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$PM_{2.5}$ and PM_{10} concentrations in urban and peri-urban environments of two Pacific Island Countries

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A R T I C L E I N F O

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A B S T R A C T

Air quality monitoring in most Pacific Island Countries, Territories, and States (PICTS) is minimal, with notable exceptions in Hawai'i and New Caledonia. However, air quality issues are increasingly significant in the region. Existing data on air quality, particularly regarding $PM_{2.5}$ and PM_{10}, are limited, with studies focusing on Fiji and New Caledonia. Our research provides the first continuous and comparative air quality monitoring in urban and peri-urban areas of Fiji and the Solomon Islands, and it is the first assessment since the introduction of the 2021 World Health Organization (WHO) Air Quality Guidelines (AQG). This study assesses health risks and air pollution trends to inform governmental recommendations. We collected $PM_{2.5}$, PM_{10}, and weather data from Honiara, Solomon Islands (February 2020–August 2023), and Suva, Fiji (April 2021–August 2023). In Honiara, $PM_{2.5}$ levels exceeded WHO AQG on 75% of days in urban areas and 51% in peri-urban areas, while PM_{10} levels surpassed guidelines on 2% of days in both areas. In Suva, urban areas had a 10% exceedance of $PM_{2.5}$ guidelines, compared to 13% in peri-urban areas. Annual $PM_{2.5}$ averages exceeded WHO guidelines every year, with levels in Suva and Honiara exceeding guidelines by 2–4 times. PM_{10} levels were 1.5 times higher than WHO AQG in urban Honiara and 1.2 times higher in peri-urban areas. These findings highlight the urgent need for governmental action to establish robust air quality standards and long-term monitoring programs in Fiji and the Solomon Islands to mitigate health risks from poor air quality.

1. Introduction

Air pollution has been declared as the leading environmental risk factor for human health by the World Health Organisation (World Health Organization, 2021a). Natural events and systems, as well as anthropogenic practices and processes, emit suites of airborne particles and gases into ambient (outdoor) air as well as confined (indoor) spaces (World Health Organization, 2021b). When present in measurable

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quantities, particle and gas data indicate whether the health-related quality of air complies with guidelines and standards: non-compliance is usually characterised as “air pollution constituting a human health risk” (Chen et al., 2021; World Health Organization, 2021a).

For Pacific Island Countries, Territories and States (PICTS), community-wide, national or regional air quality monitoring, as well as associated risk and impact assessment, are largely absent. PICTS are mostly small-economy countries, among them three (Solomon Islands, Kiribati and Tuvalu) that are categorised as Least Developed Countries by the United Nations (Brereton and Jagals, 2021; United Nations, 2024; United Nations, 2024; Hilly et al., 2024). To date only five PICTS have had any air quality peer reviewed data collection and none have considered results against the 2021 WHO Air Quality Guidelines (Hilly et al., 2024). Perceptions of island countries having an abundance of clean air (Isley et al., 2017b) masks the general perceptions and understanding of the extent of health-related air quality risk posed to the people of PICTS. However, the situation in urban and peri-urban areas of PICTS is that these have significant and sustained levels of air pollution.

Between 1978 and 2020, research on WHO-listed air pollutants in PICTS have been conducted in Fiji ($PM_{2.5}$ and PM_{10}) (Isley et al., 2017a, 2017b; Mani et al., 2022), Hawai'i ($PM_{2.5}$ and $S0_2$) (Longo, 2009; Longo et al., 2010; Reikard, 2012, 2019; Tam et al., 2016; Tang et al., 2020; Tofte et al., 2017), New Caledonia (PM_{10}, $S0_2$, O_3 and NO_2) (Bard et al., 2017) and PNG (CO) (Anderson, 1978). The 2021 WHO AQG for $PM_{2.5}$ are 15 μg/m^3 (24-h) and 5 μg/m^3(annual), and for PM_{10} are 45 μg/m^3 (24-h) and 15 μg/m^3 (annual) (World Health Organization, 2021a). A review of all studies to date against the WHO guidelines showed exceedances of acceptable concentrations of pollutants in all countries with peer-reviewed data (Hilly et al., 2024).

$PM_{2.5}$ is widely considered as the most critical air quality determinant affecting human heath (World Health Organization, 2021a). Amongst the PICTS, peer-reviewed reporting of $PM_{2.5}$ measurements has only been conducted in Fiji and Hawai'i over short periods, with these snapshots of data showing levels exceeding the 2021 WHO guideline level of 15 μg/m^3 for a 24-h average and 5 μg/m^3 annual average (Hilly et al., 2024). Monthly $PM_{2.5}$ means in urban Fiji ranged from 12 to 22 μg/m^3. Results for Hawai'i ranged from between 5 and 18 μg/m^3 across rural and urban areas (Longo, 2009; Longo et al., 2010; Tam et al., 2016; Tang et al., 2020; Tofte et al., 2017). PM_{10} has been studied in Fiji and New Caledonia over short periods, with urban Fiji reporting annual means of 17 μg/m^3 (range 5–23 μg/m^3) (slightly above the 2021 WHO AQG of 15 μg/m^3) and urban New Caledonia showing 24-h means of 18 μg/m^3 (Bard et al., 2017), which was below the WHO guideline for 24-h mean of 45 μg/m^3. These findings highlight significant air quality challenges in the region, particularly for $PM_{2.5}$.

The PICTS region has seen little baseline or ongoing health-related air quality monitoring to date and there is a clear knowledge gap on air quality and health risk in the PICTS region particularly among resource-poor countries. The summary of results comprise all peer-reviewed work to date in the Pacific as collated from individual short-term studies, as relevant to the WHO guidelines, with monitoring or sampling in the studies targeted at specific contaminants associated with particular natural or anthropogenic events/activities. The only two PICTS with long-term air quality monitoring are Hawai'i (State of Hawaii, 2023) and New Caledonia (Scal Air, 2024). No studies to monitor air quality have been carried out in Fiji or the Solomon Islands since the publication of the updated 2021 WHO guidelines (World Health Organization, 2021a).

This study aims to provide the first baseline data of ambient air quality where air quality data is absent in Honiara and adding to existing data for Suva. Further, this study aims to provide a demonstrated approach to allow comparison of results between PICTS and remedy the lack of air quality data or air quality policies in the region that is scalable across the Pacific. In order to achieve this, continuous air quality monitoring in urban and peri-urban areas of Suva, Fiji and Honiara, Solomon Islands was implemented over a four year period (2020–2023) in collaboration with national governments and local universities. The objectives are to provide the first long-term and inter-comparable air quality investigation between two PICTS to address the lack of knowledge on air quality and assess temporal and spatial trends. This work measured the levels of particulate air pollution in urban and peri-urban areas and then compare these results against the 2021 WHO AQG. The results further allow human exposure to $PM_{2.5}$ and PM_{10} concentrations to be considered over time and the identification of key sources of air pollution. Lastly, these new understandings can then be used to propose policy directions for the governments of Fiji and the Solomon Islands.

2. Methodology

Monitoring stations (Table 1) were installed according to anticipated air pollutant emission potential at urban and peri-urban sites in Suva (Fig. 1a and b) and Honiara (Fig. 2a and b). The sites were selected to provide a representative context of peri urban and urban environments, while ensuring security, and ease for accessing equipment. Their placement also allowed for investigation of varying airborne particulate concentrations and meteorological conditions characteristic of these areas. Suva's urban landscape is characterized by a diverse mix of commercial enterprises, small-scale industrial activities, residential districts, as well as land and marine transportation facilities. This area exhibits a higher population density compared to the peri-urban regions surrounding Suva. Similarly, urban Honiara features a high concentration of commercial and small-scale industrial operations. The daily activities of land and marine transport, along with the presence of a landfill, significantly contribute to emissions in these areas. Residential zones in these metropolitan areas comprise both formal and informal settlements and are more densely populated than their peri-urban counterparts.

Suva's peri-urban areas are predominantly residential, including traditional villages, settlements, formal housing, healthcare services, and educational institutions, and are situated along a key road connecting Suva and Nausori. Honiara's peri-urban zone, which houses the airport, is primarily surrounded by informal settlements that have limited access to essential government services.

In Suva, the urban site is at the Laucala campus of the University of the South Pacific, located along the Suva coastline (Fig. 1c). Within proximity of the site are sports facilities, commercial zones, and residential areas. To the north is Laucala Bay Road and to the south is Queens Road which see heavy traffic on certain times of the day. The peri-urban site is at the FNU Tamavua Campus on Princess Road which connects the surrounding communities to Suva city. On the north-west side is vegetation, north-east, predominantly residential plus the road, south side, are traditional villages, settlements, and Suva city.

The urban site in Honiara was located within the central business district (CBD) where the main shipping port, market area, administrative offices, commercial business and both formal and informal housing are located (Fig. 2c). The peri-urban site is located within the meteorological monitoring compound located at Henderson Airport, immediately surrounded by open grass and a mix of commercial, residential and small-scale industrial land use areas outside the airport boundary. The residential areas include a mix of formal and informal settlements to the north and informal settlements to the south, most of which are not connected to the power grid and not served by waste collection services.

Each site was equipped with a DustTrak DRX Aerosol Monitor 8533 (TSI, 2021) in an environmental enclosure and a Vaisala WXT536 weather station (Vaisala, 2017) (Fig. S1b), with the exception of Honiara peri-urban which used the Davis Vantage Pro 2 weather station (Davis, 2025). The DRX measures size-segregated aerosol mass concentration in real time (Wang et al., 2009). The DRX inlet and Vaisala/Davis sensors at each location were at a height of 2 m above the installation surface (roof or ground), site specifics are shown in Table 1. Each location was chosen in collaboration with National Government Ministry and local University partners to be representative of both urban and peri-urban

Table 1
Monitoring station sites and period of measurement.

City	Location & Coordinates	Height above ground level	Location description	DustTrak	Vaisala	Davis	Set-up date	Measuring period	Total days measured	Interruption days
Suva	USP Laucala Campus, −18.1492127, 178.4464444	7 m	Urban – roof top of single-story building	X	X		11/08/22	11/08/22–20/09/23	367	3
	FNU Tamavua Campus, −18.09215, 178.44663	6 m	Peri-urban – roof top of single-story building	X	X		9/04/21	9/04/21–20/07/23	793	–
Honiara	−9.4349248, 159.9544266	5 m	Urban – roof top of single-story building in existing meteorological station site	X	X		27/02/20	27/02/2020–27/08/23	1256	22
	Henderson, −9.4296875, 160.0474188	2 m	Peri-urban – open area on airport property in existing meteorological station site	X		X	27/02/20	27/02/2020–27/08/23	1068	194
					X		24/07/23			

Note. USP = The University of the South Pacific; FNU = Fiji National University.

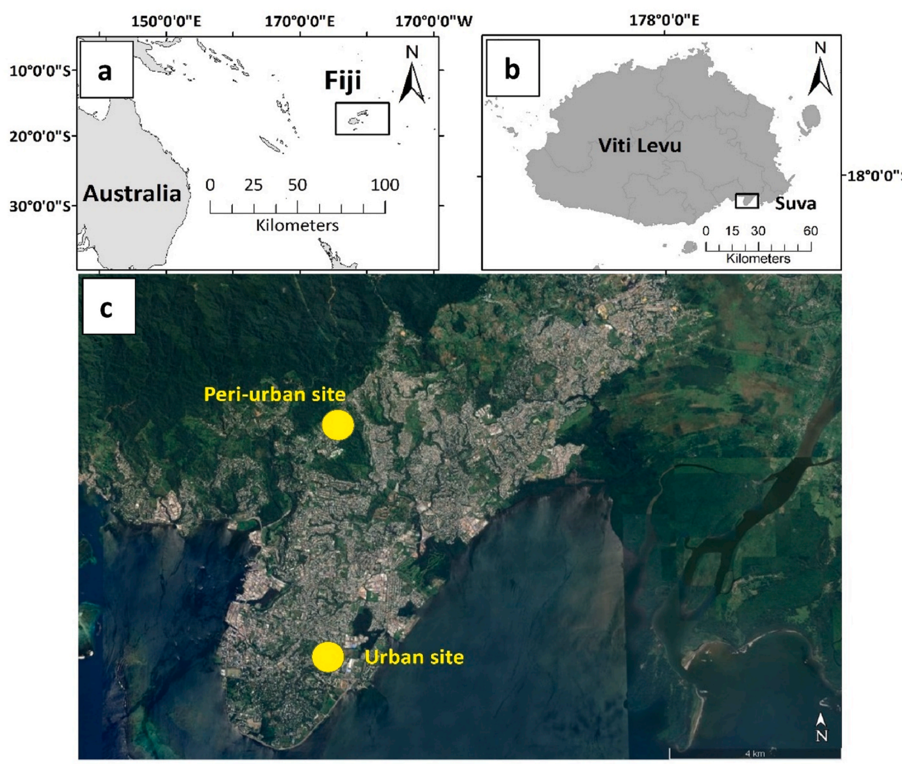

Fig. 1. The Fiji, Suva (a, b) air quality monitoring station locations in c) urban and peri-urban environments. Sites were chosen to balance their representativeness of peri urban and urban contexts, their security, and ease for accessing equipment.

environments while also secure. Airborne particulate fractions ($PM_{2.5}$ and PM_{10}) and meteorological data (wind speed, wind direction, rainfall, air pressure, humidity) were recorded at 2-min intervals with auto-zeroing occurring every 4 h. Real-time data was uploaded via telemetry and available remotely on a cloud-based platform. The data sets as specified in Table 1 were downloaded from the platform and used for analysis. Figs. S1a and S1b show the two typical monitoring station set up used in this study. While the DustTrak DRX monitors are not regulatory grade, it has been used on rigorous scientific studies (Bullard et al., 2023; Wiggs et al., 2022).

Data collected for $PM_{2.5}$ and PM_{10} concentrations were analysed for their diurnal (24-h), weekly, annual/seasonal and their interannual trends, through calculation of mean values, 5th and 95th percentiles and standard deviation. Both the 24 h and yearly means were compared with the 2021 WHO AQG (World Health Organization, 2021a) to consider the risk of exposure of particulate air pollution to urban and rural populations in Fiji and the Solomon Islands. The daily, weekly, and monthly data were further assessed to determine whether spatial trends are important in measuring ambient air quality and what role daily activities versus seasonal cycles may play in impacting air quality. Moreover, $PM_{2.5}$ and PM_{10} were analysed together with wind speed and wind direction to determine whether directional transport played a role in the measured concentrations of airborne particulates. The correlation coefficient (Li et al., 2017) was used to determine the relationship between PM and wind direction. This allowed the identification of likely $PM_{2.5}$ and PM_{10} source regions in both urban and peri-urban areas of Honiara

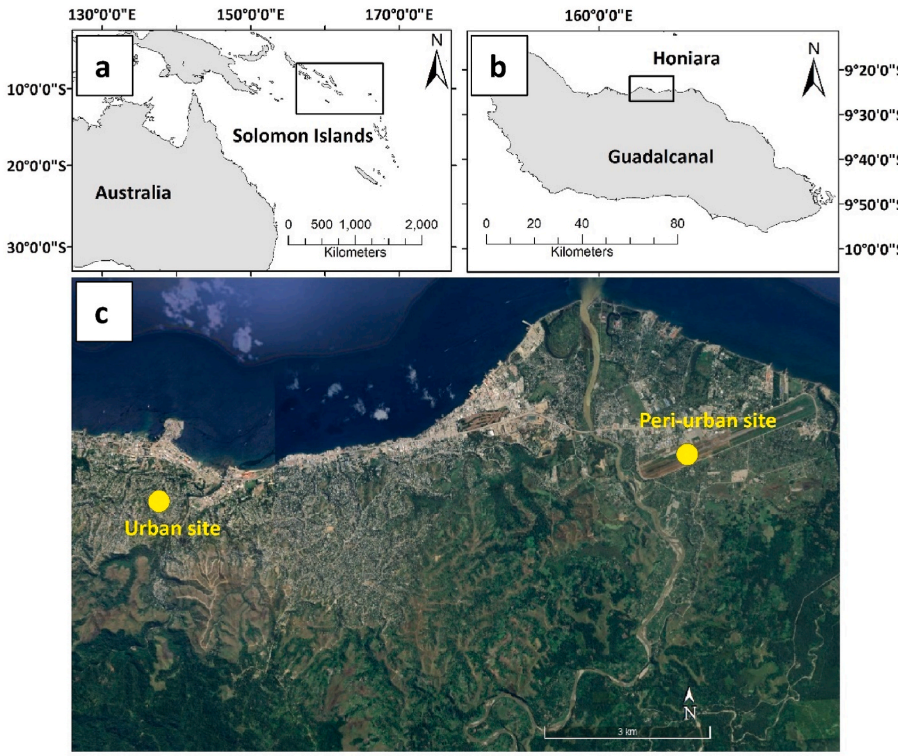

Fig. 2. The Solomon Island, Honiara (a, b) air quality monitoring station locations in c) urban and peri-urban environments. The urban site is located at the Upper Air Meteorological Station. The peri-urban site is located at the Henderson airport meteorological station. Meteorological sites were selected because they represent urban and peri-urban areas.

and Suva.

3. Results

The 2-min interval data was averaged into periods that allowed for comparison against corresponding WHO guidelines (annual average and 24-h average) as well as periods that allowed investigation of trends most relevant for seasonal and activity influence (monthly, weekly and hourly).

3.1. Annual average concentration of $PM_{2.5}$ and PM_{10}

Annual average PM concentrations for Suva urban (Fig. 3a and b), Suva peri-urban (Fig. 3e and f), Honiara urban (Fig. 3c and d), and Honiara peri-urban monitoring sites (Fig. 3g and h) demonstrated levels of airborne particulates greatly exceeding the acceptable WHO levels for $PM_{2.5}$ and PM_{10}. The study duration of average annual concentrations of $PM_{2.5}$ in urban Suva from 2022 to 2023 was 10.4 μg m^3 (SD=1.6), double the acceptable annual average. In the Suva peri-urban environment, the study duration of average annual concentration of $PM_{2.5}$ for 2021, 2022, and 2023 was 9.0 μg/m^3 (SD=1.5). Honiara reported higher annual averages, with the study duration average annual concentrations of $PM_{2.5}$ at the Honiara urban site for 2020, 2021, 2022, and 2023 being four times the WHO limit at 20.7 μg/m^3 (SD=1.3). For the same period in the Honiara peri-urban site, the study duration average annual concentration of $PM_{2.5}$ was three times the limit, 16.3 μg/m^3 (SD = 1.2). For PM_{10}, the annual averages for Suva urban and peri-urban sites did not exceed the WHO AQG. At the Honiara urban site, study duration of average annual concentrations of PM_{10} for 2020, 2021, 2022, and 2023 was 23.3 μg/m^3 (SD = 1.9), 1.5 times the WHO acceptable annual concentrations. At the Honiara peri-urban site during the same period, the average annual concentrations of PM_{10} were 1.2 times the limit, 17.4 μg/m^3 (SD=1.2).

3.1.1. Annual and seasonal trends

Seasonal factors are seen to be affecting air quality in Suva and Honiara (Fig. 4). The monthly average concentration (calculated by calendar month average over total study duration) showed a cyclical characteristic of higher airborne PM in the dry season compared to wet at both Honiara sites (Fig. 4 c, d, g, h), and to a lesser extent the Suva peri-urban site (Fig. 4e and f). The peri-urban sites showed a much greater range between the 95th and 5th percentile, with these months of higher and lower PM averages likely due to both seasonal anthropogenic (agriculture, construction) activities and possible also some background natural aerosols. The Suva urban site showed the least cyclical trend of all locations, with smaller monthly peaks in March–May and August–October (Fig. 4a and b).

3.2. 24 h average concentration of $PM_{2.5}$ and PM_{10}

The 24-h averages of $PM_{2.5}$ and PM_{10} were plotted for both urban and peri-urban environments in Suva (Fig. 1) and Honiara (Fig. 2). The highest levels of airborne particulates were reported in urban Honiara, with 75% of the 1,256 days of measurement exceeding the WHO AQG 24-h average $PM_{2.5}$ limit of 15 μg/m^3 (Fig. 5c). Air quality in peri-urban Honiara was also exceedingly poor with 51% of days exceeding $PM_{2.5}$ WHO 24-h average AQG levels (Fig. 5g). The 24-h average concentration of PM_{10} in Honiara exceeded the WHO AQG (45 μg/m^3) 2% of the days in both urban and peri-urban areas (Fig. 5d and h). The exceedances in Honiara were frequently up to double the WHO guideline level of 15 μg/m^3 (804 days (64%) were between 15 and 30 μg/m^3 and 142 days (11%) were more than double the WHO $PM_{2.5}$ limit). 13 days (1%) were above 45 μg/m^3, more than triple the 24-h average limit. In Fiji the airborne PM fractions were lower with the percentage of days with $PM_{2.5}$ concentrations that exceeded the WHO AQG being 10% in urban areas (Fig. 5a), and 13% in peri-urban areas (Fig. 5e).

When the 2-min data is converted into hourly averages representative of all days within the entire data collection period (i.e. an average

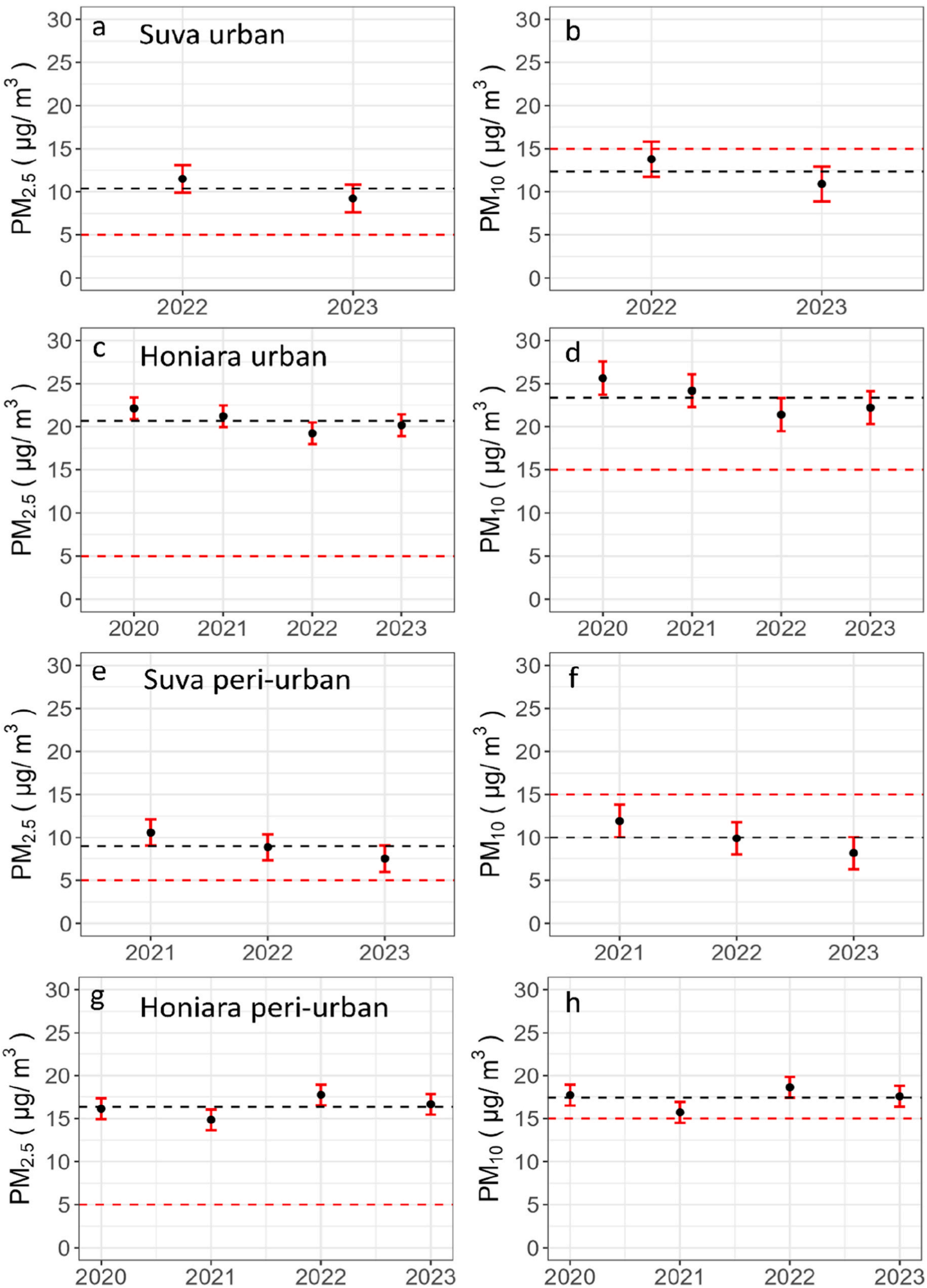

Fig. 3. Calculated annual average $PM_{2.5}$ and PM_{10} concentrations per year (black dots) and annual average (black dashed line) in Suva and Honiara urban and peri-urban environments compared to the 2021 WHO annual average limit (red dashed line).

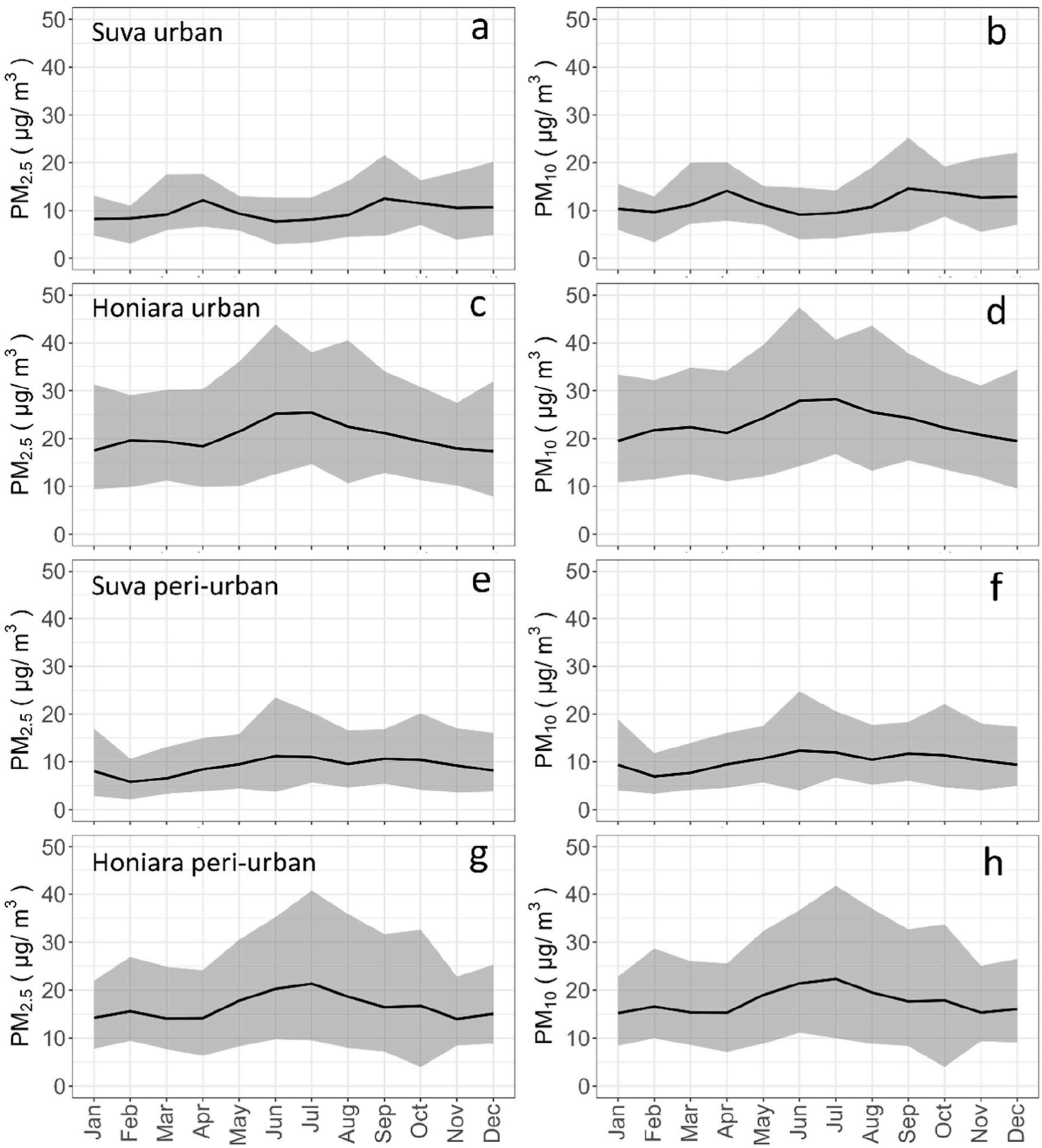

Fig. 4. Monthly $PM_{2.5}$ and PM_{10} data averaged from total data collection periods at each site (Table 1) for Suva urban (a and b), Suva peri-urban (e and f), Honiara urban (c and d), Honiara peri-urban (g and h). Upper limits of grey area = Q95, black line = Mean, Lower limit of grey area = Q5.].

calculated for each 60-min period within the 24-h of all calendar days between 00:01–24:00) (Fig. 6) a clear $PM_{2.5}$ and PM_{10} diurnal trend was observed at both urban and peri-urban monitoring sites. The mornings (06:00–07:00 h) and evenings (18:00–21:00 h) are when $PM_{2.5}$ and PM_{10} concentrations peak (Fig. 6). Table 2 shows these morning and evening periods of elevated particulate concentrations and the highest recorded concentrations for $PM_{2.5}$ and PM_{10}.

When considering the weekly trend of reported 24-h averages (Fig. S2), $PM_{2.5}$ and PM_{10} concentrations show little variation between days of the week (Fig. S2) and also appear largely uniform for all the sites. Weekday concentrations are noted to be slightly higher in Suva peri-urban ($PM_{2.5}$ 8.69 μg/m^3 - 9.89 μg/m^3, PM_{10} 9.80 μg/m^3 – 11.21 μg/m^3) and Honiara peri-urban ($PM_{2.5}$ 16.55 μg/m^3 – 17.95 μg/m^3, PM_{10} 18.01 μg/m^3-19.11 μg/m^3) environments and a small increase in $PM_{2.5}$ and PM_{10} (Figure S2 a, b, c and d) daily average concetration levels in urban environments on Mondays, Tuesdays, and Saturdays. Sundays showed the lowest average readings across all sites for both size fractions.

3.3. Wind trends

Directional factors were shown to influence PM concentrations in both Suva (Fig. 7, Fig. S3) and Honiara (Fig. 8, Fig. S4) with each site exhibiting different localised wind speed and wind strength characteristics (Figs. 7 and 8). Wind speed and airborne particle concentrations were not found to have any significant correlation at any of the sites (Fig. S5).

3.3.1. Suva

The wind speed at the Suva urban station was mostly between 1 and

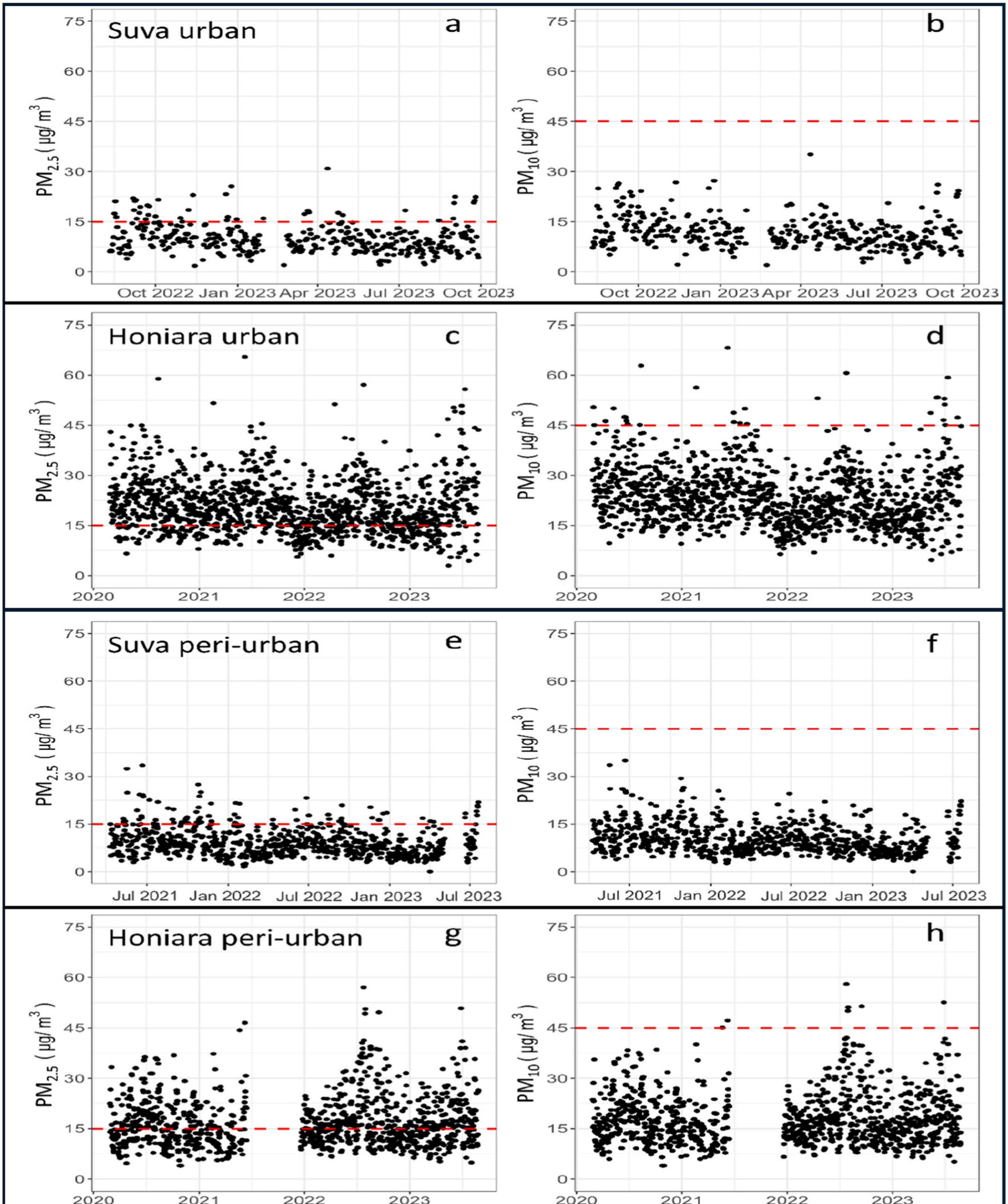

Fig. 5. Calculated 24-h averages (black dots) of measured $PM_{2.5}$ and PM_{10} concentrations at urban and peri-urban monitoring sites compared to WHO 24-h concentration limit (red-dashed line).
The WHO AQG (2021) 24-h concentration limits of 15 μg/m^3 for $PM_{2.5}$ and 45 μg/m^3 for PM_{10} are shown as a dashed red line. Each dot represents 24-h average of 2-min collected $PM_{2.5}$/PM_{10} data. Days of data collection interruption (Table 1) visible as gaps in the data set.

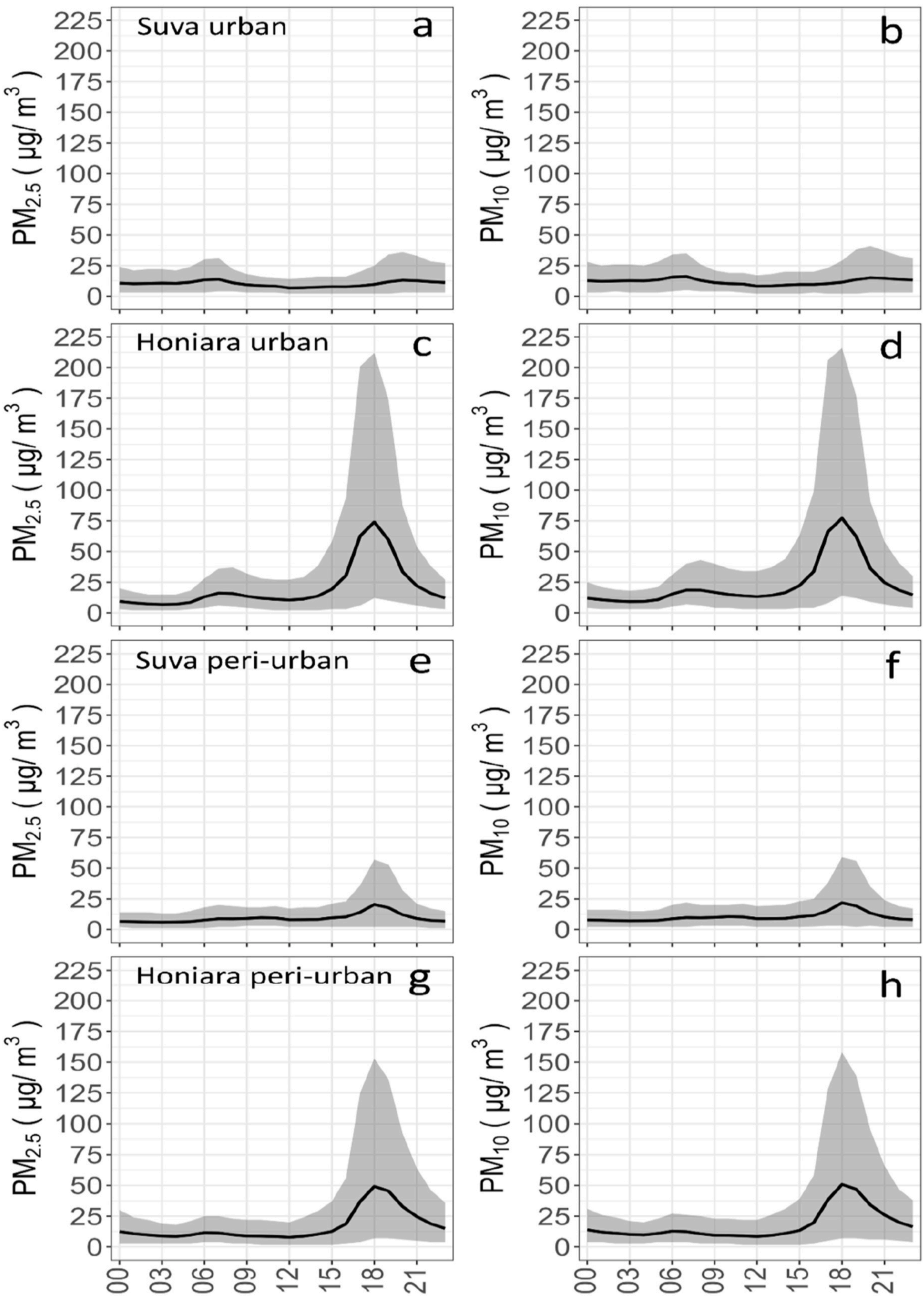

Fig. 6. Hourly $PM_{2.5}$ and PM_{10} data averaged from total data collection periods at each site (Table 1) for Suva urban (a and b), Suva peri-urban (e and f), Honiara urban (c and d), Honiara peri-urban (g and h). Upper limits of grey area = Q95, black line = Mean, lower limit of grey area = Q5.].

Table 2
Hourly average and highest peaks recorded for each site.

Site	PM	Hourly average (µg/m³)(95%CI)	Time	
			06:00-07:00 (µg/m³)	18:00 – 21:00 (µg/m³)
Suva urban	$PM_{2.5}$	10±0.82	13.55	11.7
	PM_{10}	12±0.89	15.84	13.3
Suva peri-urban	$PM_{2.5}$	9.23±1.42	8.18	14.83
	PM_{10}	10.3±1.46	9.18	16.2
Honiara urban	$PM_{2.5}$	20.53±7.32	14.55	75
	PM_{10}	23.28±7.39	16.93	77
Honiara peri-urban	$PM_{2.5}$	16.67±4.8	11.48	50
	PM_{10}	17.77±4.82	12.67	55

Note: Grey highlight = highest hourly average recorded for each day.

2 m/s and mainly from the south-southwest to south southeasterly direction (Fig. 6a). The strongest wind speeds (2–3 m/s) were predominantly from the southeast and south-south-east (Fig. 6a). At the Suva peri-urban station the wind speed was similarly mostly between 1-2 m/s (Fig. 6b). The predominant wind direction was from the south-west through to the southeast, with maximum wind strengths of up to 3 m/s recorded near-equally across all these directions (Fig. 6b). Airborne PM concentrations for both 2.5- and 10-µm size fractions mostly showed a positive relationship with wind direction at both the Suva urban and peri-urban location (Fig. 6 and Fig. S3). The highest particulate concentrations came from the southwest at the urban location (Fig. 6a and S3c). At the peri-urban site the less frequent but strongest winds recorded (2–3 m/s) south-westerly winds carried the highest concentration of $PM_{2.5}$ (Fig. 6c and Fig. S3) and PM_{10} (Fig. 6d and Fig. S3d).

3.3.2. *Honiara*

The wind speed at the Honiara urban station was between 0-5 m/s and mainly from the south-west, south, and south-east directions (Fig. 8a). At the Honiara peri-urban station, the wind speed was much stronger between 5-0 m/s and coming predominantly from the south-east (Fig. 7b) which carried concentrations up to 50 µg/m^3 ($PM_{2.5}$) and up to 75 µg/m^3 (PM_{10}). At the Honiara peri-urban station, the highest wind speed recorded was 20–25 m/s which carried concentrations of up to 50 µg/m^3 $PM_{2.5}$ (Fig. 8d and S4d). The highest levels of PM recorded were from the less frequent northeast direction (Fig. 8d and S5d). $PM_{2.5}$ (Fig. 8c and d) and PM_{10} (Fig. 8e and f) were similarly predominantly transported from these directions. Both $PM_{2.5}$ and PM_{10} mostly showed a positive relationship with the wind direction at both urban and peri-urban locations (Fig. 8 and S4). The highest particulate concentrations came from the south-east direction (Fig. 8d and f and S4d and f).

Clear directional factors were observed at both the Suva (Fig. 7, Fig. S4) and Honiara (Fig. 8, Fig. S5) sites suggesting localised sources and non-homogenous urban air. Ratings of good to extremely poor (Figs. 7 and 8), using the air quality categories from neighbouring Australia (NSW Government, 2025), days of worse air quality are seen to not be equally distributed in their direction of origin. Fig. 7 shows at the Suva urban station, the highest frequency of elevated particulate readings is from the south-west and south-east directions. Noted activities in those directions from the monitoring site are traffic, housing, shipping service, sporting facilities which are associated with traffic at key events. For the Suva peri-urban station, the highest readings are from south-west, south-east and south directions. At the south-west direction are traditional villages, formal residential housing and close to the coast is the main industrial and commercial site in Suva (Fig. 1). The main road connecting Suva to surrounding towns and villages is located on the south-east side of the site.

The highest concentrations measured at the Honiara urban site came from a southerly direction (Fig. 8a). Located to the south of the monitoring station site (Fig. 2) is a blend of formal and informal housing, roads, and commercial activities. At the peri-urban station the highest concentrations are from the south-east (Fig. 2) from the direction of the airport apron, dirt road and informal housing.

4. Discussion

This study conducted a long-term continuous air quality monitoring of $PM_{2.5}$ and PM_{10} using the DRX DustTrak and weather station (Fig. S1) in urban and peri-urban areas of Suva (Fig. 1) and Honiara (Fig. 2). The results showed that in Honiara, the urban environments had higher concentrations of PM compared to the peri-urban environments. In contrast, in Suva, the peri-urban environment had higher concentrations of PM compared to the urban environment. It is noted however that the coastal proximity of the urban site in Suva may be underreporting PM fractions compared to a more central location, and access to a secure, central urban site would be desirable for further study. Noting the potential underreporting of Suva urban airborne particulates, the differences in ambient PM concentration between the urban and peri-urban environments in Honiara and Suva may be attributed to local factors influencing air quality in each city. In Honiara, higher PM levels in urban areas could be driven by dense population, industrial activities, and heavy traffic, while the more open and less populated peri-urban site allows for pollutants to disperse more readily. Conversely, in Suva, higher PM concentrations in the peri-urban environment may be attributed to heavy traffic along a major road corridor, waste burning, and biomass burning for domestic cooking in informal settlements.

4.1. *Air quality compliance*

When comparing the concentration of $PM_{2.5}$ and PM_{10} to the 2021 WHO AQG, the readings are concerning as far as human exposure is concerning. The measurements reveal a significant disparity in air quality, with urban Honiara showing a highly concerning 75% of days (24-h average) exceeding the 2021 WHO AQG compared to 51% of days

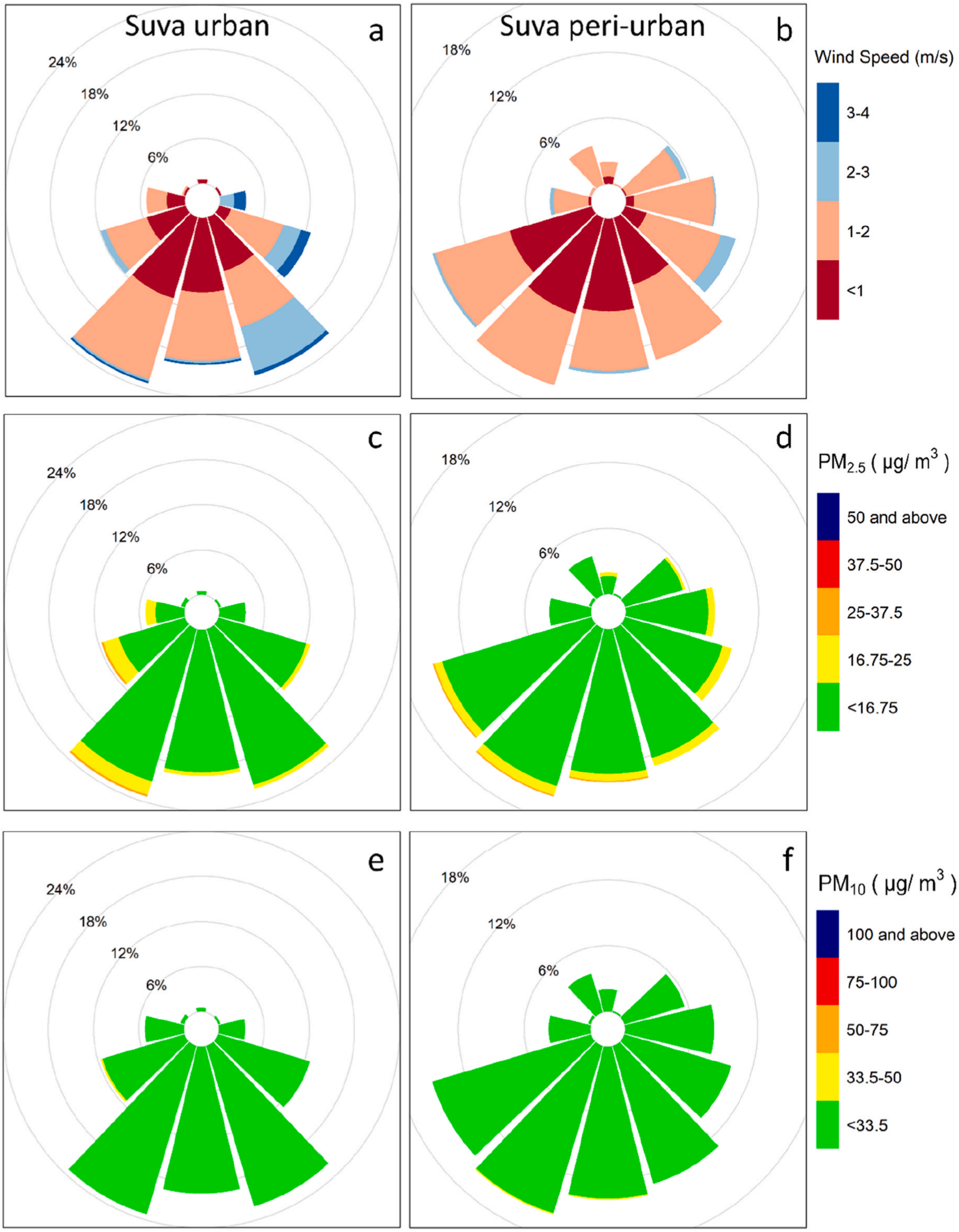

Fig. 7. Wind speed and direction data from the Suva a) urban and b) peri-urban stations. Wind direction and frequency of PM concentrations ranging from good (green), fair (yellow), poor (orange), very poor (red), to extremely poor (purple) for c) Suva urban, and d) peri-urban $PM_{2.5}$ and) Suva urban, and d) peri-urban PM_{10} concentrations. Data were collected over a 29 month period from 9th April 2021 to 20th September 2023.

in the peri-urban area. In contrast, urban Suva experienced 10% of days exceeding the 2021 WHO AQG of 15 μg/m^3 for 24-h average, slightly lower than the 13% recorded in the peri-urban area. Relocation of the Suva urban monitoring station is suggested to urgently monitor Suva urban air as centrally as possible.

The annual average of $PM_{2.5}$ and PM_{10} for Honiara urban and peri-urban exceeded the 2021 WHO AQG in all years inclusive from 2020 to 2023 (Fig. 3). The levels of $PM_{2.5}$ and PM_{10} were higher than other studies used for comparison (Table S1) for cities in Malaysia, Australia, France and Hawai'i, similar to the measurements for Seoul, Korea but less than measurements in Beijing, China, a well-known location of very poor air quality. These comparisons suggest that the air quality in pacific urban centres such as Honiara, with a population of 129,569 (Solomon Islands Government, 2023) can be worse than in cities with millions of

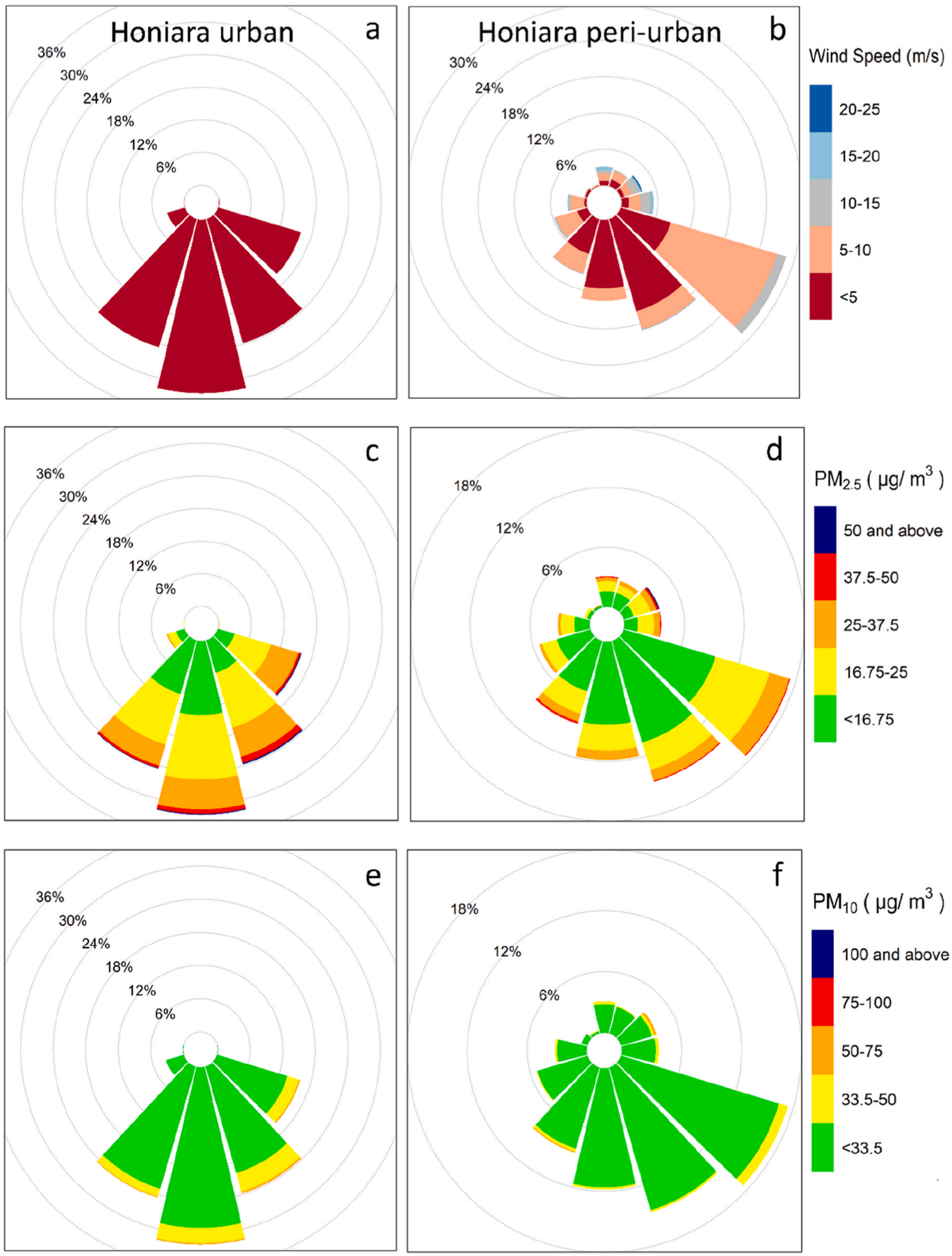

Fig. 8. Wind speed and direction data from the Honiara a) urban and b) peri-urban stations. Wind direction and frequency of PM concentrations ranging from good (green), fair (yellow), poor (orange), very poor (red), to extremely poor (purple) for c) Honiara urban, and d) peri-urban $PM_{2.5}$ and) Honiara urban, and d) peri-urban PM_{10} concentrations (NSW Government, 2025). Data were collected over a period of 42 months between the 27th of August 2020 to 28th of August 2023.

people. The disparity in air pollution levels is driven by technological differences in transport, energy production and household cooking sectors (Milindi et al., 2023; Van der Kroon et al., 2013). Suva similarly showed readings of $PM_{2.5}$ in urban (2022–2023) and peri-urban (2021–2023) environments exceeding the 2021 WHO AQG annual levels. PM_{10} in both Suva urban (2022–2023) and Suva peri-urban (2021–2023) did not exceed the 2021 WHO AQG.

Compared to the Pacific city data presented here, lower levels of annual average $PM_{2.5}$ and PM_{10} concentrations were reported in Canberra, Honolulu and Paris followed by London, Badah, Seoul and Beijing

(Table S1). The cities with cleaner air quality are attributed to regulations on emissions and compliance (ACT, 2022; AIRPARIF, 2021; City of London Corperation, 2023; DOE, 2022; Seoul Metropolitan Government, 2022; State of Hawaii, 2023). Neither Fiji nor the Solomon Islands regulated $PM_{2.5}$ while Fiji on the other hand regulated PM_{10} (Fiji Government, 2019) hence an urgent need of their development and implementation.

4.2. Health implications

Exceeding the WHO AQG for ambient air quality carries significant health implications. Vulnerable demographic groups, namely the elderly (Ji et al., 2024), women (Liu et al., 2024), and children (Nguyen et al., 2024), are particularly at risk. Anthropogenic $PM_{2.5}$ has been shown to have more severe health impacts than natural $PM_{2.5}$, including its contribution to infant mortality (Graffam et al., 2023). This raises significant concern in Honiara and Suva, where the observed 24-h trends demonstrate a strong correlation between poor air quality and human activities (Fig. 6). Short-term exposure to air pollution adversely affects years of life lost, especially among the elderly and women, underscoring the importance of improving air quality to extend population life expectancy (Liu et al., 2024). Human activity can be associated with notable increases in concentrations of $PM_{2.5}$ and PM_{10} at two-time periods every day, (1) 06:00–07:00 h; and (2) 18:00–21:00 h (Table 2), with the highest particulate concentrations being recorded during these times.

4.3. Local meteorology

While there are weak correlations between wind speed and $PM_{2.5}$ and PM_{10}, higher levels of airborne particulates could be more impacted by other meteorological conditions such as relative atmospheric humidity, temperature, rainfall, as well as human activity and behaviour. Concentrations of PM are usually high in the mornings and evenings when the relative atmospheric humidity is high (Zhang et al., 2018) and traffic rush hours (Bakirci, 2024; Patra et al., 2023; Wong et al., 2024). Additionally, increases in temperature during the day may result in dispersion of air particles resulting in low concentrations of PM and at night as temperature decreases, the compressed boundary layers may restrict the efficiency of air particle dispersion in the atmosphere resulting in accumulation of PM (Ali et al., 2022; Kumar et al., 2017; Vaishali et al., 2023). Rainfall may have contributed to wet scavenging of $PM_{2.5}$ and PM_{10} resulting in lower concentrations after rainfall events. Descending air in high-pressure areas tends to suppress vertical mixing which may lead to PM concentration close to the ground while low-pressure on the other hand is associated with unstable weather and rising air in these areas promote vertical mixing which can disperse pollutants.

4.4. Local sources

The 24-h $PM_{2.5}$ and PM_{10} concentrations, when averaged according to day-of-the-week (Fig. S2), show high concentrations during the working weekdays while recording slight decreases on Sundays. The data for Suva (Figs. S2a and S2b) reported here correlates with observations by Isley et al. (2017b) in Suva. In Fiji most businesses do not open on Sundays with commuting and urban activity lower and likely the cause for lower emissions (Isley et al., 2017a), with the same trend observed in Honiara (Figs. S2c and S2d). Increased concetraions of $PM_{2.5}$ and PM_{10} during the weekdays is indicative of exposure to very unhealthy levels of air pollution (Fig. S2) by commuters and the public in both urban and peri-urban areas (Isley et al., 2017a). For commuters during the weekdays, the mode of transport determines levels of exposure with pedestrians, passengers in open air buses, and motorbikes being most at risk. Traffic emissions likely contribute significantly to elevated PM levels, especially at sites near major roads, but the lack of direct traffic data or emission source apportionment limits our ability to fully quantify their impact on the findings. Isley et al. (2017a) reported that higher PM concentrations observed in Suva were primarily attributed to land-based emissions such as traffic, fossil fuel combustion, and open burning. This finding was also supported by Mani et al. (2020) who observed elevated concentrations of $PM_{2.5}$ in traffic-dense areas of the urban areas of Suva and Lautoka. These findings highlighted that $PM_{2.5}$ levels in these cities are predominantly influenced by local anthropogenic sources rather than long-range particle transport or upwind contributions (Mani et al., 2022).

4.5. Annual variability

Of the reported data, monthly averages (Fig. 4) may be most influenced by the scavenging effect of precipitation (Liu et al., 2020). Fiji is located in the South Pacific trade-wind belt with predominantly southeasterly winds that are strong during dry season (between May and October) but throughout the wet season (November to April) the winds are lighter, with a dominating sea breeze during the day (Mataki et al., 2006). Fiji has two distinct seasons, which are controlled by the north and south movements of the South Pacific Convergence (Chand et al., 2023; Mataki et al., 2006). The distinct wet and dry seasons of Fiji appear to influence monthly air quality average concentrations, with higher levels of $PM_{2.5}$ and PM_{10} reported in Suva during the dry months (May–October) compared to the rainy months (November–April) (Fig. 4a, b, e & f).

The Solomon Islands similarly experiences a tropical climate characterised by well-defined wet and dry seasons. The first wet season, spanning from January to March, is marked by substantial rainfall and the potential for tropical cyclones, while the dry season, extending from May to September, is typified by milder temperatures and reduced precipitation (Fleming et al., 2019; Keremama et al., 2019). Ambient PM concentrations in Honiara are shown to be higher in the dry season compared to the wet as expected (Fig. 4c, d, 4g, 4h) and as also observed in Fiji. Honiara is subject to the influence of southeast trade winds and these winds transport moist air from the ocean, contribute to the second wet season observed from November to April. Rainfall scavenging of airborne particulates may be responsible for reducing concentrations of airborne $PM_{2.5}$ and PM_{10} during this wet season. During this period, urban $PM_{2.5}$ levels ranged from 17.9 μg/m³ in November to 18.3 μg/m³ in April, while peri-urban $PM_{2.5}$ increased slightly from 14.0 μg/m³ to 14.2 μg/m³. Urban PM_{10} showed a marginal rise from 20.7 μg/m³ to 21.2 μg/m³, with peri-urban PM_{10} remaining steady at 15.3 μg/m³. In contrast, during the dry season from May to September, reduced rainfall likely led to higher airoborne PM concentrations, with urban $PM_{2.5}$ increasing from 21.5 μg/m³ in May to 21.1 μg/m³ in September. Similarly, peri-urban $PM_{2.5}$ decreased slightly from 17.8 μg/m³ to 16.5 μg/m³. Urban PM_{10} concentrations peaked at 24.3 μg/m³ in both May and September, while peri-urban PM_{10} ranged from 19.0 μg/m³ in May to 17.6 μg/m³ in September (Fig. 4 c, d, g & h).

4.6. Wind trends

Wind direction combined with PM measurements (Figs. 7 and 8) suggests transport of PM from anthropogenic sources within the local proximity of the air quality monitoring stations. Known land use and human activities that produce PM and observed during field visits for site selection/installation are roads, sea, airport, residential, and small-scale industrial sites. This implies that sources such as transport (land, sea and air), road construction, household cooking and waste burning are likely contributors to measured PM readings, with airborne particle collection and analysis needed to determine source apportionment. Identification of source areas, transport pathways, and cyclical trends are of utmost important in order to effectively inform policy making that engages with the appropriate stakeholders across transport, waste management, health, agriculture, and other industries.

4.7. Policy implications

The levels of PM reported in this study are concerning for air quality and impacts to human and environmental health. Other air pollutants that accompany PM, such as O_3, NO_2, SO_2, and CO (World Health Organization, 2021a) are also likely to be present due to the hypothesised anthropogenic nature of measured sources. However, Pacific Island Countries currently lack adequate air policy and legislature to address this alarming issue. The Solomon Islands lacks a national standard for $PM_{2.5}$ and PM_{10} (Solomon Islands Government, 2017; Solomon Islands Government Ministry of EnvironmentC. C.Disaster Management and Meteorology, 2024), while Fiji's National Air Quality Standards, governed by the Environment Management Act has provisions for PM_{10} but not $PM_{2.5}$ (Fiji Government, 2019; Mani et al., 2020). It is recommended that government policy be informed by long-term investment in air quality monitoring and source-apportioned data. Policies that support energy transition for main energy demands such as household cooking, heating, transport (Khammassi et al., 2024), and other purposes are recommended to be pursued by the national governments. Integrating air quality into broader policy frameworks allows for systemic reforms that can have a long-term positive impact on air quality. Government policies play an important role in determining the energy environment and can encourage the use of greener technologies and practices. Government policy/programs should also address the socio-economic standing of local communities as low-income household tend to be less likely to participate in such initiatives, or if they do, are likely to discontinue their involvement (Wang and Xie, 2023). The recommendation that governments invest in ongoing air quality monitoring should be undertaken with regional coordination and cohesion that allows inter-comparison of results. This will provide critical missing data and operate alongside national air quality standards/guidelines and inform compliance to both local legislations and international obligations (United Nations Environment Programme, 2021).

4.8. Future research

The identified consistent $PM_{2.5}$ and PM_{10} exceedances at the annual and 24-h averaged scale shows that there is a need for more research into the health effects of poor air quality in PICTS including other gaseous pollutants and chemical compounds such as heavy metals and polycyclic aromatic hydrocarbons (PAHs), known to be adsorbed to these size fractions of particulate matter (Liu and Shi, 2022; Tian et al., 2022). Continuation of this research, that has been supported by the Governments of the Solomon Islands and Fiji, will help to guide the development of solutions to reduce the health hazards associated with air pollution, thereby benefiting communities, and providing a healthier living environment. Continuation of this research, that has been supported by the Government of the Solomon Islands and the Government of Fiji, will help to guide the development of solutions to reduce the health hazards associated with air pollution, thereby benefiting communities, and providing a healthier living environment.

5. Conclusion

This study demonstrates that air quality in the urban and peri-urban areas of Suva and Honiara frequently exceed the 2021 WHO annual and daily AQG average limits, posing a significant health concern for Pacific Island populations. Continuous monitoring from 2020 to 2023 has revealed that $PM_{2.5}$ annual averages exceeded WHO guidelines each and every year in both the urban and peri-urban environments in Suva (twice the annual guideline level) and Honiara (by four times the annual guideline level in urban and three times in peri-urban areas). Additionally, annual averages of PM_{10} concentrations surpassed the 2021 WHO AQG by 1.5 times in the urban and 1.2 times in the peri-urban environments of Honiara.

Ambient air in urban Honiara was identified as the most polluted area in the study, with 75% of the 1,256 days of measurement exceeding WHO standards, often by double or triple the recommended levels, posing a major health concern for the local population. In contrast, airborne PM fractions in Fiji were lower, with $PM_{2.5}$ concentrations exceeding the WHO AQG on 10% of the days in urban areas (Fig. 5a) and 13% of the days in peri-urban areas (Fig. 5e). It is expected that PM levels in urban Fiji would be higher in a more urban representative setting; thus, further study in a more central location is recommended.

Some notable trends that are of concern for human exposure to polluted air are the observed increases in airborne PM concentration in the mornings and evenings. These times of day align with anthropogenic activities and are also influenced by environmental factors. When wind direction is considered, source regions in Suva and Honiara suggests emissions from anthropogenic activities such as land transport, marine transport, air transport, road construction, waste burning, domestic cooking and small-scale industrial activities. At the monthly scale a clear seasonal trend is observed with the wet season months having lower airborne PM concentrations than in the dry season. This study has clearly shown highly concerning levels of air pollution in Pacific Island urban and peri-urban environments. Source apportionment is urgently needed in order to effectively mediate the most harmful sources of emission. This should be supported with expanded monitoring in rural areas and other PICTS where dangerously high levels of air pollution, similar or worse to that of major cities, may also be present. With local sources of air pollution identified, PICTS can remedy the emission of harmful particulates through policy development and implementation. Ongoing monitoring using the stations in this study will allow the effectiveness of these policies to be measured and improvement measured in real time.

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CRediT authorship contribution statement

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Declaration of competing interest

The authors have no competing interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apr.2025.102454.

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