Where She Blows! A Ten Year Dust Climatology of Western New South Wales Australia

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Abstract: Dust emissions contribute significantly to atmospheric processes impacting the functioning of various earth and human systems. The question is often asked "how much dust is acceptable?" From a land management perspective, the aim is to reduce the degradation effects of wind erosion over time. To do this, we need to know the range of dust activity over a long time period and to set a target that shows a reduction in dust activity. In this study, dust activity is described by the number of dust hours per July to June period (dust storm year, DSY). We used the DustWatch network of high resolution particulate matter less than 10 μm (PM10) instruments to characterise the dust climatology for a ten year period for western New South Wales (NSW), Australia. The ten year study period covered one of the driest and wettest periods in south-eastern Australia, providing confidence that we have measurements of extremes of dust (0 to 412 h/DSY), rainfall (98 to 967 mm/DSY), and ground cover (0 to 99% of area/DSY). The dust data are then compared to remotely sensed ground cover and measured rainfall data to develop targets across a rainfall gradient. Quantile regression was used to estimate the number of dust hours for a given DSY rainfall at 21 DustWatch Nodes (DWN). The 75th percentile is used to determine the target number of dust hours for a ten year average DSY. The monitoring network clearly identified locations of high dust activity and changes in dust and ground cover that are associated with rainfall. The dust hour targets for NSW indicated that for every 100 mm increase in DSY rainfall (between 250 and 650 mm) there is a 10 h decrease in dust hours. The dust target enables us to evaluate whether wind erosion is decreasing with time for sites with different rainfall.

Keywords: dust storms; climatology; PM10; monitoring; DustWatch

1. Introduction

Dust emissions can come from natural sources, like the Sahara [1] or anthropogenically modified sources like the Mallee in Australia or the Great Plains of the United States [2]. Anthropogenic sources are generally a sign that the land is not being managed within its capacity and the soil resource is degrading. Understanding where and why dust emissions are changing is fundamental to implementing better Natural Resource Management programs [3,4]. From a land management perspective, the aim is to reduce the degradation effects of wind erosion over time. To do this, we need to know "how much dust is acceptable?" In this context, acceptable is about improvement in land condition, or a reduction in wind erosion.

Government environmental reporting programs, such as the State of the Environment reporting in Australia [5–7], State and Outlook Report from the European Union (EU) [8], and the Report on the

Environment in the U.S. [9] increase the awareness and heighten the need for monitoring programs [5,10]. However, land management practice change is a slow process. It took 13 years to increase the use of best land management practices from 16 to 66% in the Mallee in Australia [11]. Measuring change therefore requires long term monitoring that captures not only management change, but also the seasonal climate variations [12]. Critical to all monitoring is that measurements are at the appropriate spatial and time scales.

There are many examples of long term monitoring of dust activity from sediment and ice cores; however, most core data are resolved at decadal or greater resolution. Sediment cores in China have revealed a 1000 year history of dust activity in which authors conclude climate as the dominant driver [13]. Lake sediment core analyses from the San Juan Mountains of south-western Colorado, USA show increased dust deposition following the arrival of western settlement and livestock grazing in the nineteenth and the early twentieth century [14]. Ice-core samples from the Antarctic Peninsula showed dust deposition doubled in the twentieth century due to increasing temperatures, decreasing relative humidity, and widespread anthropogenic activity in Patagonia and northern Argentina [15]. Analysis of a 3200 year marine core off West Africa at the century scale shows a marked increase in dust activity at the beginning of the nineteenth century. This increase was linked to the advent of commercial agricultural activity in the Sahel region [16]. While these very long term studies provide clear evidence of variable dust emissions, and are even able to link increased dust with periods of land use change, the temporal scale is too coarse to inform about land management practices and the spatial scale is limited.

Global modelling of dust source areas and aerosol loads have also been used to identify spatial patterns of wind erosion. A six year simulation (1990 to 1995) using $1.8° \times 1.8°$ horizontal grid run on six-hourly time steps found that the Sahara accounts for 58% of global dust emission and Australia only 5.6% [17]. Whilst such studies provide 'relative measure' of global sources, the large grid sizes and assumptions in the models, such as no soil disturbance, limit the modelling for monitoring. A single year simulation (2000) using ~$1.1° \times 1.1°$ tested two soil input schema [18]. It found that increasing the soil particle size distribution from three to four soil populations improved the model. The complexity of these land/air models often results in multiple assumptions being tested and compromises being made. For example, while soil population data may have improved, the fraction of ground cover for each biome is estimated using a leaf area index and potential dust source regions, as defined by use of the Olson's global ecosystem biomes [19]. Using global ground cover and soils data at this scale averages out heterogeneity within a grid cell.

In recent years, there have been many studies using remote sensing to map and identify dust source regions. Total Ozone Mapping Spectrometer (TOMS) has provided valuable global measurements at daily temporal resolution with the trade-off of lower spatial resolution (50 by 50 km at nadir). Use of TOMS data has identified global dust sources from multiyear studies [20–22], and critically, linked dust sources with intermittently flooded regions [20,22], anthropogenic activity [20], and climatic drivers [21]. In Australia, a 32 year record using TOMS linked dust emission to geomorphic environments with pluvial activity [23]. This long record shows the importance of the Lake Eyre region in central Australia, as reported by others [24]. However, like most remote sensing and modelling studies, it fails to note the anthropogenic dust emission regions of the Mallee and other agricultural areas in southern Australia. We believe this is consistent with areas in Kuwait, United States, and the former Soviet Union where near surface dust is a common feature because dust storms are often associated with cold fronts [25], which limit the dispersion of dust into the upper atmosphere [26].

The Moderate Resolution Imaging Spectroradiometer (MODIS) has increased both spatial and temporal resolution, producing images of 10×10 km twice a day. Using the cloud screened and quality assured deep blue aerosol optical depth product derived from the Aqua platform of MODIS over a seven year period (2003 to 2009), Ginoux et al. [27] differentiate global natural and anthropogenic dust sources. Ginoux's figure 5 shows a wider spatial distribution in eastern and northern Australia than other remote sensing and modelling projects. However, it suffers similar issues to TOMS regarding missing events with cloud cover.

Most dust monitoring studies utilize meteorological records that record observed dust events. Studies can be grouped as regional and global scales. Probably the longest regional record is that for South Korea [28], which covers the time period 57BC to 2015. The later part of the record 1915 to 2015 was based on meteorological records. Lee, et al. [29] report the 42-year record (1947 to 1989) for Lubbock, Texas. They report that wind and drought indexes are poor predictors of dust activity due to the impact of agricultural land management practices. Middleton also under took several studies in Australia [30], the Middle East [31], and south east Asia [32]. Using surface synoptic observations (SYNOP) observations from 121 stations between 1960 to 2008, McTainsh et al. [33] undertook Australia's most detailed assessment of dust activity. For the meteorological data that they used, they acknowledged how observational frequency, which ranges between one to eight times a day, can bias results towards stations with high frequency of observations. This observational bias is generally ignored in most studies. A longer time series using Australian meteorological records was used to compare two periods (1937–1946 to 2001–2010) to investigate how dust levels changed between the World War II drought and the Millennium Drought [34]. Global analysis has also been undertaken by looking at specific regions over multiple decades of the world [35] and report how drought and anthropogenic influences increase dust activity.

Meteorological records, such as SYNOP and Meteorological Terminal Aviation Routine (METAR), have been a fertile source of data. As O'Loingsigh, et al. [36] explain, the METAR offer better data because they are taken more frequently (5–30 min intervals) and can be taken for a full 24 h as airports have lights. Their study of the Millennium Drought (2000–2010) is probably one of the highest quality studies using meteorological observations due to the duration and frequency of data; however, the extent is limited to larger cities with airports. As Leys, et al. [37] point out, meteorological observations are declining and so this data source is declining with time. Observers are being replaced by instruments (e.g., nephelometers). Presently, in the drier western part of NSW, five nephelometer stations exist, whereas 10 years ago, twice the number of observation sites existed.

While advances in regional to global-scale remote sensing [27,38], field measurements [39,40], and modelling techniques [18,41] have provided much improved data at moderate to high spatial scales, they each have limitations. Remote sensing is not a continuous record and cloud cover is an issue. Modelling, while improving all the time, still has large uncertainties that are caused by data scale and availability. Field measurements also have limitations, such as cost and spatial coverage; however, in the western New South Wales (NSW) region of south eastern Australia, we are fortunate to have set up the DustWatch network of dust monitors a decade ago. These monitors collect data on one minute time intervals 24 h a day. This overcomes the limitation of night time observations, cloud coverage, and low frequency of observations.

With this network, this study aims to answer commonly asked monitoring questions about wind erosion in western NSW.

- Where are the dusty places?
- What are the trends in dust activity?
- What thresholds of annual dust hours should we be striving to be below?

2. Materials and Methods

This study utilizes two data sets, rainfall and total vegetation cover, to explain the variation in dust data across western NSW.

2.1. Dust Data

The 21 continuous dust monitoring sites (referred to as DustWatch Nodes—DWN, Figure 1) used in this study form part of the Community DustWatch network [37] which in 2018 had 40 DWN (http://www.environment.nsw.gov.au/topics/land-and-soil/soil-degradation/winderosion/community-dustwatch).
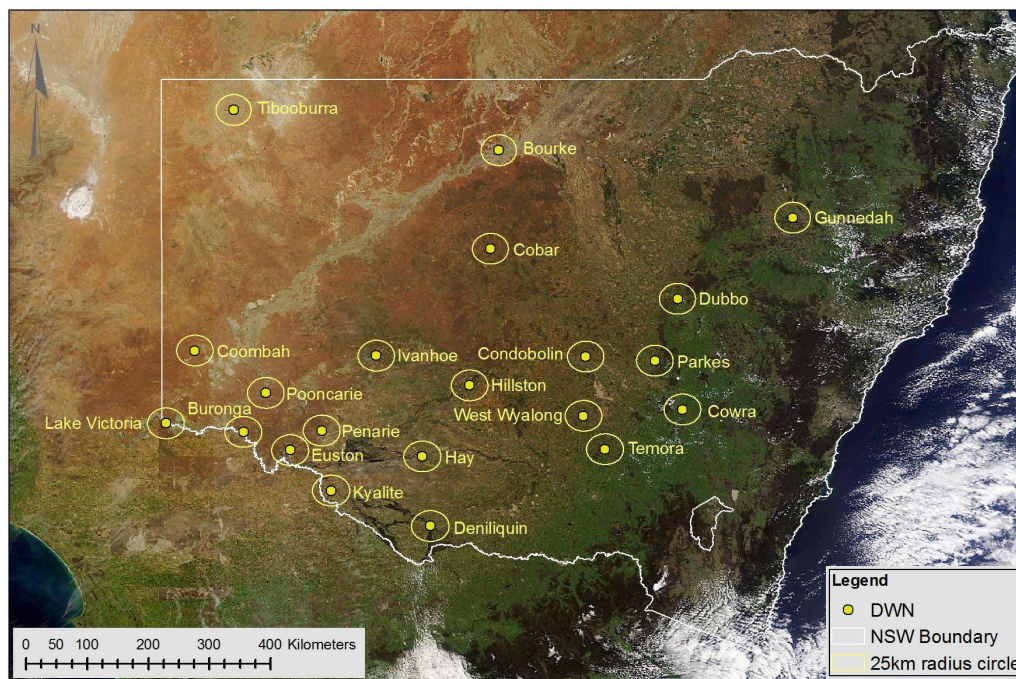
Figure 1. Location of 21 DustWatch Nodes (DWN) with >10 years of records in western New South Wales (NSW) Australia, the 25 km radius sample circles used in study, and moderate-resolution imaging spectroradiometer (MODIS) Terra 24 October 2016 satellite image showing land cover.

At each DWN, an 8520 model DustTrak® instrument measures the atmospheric aerosol concentration of PM10, which is located inside the manufacture's weatherproof environmental enclosure. The DustTrak draws aerosols in a continuous stream through a non-heated sample inlet and uses light scattering technology to determine mass concentration in real-time. The DustTrak is programmed to sample every 15 min, increasing to one minute intervals when the PM10 concentration exceeds 25 µg/m^3. Data is transferred to the Community DustWatch information interface (CoDii) every 10 min where weighted hourly averages are calculated. If the hourly average concentration exceeds 25 µg/m^3, then it is counted as one dust hour. We used 25 µg/m^3 to signify a dust hour because this equates to about a reduction of visibility to about 20 km [42]. From our experience with volunteer DustWatchers, this is when they start to notice and report dust. We use the count of dust hours as a measure of dust activity in this study.

Quality control for each DustTrak is undertaken as follows:

- Factory calibration is undertaken annually by the Australian distributor adjusted to respirable mass standard ISO 12103-1 Al Test Dust Arizona Dust. Calibration for a particular source material is not warranted as the network covers many sites across southern Australia with multiple dust source types.
- Instruments are calibrated on site each month to have a zero (clean air) reading of ±3 µg/m^3. Inlets are cleaned and water bottles are emptied.
- Every 15 min a zero reading is taken through the manufacturers 'zero filter' and stored in the database. This value is then subtracted from all of the ambient readings until the next zero filter reading is taken. This overcomes the problem of temperature variations or instrument drift.

DustTraks measure all of the aerosols that are less than or equal to 10 µm aerodynamic diameter. We subjectively classify the data in to fog, smoke, and dust. The standard operating method used to classify DustWatch data is:

- All data are held within a purpose built supervisory control and data acquisition (SCADA) application called CoDii.
- Each hourly reading is quality checked. CoDii downloads the data hourly and calculates the hourly time averaged aerosol concentration.
- Values below 10 µg/m^3 are not quality assessed because the DustWatch project is interested in higher concentrations for the detection of dust events.
- Meteorological data from the nearest Australian Bureau of Meteorology automatic weather station and NASA MODIS Rapidfire data (http://lance-modis.eosdis.nasa.gov/imagery/subsets/?project=other) are used to ascribe the hourly reading as dust, smoke, or fog using the following rules:

    1. If values are above 10 µg/m^3—flag as dust unless following criteria are met. Note: While the manufacturer suggests instrument accuracy is about 3 µg/m^3, we choose to be conservative and do not use values less than 10 µg/m^3.
    2. Flag as fog if:

        a. humidity is high (>80%) and wind speed is low (<20 km/h); and,
        b. observers report fog at that time.

    3. Flag as smoke if:

        a. wind speeds are less than 20 km/h within $\pm$ 3 h of reading;
        b. fires and/or smoke are reported by observers within the area or the smoke plume visible on MODIS images; and,
        c. values spike early morning and late afternoon in cooler months and wind speed is low (<20 km/h) as this is likely to be smoke from wood heaters in populated areas.

    4. Flag as malfunction if:

        a. dust values are below 0;
        b. dust values are erratic or extremely high without obvious reason;
        c. the DustTrak displays an error message; and,
        d. local knowledge suggests a malfunction.

Dust hour data for this study were extracted from CoDii for those DWN with greater than 10 years of records. The hourly data were summed for each dust storm year (DSY, i.e., July to June) for the years 2007/08 to 2016/17. We use dust storm years because the majority of dust activity occurs in the summer months (December to February). As the summer season spans two calendar years, it makes more sense to have the consecutive summer months together in a DSY.

2.2. Rainfall and Ground Cover Data

Rainfall data were sourced from the Bureau of Meteorology (BoM). Monthly five kilometre (km) grids that were downloaded from BoM web site (http://www.bom.gov.au/jsp/awap/rain/archive.jsp). The monthly average rainfall within 25 km of the DWN was calculated.

We use the CSIRO Land and Water algorithm for fractional cover derived from the moderate-resolution imaging spectroradiometer (MODIS) [43] satellite MODIS (http://data.auscover.org.au/xwiki/bin/view/Product+pages/Fractional+Cover+MODIS+CLW). The algorithm calculates the fraction of ground with in the 500 m pixel that is Photosynthetic Vegetation (PV), Non-Photosynthetic Vegetation (NPV), and Bare Soil (BS). We calculate the area within 25 km of each DWN, which has a monthly total fraction of ground cover (PV+NPV) that is greater than 50% ground cover. The cut-off of 50% groundcover is used as this is the amount of ground cover required to control wind erosion [44]. The calculated values are stored in CoDii.

In the study area of western NSW, ground cover changes with the seasons. Figure 2 shows the monthly average of the 21 sites for the 25 km area around all the DWN during this ten year study. The area with <50% ground cover is least in winter months (June, July, August) and the greatest in summer months (December, January, February). Because wind erosion and dust emission are associated with low ground cover, we use only the percentage average area with <50% ground cover for summer months (GCA < 50) in this study.
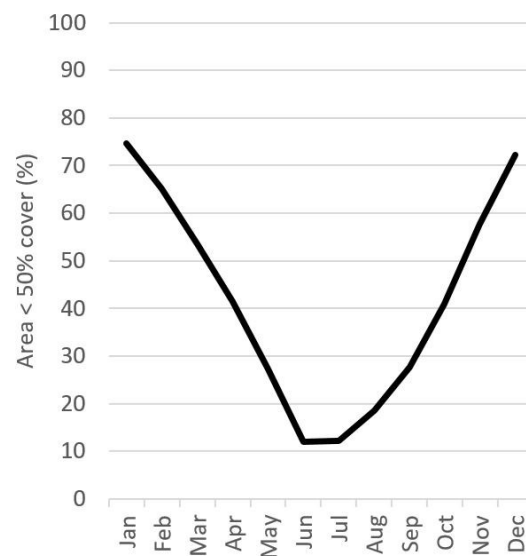

Figure 2. Ten year average percentage average area < 50% ground cover within 25 km of the 21 DWN.

3. Results

3.1. Dusty Places

Figure 3 shows that Tibooburra is the dustiest DWN site in NSW over the study period (2007/08 to 2016/17), followed by Pooncarie (87% of Tibooburra hours), Euston (85%), and Ivanhoe (77%). All of the other sites have less than 60% of the hours at Tibooburra, with Gunnedah the lowest (31%).
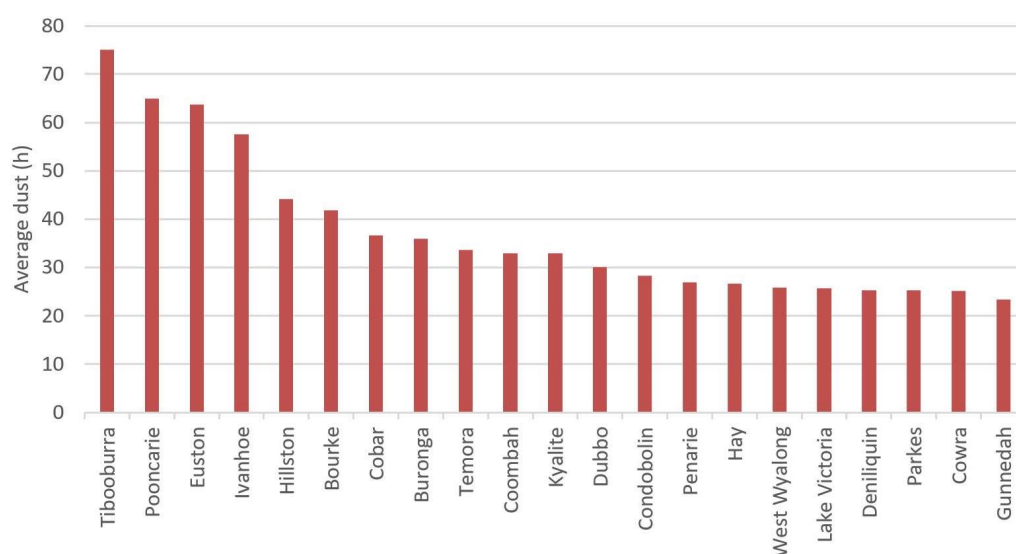

Figure 3. Ten year average of dust hours for the 21 DustWatch Nodes (DWN).

3.2. Trends

The number of hours of dust, rainfall, and area with groundcover < 50% within 25 km of each DWN changes from year to year (Figure 4). The first three years from 2007/08 to 2009/10 were during the end of the Millennial Drought. During this dry time, the area of ground cover < 50% and dust hours where the highest. Very high rainfall was recorded in 2010/11, and the area of ground cover < 50% and dust levels dropped dramatically.
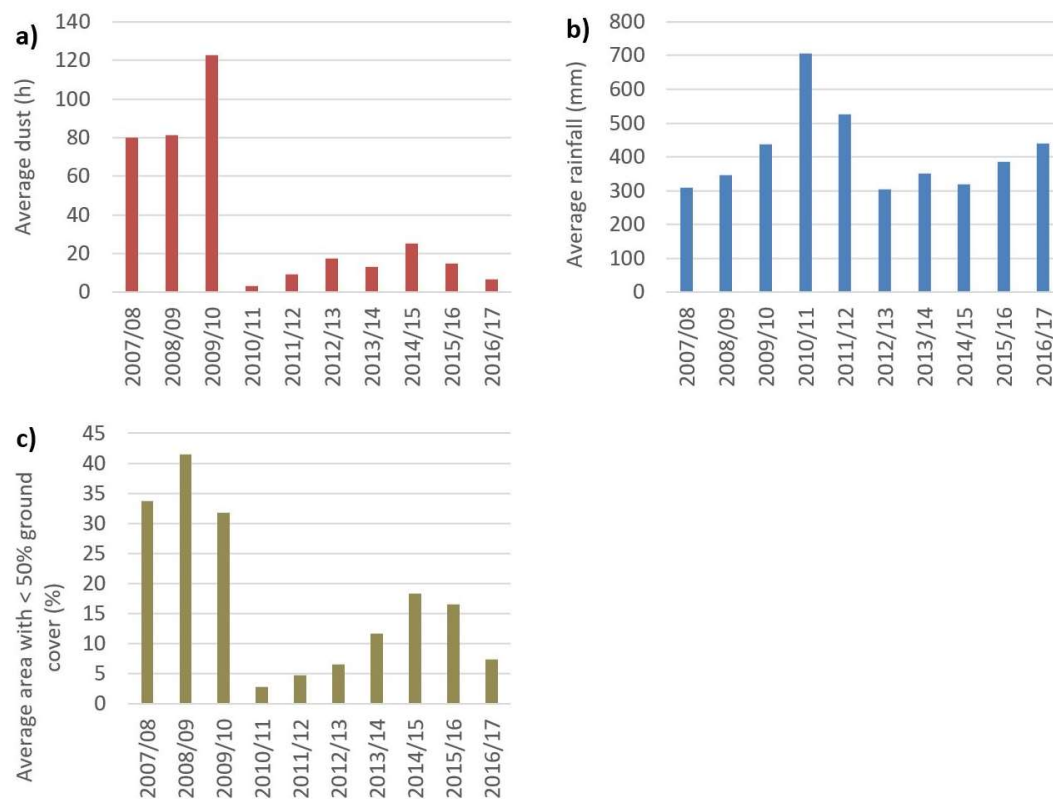

Figure 4. (**a**) Average dust hours for the 21 DustWatch Nodes (DWN), (**b**) average rainfall within 25 km, and (**c**) average area with less than 50% ground cover for each Dust Storm Year (DSY).

3.3. Dust Targets

Each DWN has a different range of observed dust hours. But, what is the 'normal' level of dust hours for NSW across the 98 to 967 mm rainfall gradient? As McTainsh and Leys [45] and many other authors have shown, the level of dust activity increases with a decrease in rainfall. In this paper, we define a dust 'target' as 'a level that is better than what is currently being achieved'. To determine what the target dust hours should be across the rainfall gradient, we used quantile regression methods [46] (Figure 5). The concept is that, ideally, a DWN with a given DSY rainfall should have less dust hours than the 75th percentile of the benchmark decade between 2007/08 and 2016/17 (red line in Figure 5). The results for the 75th percentile regression results in Equation (1):

$$DT = -0.10 \times DSY + 92.45, \tag{1}$$

where DY = dust target (h) and DSY = average DSY rainfall (mm). This closely approximates a 10 h reduction in DSY dust hours for each 100 mm increase in DSY rainfall, between 250 and 650 mm.

The number of dust hours measured at each DWN for each DSY and the target dust hours for each DWN based on Equation (1) are given in Table 1.
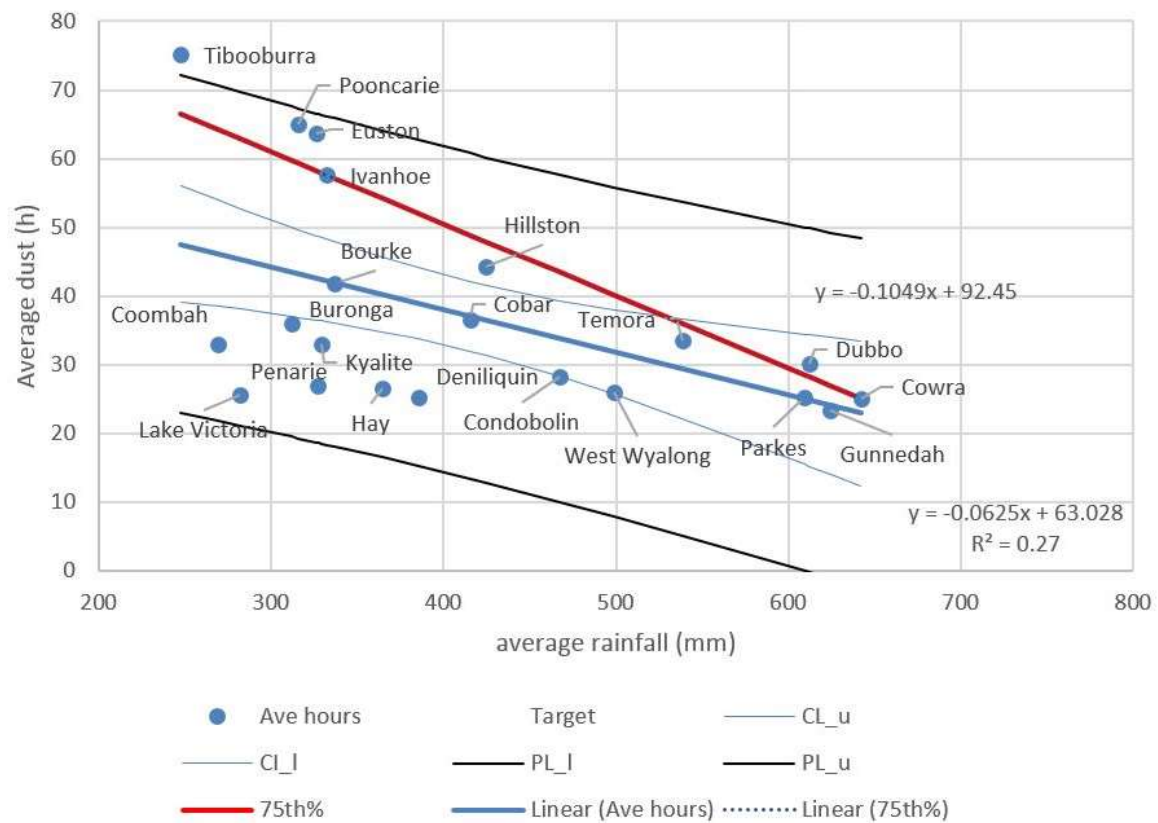
Figure 5. Relationship between average DSY rainfall and average dust hours for 21 DWN. Standard regression (Linear Ave hours—thick blue line), 90% confidence (CL_u and CL_l—thin blue lines) and prediction (PL_u and PL_L—thin black lines) limits. Target dust hours represented by 75th percentile regression line (75th%)—thick red line.

Table 1. Hours of dust for each DustWatch Node (DWN) for each DSY, average hours and the target number of dust hours (h) from Equation 1.

DWN	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	Average	Target
Bourke	86	49	201	2	22	13	23	19	0	4	42	57
Buronga	54	74	113	7	30	25	14	33	9	1	36	60
Cobar	85	77	128	5	13	16	12	23	1	6	37	49
Condobolin	95	77	50	3	4	9	16	19	9	1	28	43
Coombah	45	49	155	1	0	20	26	17	16	1	33	64
Cowra	44	43	135	0	1	5	1	14	1	7	25	25
Deniliquin	57	61	36	2	14	20	13	28	16	6	25	52
Dubbo	34	62	110	2	2	12	32	34	5	8	30	28
Euston	85	135	141	2	15	107	12	61	63	16	64	58
Gunnedah	52	19	113	1	0	5	17	12	14	1	23	27
Hay	47	84	61	1	1	10	16	29	11	6	27	54
Hillston	98	138	113	4	14	12	11	33	8	11	44	48
Ivanhoe	131	168	216	3	11	5	3	15	17	7	58	58
Kyalite	65	75	43	2	15	25	13	29	44	18	33	58
Lake Victoria	43	35	108	5	10	11	3	9	29	4	26	63
Parkes	77	46	95	2	2	10	0	15	3	3	25	29
Penarie	63	67	35	2	9	23	16	20	30	5	27	58
Pooncarie	210	195	143	6	3	12	18	39	10	14	65	59
Temora	113	82	85	10	4	2	4	22	8	6	34	36
Tibooburra	116	121	413	0	16	6	23	37	15	4	75	66
West Wyalong	75	47	82	3	4	18	4	18	3	5	26	40

4. Discussion

The results of this study cover a wide range of dust, rainfall, and ground cover levels. This is because the ten year study period covered one of the driest [47] and wettest periods [48] in south-eastern Australia. Having a data set that covers such climate extremes is fortunate, as it gives us confidence we have measurements of extremes of dust (0 to 412 h/DSY), rainfall (98 to 967 mm/DSY), and ground cover (0 to 99% of area/DSY). While it is possible to derive individual rainfall/dust hour relationships for each DWN, the aim here was to look at dust activity across western NSW; thus, we use a regression model based on all sites and set a target that is based on the ensemble of all sites.

Our results support the findings of McTainsh and Leys [45] that rainfall is a driver of dust activity; however, the relationship in Figure 5 is not strong ($R^2 = 0.27$). This is not surprising as there are many other factors that influence wind erosion. These include soil erodibility, if a site has perennial or annual vegetation, and anthropogenic activities, like farming. Sandy soils have higher erodibility [49,50] and cropping areas often have bare soil prior to planting crops (fallow phase) that have high erodibility [44,50]. Sites that are close to fluvial basins are often highly erodible [51,52]. In Figure 5, there are several DWN that sit outside the 90% confidence intervals (CI). For example, Coombah and Lake Victoria have permanent native vegetation with trees around them, Euston and Pooncarie are in farming areas with sandy soils, and Tibooburra is located down wind of Australia's largest dust source, the Lake Eyre Basin [12,52,53]. All of these factors add to the spread in the data.

The trends show the influence of the changing rainfall over the period (Figure 4). That is, when dust activity was high in the beginning of the study period (Figure 4a) when rainfall (Figure 4b) was comparatively low and the corresponding area with ground cover < 50% was high (Figure 4c). With the high rainfall in 2010/11 and 2011/12 the area with low ground cover ground cover area decreased and so do the dust hours. The curvilinear relationship between rainfall and percentage area < 50% ground cover in summer is shown in Figure 6. We have used a logit transformation of the response variable because of the sigmoidal shape of the relationship with rainfall, but equally importantly to ensure that the fitted values and derived confidence and prediction limits remain within the sensible bounds of 0% and 100% area with <50% cover. The relationship between average rainfall and percentage area < 50% ground cover in summer is quite good at $R^2 = 0.82$. All of the sites in Figure 6 above the upper CI 90% are cropping sites except for Tibooburra and Ivanhoe, which are both rangeland sites. Cropping systems use burning, cultivation, and chemicals to modify cover levels, so it not surprising these areas are barer than rangelands, which are only modified by grazing levels. For Tibooburra, much of the landscape is covered in gibber (the surface is covered with closely packed pebble and cobble size stones) and rocks of the Grey Range. For Ivanhoe, the authors are aware that there are areas of scalds or clay pans that have little growth, regardless of rainfall. Overgrazing is another possibility, but we have no evidence for this.

The linear positive relationship between and percentage area < 50% ground cover in summer and hours of dust ($R^2 = 0.41$) is highly leveraged by Tibooburra (Figure 7). Once it is removed from the regression, the R^2 drops to 0.16, indicating little relationship at the scale of this data. Interestingly the sites above the CI 90% level are Euston, Pooncarie and Ivanhoe. As discussed above, this role of farming in the more semi-arid DWN appears important at increasing dust activity. In future work, ground cover dust relationships, like that in Figure 7, could be established for individual DWN. The 75th percentile dust hours for an individual DWN could be used to determine the percentage area < 50% ground cover in summer and this could become the ground cover target for an area.
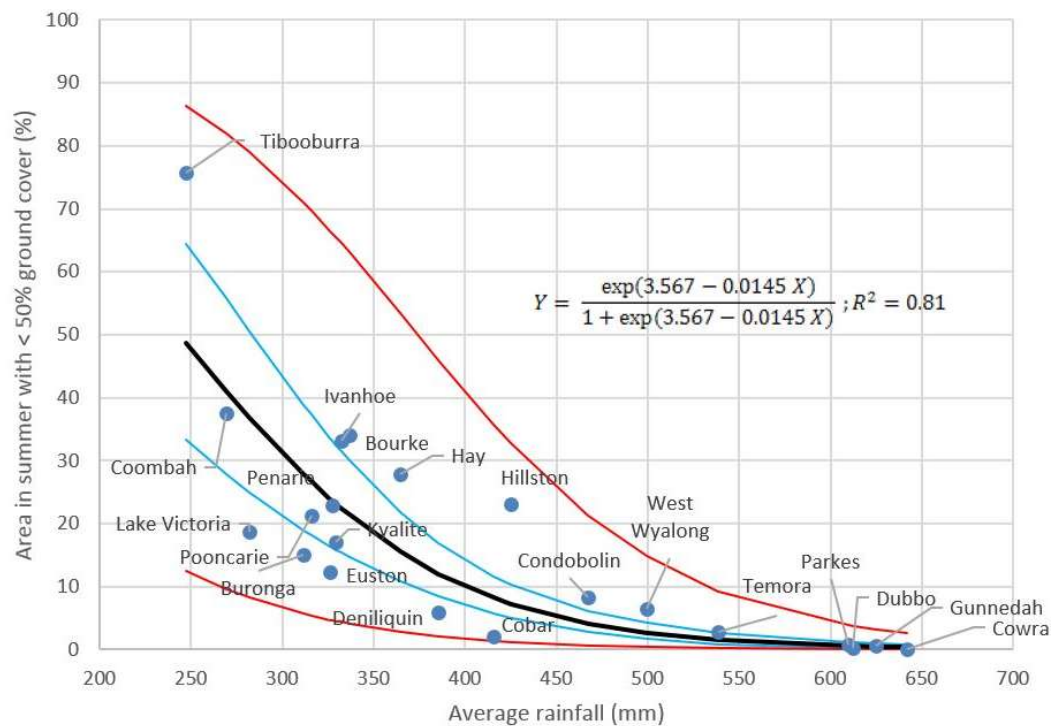
$$Y = \frac{\exp(3.567 - 0.0145\,X)}{1 + \exp(3.567 - 0.0145\,X)}\;; R^2 = 0.81$$

Figure 6. Relationship between average DSY rainfall and percentage area < 50% ground cover (in summer months of DJF). Standard regression (Curvilinear GCA < 50%—thick black line), 90% confidence (CL_u and CL_l—thin blue lines) and prediction (PL_u and PL_L—thin red lines) limits.
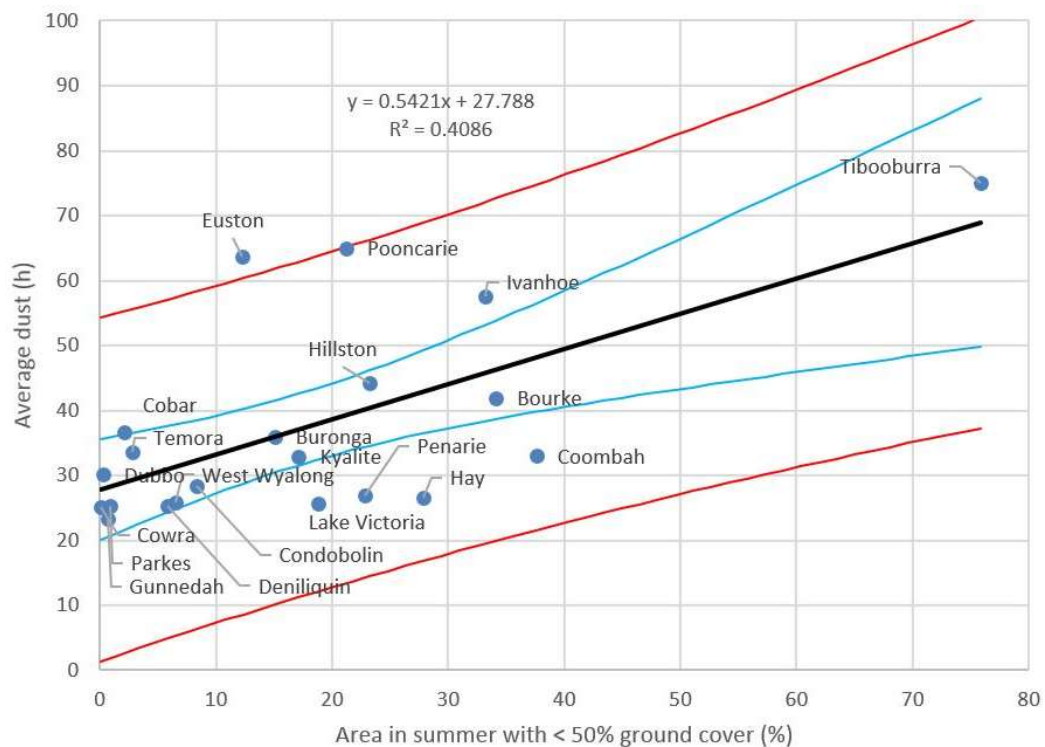

$y = 0.5421x + 27.788$
$R^2 = 0.4086$

Figure 7. Relationship between percentage area < 50% in summer months and dust hours. Standard regression (Linear Ave hours—thick black line), 90% confidence (CL_u and CL_l—thin blue lines) and prediction (PL_u and PL_L—thin red lines) limits.

Partitioning dust emissions from either natural or anthropogenic sources is extremely difficult in a region of mixed land uses, such as south eastern Australia. Climate drives large geomorphic dust sources, such as the Lake Eyre floodplains [38,53], along with incremental changes in ground cover associated with season or drought [29,33–35]. Whilst remote sensing techniques, such as TOMS and MODIS, can provide valuable data regarding aerosol loading [20,27] and even locate small dust source areas [38], they cannot reliably inform us about the anthropogenic nature of the dust, particularly in the rangelands. Frequently, land use maps are used as determinants of natural or anthropogenically modified surfaces in modelling and remote sensing studies. Prospero et al. [20] argue the Tegan and Fung [54] estimate of 20–50% of global dust emissions that are associated with land use as being overly high given that the largest dust sources are associated with very low populations. However, rangelands are managed for grazing and thus have anthropogenic influences. Using MODIS Deep Blue, Ginoux et al. [27] estimate anthropogenic dust to be 25% due to land use. This study shows that the low population areas, like Tibooburra (90 people within 25 km—2011 census) and Ivanhoe (231 people within 25 km—2011 census), have high dust activity and low population. We believe there is a strong anthropogenic contribution to dust emission in rangelands of eastern Australia.

The DustWatch network across NSW has provided an alternative approach to identify regions that record higher hours of dust than expected. By setting yearly dust hour targets for NSW based on the DSY rainfall we see an average 10 h drop in the dust target hours for every 100 mm increase in DSY rainfall between 250 and 650 mm.

These targets are a guide as to what dust activity might be achieved across the rainfall gradient of western NSW. Whilst the overall trend in dust activity over the decade was one of decline, there are two stations that have reversed the strong influence of rainfall, suggesting that land management is driving the dust emission (Table 1). Euston DWN is a farming area on high erodible sandy soils and is also down-wind of the dryland farming areas of north-west Victoria, which are infamous for its wind erosion [2]. The largest exceedance for Euston was in 2012/13, and was due to poor crop growth in the 2012 growing season that resulted in very low ground cover in the region. The following quote from the February 2013, DustWatch report [55], outlines the cause of the dust. "Although the majority of paddocks in the northern Mallee have the previous season's stubble present, there is low groundcover remaining, due to low 2012 growing season rainfall; low 2012/13 summer rainfall; and summer grazing pressure. The stubble is very thin through-out most paddocks and the wind has started to blow some of the higher areas". Dubbo is the other DWN that had exceedances in 2013/14, and 2014/15. There was wide spread dust activity in January and February 2014 to the north of Dubbo, and in November 2014, Walgett had 139 h of dust [56–58]. It is probable that dust has blown south to Dubbo. This long-range transport of dust indicates one of the limitations of this analysis; that is, dust at one DWN may not be local. However, these targets are based on the 21 DWN and are based on the sample population, representing western NSW, and not a specific site. Therefore, we can now assess the level of dust in future years against the benchmark 75% percentile dust targets. The aim being to not exceed the target for a given DSY rainfall. If the targets are exceeded, then investigation should occur to see why there is excessive dust.

5. Conclusions

This paper posed the following three questions, and the answers are:

- Where are the dusty places? Not surprisingly, Tibooburra is the dustiest place in NSW. This is a function of its low rainfall and location down-wind of the Lake Eyre Basin. The data also indicates that semi-arid dryland farming areas, like Euston and Pooncarie, are dusty. Once again, not surprising considering the low rainfall and the risks of semi-arid dryland farming.
- What are the trends in dust activity? The trend over the last decade in NSW has been downwards; however, this is a function of rainfall. Within the rainfall dust relationship, are other factors, like land use (farming), erodibility of the landscape (sandy soil areas have higher erosion), and perenniality of the vegetation (treed areas tend to have less dust).

- What levels of dust should we be aiming for? This data set has enabled us to set DSY dust hour targets for NSW based on the DSY rainfall. Basically, there is a 10 h drop in the dust target for every 100 mm increase in DSY rainfall between 250 and 650 mm. These targets are guides as to what dust activity might be expected across western NSW. They can be used to investigate the performance of the land management systems and to report the state of the environment of NSW.

Future research aims to set dust targets for each DWN. With over forty DWN in the Community DustWatch network, this will provide an excellent way of reporting against Government environmental programs, such as the State of the Environment. Also, the approach that is used in Figure 7 could be used to set ground cover targets for individual DWN.

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