated at full throttle, running around 2200-4000 rpm for forty-five (45) seconds and then stopping. The exercise is repeated three times to obtain an average reading. The computer analyzed the input gas from the engine. It gave results in percentage concentration (% conc.) of CO, CO2, and HC for petrol engines while reading opacity as K-value for diesel engines.

Figure 2: Securing emission test probe into exhaust pipe of a vehicle at NIT Vehicle Inspection Centre

Results and Discussion

Countries such as Tanzania, Rwanda, Ghana, and the U.K. generally have their norms/requirements on allowable levels of pollutants from engine exhaust systems to control exhaust emissions. The U.S.A. was the first to establish emission test standards, followed by the U.K. in Europe (Tiwari &Mandloi, 2019), and their standards were used to benchmark the emission levels. The U.K and U.S.A. standards are most frequently used to benchmark emission levels. According to TZS 698:(2012) & TZS 239:(2013), the emission level tested are Hydrocarbons, Carbon Monoxide, and Carbon Dioxide , for petrol engines, and opacity (soot contents) for diesel engines, while Nitric Oxides and Sulphur Dioxide are not tested. The standard levels are compared to other countries, as shown in Table 1.

Table 1: Emission Limits for Petrol and diesel vehicles in the UK, Tanzania, Ghana, and Rwanda

Country	Engine type	CO (% by V conc)	Opacity (m^{-1})	HC (PPM)	References
UK	Petrol	0.3	NA	200	(Tiwari & Mandloi, 2019)(Ayetor et al., 2021)
	Diesel	0.3	1.5	200	
Tanzania	Petrol	4.5	NA	1200	TZS 698:2013
	Diesel	4.5	2.5	1200	
Ghana	Petrol	3.5	NA	1200	(Tiwari & Mandloi, 2019)(Ayetor et al., 2021)
	Diesel	3.5	3	1200	
Rwanda	Petrol	1	NA	400	(Tiwari & Mandloi, 2019)(Ayetor et al., 2021)
	Diesel	1	1.5	400	

The study is based on 403 vehicles, 250 (diesel) and 153 (petrol) vehicles of various sizes and brands, which visited the NIT-VIC to ascertain quality and roadworthiness issues for 2020, 2021, and 2022. 380 (94%) vehicles passed the tests, whereas 23 (5.7%) failed. Based on fuel type, 242 (96.8%) diesel engine-powered vehicles passed, whereas 8(3.2%) failed the emission tests. For the case of vehicles powered by petrol engines, 138 (90.2%) vehicles passed, while 15 (9.8%) failed the test, as summarised in Fig. 3 (a & b). The emission level was tested based on engine capacity, age, and odometer reading.

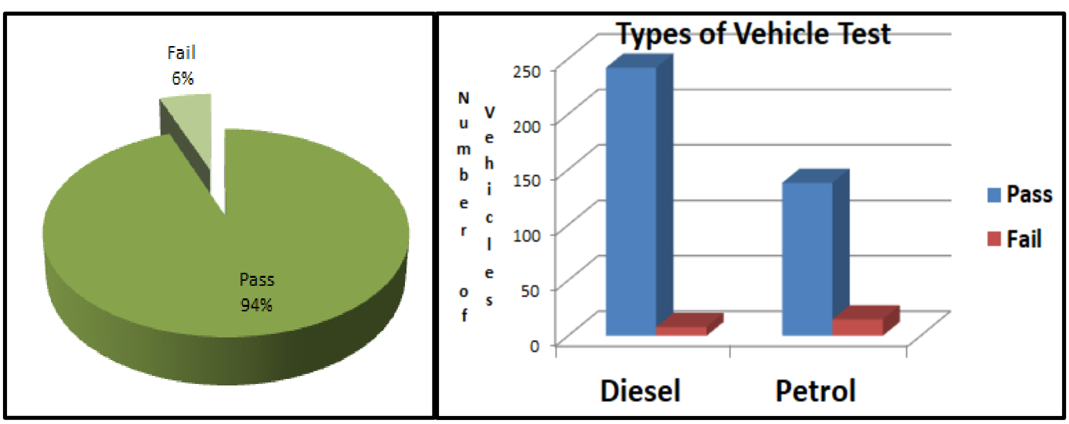
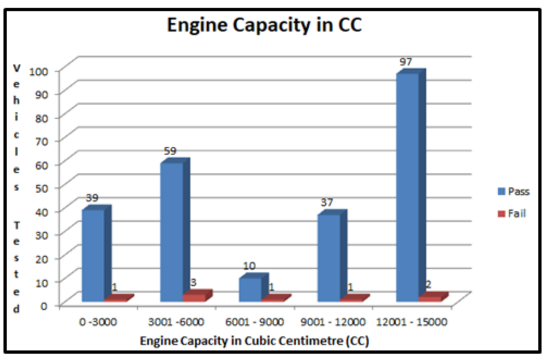


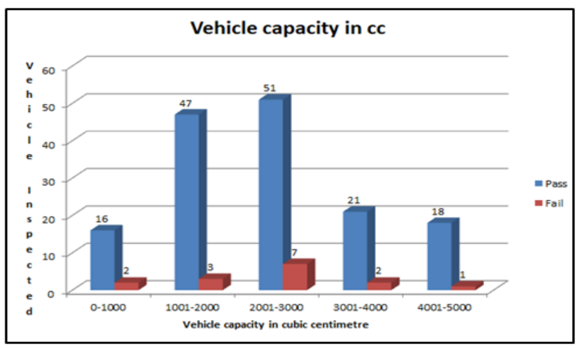
Figure 3: (a) Status of vehicles tested (b) Diesel and petrol vehicles passed and failed the emission tests

Vehicle engine capacity

Vehicle engine capacity can be identified in various ways, such as through torque produced (Newton meter –Nm), the power developed (horsepower–HP), and engine volume or displacement (cubic centimeters cc or literslt r). Engine volume/displacement measures the total amount of air and fuel entering the engine cylinder measured in cubic centimeters or liters. Hence the higher the engine volume, the higher the power produced. The higher the air-fuel ratio the engine utilizes, the higher the number of by-products released from combustion. The vehicles tested for emission in the study have engine volumes ranging from 1200 to 14,000 cc for diesel engines and 672 to 4200 cc for petrol engines Fig.4 (a). The study shows that diesel engine vehicles with engine volume ranging from 3001 to 6000 cc (23.6%) have higher emission levels of 37.5% compared to vehicles with engine capacity ranging from 12001 to 15000 (38%) of diesel vehicles which emit 25% of GHG. On the other side, petrol engines are characterized by having a small engine range of up to 5000 cc. Fig.4 (b) presents petrol vehicles whereby the vehicles with engine capacity ranging from 2001 to 3000, which account for 33.3% of petrol vehicles, exhibit higher emission levels of 46.7% compared to 6.7% of the vehicles with engine capacity ranging from 4001 to 5000 cc. Hence, the results for both vehicles are contrary to the phenomenon that the higher the volume, the higher the by-products. Therefore, the study found that higher engine volumes do not necessarily produce higher emissions.



(a)



(b)

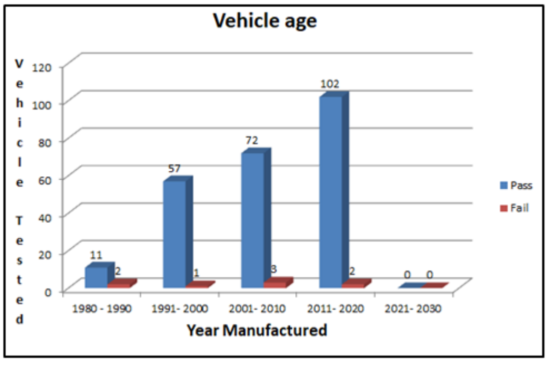
Figure 4: Vehicle inspection status based on engine capacity for (a) Diesel engine and (b) Petrol engine

Vehicle age

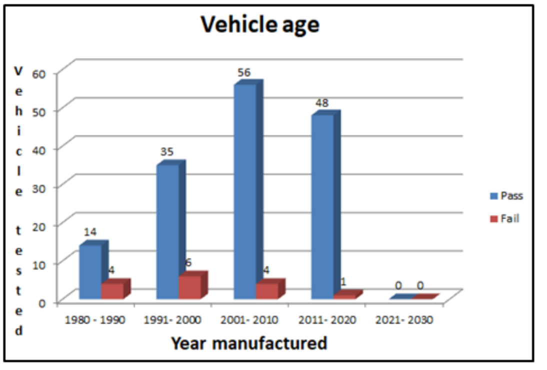
The age of the vehicle is specified by the year the model of that particular vehicle was manufactured. The vehicle's age determines the depreciation rate due to tear and wear, maintenance costs, and technological advancement. In a few decades, we have experienced rapid advancement in vehicle technology, especially for internal combustion engines aiming to achieve high engine performance, better fuel economy, and minimize exhaust emission (Faculty et al., 2017; Tiwari et al., 2019). In minimizing exhaust emission, various advancements like improving engine design and fine-tuning, the introduction of new technologies for engine management systems, catalytic converters, NOxreduction, evaporative emission controls, particulate matters reduction, and fuel quality measures (EURO I-VI) were introduced.

Fig. 4(c & d) shows emission levels for diesel and petrol vehicles for the vehicles tested at NIT-VIC manufactured between the 1980s to 2022s, respectively. Fig. 4(c) presents a summary of tested diesel vehicles manufactured between 1980 to 1990 (4.4%)

and 1991 to 2000 (22.8%). These vehicles have higher emission levels of 13.3% and 20%, respectively, compared to vehicles manufactured between 2011 to 2022. Petrol vehicles also show the same trend in which vehicles manufactured between 1980 -1990 (5.6%) and 1991-2000 (14%) have higher emissions of 26.7% and 40%, respectively, compared to vehicles manufactured between 2011 and 2022. The emission reduction possibly is due to the technological advancement of vehicles. The result agreed with Kouridis et al. (2014) that emission increases with vehicle age.



(c)



(d)

Figure 5: Vehicle inspection status based on vehicle age for (c) Diesel engine and (d) petrol engine

Odometer reading (kilometertraveled)

Besides technological factors such as engine design, fuel quality, operational behaviour, etc., vehicle pipe tail emission can be attributed to vehicle usage. The kilometers a vehicle has travelled determines how much the vehicle has been used. Higher kilometers of travel is likely to cause higher emissions due to tear, wear, and parameter deviations. From the study, diesel vehicles with kilometers of the run (odometer reading) ranging between 300,001 – 400,000 (27.2%) have higher emission levels (20%), whereas vehicles travelled between 400,001 – 500,000 (1.6%) are likely to have higher emission levels concerning the number of vehicles involved in the experiment, Fig. 4(e). The same is shown by petrol vehicles where vehicles traveled in the range of 200,001 – 300,000(13.1%) emitted 46.7% and the vehicles with the range of 300,001-400,000 kilometers of travel (3.9%) and 400,001 – 500,000(0.65%) look likely to have higher emission levels. Therefore, at higher kilometers of travel, there is a higher risk of engine deterioration that results in pipe tail emissions.

When these combustion by-products are released into the atmosphere, some react negatively and harm our health when inhaling them. For this purpose, authorities worldwide impose emission testing for vehicles to ascertain the levels of emitted harmful gases.

Conclusions

This study investigates the status of vehicular emissions from used vehicles in the city of Dar es Salaam-Tanzania. Before the study, the hypothesis was that most used vehicles would register a very poor emission record because most would have traveled several thousand kilometers already, leading to their anticipated poor emission records. However, from the samples randomly picked for three different batches, this study has found that a vehicle odometer reading does not necessarily correlate to vehicle failure in emission tests but rather to the emission-preventing technology employed and the vehicle's maintenance.

Out of 403 vehicles, 250 (diesel) and 153 (petrol) visited the NIT- VIC to be ascertained for quality and roadworthiness issues for the entire period, 380 (94%) passed, whereas 23 (5.7%) failed the test. Petrol vehicles recorded higher failure rates of 9.8% than diesel vehicles at 3.2%. The assessment is based on engine capacity, age, and odometer reading. For the case of engine capacity, unlike the phenomenon that the higher the engine volume, the higher the emission, the study found that engines with a small capacity of 3001-6000 cc diesel and 2001-3000 petrol emit more by 37% and 46.7% compared to 12001 – 15000 and 4001-5000 which emit 25% and 6.7% of GHG respectively.

Unlike vehicle capacity, vehicle age and kilometer run/usage show different trends, in which old vehicles with many years of travel have shown higher emission rates. Diesel vehicles manufactured between 1991 and 2000 and those with kilometers of travel range of 300001 – 500,000 have higher emission rates of 22.8%, 20%, and 1.6%, respectively. The same trend is shown by petrol vehicles manufactured in 1980 – 1990, and 1991 – 2000 and for the vehicles which traveled 200,001 – 300,000 km have emission rates of 26.7%, 40%, and 47.7% respectively. Therefore, vehicle age and kilometers of travel have shown a direct correlation to exhaust pipe emissions.

Diesel-powered vehicles sampled in this study were primarily large trucks owned by large transportation companies in the country, most of which have well-scheduled maintenance programs for their fleet. This might be why the samples show more remarkable emission test pass rates than expected. Nevertheless, there is a vivid indication that individually owned vehicles still fail in emission tests compared to those owned by transportation firms. The results of this study can never be conclusive because there is no mandatory vehicle emission testing yet for all vehicles in Tanzania. This leads to the availability of only a small sample of well-maintained vehicles from well-established transportation firms to send their vehicles for such testing. Others only opt for general inspection for roadworthiness to enable their vehicles to get registered.

Recommendations

From the numerous studies conducted on health hazards of emission and the fact that good records of exhaust emission depend primarily on the installed emission technology and well-planned and regular upkeep of a vehicle, countries should strongly impose emission testing measures on all vehicles. This includes mandatory testing for emissions after a certain period of running a vehicle. This is such an essential aspect in the sense that, as of now, our country does not have mandatory and periodic emission testing for every vehicle. Vehicles are brought for general roadworthiness testing but not for emission tests, which are only done at the owner's discretion. The study suggests that the pre-registration inspection for a vehicle's roadworthiness should include emission testing as a compulsory inspection component. The study further urges vehicle owners to regularly maintain catalytic convertors and other parts of their vehicles that are vital for emission control. Finally, the country should encourage using clean energy vehicles like electric, hybrid, and Compressed Natural Gas (CNG) powered vehicles to help prevent vehicular emissions in our environment.

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