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Empirical modelling of directional dust from industrial sites

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Abstract

This paper describes a preliminary investigation into relationships between stickypad dust data and meteorological factors at two industrial sites. Site A is a construction site near the coast of the Caspian Sea where dust problems are anticipated due to strong winds from the north. Site B is a small sand and gravel quarry in central England, where dust movements towards the north east are monitored due to the proximity of a sensitive receptor. It was chosen due to the flexibility available for dust monitoring and for contrast with site A. At both sites dust samples were collected on an array of sticky-pad directional dust monitors. Samples were sealed and scanned for dust coverage (AAC%) and dust soiling (EAC %). Each site also had a weather station, such that results could be examined in relation to rainfall, wind conditions and temperature. For this exercise, samples were selected on the basis of their exposure to background dust, in order to reduce influence from anthropogenic dust sources workings but allow for further work once basic principles are determined. Models were developed via a correlation matrix between all weather measurements and the relevant temporal dust level. The strongest correlations were established, and linear regression was used to explore potential coefficients. Rainfall parameters included daily & weekly rainfall, as well as factored rainfall based on immediacy. Temperature measurements were averaged over the dust monitoring periods and compared with monthly dust trends. Increases in dust were observed at site A when temperatures remained high, so a constant was created which reflected this. A unique 'wind-risk' constant was established with relation to wind direction, strength and frequency. Both site models rely heavily on wind speeds from the appropriate direction, but site A also had strong seasonal fluctuations based on temperature. The final models were made using linear regression to incorporate all relevant parameters to form an effective representation of the dusting patterns observed. Improvements being considered include refining dust predictions to include site activities and adaptation to additional sites.

Keywords: Dust; directional dust; fugitive dust; sticky-pad; empirical modelling;quarry; industrial site.

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1. Introduction

This paper describes a preliminary investigation into relationships between sticky pad dust data and meteorological factors at two industrial sites. The study uses primary directional sticky-pad dust data collected from two sites and outlines a basic approach to predict future dust movements using empirical dust modelling. Dust monitoring data from two sites are compared to basic weather parameters to establish trends and patterns, with future predictions made for model evaluation.

2. Sticky pad dust monitors

This study uses directional sticky pad dust monitors designed and developed by DustScan Ltd (Datson & Birch, 2006). The design (Fig. 1) incorporates an A4 sized sticky pad fitted around a plastic cylinder, oriented to north and placed on a post two meters above ground level. The sticky pads can be left exposed for up to two weeks and are widely used at UK industrial sites to pinpoint potential dust sources and pathways. The dust monitor shown also includes a depositional dust gauge, known as a DustDisc™, which collects deposited dust. Sample gauges can be installed anywhere around potential sites with an array setup recommended including monitors on site, at background locations, site boundaries and progressively closer to and at receptors.

Fig. 1. A directional and depositional dust monitor.

Once dust samples have been collected they are sealed using an acetate sheet (Fig. 2) and scanned and analysed using bespoke software. The software allows the quantification of the dust by means of dust coverage (Absolute Area Coverage - AAC %) and dust soiling (Effective Area Coverage - EAC %) (IAQM, 2012). Dust coverage relates to whether any dust is present on the sticky pad and dust soiling measures the 'darkness' of the sticky pad in comparison with a blank reference area. Results are given in 15 degree segments representative of the direction the dust appears to have come from and can be plotted on a 360° dust rose for visual reference (Fig 3.). Dust samples can also be removed from the sticky pad matrix if necessary via an organic solvent for further analysis, including gravimetry, mass spectrometry or SEM (Datson et al., 2012).

Fig. 1. A sealed directional sticky pad dust sample.

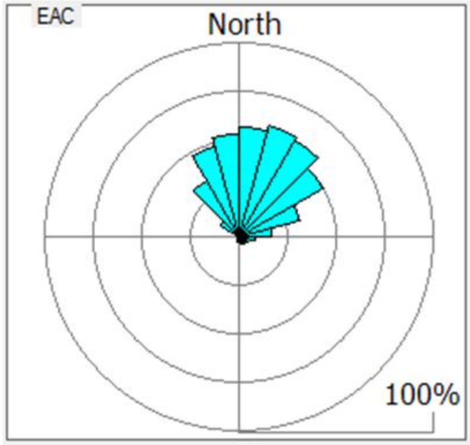

Fig. 2. A directional dust rose showing EAC%.

3. Site descriptions

3.1 Site A

Site A is a large oil and gas terminal in south east Europe which has recently undergone a large construction phase. Its location in a semi-arid area means that dust is a natural concern occurring frequently due to strong winds from the north of the site. A large, high quality data set is available due to a recent environmental and social impact assessment, with an array of 15 dust monitors present around the site for a period of 18 months. Samples were collected at site boundaries, near site activities and at receptors in the form of nearby settlements. A meteorological station is also present within the premises of the site.

3.2 Site B

Site B is a small sand and gravel quarry located in central England. The site contrasts Site A in respect of weather, size and dust monitoring flexibility. Dust movements away from the north east of the site have been monitored in relation to the proximity of a sensitive receptor, and more than six months of data was available at the start of the study; dust monitoring is ongoing. The site has an array of 8 depositional and directional dust monitors, including two key samplers placed at the quarry boundary, and a line of four monitors from the quarry towards the eastern receptor. There is also an electronic weather station located on the quarry boundary.

4. Model development

4.1 Background dust

For this preliminary study, samples were selected on the basis of their exposure to ‘background dust’, in order to reduce influence from surrounding anthropogenic dust sources. For Site A 'background dust' was defined as that arising from the north (330 – 30°) and captured on the four most northern monitors. For Site B all dust was assumed to have arisen from natural causes (i.e. wind) due to the small scale of the operations taking place at the site. This allowed the simplification of the initial model and for basic constraints to be established before undertaking further work to quantify dust attributable to site workings.

4.2 First steps

A correlation matrix was calculated between all weather parameters and the relevant temporal dust levels. Rainfall parameters included daily & weekly rainfall, as well as rainfall factored on how recently it had fallen. Temperature measurements were averaged over the dust monitoring periods and compared with dust trends over the monitoring period. Winds were analysed with respect to direction, average wind speed over half-hour periods and frequency from the specific arc of interest. Increases in dust were observed at Site A when temperatures remained high and trends showed a decrease in dust levels during and proceeding rainfall. Dust levels at Site B however appeared to largely depend on wind levels with rainfall and temperature having limited impact. For both sites the key weather influence was that of wind from the specific arc of interest: from the north (330°-30°) for Site A and from the south west (180°-270°) for Site B. A 'wind-risk' constant was created that reflected this and was dependent on the average wind speed from that arc and the proportion of time the wind was from that direction.

4.3 Linear regression modelling

At both sites the strongest correlations were established for each weather parameter, and multiple linear regression was used to explore the combination which resulted in the best fit with the measured dust levels. The final models were established at both sites by comparing each linear regression model with monitored dust trends and expected dust levels based on weather data.

Both models were based on an original data set; Site A used one year of data, and Site B used six months of data. The graphs in Fig. 4 & 6 show the measured dust levels as EAC% per monitoring period compared with modelled dust levels for each respective period. The model for Site A fit the data well (r^2 = 0.67) but failed to capture some of the larger peaks. The model for Site B also fitted the data very well (r^2 = 0.81) with most peaks captured accurately. Scatter plots (Fig. 5 & 7) are also given to illustrate the variability of the data.

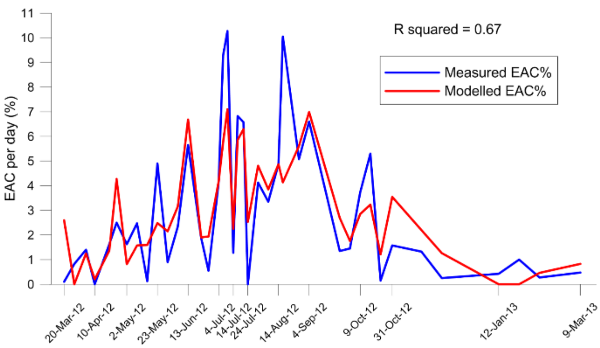

Fig. 4. Model for Site A over time.

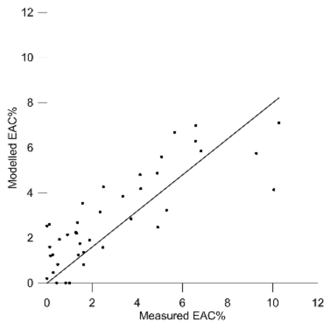

Fig. 5. Scatter graph for Site A model.

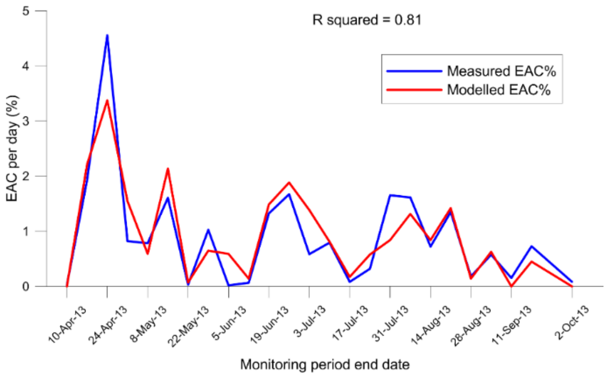

Fig. 6. Model for Site B over time.

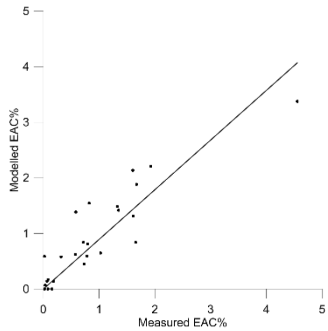

Fig. 7. Scatter graph for Site B model.

5. Model evaluation

Models were tested against supplementary data, with a further six months available for Site A and ten weeks available for Site B. Figs. 8 and 9 show the model test for Site A with a very good fit (r^2 = 0.76) to the supplementary data; the red dotted lines indicate the predicted dust levels. The model captures both the peaks and troughs in dust levels for the six month test period. Figs. 10 and 11 show the model evaluation for Site B, which also gives an accurate prediction of dust trends (r^2 = 0.76) but over predicts absolute dust levels.

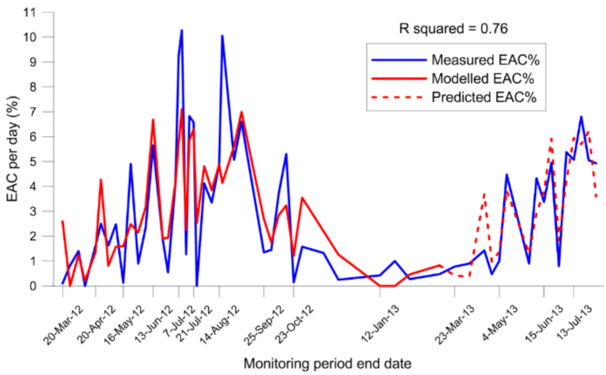

Fig. 8. Model evaluation for Site A.

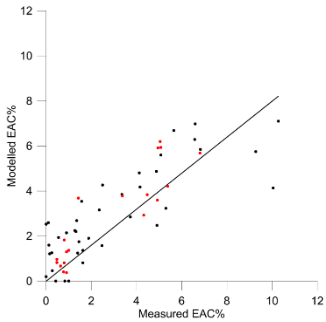

Fig. 9. Scatter graph for Site A model evaluation.

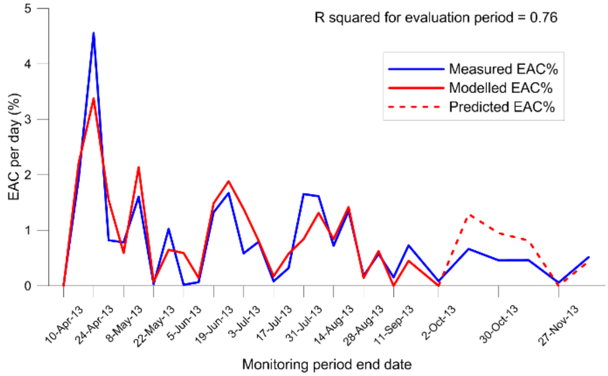

Fig. 10. Model evaluation for Site B.

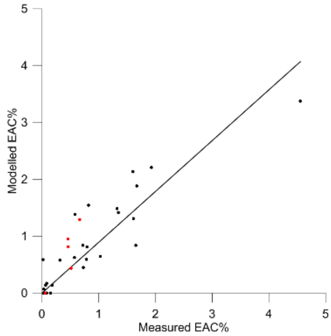

Fig. 11. Scatter graph for Site B model evaluation.

6. Findings

Both models show strong promise for the prediction of dust movements from a basic meteorological data set. One limitation of Site A's model appears to be in the prediction of the highest peaks; this could be due to the limitations of linear regression modelling. A small difference in wind speed results in a big difference in wind energy; wind energy is proportional to the cube of its speed (Andrews & Jelley, 2013). The model may therefore require adaptation to a non-linear coefficient for wind speed to more accurately predict dust during periods of high wind speeds. Future developments include the addition of site and engineering workings into the model and ultimately adaptation to additional industrial sites.

7. Acknowledgements

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