

Uncertainty of dustfall monitoring results

Martin A. van Nierop¹, Elanie van Staden^{*1}, Jared Lodder¹, and Stuart J. Piketh²

¹Gondwana Environmental Solutions, 562 Ontdekkers Road, Florida, Roodepoort, 1716, South Africa, info@gesza.co.za

²Unit for Environmental Sciences and Management, North-West University, Potchefstroom, 2520, South Africa

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Abstract

Fugitive dust has the ability to cause a nuisance and pollute the ambient environment, particularly from human activities including construction and industrial sites and mining operations. As such, dustfall monitoring has occurred for many decades in South Africa; little has been published on the repeatability, uncertainty, accuracy and precision of dustfall monitoring. Repeatability assesses the consistency associated with the results of a particular measurement under the same conditions; the consistency of the laboratory is assessed to determine the uncertainty associated with dustfall monitoring conducted by the laboratory. The aim of this study was to improve the understanding of the uncertainty in dustfall monitoring; thereby improving the confidence in dustfall monitoring. Uncertainty of dustfall monitoring was assessed through a 12-month study of 12 sites that were located on the boundary of the study area. Each site contained a directional dustfall sampler, which was modified by removing the rotating lid, with four buckets (A, B, C and D) installed. Having four buckets on one stand allows for each bucket to be exposed to the same conditions, for the same period of time; therefore, should have equal amounts of dust deposited in these buckets. The difference in the weight (mg) of the dust recorded from each bucket at each respective site was determined using the American Society for Testing and Materials method D1739 (ASTM D1739). The variability of the dust would provide the confidence level of dustfall monitoring when reporting to clients.

Keywords

Buckets, confidence, dust, dustfall, monitoring, precise, uncertainty

Introduction

Fugitive dust is a nuisance and a source of air pollution (Datson, Hall and Birch 2012). Anthropogenic sources of fugitive dust include, but are not limited to, construction, industrial and mining activities. These sources are regulated under the National Dust Control Regulations (NDCR) of 2013 (NEMA: AQA 2013). The purpose of the NDCR is to prescribe general measures for the management and monitoring of dustfall using the American Society for Testing and Materials method D1739:1970 (ASTM D1739: 1970) or equivalent internationally approved method.

Little has been published on the repeatability, uncertainty, accuracy and precision of dustfall monitoring. The aim of this study was to improve the understanding of the uncertainty and the confidence level of dustfall monitoring using the ASTM D1739: 1970 method.

Methods

A dustfall monitoring network was established along the perimeter of a lime processing facility in Gauteng and monitored for 12 months. The network consisted of 12 directional dustfall samplers that were modified by removing the rotating lid. Each sampler contained four buckets (A, B, C and D) with the dimensions 238 mm (height) and 175 mm (diameter). (Figure 1).

The basic premise with the four buckets per stand was to ensure that each bucket would be exposed to the same conditions and for the same period; therefore, should have equal amount of dust deposition. This assumes that dustfall rates for each of the four buckets are not impacted by the close proximity of the four buckets to each other on the stand. This is an untested limitation of this study. The difference in the weight (mg) of the dust recorded from each bucket at each respective site is observed.



Figure 1: Converted Directional Dust Bucket Stands.

Statistical analysis

The variability of each bucket at each site was calculated to determine the difference in the dust collected for each bucket by calculating the standard deviation for each sampler. This gave an indication of precision. Box plots for all of the sites for every month show the distribution of the data.

A margin of error for each site was calculated using the following

$$E = (t_c) \frac{\sigma}{\sqrt{n}} \quad (1)$$

Where; E = margin of error

t = critical value for confidence level c (at 90%)

σ = standard deviation

n = amount of samples

To calculate the uncertainty of the results, the mean of each site was determined. The upper and lower limits (plus/minus 10% from the mean) was used to determine what percentage of samples were outside this band.

Thereafter, the relative standard deviation (%RSD) was calculated to compare the precision of the absolute deposition values between sites.

Results

Some of the results are presented in this section, the balance can be found in appendix A to C.

The standard deviation of 144 samples (12 sites monitored for 12 months) was calculated (Figure 2). 91% of the data points had a standard deviation below 400 mg/m²/day, 81 % of the data points had a standard deviation below 300 mg/m²/day, and 38% had standard deviations below 100 mg/m²/day, this gives an indication of the range of deviation for the entire data set.

The analysis of variance for the results is presented using box plots (Figures 3 and 4). These plots (representing two of the 12 months sampled) are a visual representation of the spread of the data collected for each site. The smaller the box plot, the lower the variance, and in this case the uncertainty.

Outliers are those data points that are statistically uncertain.

A second method of measuring the uncertainty was to plot the 90% confidence interval (Figures 5 and 6) and to determine the percentage of data points that fell outside of this interval. The majority of data points (51%) at all site fell outside of the 90% confidence level.

The third method of measuring the uncertainty was to provide a band of plus/minus 10% from the mean of the four data points and determine the number of samples lying outside of the band. This is represented graphically for sites 4 and 11 (Figures 7 and 8). 28% of the 288 results were outside the band.

Finally, the relative standard deviation is calculated to compare the precision of the absolute deposition values between sites. A high RSD value indicates a high uncertainty. The average RSD for all sites and for all months was calculated at 11.69%. Most of the sites have a low percentage RSD indicating a small spread between the points (Table 1). There are some points within the dataset that have a higher variability. The cell shading in Table 1 represent the following:

- No colour: RSD below 15%
- Light red: RSD between 15 and 20%
- Red: RSD above 20%
- Dark Red: RSD above 40%

Discussion

Standard deviation is used to show how far the data spreads from the mean. The higher the standard deviation the more spread out the data is. A low uncertainty would be represented by a standard deviation of less than $\pm 5\%$ of the mean. The buckets at each site were exposed to the same environments; therefore, it is expected that they should collect the same amount of dust.

The box plots are a visual way of representing the data from the sample. It shows the minimum, maximum, median, interquartile ranges and outliers. They are only able to show the outlier with the greatest or the smallest value. This is due to the small data groups (populations of 4). Therefore, when the area of the box is minimal, it indicated a closely spaced dataset, which in turn means precise data, i.e. lower uncertainty. Whereas a large area within the box represents spread data with large ranges between the results, i.e. greater uncertainty. It should be considered that the amount of dust per site would vary; therefore, only the size of the box should be taken into consideration and not its position on the y-axis of the graph.

The area in which the test was conducted has a dust standard of 1,200 mg/m²/day (NEMA: AQA, 2013). The margin of error was calculated to see if it is possible for the value of the reading to shift around this standard. That is, if the weight was just below or above the standard, would it be possible for the actual dust deposition to be above or below the standard, respectively. This confidence interval (Figures 5 and 6) indicates that for some of the samples with readings close to the standard it is possible for the result to provide a false exceedence or false conformance to the Standard.

The ASTM D1739–98 reported a standard deviation of 18% in the recovery measurements of water insoluble dustfall from Project Threshold (ASTM D1739–98. 1998), and that there was no link found between dustfall rate and reproducibility or repeatability. Repeatability and reproducibility was not conducted in this current study; however, it is aligned with the Project Threshold study. No link between the dustfall rate and repeatability (standard deviation) was found. The RSD was used to obtain an uncertainty for the entire process whereas Project Threshold

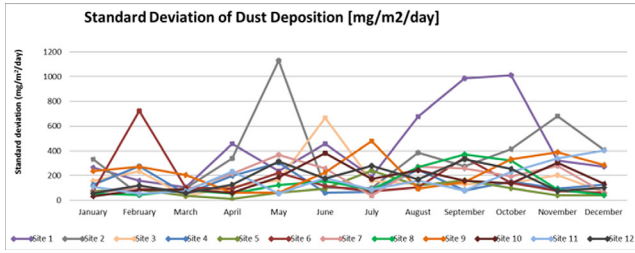


Figure 2: Standard deviation of all the sites over 12 months.

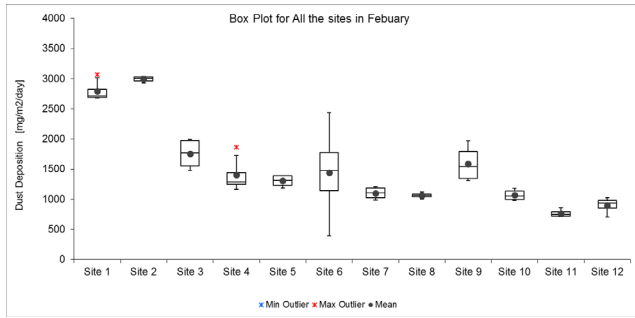


Figure 3: Box Plot indicating the data distribution for all the sites in February.

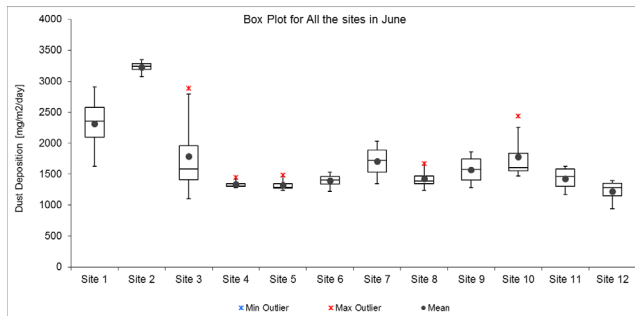


Figure 4: Box Plot indicating the data distribution for all the sites in June.

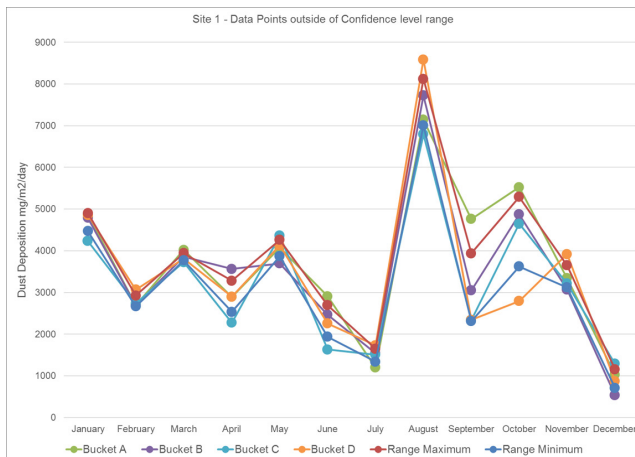


Figure 5: Indication of data with respect to a 90% confidence interval.

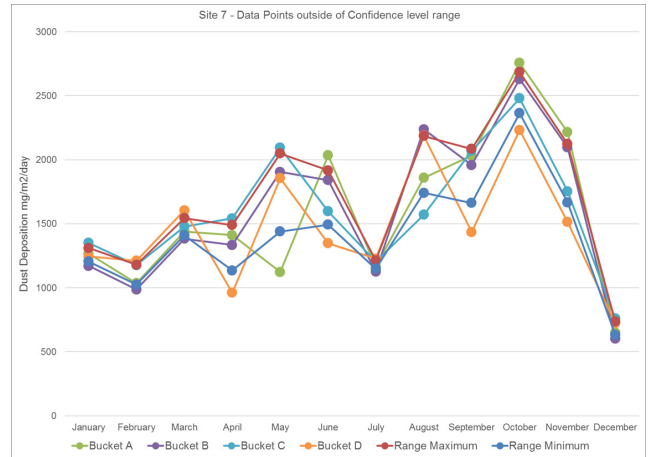


Figure 6: Indication of data with respect to a 90% confidence interval.

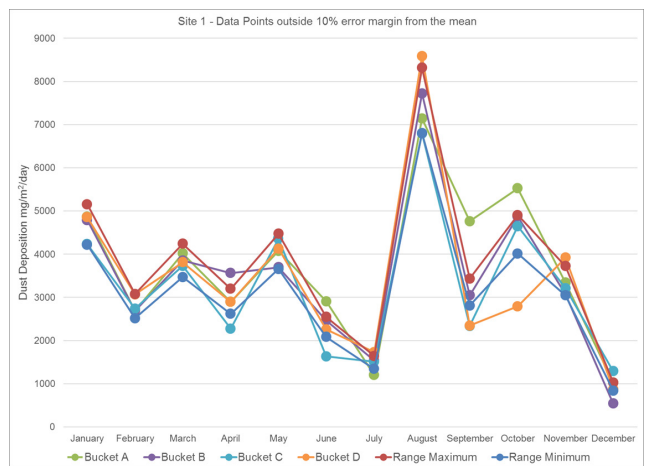


Figure 7: Indication of data with respect to a 10% margin from the mean.

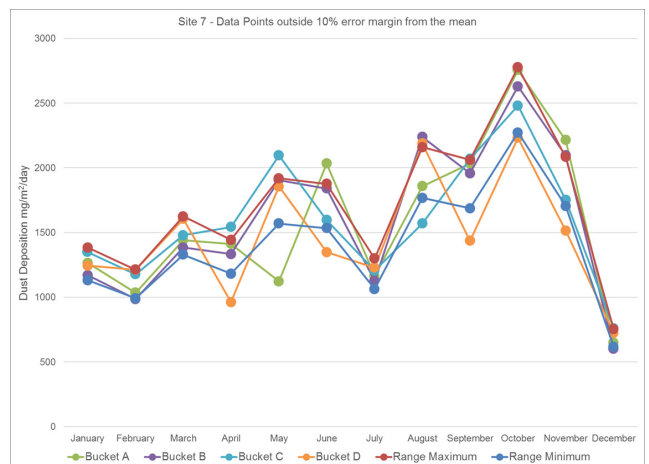


Figure 8: Indication of data with respect to a 10% margin from the mean.

Table 1: The relative standard deviation

	January	February	March	April	May	June	July	August	September	October	November	December
Site 1	5.65%	5.61%	2.75%	15.69%	5.82%	19.84%	12.77%	8.98%	31.69%	22.76%	9.53%	29.13%
Site 2	10.60%	1.53%	3.03%	13.76%	33.08%	3.11%	7.22%	14.44%	11.25%	10.28%	26.15%	22.47%
Site 3	8.10%	13.14%	1.99%	9.10%	12.22%	37.30%	10.38%	8.61%	6.53%	6.36%	12.80%	5.06%
Site 4	7.88%	19.60%	3.76%	19.86%	25.38%	4.68%	5.94%	12.64%	4.20%	6.85%	7.65%	19.05%
Site 5	5.41%	6.67%	2.89%	1.25%	4.88%	7.05%	17.68%	7.03%	10.12%	5.81%	3.09%	5.81%
Site 6	4.94%	50.16%	7.13%	5.39%	9.78%	8.15%	4.57%	7.56%	21.47%	9.11%	7.44%	9.68%
Site 7	5.09%	8.56%	5.52%	16.45%	21.19%	15.12%	3.29%	13.75%	13.67%	7.73%	14.64%	9.04%
Site 8	4.80%	4.22%	6.29%	4.66%	8.94%	10.95%	7.20%	18.79%	20.88%	16.96%	7.38%	9.66%
Site 9	14.36%	17.18%	11.56%	4.80%	4.29%	14.35%	19.44%	6.64%	7.99%	15.89%	14.39%	20.46%
Site 10	2.76%	7.84%	6.55%	4.50%	8.80%	21.61%	9.84%	16.80%	9.43%	7.78%	12.94%	20.25%
Site 11	10.49%	7.64%	5.93%	11.14%	7.03%	12.72%	4.35%	13.70%	5.17%	17.57%	24.69%	50.76%
Site 12	6.98%	13.28%	5.07%	3.97%	11.04%	14.28%	19.14%	8.91%	41.00%	9.07%	9.04%	15.69%

reported on the laboratory component of dustfall monitoring only. The current study identifies environmental conditions that have a greater contribution to the calculated uncertainty of the method.

Conclusion

The dustfall rate for each group of four samplers per site was expected to have a low variability given that they were exposed to the same conditions. However, variation in the dustfall rate indicates some level of uncertainty. The results of this study show that there is uncertainty in the results from the dustfall samplers. Although some uncertainty could be attributed to sample handling, the majority is considered to be from environmental factors.

The proximity of the four buckets on each stand could affect the flow pattern around these buckets and potentially affect the deposition into the bucket. For this study it was assumed that the effect each bucket has on the others is equal. Future work for this study will correlate the highest mass of the four buckets with the dominant wind direction.

References

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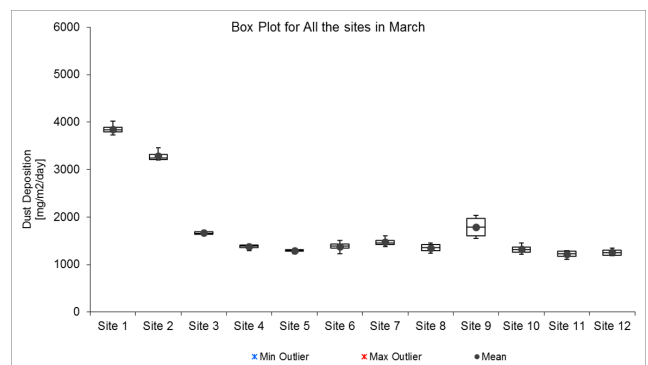
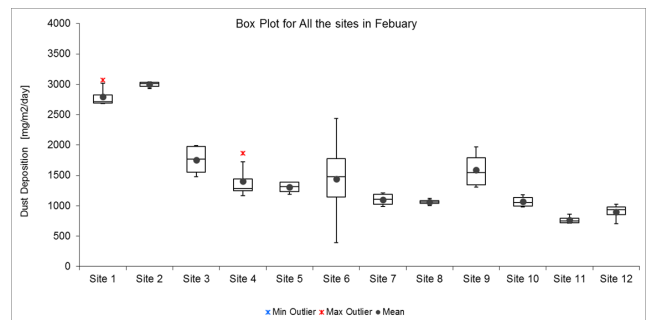
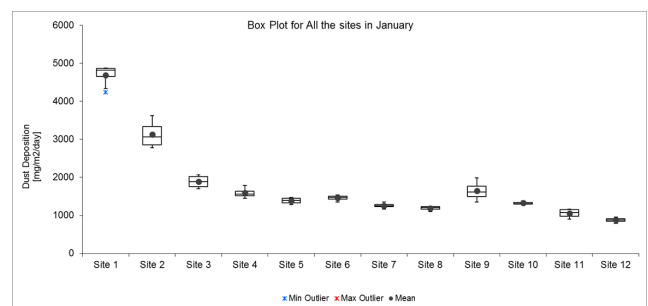
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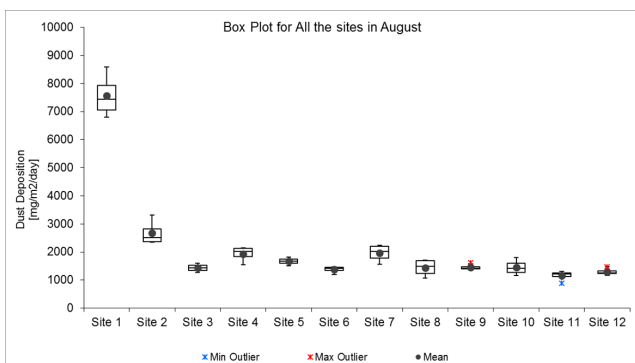
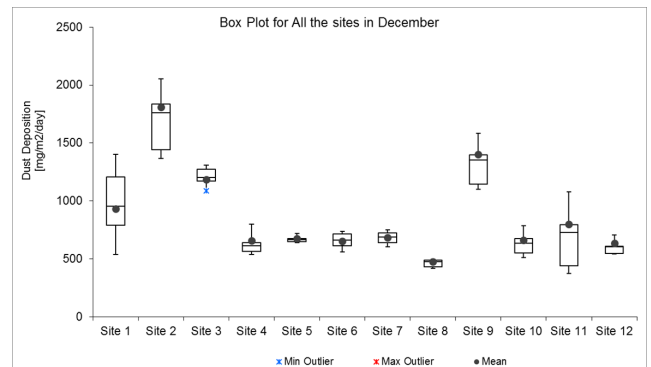
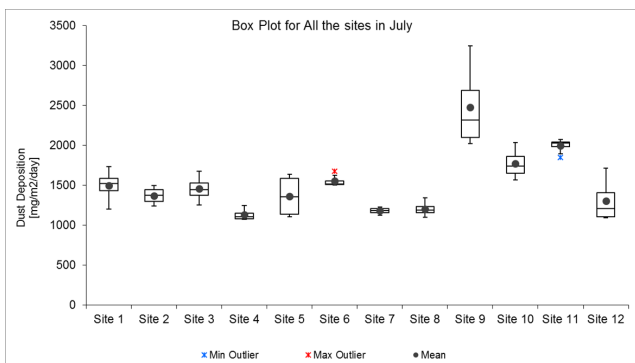
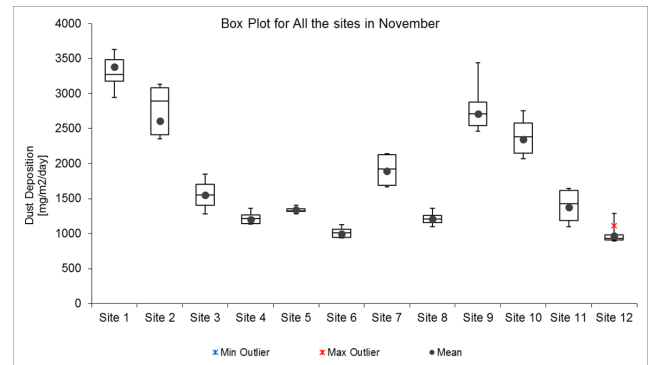
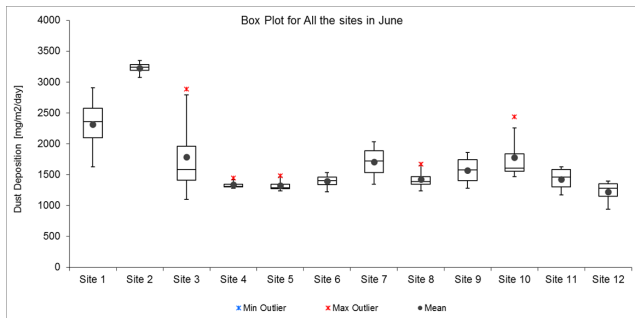
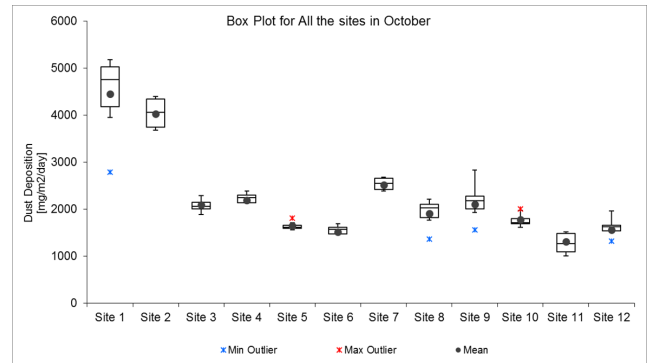
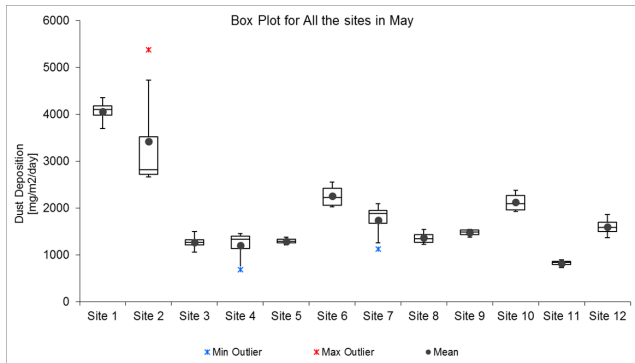
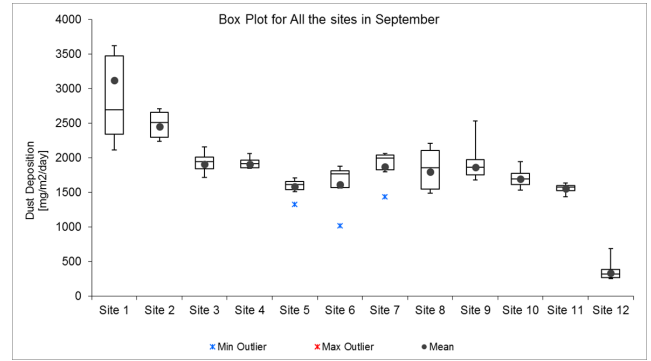
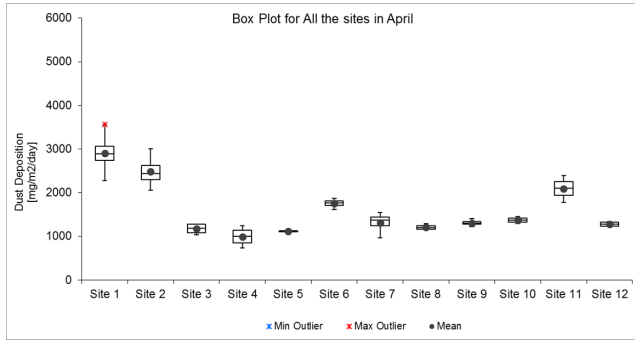
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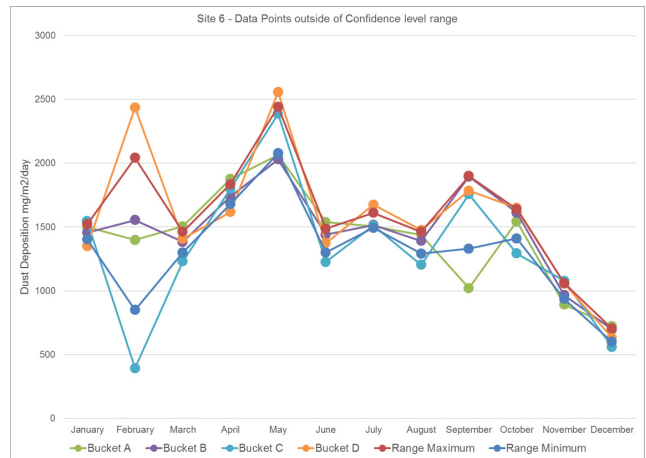
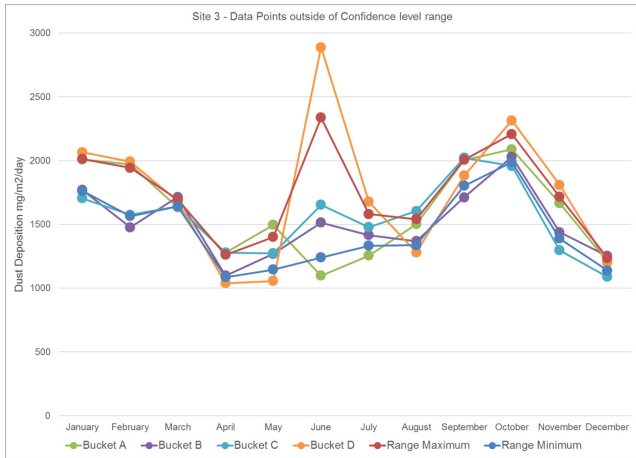
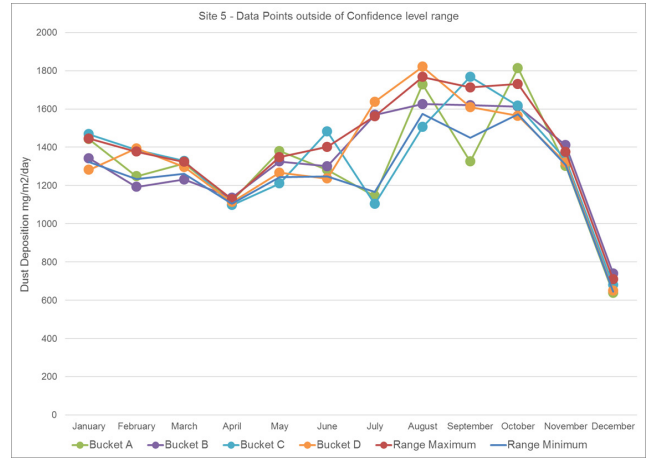
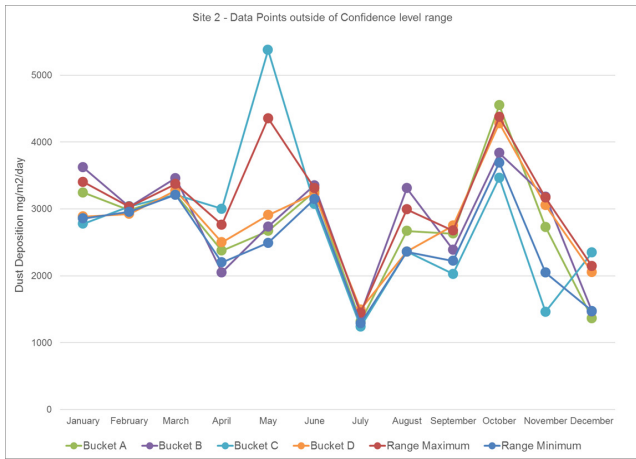
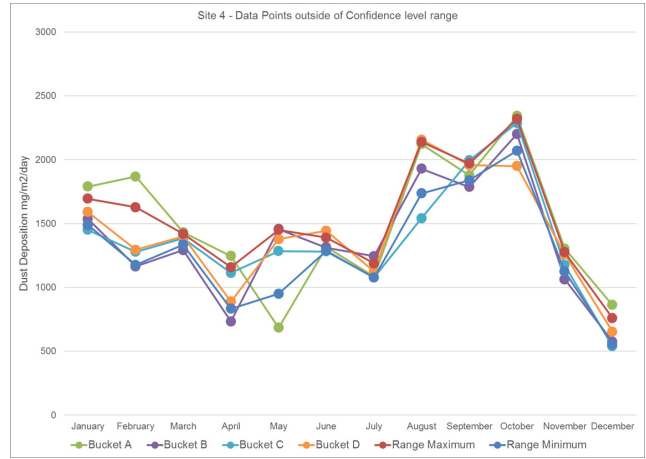
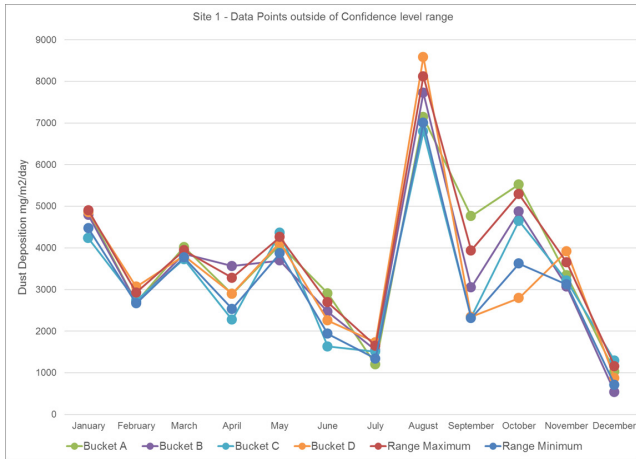
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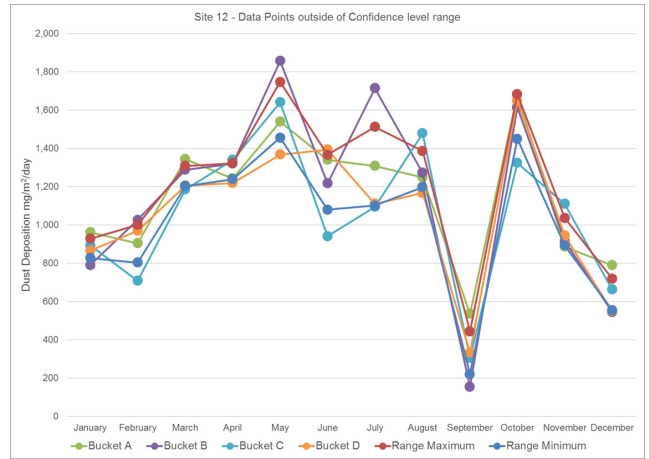
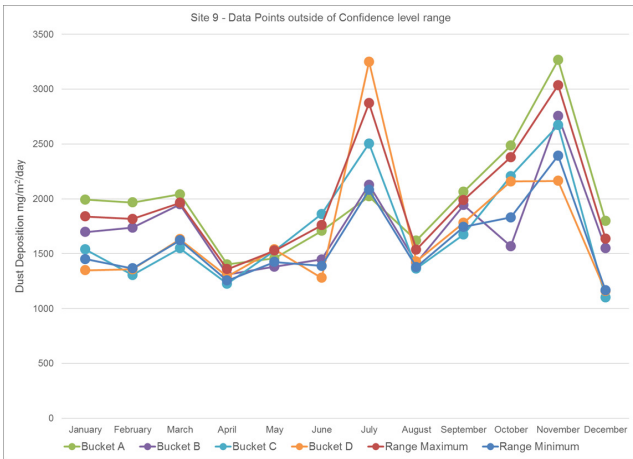
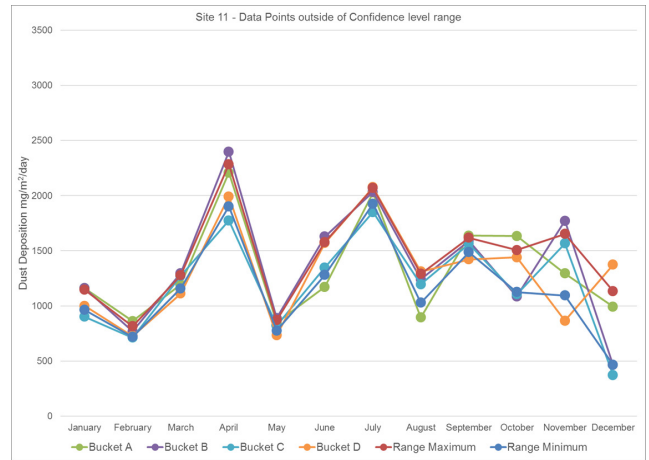
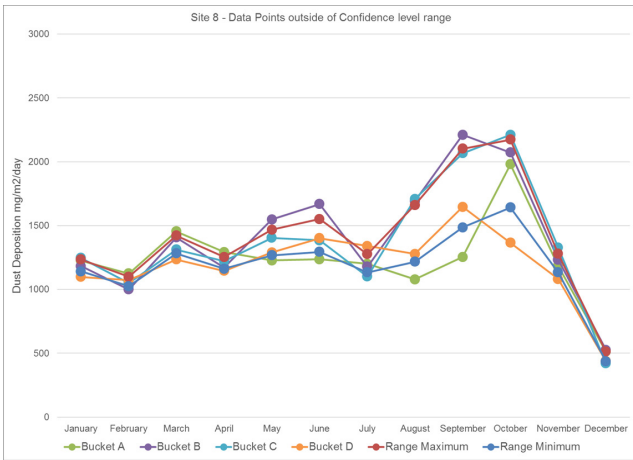
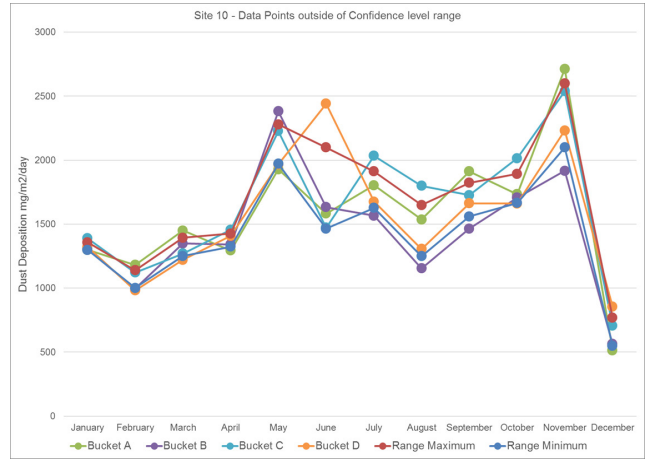
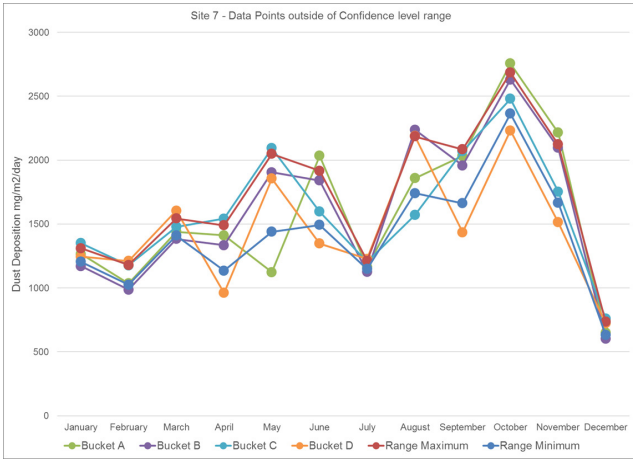
Appendix A: Monthly Box Plots





Appendix B: 90% Confidence Interval Graphs





Appendix C: 10% Error Margin Graphs

