Transportation Research Part D 87 (2020) 102519

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Traffic related $PM_{2.5}$ air quality: Policy options for developing Pacific Island countries

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ARTICLE INFO

Keywords:
Fine particulate matter ($PM_{2.5}$)
Traffic emissions
Air quality
Emission control
Pacific Island countries

ABSTRACT

Traffic related $PM_{2.5}$ air pollution data remain largely absent in the Pacific Island Countries (PICs). Increased use of second hand cars and inadequate emission control policies may result in harmful levels of roadside $PM_{2.5}$ concentrations. To bridge the data gap, we monitored roadside $PM_{2.5}$ concentrations in two of the largest cities in the PIC's, Suva and Lautoka, both of Fiji using high volume air sampler. Daily mean roadside $PM_{2.5}$ concentrations in Suva and Lautoka cities were reported to be 21.6 ± 13.3 μg/m^3 and 67.2 ± 35.2 μg/m^3 respectively. In comparison, mean $PM_{2.5}$ concentration determined at the roadside site in Lautoka city was more than twice the World Health Organisation 24 h mean guideline concentration of 25 μg/m^3. Elevated $PM_{2.5}$ in Lautoka may have serious public health implications. This work investigates existing vehicle emission and importation related polices and approaches in reducing land transport based emissions in the PICs.

1. Introduction

Air quality as an environmental and public health risk factor in the developing Pacific Island Countries (PICs) remain relatively unknown. The rapid increase in land based transport sector, poor infrastructure and consequently, heavy traffic maybe significant contributors in the deterioration of air quality in the PICs. Opportunities to reduce air quality related risks are being lost due to non-existence or inadequate air quality related policies in these countries. To reduce the impact of the rapidly increasing number of vehicles, stronger transport emission related policies are needed. However, the absence of technical data related to environmental indicators, including air pollution is a constraint for effective policy making and development planning (Government of Fiji, 2013). It can also be argued that data gaps in air quality are contributing factors to the delay of implementing national air quality and emission control standards. Road traffic is seen as the largest contributor to deteriorating air quality in many urban centres, contributing to as much as 90% of urban air pollution (Karagulian et al., 2015; Kinney et al., 2011). Indoor air quality is also affected greatly by traffic related air pollution in urban environments (Tong et al., 2016b). Traffic related $PM_{2.5}$ emissions have been associated with increased risk of asthma and respiratory diseases (Bråbäck & Forsberg, 2009; Guaita et al., 2011; Guarnieri & Balmes, 2014; McConnell et al., 2010), cardio-vascular diseases (Beckerman et al., 2012; Hoffmann et al., 2006), cancer (Hamra et al., 2014; Vineis et al., 2004) and increased chances of hospitalisation (Deng et al., 2017; Horne et al., 2018; Pirozzi et al., 2018; Winckelmans et al., 2017; Zhang et al., 2018b). Despite strong evidence of health effects, $PM_{2.5}$ continues to be unmonitored and unregulated in many small developing countries.

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https://doi.org/10.1016/j.trd.2020.102519

The Pacific Island Countries (PICs) are such examples where traffic related $PM_{2.5}$ data are absent. Fiji is the fastest developing among the PICs with strong economic growth (Juswanto, 2016). The transport sector in Fiji has seen rapid growth with rapidly increasing number of new vehicle registrations in recent years. Between 2001 and 2019, the total number of vehicles in Fiji has doubled. A 44% increase in vehicles numbers was noted between 2009 and 2019, in comparison to only 26% increase in Australia (Australian Bureau of Statistics, 2009, 2019b; Fiji Bureau of Statistics, 2019a). In 2019, there were 119 960 registered vehicles in Fiji.

A large portion of vehicles imported into PICs like Fiji are second-hand (used) or re-conditioned vehicles. Second hand vehicles made up more than 50% of newly registered vehicles in years 2016, 2017 and 2018 (Land Transport Authority, 2019b). These vehicles are less expensive to purchase than brand new vehicles and therefore the country has seen consistent growth in ownership. However, second hand vehicles are older and are associated with higher automotive emissions (Carbajo & Faiz, 1994; West, 2004). Moreover, Caserini et al. (2013) reported that the mileage for diesel and gasoline vehicles drop by approximately 50% as the vehicles reach the age of 8 years, which implies that these vehicles consume greater amount of fuel than comparable but newer vehicles. Vehicle age as well as other factors including engine design and operating conditions, fuel type and quality, environmental conditions and after treatment technologies have significant influence on the amount of vehicle emissions (Cheung et al., 2010; Kim Oanh et al., 2010). It is also noteworthy that diesel emissions in developing countries (such as Fiji) could differ greatly in comparison to developed countries due to old and poorly maintained fleets and scarce emission control technologies (Kim Oanh et al., 2010).

The transport sector consumes around 60% of the total imported petroleum in Fiji, 16% of which is attributed to land transport (Government of Fiji, 2014). Spending on fuel related mineral imports in Fiji concomitantly increased by 58%, with diesel recording a 60% increase between 2016 and 2018 (Fiji Bureau of Statistics, 2019b). A rise in the number of second hand and new vehicles has also been reported to be putting stress on existing and outdated road infrastructure in Fiji and other PICs (Pacifc Community, 2017). While built-up areas in Fiji are already facing traffic congestion (Kumar, 2017), peak hour traffic is projected to further increase by 22%, resulting in a 25% increase in travel time by 2030 (Fiji Roads Authority, 2014). Traffic related emissions are avenues of high pollutant exposure with associated health risks, even at low levels (Janssen, 2012). An increase in travel time also leads to extended exposure to higher concentrations of $PM_{2.5}$ which increases exposure dose and concomitant health outcomes.

In recent years, Fiji has noted greater health concerns such as higher asthma and "wheezing" rates (Isley et al., 2017). Fiji has the highest rate of asthma related mortality in the world when considering age normalized asthma related deaths (The Global Asthma Network, 2018). There were more than 2200 asthma related hospitalizations at the major hospitals in Fiji between 2010 and 2014, 16% of which resulted in mortality (Ministry of Health and Medical Services, 2017). Many studies have associated elevated $PM_{2.5}$ concentrations with increased asthma related hospitalizations (Tecer et al., 2008a; Xing et al., 2016). Non-communicable diseases such as asthma comprise most of the top ten causes of mortality and disability in Fiji (Asian Development Bank, 2017). Fiji also has one of the highest rates of diabetes related amputations and cardiovascular disease cases in the world (Chand, 2018; Morgan, 2015). Both diabetes and cardiovascular diseases have been positively associated with long term air pollutant exposures including $PM_{2.5}$ (De Marco et al., 2018; Fiordelisi et al., 2017; Pearson et al., 2010). Exposure to air pollutants near roadways have been noted to increase the risk of adverse human health effects (Tong et al., 2016a, 2012). While quantitative associations of air pollution and health effects are beyond the scope of this paper, air quality should be acknowledged as possible contributing sources to prevalence of these diseases.

The lack of resource and expertise combined with the perception of clean air in the Pacific (Isley et al., 2017), has delayed meaningful traffic related $PM_{2.5}$ assessments. In order to address this, there is a need for high quality data that quantifies aerosol concentrations and this must be used to understand the influence of motor vehicle and traffic emissions on air quality in PICs. In this paper, we present novel roadside concentration of fine particulate matter in heavy traffic areas in Suva and Lautoka cities in the Republic of Fiji, a model Pacific Island Country. We also examine the effectiveness of current policies surrounding motor vehicle importation, operation and emission. Finally, we compare the options that small developing countries in the South Pacific like Fiji could adopt to maintain balance between the rapidly developing transport sector and improving public and environmental health.

2. Experimental methods

The study was conducted in the Fiji Islands, located in the South Pacific Ocean and part of the Melanesia subregion (Fig. 1). Ambient concentrations of fine particulate matter were monitored in heavy traffic areas in Lautoka and Suva. These are the only two cities in Fiji and have quite high population density as well as strong economic activity.

2.1. Sampling sites

The field campaign in Suva city was undertaken at the Fiji National University's (FNU) Derrick Campus in Samabula (latitude: −18.1262, longitude: 178.4402). Although Suva has a population of 93 870 people, the site is representative of similar developing urban centers sprawled throughout the Suva-Nausori areas with a combined population of 243 795 people (Fiji Bureau of Statistics, 2018). The site is in a centrally located area with high economic activity, schools, university campuses, banks, hospitals and approximately 4510 homes (Fiji Bureau of Statistics, 2018), 2 km away from the main city. This site was selected as it is positioned in the middle of key road networks (Fig. 2) and used largely to commute to and out of the main Suva Central Business District (CBD) by residents of Nausori and Nasinu. The site was at the convergence of several main roads heavily used by commuters. A nearby traffic sensor facing Ratu Mara Road indicates vehicle counts of around 27 000 vehicles per day, approximately 89% of which are passenger vehicles. The traffic sensors are maintained by the Land Transport Authority, having the capacity to count and categorize vehicles into small and large vehicles. Vehicles also arrive at the sampling point via Edinburgh Drive and Princess Road. Thus, the number of cars passing the site is greater than the vehicle count recorded by the traffic sensor making it one of the most heavily trafficked

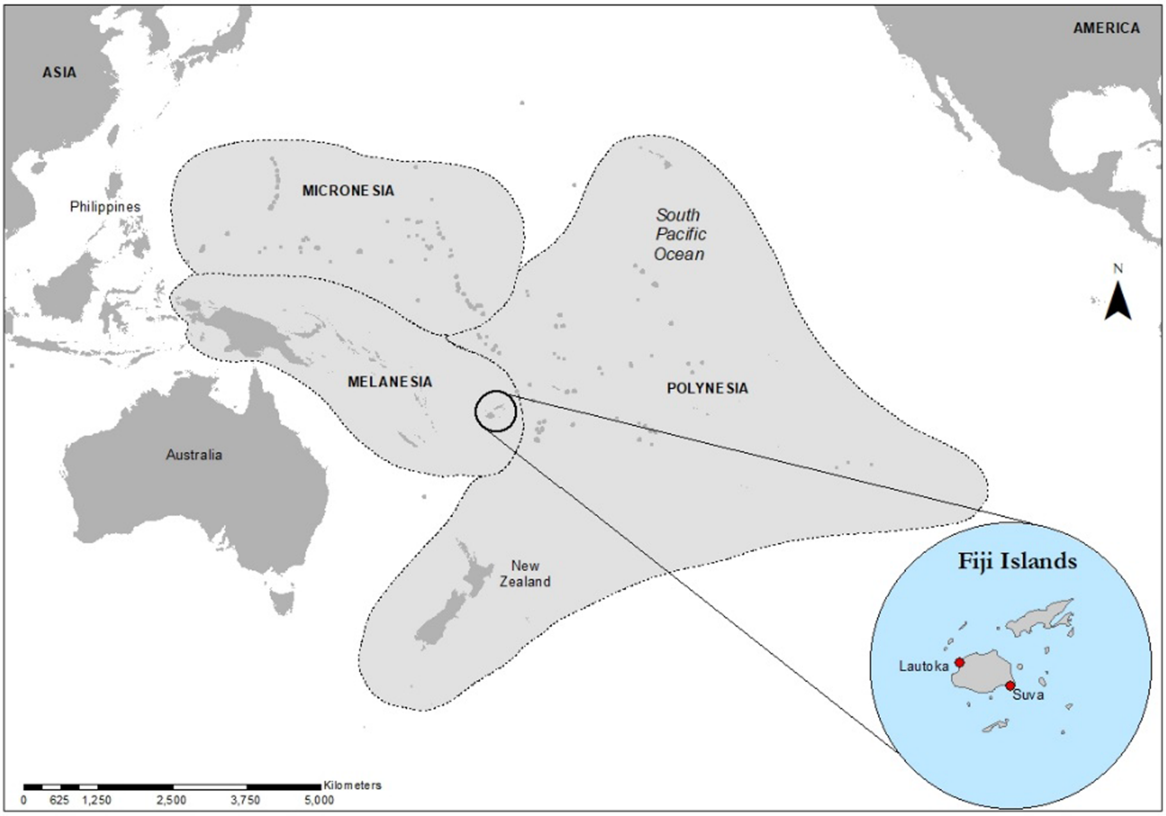

Fig. 1. Location of Fiji and surrounding countries.

locations in Suva city. Traffic is usually heavy between 07 00 to 09 00 h (morning rush hours) and between 16 00 to 19 00 h (evening rush hours). While traffic volumes are similar between Monday till Saturday, it is lower on Sundays. Sunday is considered a holiday in Fiji and most business are usually closed.

The second campaign was conducted in Lautoka city, a rapidly developing city in Fiji. Lautoka has a population of 71 573 people (Fiji Bureau of Statistics, 2018) and serves as the main commercial activity point for residents of Lautoka as well as Nadi and Ba. Unlike Suva, Lautoka is characterized by more local industries, such as sugar mills, food processing factories and wood chip mills, which may influence traffic emissions. Despite being surrounded by industrial activities and business hubs, close to 2545 households are situated in close proximity to the site. The site was located in the city center, adjacent to the Lautoka bus station and market (latitude: −17.6038°S, longitude: 177.4538°E). Samplers were positioned near the exit way of buses that enter the main bus station in Lautoka (Fig. 3).

Traffic sensors located nearby (Kings Road) the sampling site show an average of 11 381 vehicles per day of which around 84.5% vehicles are passenger vehicles. While the average vehicle number is less than half of that in Suva, large vehicles make 15.5% of average vehicles in Lautoka in comparison to 11% in Suva. Moreover, traffic sensors in Lautoka does not include vehicles arriving in Lautoka city from Suva and Nadi via Queens's road. Traffic sensor located 12 km away from the site in Queens's road shows a greater number of vehicles with an average of 15672, approximately 10% of which are large vehicles. Traffic patterns over the week are similar to that of Suva, including rush hours. Moreover, traffic is also lower in Lautoka on Sunday in comparison to the weekdays.

For background measurements, $PM_{2.5}$ concentrations was monitored at the University of the South Pacific (Lower Laucala Campus). This site is situated beside the sea and has been previously characterized by Isley et al., (2017) to be largely having winds from the ocean. It is situated away (and upwind) from major roads at a height of 5 m and provides an ideal site that is less affected by industrial and traffic related emissions.

2.2. Gravimetric analysis

$PM_{2.5}$ was collected using an Ecotech 3000 HiVol sampler at a flow rate of 67.8 m^3/hr (Ecotech, 2013; Vojtisek-Lom et al., 2015; Zhu et al., 2018), following a 1 in 3 day sampling schedule. The HiVol sampler was calibrated using an orifice and digital manometer through a calibrated pressure drop every four weeks to maintain optimum operation and in accordance with the guideline (US Environmental Protection Agency, 2016). In Suva, the instrument was positioned 4 m away from curbside, at a height of 3 m while in Lautoka it was positioned 3.8 m from curbside with a height of 2.8 m. A 24 h sample was collected beginning 00 00 hrs (midnight) to the next midnight. A total of 42 samples were collected in Suva from 2nd September to 3rd January 2019 and 23 samples collected in

Fig. 2. Major road networks in Suva city.

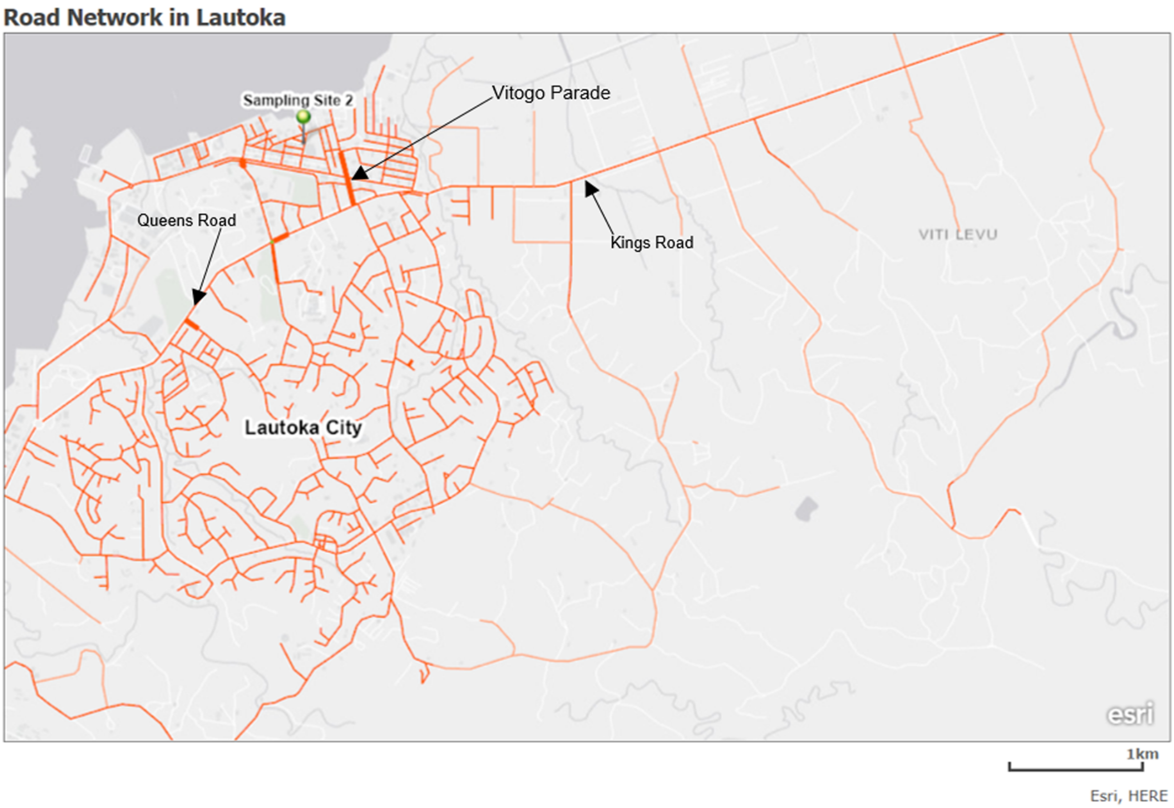

Fig. 3. Major road networks in Lautoka city.

Lautoka from 13th January to 8th March 2019.

For gravimetric analysis, borosilicate filters bonded with polytetraethyelene (PTFE) (Pall Corporation, Pallflex Emfab TX40H120-WW, USA) were used to collect the samples. Emfab filters have been known to show extremely low variability in mass, demonstrating remarkable stability in comparison to quartz and non-bonded glass filters (Brown et al., 2006). The filters were conditioned in a controlled environment before and after sampling. The conditioning was done in batches for 72 h as recommended by US Environmental Protection Agency (2016), at 21.1 ± 1.5 °C and 34 ± 3% RH, in a small and isolated clean room, located inside an air conditioned laboratory. The mass of each filter was determined using A&D BM-20 (A&D Australasia Pty Ltd, Australia) ionizing microbalance. Each filter was ionized before being weighed to eliminate the influence of static electricity. Once gravimetric analysis was completed, the filters were stored for further analysis of heavy metals and ions.

A weather station (Vantage PRO2, Davis Instruments, Australia) was used to monitor meteorological variables in Suva. In Lautoka, meteorological data was obtained from the Sugar Research Institute and Australian Bureau of Meteorology. Spearman's rank correlations was done to see the correlation between the meteorological variables and $PM_{2.5}$ concentrations (Chen et al., 2016; Wang & Ogawa, 2015).

3. Results

Because most air quality regulations are based on arithmetic mean concentrations (Chaloulakou et al., 2003), here, we report mean concentrations of our observations. A statistical summary, including monthly mean and median $PM_{2.5}$ concentrations are presented in Table 1.

The daily mean $PM_{2.5}$ concentration for the roadside site in Suva city was 21.6 ± 13.3 μg/m^3 (median, 17.9 μg/m^3). The daily mean weekday concentration was higher (23.8 ± 14.8 μg/m^3, median, 21.7 μg/m^3) than weekend concentrations (15.2 ± 5.4 μg/m^3, median, 13.9 μg/m^3). In Lautoka, the daily mean fine particulate matter concentration was greater than the mean concentrations

Table 1
Descriptive statistics of monthly $PM_{2.5}$ concentrations (μg/m^3).

City	Month	Mean ± SD	Median	Max	Min
Suva	September	26.1 ± 17.2	23.8	71.3	9.6
	October	22.9 ± 17.9	21.2	69.6	8.5
	November	19.0 ± 7.56	15.7	35.2	12.2
	December	18.2 ± 7.3	16.1	33.0	10.0
Lautoka	January	48.7 ± 24.6	43.6	95.2	24.5
	February	74.2 ± 38.8	59.0	177.6	30.1
	March	72.1 ± 33.8	57.4	122.6	51.2

Environment Protection Authority Victoria (2018)

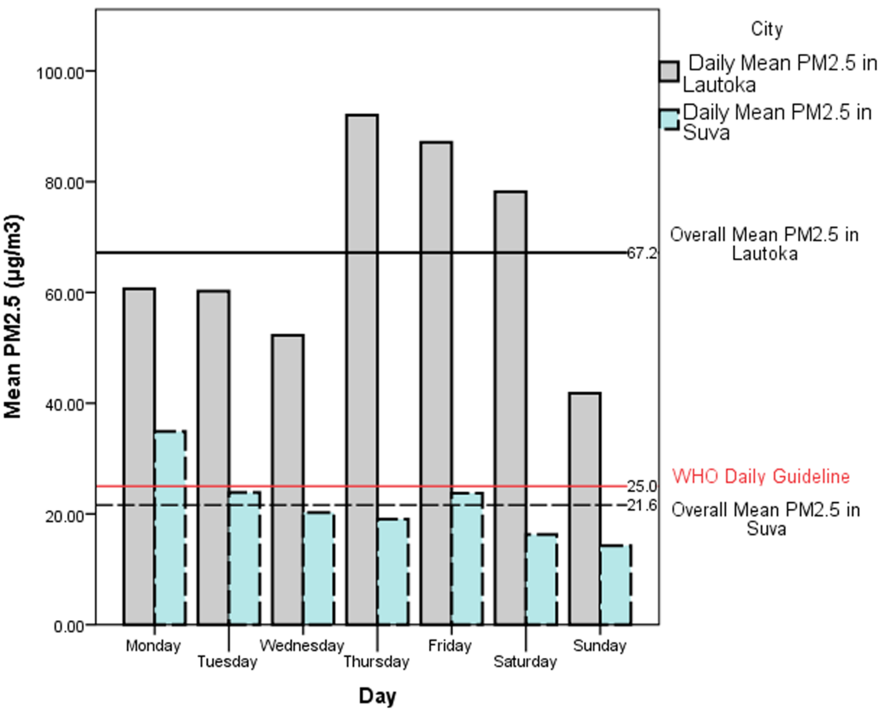

Fig. 4. Mean PM2.5 concentrations categorised by day.

in Suva city (see Fig. 4), at 67.2 ± 35.2 μg/m^3 (median, 58.1 μg/m^3). The average weekday and weekend roadside $PM_{2.5}$ concentration in Lautoka City were determined to be 71.4 ± 36.5 μg/m^3 (median, 58.9 μg/m^3) and 57.3 ± 32.7 μg/m^3 (median, 47.1 μg/m^3) respectively. Lower concentrations were typically observed for the months of November, December and January. Mean concentration of $PM_{2.5}$ was found to be 5.5 ± 2.8 μg/m^3 at the background site. Mean $PM_{2.5}$ concentrations are relatively low compared to concentrations from the Suva site.

Based on these data, the WHO daily mean guideline was exceeded 26% of the time in Suva and 95.6% in Lautoka. 65% of the daily $PM_{2.5}$ concentrations were more than twice the WHO guideline. On average, all days of the week except Monday have mean $PM_{2.5}$ concentrations lower than the WHO guideline in Suva. The daily mean $PM_{2.5}$ concentrations by day for all the days except for Sunday was more than twice the WHO guideline of 25 μg/m^3 at the roadside site in Lautoka.

Considering the meteorological correlations, Moderate negative correlation (r_s = -0.354, $p < 0.05$) between the fine particulate matter concentration and total rain was found in Suva City. However, no significant correlation was found between rain and $PM_{2.5}$ concentration in Lautoka City. Moreover, each sampling day in Suva received on average 12.8 mm of rainfall compared to only 5.7 mm in Lautoka. Historical data on rainfall also shows greater amount of precipitation in Suva than in Lautoka. Suva experiences around 3000 mm of rainfall per year in comparison to around 2000 mm of rainfall in Lautoka (Fiji Meterological Service, 2019; Pacific Climate Change Science, 2014). Rain has a negative effect on the concentrations of $PM_{2.5}$. Rainfall has been noted to "washout" and "scavenge" (wet deposition) fine particulate matter, thereby decreasing the concentrations. (Tecer et al., 2008b; Wang & Ogawa, 2015).

Statistically significant negative correlation was found between $PM_{2.5}$ and wind speed in Suva City, with a correlation coefficient of −0.671, $p < 0.01$. The dominant wind direction at the Samabula site was SSW with average wind speeds of around 6.4 km/h. No significant correlation was found between wind and $PM_{2.5}$ in Lautoka City. Lower wind speeds with an average of 2.2 km/h were recorded at the Lautoka Bus Station with a dominant wind direction of WNW. Lautoka City is on the leeward side of the main island having lower wind speeds and is drier. It can also be argued that the position of Lautoka Bus Station is an important contributing factor to the higher levels of $PM_{2.5}$. The bus station is surrounded by a cluster of buildings which are taller than the bus station. These building contribute to the "wall effect" (Yim et al., 2009) by blocking the flow of air. With reduced air flow, the air at the Lautoka Bus Station stagnates, accumulating pollutants such as $PM_{2.5}$ in the process, thereby contributing to higher concentrations. The correlation coefficient between humidity and $PM_{2.5}$ was −0.285 at $p < 0.01$ in Suva, with mean relative humidity at 83.59%. No significant correlation was found between RH and $PM_{2.5}$ concentration in Lautoka City. Statistically significant correlation between temperature and $PM_{2.5}$ concentrations were found only in Lautoka with a correlation coefficient of 0.358, $p < 0.01$ while no significant correlations were noted between temperature and $PM_{2.5}$ in Suva. The mean temperature in Suva over the sampling period was 25.25 ± 1.47 °C while that in Lautoka was 2 °C higher with a small standard deviation, at 27.68 ± 0.67 °C.

$PM_{2.5}$ concentrations observed for the roadside sites in Suva and Lautoka were used to assess the air quality and its impact on local population using the Australian standards (Environment Protection Authority Victoria, 2018; Keywood et al., 2016). The Environmental Protection Authority of Victoria (EPA Victoria) provides qualitative parameters for air quality, and categorical parameters for its influence on health, based on 24 h mean $PM_{2.5}$ concentrations and are presented in Table 2.

Based on this rubric, air quality was fair during 27% of the days in Suva, and only 4% in Lautoka. 5% of the days had air quality classified as 'very poor' in Suva while 87% of samples in Lautoka were classified as very poor. Over the entire campaign, Lautoka had poor or very poor air quality for approximately 96% of the sampling days. This meant that level of $PM_{2.5}$ concentrations induced unhealthy effects on all age groups on 78% of the days and very unhealthy effects on 9% of the days (Fig. 5). It is noteworthy that roadside concentrations of $PM_{2.5}$ do not necessarily reflect the concentrations that the whole population of both the cities are exposed to, rather, highlight exposure levels in heavy traffic areas.

Moreover, while 73% of the sampling days in Suva had moderate effect on the public health, only 4% of days in Lautoka had the same effect. Suva also saw 2% of the days with very low effect on health while no sampling days in Lautoka were classified as low health risk. The high frequency of poor and very poor air quality days as well as the subsequent high rates of unhealthy and very unhealthy conditions demonstrates the need for immediate action in terms of air pollution mitigation in Lautoka.

4. Discussion

4.1. Air Quality: Where do we stand globally?

While below the WHO guideline, the influence of roadside emissions in Suva can be observed when in comparison to $PM_{2.5}$ concentrations reported by Isley et al. (2017). Isley's study conducted in Suva city in 2013–2014 reported the ambient $PM_{2.5}$

Table 2
Mean 24 h $PM_{2.5}$ concentration with air quality and health impact categories.

24 h $PM_{2.5}$ (μg/m^3)	Air Quality	24 h $PM_{2.5}$ (μg/m^3)	Health Category
0–8.2	Very good	0–8.9	Low
8.3–16.4	Good	9.0–25.9	Moderate
16.5–25.0	Fair	26.0–39.9	Unhealthy – Sensitive
25.1–37.4	Poor	40.0–106.9	Unhealthy – All
≥37.5	Very Poor	107.0–177.9	Very Unhealthy – All
		> 177.9	Hazardous (high)
		> 250	Hazardous (extreme)

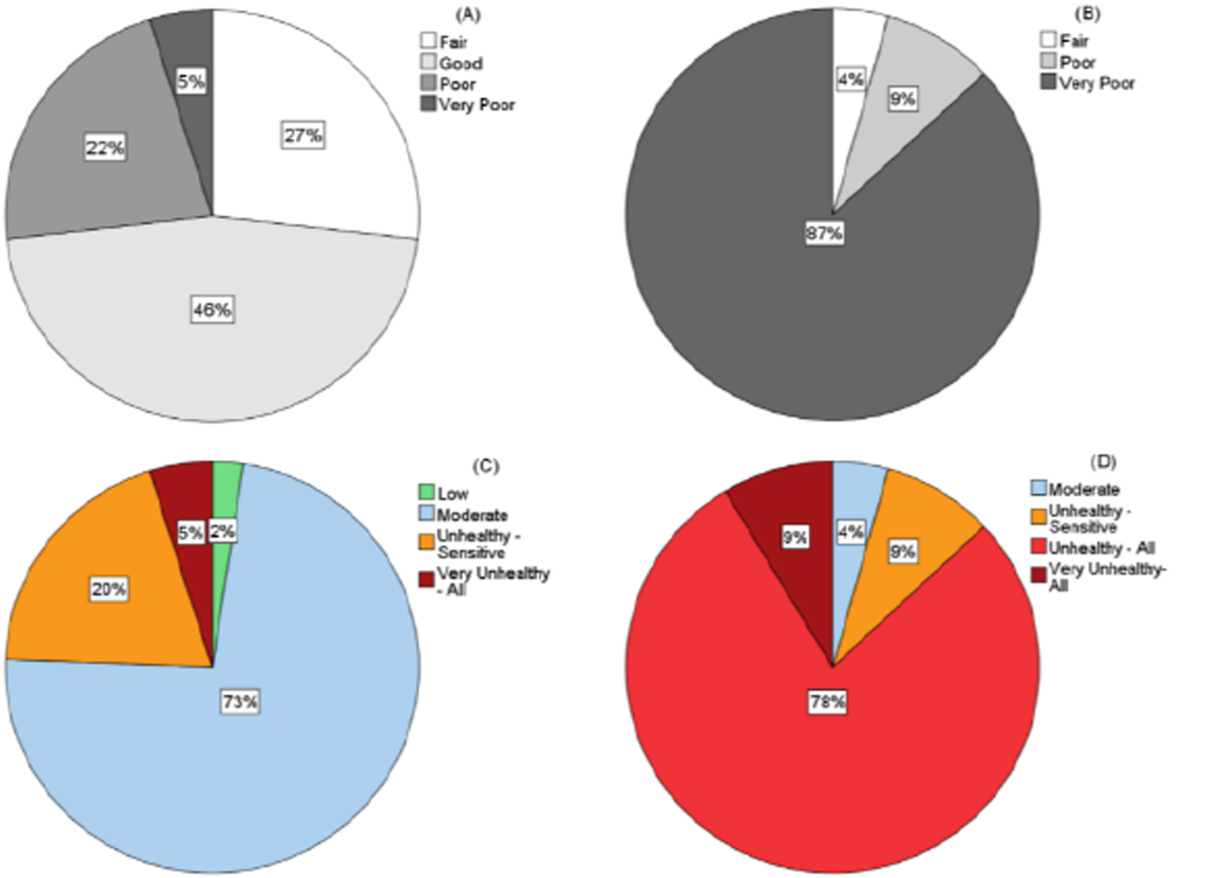

Fig. 5. Quality of air during days of sampling in Suva (A) and Lautoka (B); Level of health effect on exposed population in Suva (C) and Lautoka (D).

concentrations to be at 7.4 μg/m^3. The current study distinguishes itself from the previous study by focusing on roadside and traffic related emissions in areas of high population density and activity. Isley reported lower concentrations, likely attributed to the higher sampling height of this study (18 m above ground, on a building located at Suva wharf). This work (Isley et al., 2017, 2018) noted lower concentrations and a larger influence of marine aerosols in the composition of fine particulate matter. This study showed that marine aerosols were the largest contributor to $PM_{2.5}$ mass with high amounts of Na, Ca and K ions. Taking Isley's work as ambient concentrations, the difference in $PM_{2.5}$ concentrations between Isley's and present study suggests a substantial difference attributed to influence of traffic related emissions on the concentrations of $PM_{2.5}$. The number of vehicles have also increased notably in Fiji since Isley's study, with 25% more vehicles on road in 2019 (Fiji Bureau of Statistics, 2019a). The present study accounts for the increase in the number of vehicles in contrast to when sampling by Isley et al. (2017) took place and highlights traffic influence on the overall air quality in Suva. Moreover, the difference in the $PM_{2.5}$ concentrations between Suva City and the background site also demonstrates traffic to be an important contributor to elevated $PM_{2.5}$ concentrations at the sampling site. Notably, (Isley et al., 2017) found $PM_{2.5}$ concentrations to be 3.88 μg/m^3 at the same background site, which is slightly lower than the background concentration determined by our study. This may also suggest that air quality in general is deteriorating in Fiji.

The roadside $PM_{2.5}$ concentrations in Lautoka city ranged from 24.5 to 177.6 μg/m^3 with a mean concentration of 67.2 μg/m^3. This is the first air quality study in Lautoka city and no previous literature or data exists to make time based comparisons of $PM_{2.5}$ concentrations in recent years. Mean $PM_{2.5}$ concentration over the sampling period at the roadside site in Lautoka, however, was more than twice the WHO guideline and three times that of Suva.

As the more polluted of the two cities under study, $PM_{2.5}$ concentrations in Lautoka are compared to other represented urban environments (Fig. 6). Cities such as London and Madrid have mean roadside concentrations of 19.4 μg/m^3 and 20.63 μg/m^3 respectively (Kassomenos et al., 2014). The sampling in London and Madrid took place at 1 m and 10 m away respectively from kerbside at major roads with heavy traffic congestions, similar to our study design in Fiji.

Comparing our results elsewhere, $PM_{2.5}$ concentrations in Singapore were reported to be at 28.9 μg/m^3 (Zhang et al., 2017). This is much lower than the concentrations observed in Lautoka, a city of 5 million fewer people. Similarly, $PM_{2.5}$ concentrations in Istanbul were 40.5 μg/m^3 (Onat et al., 2013), which is lower than the concentrations observed in Lautoka. It is noteworthy that Istanbul, a city of 2.5 million vehicles and greater traffic congestion, showed lower roadside $PM_{2.5}$ concentrations than Lautoka city.

The high levels of traffic related roadside $PM_{2.5}$ concentrations and deteriorating urban air quality (Secretariat of the Pacific Regional Environment Programme, 2014), particularly in Lautoka risks serious public health repercussions. This accentuates $PM_{2.5}$,

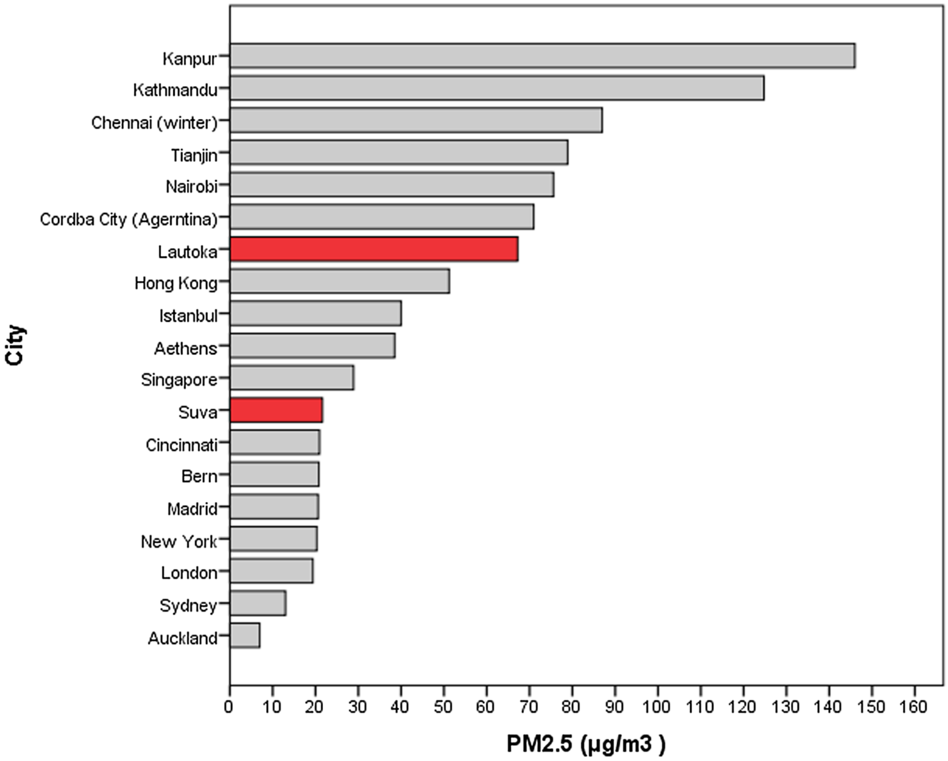

Fig. 6. Mean Roadside $PM_{2.5}$ concentrations of some global cities. References for the illustrated cites are as follows; Kanpur, Sharma and Maloo (2005); Kathmandu, Shakya et al. (2017); Chennai, Srimuruganandam and Shiva Nagendra (2012) ; Tianjin, Zhang et al. (2018a) ;Nairobi, Kinney et al. (2011); Cordoba, López et al. (2011) ; Hong Kong, Lee et al. (2006); Istanbul, Onat et al. (2013); Athens, Kassomenos et al. (2014); Singapore, Zhang et al. (2017); Cincinnati, Martuzevicius et al. (2004); Bern, Gehrig and Buchmann (2003); Madrid, Kassomenos et al. (2014); New York, Patel et al. (2010); London, Kassomenos et al. (2014); Sydney, Wadlow et al. (2019); Auckland, (Davy et al., 2017).

and air pollution in general as a national issue. It further effaces the idea that fine particulate matter is an irrelevant issue in the South Pacific countries and warrants caution as the nations increase importation of motor vehicles without consideration of its impacts on air quality and health.

4.2. Vehicle numbers in Fiji: A closer look

Fiji has had a notable rise in the number of motor vehicles and similar trends were observed for other PICs including Tonga and Samoa (Asian Development Bank, 2011; Isley et al., 2016, 2017; Samoa Burea of Statistics, 2020). The high number of second hand vehicles that are entering the PICs also has raised arguments on the PICs being a "dumping ground" for vehicles that other countries do not need (Sanerivi, 2017). As stated, second hand vehicles made up 67%, 54% and 55% of newly registered vehicles in 2016, 2017 and 2018 respectively in Fiji. Fig. 7 represents the number of new registrations in Fiji over the last decade.

Fig. 7 demonstrates the strong growth in motor vehicles from 2013 onwards, reaching peak in 2016. While the increase in vehicles registration rates were generally below 5% per annum from 2008 to 2013, an increase of around 10% per year was noted after 2014 (except in 2017). The type of registrations should also be examined as it consequently influences the type of fuel used and the amount of emissions made. In Fig. 7, the number of private cars being registered is dominant, however, an increase in government vehicles, goods vehicles and buses can be seen as well. Goods vehicles and buses are heavy duty vehicles and typically use diesel as fuel. Diesel vehicles have been reported to emit higher amount of PM by 1 – 2 orders of magnitude in comparision to other fuel type vehicles (Shields et al., 2007).

Data on fuel types of newly registered vehicles is only available from 2016 (Fig. 8). Petrol, Electric/Petrol and Diesel vehicles account for close to 80 to 90% of all newly registerd vehciles. Electric/ Petrol vehicles are more recognised locally as "hybrid" vehicles and are largly used in Fiji for private and taxi use. More importantly, Fig. 8 also highlights a continous increase of diesel based vehicles from 2016 to 2018. Wichmann (2007) reported that particulate matter from diesel motor emissions (Diesel Particulate Matter or DPM) excerbated allegernic responses and caused acute irrrtation as well as neurological, respiratory and asthma-like symptoms.

Heavy duty diesel vehicles are significant contributors to on road particulate matter concentrations (Dreher & Harley, 1998). Moreover, DPM contains high fractions of black carbon (BC) and diesel engines account for approximately 90% of BC emissions from the transport sector (Fruin et al., 2004; Minjares et al., 2013). BC is an important marker of DPM (Fruin et al., 2004) and Isley et al., (2017) has previously highlighted diesel based vehicles as an important source of BC and particulate matter in Fiji.

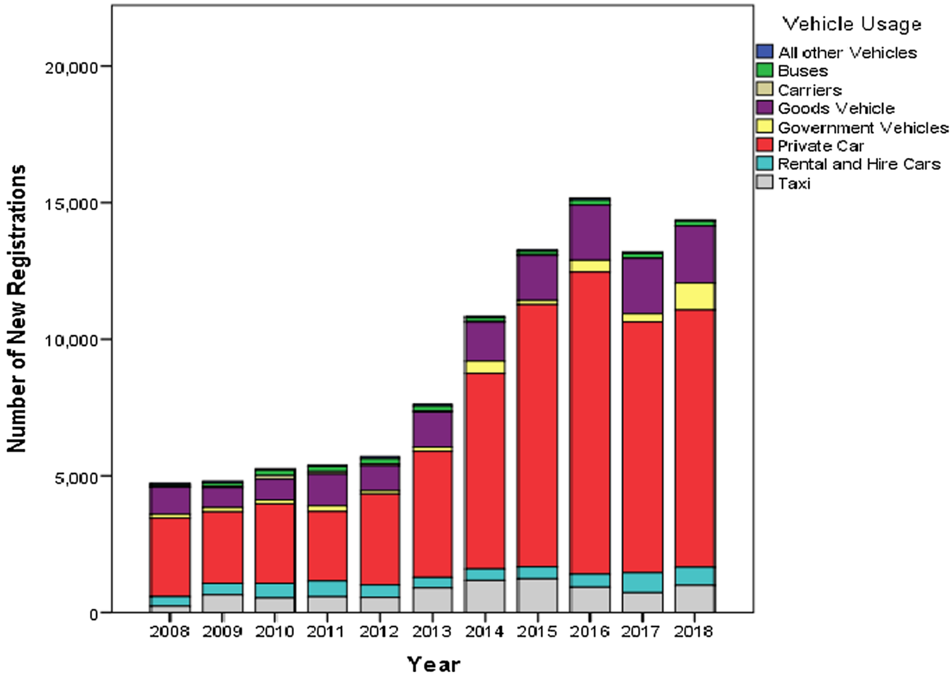

Fig. 7. New Registrations categorised by vehicle use from 2008 to 2018.

Coutries such as New Zealand also show higher number of vehicles yet lower concentrations of roadside $PM_{2.5}$. To understand the importance of policies in mitigation of air pollution from transport sector, we consider the vehicles per capita (Table 3).

The vehicles per capita is a measure to see the *amount* of vehicle available *per person*. Between the countries presented in Table 2, New Zealand has the highest ratio (Ministry of Transport, 2017; Stats, 2019). This implies that there is very close to one (0.86) vehicle for every person in New Zealand. Higher number of vehicle to population ratios are also observed for Australia and UK. Singapore has strong policies regulating the number of vehicles, hence has a lower value, with approximately 1 car available for every 5 people. Fiji has the lowest vehicle per capita in comparison to the aforementioned countries, with around 1 car available for every 7 people. This demonstrates that although there is increasing number of cars in Fiji, it still has a lower ratio of cars to population which is typical of developing countries. However, Fiji has a higher concentration of traffic related $PM_{2.5.}$ The effect of motor vehicle related policies therefore may be more important in defining air quality in the South Pacific islands, including Fiji, than previously anticipated.

4.3. Comparison of current policies and options: A global perspective for a regional approach

While air pollution has been noted as an important environmental issue by the Department of Environment (DoE), Fiji is yet to implement a National Air Quality Policy, inclusive of fine particulate matter standards (Isley & Taylor, 2018; United Nations Environment Programme, 2015). Existing policies such as the Environmental Management Regulations (2007) have provision for emission license for industries, while plans such as the National Air Pollution Control Strategy (endorsed under the Environment Management Act (2005)) layout long term strategic framework for air pollution control (The Government of Fiji, 2012; United Nations Environment Programme, 2015).

A few approaches could be taken up by Fiji to remedy traffic related emissions, which could serve as a model to other PICs. Currently, the Land Transport Authority (LTA) of Fiji, within the bounds of Land Transport Act of 1998 and Land Transport (Vehicle Registration and Construction) Regulations (2000), has the authority to issue Traffic Infringement Notices (TIN's) and or Vehicle Defect Notices for vehicles that emit excessive smoke for greater than 10 s (High Court of Fiji, 2004; Parliment of the Republic of Fiji, 1998). The current smoke opacity standard in Fiji is 50%. Even with a lower standard as such, around 200 vehicles per month fail smoke opacity test at authorized testing centers (Pratibha, 2017). Rules surrounding on-road vehicle smoke emissions are very rarely enforced (Isley et al., 2016; Secretariat of the Pacific Regional Environment Programme, 2014; Sevura, 2005) in Fiji. Due to the lapse in policy and enforcement, poorly maintained old vehicles (primarily HDDV) with high emission rates remain in service. Older diesel vehicles have also shown significantly higher emission factors for BC in comparison to new vehicles (Ježek et al., 2015) adding on to the air pollution burdens.

Comparing smoke emission standards, Singapore has a tighter standard at 40% Hartridge Smoke Unit (HSU) for all vehicles. Moreover, the Environmental Protection and Management (Vehicle Emission) Regulations makes it an offence for any vehicle to emit visible smoke while on road in Singapore (National Environment Agency, 2019). New Zealand also has a rigorous *snap acceleration* test for old diesel vehicles, setting the standard to be no more than 25% (Ministry of Transport, 2007). Australia has emission standards analogous to the Euro V emission standards, while a review is in progress to shift to Euro VI guidelines (Australian

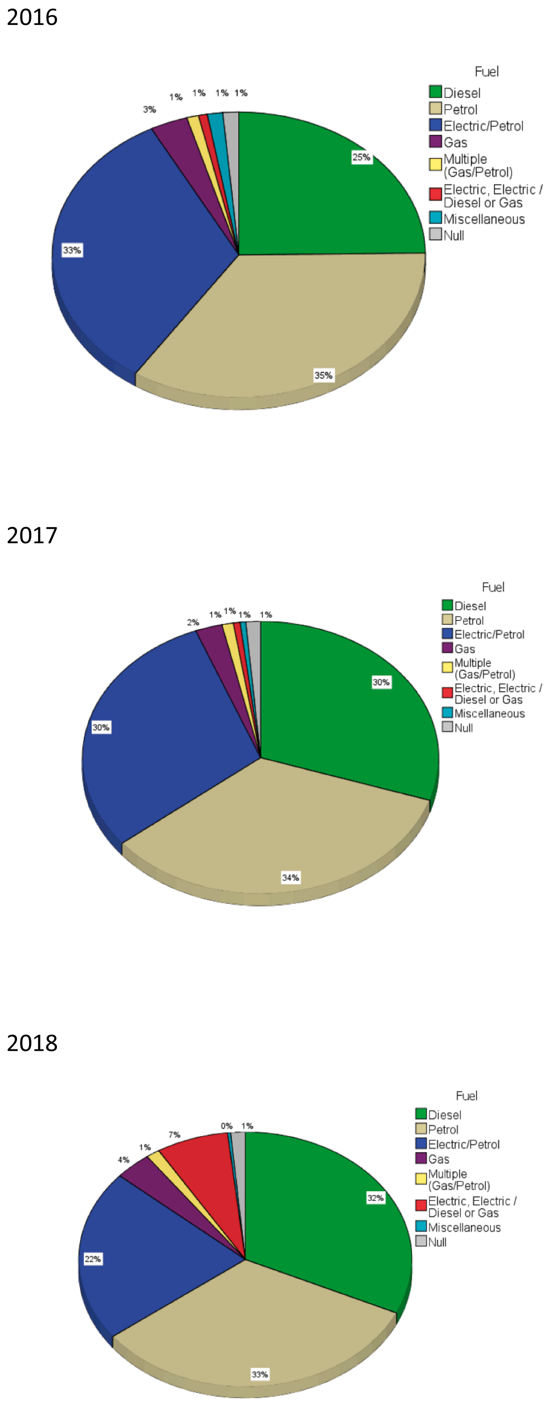

Fig. 8. New vehicle registration caterogized by fuel type.

Government, 2018). The Euro V standards include limits for NO_x, HC (hydrocarbons), CO (Carbon Monoxide) and particulate matter (Australian Government, 2018).

If Fiji is to attain a sustainable transport sector, then higher standards should be considered as future initiatives by LTA. However, present goals should include training technical staff with expertise in assessing vehicles emissions. Further investments should be made in portable and relevant technologies so that meaningful emission on road checks can be carried out. This will be instrumental in reducing the number of high emitting old vehicles and encourage timely maintenance of in-service vehicles thereby lowering

Table 3
Vehicles per capita for countries.

Country	Population	Licensed Vehicles	Vehicles per capita
Australia	25, 180, 000[a]	19, 173, 279[b]	0.76
Singapore	5, 640, 000[c]	957, 006[d]	0.17
New Zealand	4, 844, 400[e]	4, 154, 891[f]	0.86
UK	66, 435, 600[g]	38, 200, 000[h]	0.57
Fiji	884, 887[i]	119, 960[j]	0.13

[a] Australian Bureau of Statistics (2019a).
[b] Australian Bureau of Statistics (2019b).
[c] Department of Statistics Singapore (2019).
[d] Land Transport Authority (2018).
[e] Stats (2019).
[f] Ministry of Transport (2017).
[g] Office for National Statistics (2019).
[h] Department for Transport (2019).
[i] Fiji Bureau of Statistics (2018).
[j] Fiji Bureau of Statistics (2019a).

contributions of the transport sector. Moreover, this approach will help address the lack of equipment and human resources to monitor air quality in Fiji (Ministry of Health and Medical Services, 2018) and create a stronger monitoring network which is needed to reduce vehicle emissions (Secretariat of the Pacific Regional Environment Programme, 2014).

While monitoring the existing fleet, PICs including Fiji should strengthen laws and regulations surrounding motor vehicle importation in order to protect and improve air quality. Implementing age restrictions for second hand vehicles is an effective start to reducing emissions. From 2019, used diesel and petrol vehicles imported into Fiji must be Euro IV compliant and be no more than 5 years old. Similarly, Liquefied Petroleum Gas (LPG) and special use vehicles should also be Euro IV compliant but are allowed a maximum age of 8 years (Fiji Revenue and Customs Service, 2019). Cities such as Beijing have noted a decrease in air pollutants by replacing old buses with new Euro IV compliant and Compressed Natural Gas (CNG) based buses. Other PICs such as Samoa have also imposed stronger age restriction of 8 years for vehicle importation, however, effectiveness of this policy in Samoa remains a question as old vehicles continue to be imported (Sanerivi, 2017; Tong, 2016). The import age regulations in Fiji are now similar to that of New Zealand, however, Singapore has a much more defined and strict vehicle importation policy where imported vehicles can be no more than 3 years from first registration or manufacture (Land Transport Authority, 2017).

Reducing sulfur in fuel is also an effective method to lower emissions. Studies done through modelling show reductions in $PM_{2.5}$ concentrations by reducing the sulfur content in fuels (Leelasakultum et al., 2012). This option has also proved to be beneficial in reducing maritime transport emissions by lowering SO_2 emissions from ships and consequently reducing both primary and secondary aerosol formation (Contini et al., 2015). Blumberg et al. (2003) argued that by reducing the sulfur content in fuels, developing countries can allay mounting human health impacts with increasing vehicles numbers. Moreover, it can also reduce the burden associated with cleaning up existing vehicles. Heavy sulfur based fuels are important sources of particulates in the atmosphere. Many countries have adopted near zero (< 10 ppm) fuel sulfur concentrations. Australia currently allows 50 ppm and 10 ppm in petrol and diesel respectively (Australian Government, 2019). New Zealand has standardized 10 ppm for both petrol and diesel since 2018 (New Zealand Government, 2017). Singapore has implemented fuel standards restrictions in line with Euro VI standards, limiting sulfur content to 10 ppm for heavy duty vehicles (National Environment Agency, 2019). Fiji has adopted standards parallel to Australia, with sulfur content limits of 50 ppm and 10 ppm for petrol and diesel, respectively, since 2019. Moreover, the reduction of sulfur in petrol from 50 ppm to 10 ppm will come into effect from 2021 (Government of Fiji, 2019). While these limits where standardized almost a decade later than Australia, it will be a critical measure in reducing transport based emissions.

Another approach to strengthen the transport sector and reduce emissions is to assess the vehicles before it can be imported. Fiji has introduced offshore JEVIC (Japan Export Vehicle Inspection Center) inspections for second hand vehicle imports from Japan, New Zealand and Australia, commencing from the 1st of October 2019 (Land Transport Authority, 2019a). Inspections as such have been carried out in New Zealand with further requirements including emissions and fuel consumption certifications (NZ Transportation Agency, 2019). In comparison, Singapore vehicle importation policy has a greater progressive approach to safeguard environmental and public health. Apart from smoke emissions, recently introduced Vehicle Emission Scheme sets out standard for CO_2, CO, NO_X and particulate matter emissions (Land Transport Authority, 2017). Furthermore, depending on the amount of emissions that the vehicles makes, rebate and penalties have been implemented. These policies encourage people to purchase vehicles with as low emission rates as possible to qualify for a rebate. Moreover, vehicle certifications, apart from safety mechanisms also include diesel smoke testing and fuel consumption testing (Land Transport Authority, 2017). Certifications as such should also be included in the PICs to prevent importation of vehicles which are not economically viable in terms of fuel consumption and performance. This will also be a screening measure to prevent the PICs from becoming a dumping ground for second hand vehicles. Vehicles with a better fuel economy and lower emissions will aid in improving air quality in the PICs.

The transport sector of Singapore can act as a model for the developing PICs. Singapore has a unique system that regulates the number of vehicles. To own a vehicle, prospective owners need to bid for a Certificate of Entitlement (COE), which lets the owner use and own a vehicle for 10 years with options to renew the COE thereafter (Ministry of Transport, 2019). This encourages the use of public transportation and effectively regulates vehicle population. While polices as such would be difficult to implement in the PICs given the financial limitations, it serves as a guidance to greater strategic development plans. Regulating the transport sector and encouraging public and non-motorized transportation may also raise benefits for the struggling health sectors. Non-motorized transportation may conversely affect to reduce obesity issues (Giles-Corti et al., 2010), an epidemic from which the PICs heavily suffer (World Health Organisation, 2010). Reducing emissions from the transport sector will also act to reduce greenhouse gas emissions and pollutants. Chapman (2007) highlights that the transport sector is one of the few industrial sectors in which emissions are still growing, accounting for 26% of global CO_2 emissions. Climate change also affects air quality by altering local weather patterns including wind and rain, thereby, influencing the distribution of air pollutants (Younger et al., 2008). Younger et al. (2008) also suggests opting for alternative transport options such as non-motorized transport will reduce transport related greenhouse gas emissions and improve on air quality coupled with health benefits.

Moreover, to have such policies in place in future, the PICs must first act to improve current infrastructure including public transportation. Implementing a stronger monitoring network to assess the current fleet may prove to be successful with faster results. While Fiji has taken steps that may work in favor of reducing vehicle emissions, localized assessments and characterization of roadside $PM_{2.5}$ should be done to comprehend the effect of high roadside concentrations on the health of the Fijian population. Other PICs should also follow and improve current existing vehicle importation and use policies if sustainable transport in balance with environment and health sectors is to be achieved in the Pacific.

5. Conclusion

The substantial increase in vehicles, particularly, of used and second hand cars has caused deterioration in urban air quality in Suva and Lautoka. Mean concentration of traffic related $PM_{2.5}$ was greater than twice the WHO daily guidelines in Lautoka. The increased vehicle count and the lack of enforcement of some traffic related regulations may further act to aggravate the air quality and have consequent public health repercussions. While some prospective polices are being implemented, Fiji must strengthen vehicle inspection and importation certification. To curb high emissions from existing fleet, investments should be made in relevant technologies and effective training to enforce smoke emission related regulations. Furthermore, studies including traffic related $PM_{2.5}$ characterisation should be done to understand the possible health related effects.

6. Funding Source Declaration

The work was supported by the Pacific Islands Universities Research Network (Grant Number: F7311-RI001-ACC-001)) and the Faculty of Science, Technology and Environment as well as the Research Office of the University of the South Pacific.

CRediT authorship contribution statement

S.A. Mani: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **F.S. Mani:** Conceptualization, Methodology, Investigation, Writing - review & editing, Supervision, Funding acquisition. **A. Kumar:** Formal analysis, Resources, Writing - review & editing, Supervision. **S. Shah:** Writing - review & editing. **R.E. Peltier:** Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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