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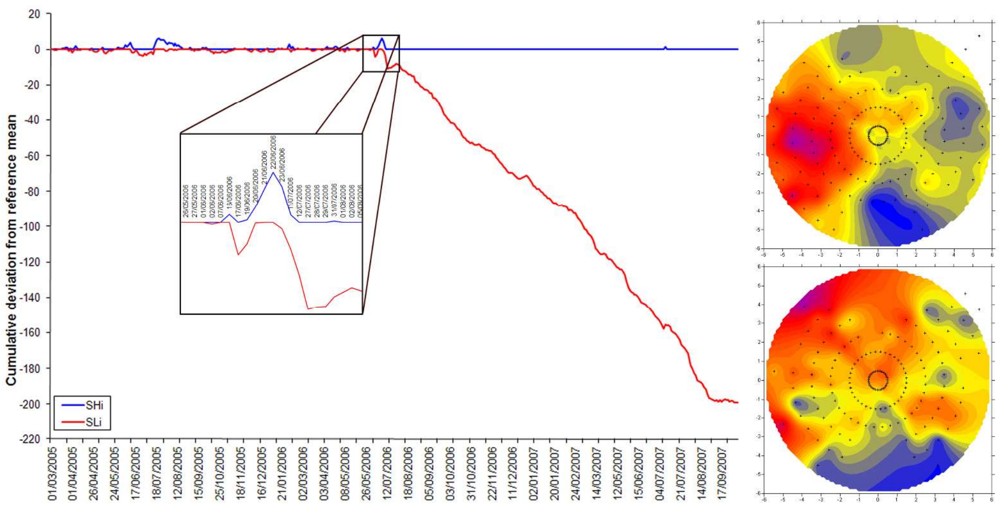

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Intervention assessments in the control of PM_{10} emissions from an urban Waste Transfer Station

A case study presenting novel analysis techniques for evaluating particulate air pollution mitigation measures at an industrial site in London.

Environmental Impact Statement:
This study considers the impact of air pollution mitigation measures at an industrial site in a densely populated area of London. It develops techniques for identifying which specific processes are responsible for elevated ambient particulate (PM_{10}) levels and assesses the success of mitigation methods. Long term monitoring across London has shown that it is these processes, not vehicle emissions, which lead to the highest concentrations of particulate matter. Further mitigation is required if areas surrounding such sites are to meet EU Air Quality Limit Values. The techniques developed in this study will enable licensing authorities to more effectively characterise and mitigate particulate matter generated by urban industrial activities, thereby improving the health and quality of life of the local population.

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ARTICLE

Intervention assessments in the control of PM_{10} emissions from an urban waste transfer station

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While vehicle emissions present the most widespread cause of breaches of EU air quality standards in urban areas of the UK, the greatest PM_{10} concentrations are often recorded close to small industrial sites with significant and long-term public exposure within close proximity. This is particularly the case in London, where monitoring in densely populated locations, adjacent to waste transfer stations (WTS), routinely report the highest PM_{10} concentrations in the city. This study aims to assess the impact of dust abatement measures taken at a WTS in West London and, in so doing, develop analysis techniques transferrable to other similar industrial situations. The study was performed in a 'blinded fashion', i.e., no details of operating times, activities or remediation measures were provided prior to the analysis. The study established that PM_{10} concentrations were strongly related to the industrial area's working hours and atmospheric humidity. The primary source of local particulate matter during working hours was found to be from the industrial area itself, not from the adjacent road serving the site. CUSUM analysis revealed a strong, sustained change point coinciding with a number of modifications at the WTS. Analysis suggested that introducing a vehicle washer bay, leading to a less dry and dusty yard, and ceasing stock piling and waste handling activities outside of the open shed had the greatest effect on PM_{10} concentrations. The techniques developed in this study should empower licensing authorities to more effectively characterise and mitigate particulate matter generated by urban industrial activities, thereby improving the health and quality of life of the local population.

1. Background

A number of EU member states are struggling to meet the required standards of PM_{10} (approximately defined as particulate matter with an aerodynamic diameter of less than 10 µm) concentrations, including the United Kingdom[1]. While vehicle emissions present the most widespread cause of breaches of EU air quality standards in urban areas[2], it has been shown that the highest PM_{10} concentrations are often recorded close to small industrial sites with significant and long-term public exposure within close proximity[3,4].

Waste transfer stations (WTS) are of particular concern with regards PM_{10} emissions. They are long-term or permanent facilities, often sited amongst high density residential areas that attract a steady flow of heavy goods vehicles and movement of dry waste materials[5]. Furthermore, Godri *et al.*[6] found that particulate matter (PM) emissions from a WTS in London had elevated trace metal concentrations and, as a consequence, increased oxidative potential. They concluded that PM released by WTS activity should therefore be considered a potential health risk to surrounding residential communities.

Studies have investigated emissions from industrial and construction sites that emit high levels of particulate matter[7,8,9]. Poulsen *et al.*[10] reviewed the occupational health hazards associated with waste transfer and central recycling stations, including suspended dust and other particulate matter. These studies aimed to quantify and/or characterise emissions from such sites through detailed expensive monitoring programmes or simple time series analysis, but did not propose methods for identifying change points in emissions profiles, or characterising the effects of mitigation measures. The latter are necessary to provide a level of accountability to such measures and provide a feedback loop for further improvement. In contrast, straightforward examination of time series data is not sufficient in most cases, as change points are obscured by measurement noise attributed to the effects of meteorology, variable site activity and unrelated PM sources.

This study aimed to assess the impact of dust abatement measures taken at a WTS using ambient air-quality monitoring at downwind receptors and, in so doing, develop analytical techniques transferrable to other similar industrial situations. This issue is particularly significant in the UK, as the environment ministry, Defra, has recently concluded that the monitoring site used in this study falls within the siting criteria laid out in EU Air Quality Directive 2008/50/EC. Therefore results from the site from 2013 onwards will be reported to the EU for assessment against legislative compliance. In order to meet the relevant EU Limit Values, PM_{10} concentrations in this location will require effective mitigation.

The study was carried out over 31 months around a mixed use industrial area in West London, including a WTS. Continuous monitoring close to the site perimeter at sensitive receptors indicated that PM_{10} concentrations exceeded the WHO health guideline and EU Limit Value concentration of 50 µg m^{-3} (daily mean) on 75% of all days throughout the year, and were amongst the highest recorded in London. However, during the study period, local environmental officers worked with the site operators to reduce emissions from and relating to the site activities.

The study was performed 'blind', i.e., no details of operating times, activities or remediation measures were provided prior to the analysis. Once the initial analysis was complete, details were provided and cross checked with the results of the 'blind' analysis to identify probable cause and effect.

2. Data

2.1. PM_{10} measurements

The primary source of data used within this study were from R&P Tapered Element Oscillating Microbalance 1400AB ('TEOM') analysers operated within the London Air Quality Network (LAQN – www.londonair.org.uk). As such, each was operated to defined QA/QC standards meeting those required by national monitoring guidelines[11].

The EU limit value requires PM_{10} to be measured using the gravimetric method. It has been observed that the TEOM produced a lower measurement of PM_{10} than that derived gravimetrically due to greater sampling losses of semi-volatile particulate from the TEOM[12,13]. However, as emissions from waste handling operations are not associated with volatile matter the use of such analysers was considered acceptable. In all cases, PM_{10} measurements from TEOM analysers have been multiplied by a conversion factor of 1.3, as recommended by Defra[11].

Limited particulate monitoring was also undertaken at two locations on the industrial site itself by the respective operators using Turnkey Osiris monitors. Osiris monitors provide a relatively cheap method of continuous PM_{10} monitoring via a light scattering technique. However, due to poor data availability and limited QA/QC procedures, these data were only used for qualitative analysis.

2.2. Isolation of PM_{10} arising from local industrial activities ('local PM_{10}')

This study was concerned with the nature and changes in local sources of PM_{10}. Therefore, PM_{10} from background sources was isolated and removed. PM_{10} measurements (TEOM*1.3) from an urban background monitoring site 3.6 km to the east of the study location were used to represent background concentrations, i.e., the average level of PM_{10} in west London away from major roads and localised sources of PM_{10}. This particular site was selected as it was the closest available to the study location and had no strong local sources of PM_{10}, confirmed with a bivariate polar plot analysis (data not shown). 15 minute mean concentrations from the background site were subtracted from each 15 minute mean concentration recorded at the main study monitoring site to form a 'local' PM_{10} dataset. Where this method yielded 'local PM_{10}' concentrations less than -10 µg m^{-3}, the record was removed (632 records - 0.6% of the dataset).

2.3. Meteorological measurements

No meteorological data other than ambient temperature and pressure were recorded at the main study monitoring site. Wind speed, wind direction, rainfall and relative humidity measurements were taken from two monitoring sites approximately 8 km to the east. These sites are in open locations and measurements were considered representative of regional scale meteorology and therefore a good approximation for the study location.

2.4. Study monitoring site details

A site plan is shown in

Figure 1. The primary data source for this study was the Ealing 8 ('EA8') PM_{10} monitoring site to the west of a single carriageway road with vehicle flows of approximately 15,500 vehicles north bound and 9,000 vehicles south bound per day[14].

The monitoring site was installed on a grass verge to the west of the main road, but to the east of a small side road serving local shops. The location was relatively open with terraced two-story houses and shops to the west and semi-detached three to four storey houses to the east. PM_{10} monitoring commenced in February 2005. This study incorporated measurements from 1st March 2005 to 1st November 2007.

TEOM PM_{10} measurements from a roadside site approximately 1,200m to the south of the study location (Ealing 2 – 'EA2') were also utilised for comparison in the time series analysis

Figure 1: GIS map showing the location of the EA8 monitoring site on Horn Lane and the industrial area to the south west. Monitoring locations are shown as dots.

The industrial area under investigation comprised of a collection of businesses, three of which had the potential to generate large volumes of suspended dust over a sustained period; a waste transfer depot, a cement batching depot and an aggregates depot. The waste transfer depot accepted mixed demolition waste, delivered by Heavy Goods Vehicle (HGV), which was separated and exported according to material type. The three businesses were regulated by the UK Environment Agency and by the local authority (London Borough of Ealing). The locations of the two Turnkey Osiris monitoring sites run by the site operators are also shown in

Figure 1. The Osiris 1 monitoring site was on a single storey building within the waste transfer depot in an enclosed location with high buildings immediately to the north and east. The Osiris 2 monitoring site was on a two storey building within the aggregates depot in an open location. Limited datasets were available from each site. Valid PM_{10} measurements were available from 16th March 2007 to 6th May 2007 at 'Osiris 1', and from 1st May 2006 to 1st June 2007 (excluding April) at 'Osiris 2'.

3. Analysis methods

Note that all measurements used in this study are tied to the prevailing local time, i.e., GMT during the winter and BST (British Summer Time) during the summer, to tie in with industrial site working hours of operation. Unless specifically stated, analyses were carried out using the TEOM study site 'EA8', not the two Osiris monitoring sites, as explained in Section 2.1.

3.1. Time series and diurnal characterisation

A time series plot of weekly mean PM_{10} concentrations was first produced to examine the seasonal variation of the EA8 dataset. A smoothed trend line (R software package 'openair' with smoothTrend function) was added to show trends over the 33 month study period. Weekly diurnal plots were then produced to investigate variation in pollutant concentrations over weekdays and weekends. These were calculated by taking the mean 'local' PM_{10} concentration recorded throughout the input period on each 15 minute or hourly period on each day. Public holidays were excluded from the input dataset.

3.2. Bivariate polar plot analysis

Bivariate polar plots were produced in order to identify the major particulate sources surrounding the monitoring locations in terms of wind speed and direction. The use and production of polar plots in characterising ambient air pollution sources is described in Carslaw *et al.*[15]. Briefly, these relate pollution concentrations with wind speed (radial axis) and direction (polar axis). In each of the analyses, grid bins of less than four or ten ('working hours' and 'non-working hours' analyses respectively) 15 minute measurements were excluded. Similarly, plots were bounded at 6 m s^{-1} wind speed. Kriging was used as the surface interpolation method using Surfer v8.00.

3.3. Cumulative Sum (CUSUM) analysis

While it was developed primarily for process control, the cumulative sum (CUSUM) change point analysis method has been shown to be successful in identifying the approximate date of sudden changes in air pollution concentrations within a time series, and whether this change is sustained[16,17]. This CUSUM method was applied to the EA8 PM_{10} dataset in order to establish the presence and timing of any sustained decrease in mean concentrations. This, in turn, could then be related to dust abatement or preventative action taken by the industrial site operators once such information was made available.

The analysis took a reference mean as the mean local PM_{10} concentration over the first twelve months of the study (1st March 2005 to 1st March 2006). This reference value was subtracted from each daily mean concentration in turn over the full analysis period, with the cumulative deviations from this reference value forming the cumulative sum according to the equations suggested by Lucas[18]:

$$S_{Hi} = \min[0,(z_i - k) + S_{Hi-1}] \text{ and } S_{Li} = \max[0,(z_i + k) + S_{Li-1}]$$

Where S_{Hi} represents the standardised cumulative increase in concentrations and S_{Li} the cumulative decrease. The parameter, k, is the allowable 'slack' in the process and is usually set to be one half of the mean shift (in z units) one wishes to detect.

4. Results

4.1. Time series

A time series plot of weekly mean PM_{10} concentrations measured at the EA8 monitoring site over the period 1st March 2005 to 1st November 2007 is shown in

Figure 2. Comparison of measurements at the EA8 site with those recorded at a nearby roadside monitoring site showed that PM_{10} concentrations were strongly seasonal, with the highest peaks recorded during the summer months. It also indicated that a change occurred sometime during mid to late 2006 resulting in a marked decrease in peak concentrations. Conversely, there is evidence of an increase in concentrations towards the end of the time series, in mid-2007.

Figure 2: Weekly mean time series plot of PM_{10} concentrations with smoothed trend line at the EA8 monitoring site. Concentrations from a nearby roadside site ('EA2') are shown for comparison (also with smoothed trend line).

4.2. Diurnal characterisation

The hourly mean weekly diurnal plot (

Figure 3) revealed a number of striking characteristics of the dataset. Similar patterns were seen each Monday to Friday, although peak mean concentrations were slightly lower on Monday than other weekdays. Mean concentrations rose very rapidly from 10-20 μg m^{-3} at 6am to 60-80 μg m^{-3} at 7am from Monday to Saturday, with equally rapid decreases at 5pm (noon on Saturday). The weekday peak coincided with minimum diurnal relative humidity, so is likely to relate to the driest part of the day. Although less pronounced, the early afternoon is also often the windiest part of the day, increasing the potential for resuspension of dust. Mean concentrations were elevated far above typical roadside concentrations at all times except between 1am and 4am (10pm and 4am on Sunday/Monday). Identifiable dips in concentrations occurred at 8am and noon each weekday. Elevated concentrations on Sundays were spread across the period (10am to 4pm), suggesting a different source characteristic than on weekdays; one related more to vehicle movement on the adjacent road causing resuspension of settled dust along the road and gutter rather industrial site activities.

Figure 3: Diurnal variation in hourly mean local PM_{10} at the EA8 monitoring site, 1st Mar 2005 to 1st Nov 2007. Dips at 8am (squares) and noon (circles) have been highlighted. Local PM_{10} concentrations from a nearby roadside site ('EA2') are included for comparison.

The diurnal analysis was repeated using 15 minute resolution data for 'year 1' (1st March 2005 to 1st March 2006) and 'year 3' (1st November 2006 to 1st November 2007). These two 12 month periods were selected as either side of the change point suggested in the time series analysis. This more detailed analysis clearly showed 'working hours' as 7am to 5pm Monday to Friday and 7am to 1pm Saturday. It also showed that mean concentrations during working hours approximately halved between year 1 and year 3. Mean concentrations during non-working hours, including Sunday, also decreased.

4.3. Bivariate polar plot analysis

Polar plots were produced of local PM_{10} concentrations at the EA8 monitoring site during working hours and non-working hours in year 1 and year 3. The results are shown in **Figure 4** with concentration scale in $\mu g\ m^{-3}$, shown to the right of the plots. Note that the plots for non-working hours are presented with a 1/10th scale.

Figure 4: Bivariate polar plots showing mean local PM_{10} concentrations at the EA8 monitoring site. Wind speed in $m\ s^{-1}$ is shown on the radial axis (0-6 $m\ s^{-1}$), wind direciton on the polar axis (0 to 350 decrees, 0 representing north), the colour scale indicates PM_{10} concentration in $\mu g\ m^{-3}$, grid points with available data are indicated with '+' symbols. Regions where no data are available, e.g. southerly winds >3 $m\ s^{-1}$) should be interpreted with caution.

During working hours, a very clear source of PM_{10} can be seen to the west (c. 220 to 290 ^{o}N) of the EA8 monitoring site in year 1, with mean concentrations of up to 250 $\mu g\ m^{-3}$. This source remained evident in the year 3 plot, albeit with a much lower mean concentration of around 100 $\mu g\ m^{-3}$. Perhaps surprisingly, there was no clear indication of a strong source related to the adjacent main road, which ran north-south to the east of the site. Aside from this westerly source, it is worth noting that concentrations relating to a range of wind directions were elevated well above background during working hours; yellow contours represent an additional contribution from local sources of 50 $\mu g\ m^{-3}$ or more in **Figure 4**.

As expected from the diurnal analysis, concentrations during non-working hours in both periods (year 1 and year 3) were low in comparison to working hours. Concentrations during non-working hours were so low as to require a separate 1/10th scale to distinguish contour variations. At this scale, it could be seen that the source to the west was no longer dominant. In year 1, higher concentrations appeared to be related to higher wind speeds from a range of wind directions, possibly related to resuspension of dust deposited during working hours. This phenomenon was less evident in year 3, when there was a range in concentrations of only 8 $\mu g\ m^{-3}$.

4.4. Analysis of additional monitoring carried out by site operators

Although limited, this additional monitoring across the industrial area provided an opportunity to triangulate local particulate sources via polar plots (
Figure 5). It should be noted when interpreting
Figure 5 that this analysis was less robust than that presented in **Figure 4** due to short and differing monitoring periods, the use of different monitoring technology to separate local (by Osiris) and background (by TEOM) particulate measurements and limited local QA/QC procedures. Analysis dates of 1st May 2006 to 1st June 2007 were selected in order to maximise the available data from the Osiris sites. Note that even within this truncated analysis period, valid PM_{10} measurements were only available from Osiris 1 between 16th March 2007 and 6th May 2007.

Figure 5: Polar plot results from the three monitoring datasets overlaid on area map. Note: for qualitative analysis only – monitoring methods, analysis periods and concentration scales differ between sites. Only 52 days data available from 'Osiris 1', therefore some wind conditions may be under represented.

The polar plot analysis for the EA8 monitoring site identified the principal source as being to the west in the general direction of the industrial site (**Figure 4**). The Osiris 2 analysis was able to split this industrial site-related local particulate source in two. The principal source was to the east in the direction of the WTS and the cement batching plant. A lesser source was identified to the west in the direction of the aggregates depot. Note that moderate to strong winds from the north and north east were very infrequent during this period. The Osiris 1 analysis gave similar results to the EA8 monitoring site analysis, with the principal source to the west/southwest. This result is notable as it indicates that the major source of local particulate was the WTS depot yard and materials handling building, rather than the entrance to the industrial area shared by all three depots.

4.5. Cumulative Sum (CUSUM) analysis

Barratt *et al.*[16] identified serial correlation, principally in the form of seasonality, as a major limiting factor of the CUSUM method. It was therefore clear from the time series analysis that the effectiveness of the CUSUM analysis would be severely restricted by the strong influence of meteorological conditions on the input data. In order to improve the effectiveness of the CUSUM method, this analysis utilised a statistical model to remove this meteorologically-driven variation in the data that remained after a series of data filters had been applied.

First, the input dataset of hourly mean local PM_{10} concentrations was filtered to only include measurements taken during working hours. Second, the remaining data were filtered to only include those specific wind conditions identified by the polar plot analysis as relating to the principal particulate source, i.e., wind direction between 220 and 290 degrees from north, wind speed between 1 and 6 m s^{-1}. Daily mean PM_{10} concentrations were then calculated from the remaining data to create a 'local filtered' PM_{10} concentration.

A best-fit regression analysis was carried out on the local filtered PM_{10} dataset for year 1 to establish which meteorological variables best described the variability in PM_{10}. Five input variables were tested - daily mean barometric pressure, temperature, relative humidity, incoming solar radiation and daily total rainfall.

No. Variables	R^2	R^2 (adj)	Bar. pressure	Temperature	Incoming solar rad.	Rainfall	Rel.ve humidity
1	57.8	57.5					X
1	46.9	46.6			X		
1	37.7	37.3		X			
2	62.1	61.6		X			X
2	59.9	59.4			X		X
2	57.8	57.3	X				X
3	62.4	61.7		X		X	X
3	62.4	61.7		X	X		X
3	62.1	61.3	X	X			X

Table 1: Best subsets regression analysis results - local filtered PM_{10} against the five meteorlgical input parameters. The favoured regression equation is highlighted. Input data were 1st March 2005 to 1st March 2006.

This analysis revealed a good relationship between relative humidity and local filtered PM_{10}, with an R^2 value of 58%. This relationship was improved significantly with the inclusion of temperature, but the addition of a third variable made little improvement (
Table 1). Therefore a statistical model was created of the form:

$$PM10_{lf} = 387 + 3.86T_a - 4RH_a \qquad R^2 = 0.62$$

Where $PM10_{lf}$ is the local filtered PM_{10} recorded at the EA8 monitoring site, T_a is the daily mean ambient temperature in ^oC and RH_a is the ambient daily mean relative humidity (%). The strength of the relationship between PM_{10} concentrations and relative humidity was far stronger than that expected in urban situations (a repeat analysis using PM_{10} data from a nearby roadside site ('EA2' - Acton High Street) over the same period produced an R^2 value of 0.03). This indicated the dominance of fugitive and resuspended and sources of PM over combustion emission sources at this location.

This statistical model, constructed from measurements during year 1 only, was used to forecast filtered local PM_{10} concentrations over the remainder of the analysis period based only on temperature and relative humidity measurements.

Figure 6 shows a time series plot of measured, modelled and forecast local filtered PM_{10} concentrations from 1st March 2005 to 1st November 2007. The model predicted PM_{10} concentrations well up to mid-2006, when a clear over prediction began and continued to the end of the series.

Figure 6: Measured, modelled and forecast local filtered PM_{10} concentrations at the EA8 monitoring site.

A time series of model residuals was then created by subtracting modelled concentrations from measured. CUSUM analysis was then applied to this derived dataset (Figure 7). With the effects of meteorology removed, the CUSUM chart identified a clear change point and subsequent steady decline. The apparent increase in concentrations in mid-2007, suggested by the upward turn in the time series analysis, was no longer evident, indicating that this increase was related to meteorological conditions, rather than a change in emissions. The inset in Figure 7 shows the change point in more detail, being between the end of June to the beginning of July 2006. Unfortunately, there was no wind from the major source sector between 23rd June and 11th July 2006 preventing a more precise estimate.

Figure 7: CUSUM plot of deviation from forecast filtered daily mean local PM_{10} at the EA8 monitoring site. SHi represents positive deviation, SLi represents negative deviation from the reference mean. Inset shows change point detail.

4.6. 'Unblinding' the analysis

Following completion of the analysis, a site visit was made to relate the results to operator activities and remediation measures over the analysis period. A visual assessment was made of the aggregates, waste transfer and cement batching depots.

The site operators described a number of dust remediation measures that had been taken over the analysis period, as shown in
Table 2. The reported site hours of operation coincided with those estimated from the diurnal analysis (
Figure 3). The site opened at 7am and immediately took a large influx of laden vehicles. Most drivers were required to take a break at around 10:30am, causing a second rush following the break at 11am. It appears, therefore, that the dips identified in the diurnal profiles at 8am and 12am were not related to periods of low activity. It is more likely that what appeared as dips were actually abnormally high concentrations in the previous hour (7am and 11am) as a result of these high frequency vehicle movements.

Industrial Area (see Fig 1)	Dust remediation measures	Approximate date
Waste Transfer Depot	1. Yard enclosures erected. 2. Washer bay installed. 3. Stockpiling of waste outside of sorting shed ceased (not strictly enforced).	July - August 2006
Cement Batching Depot	Jet wheel wash system (disconnected)	Winter 2007
Aggregates Depot	No major changes	Continuous

Table 2: Dust remediation measures taken across the three sites during the study period.

The CUSUM analysis identified a step change in concentrations coinciding with the remediation measures carried out in July 2006. This study was unable to specifically differentiate between the relative impact of each co-incidental measure, however, when combined it is clear that a significant reduction in PM_{10} concentrations was achieved. As the bivariate polar plot analysis indicated that the WTS yard was the principal local source of particulate, it is likely that a combination of the introduction of the vehicle washer bay at the entrance to the WTS yard, leading to a less dry and dusty yard and the cessation of stock piling and waste handling activities outside of the open shed had the greatest effect. The impact of a cleaner road and industrial site entrance brought about by the wheel wash would appear to be of secondary importance.

The aggregates depot operators had a programme of continuous improvement in dust abatement measures and could not identify any major changes to relevant practises during the analysis period. A passive wheel wash system and saline sprinkler system were already in place prior to the study commencement date. This information, coupled with evidence from the polar plot analysis made it unlikely that emissions from the aggregates depot caused the stepped decrease in measured concentrations in June/July 2006.

5. Discussion

This study aimed to characterise PM_{10} emissions, leading to frequent and extreme breaches of national air quality standards, from an industrial site adjacent to a residential area. It also aimed to identify the timing and impact of mitigation measures taken by the site operators. Many of the findings were non-specific to the whole of the industrial area to the south west of the monitoring site. However, the inclusion of limited additional measurements from within the industrial area itself did allow some degree of source apportionment to differentiate between emissions from specific operators within the industrial area.

The study established that PM_{10} concentrations were strongly related to the working hours of the industrial area. A second, strong relationship between PM_{10} concentrations and relative humidity indicated that atmospheric humidity (rain and dampness) suppressed dust suspension at the site. Consequently, peak concentrations were recorded during the driest part of the day (2pm) and not periods of peak activity at the aggregates and waste transfer depots (7-8am) or vehicle flows on the adjacent main road (9am). Some relationship between increased HGV activity at the waste transfer depot and diurnal concentrations could be seen as spikes in the diurnal profile at 7am and 11am.

Elevated local PM_{10} concentrations were recorded during non-working hours, including Sundays. There was no clear relationship between wind conditions and particulate concentrations during these periods, suggesting that fugitive dust emitted during working hours may have been resuspended by wind and vehicles on the main road.

Importantly, the primary source of local particulate during working hours was found to be from the industrial area itself, not from the adjacent road serving the site. CUSUM analysis revealed a strong change point relating to a sustained decrease in local PM_{10} emissions in June/July 2006. This decrease affected PM_{10} concentrations during both working and non-working hours, indicating an improvement in conditions both within and surrounding the site. This change point coincided with a number of modifications at the waste transfer depot, the specific effects of which were indistinguishable by the analysis. However, the analysis did suggest that a combination of introducing a vehicle washer bay, leading to a less dry and dusty yard, and ceasing stock piling and waste handling activities outside of the open shed had the greatest effect on PM_{10} concentrations.

The study also highlighted the extremely high PM_{10} concentrations in densely populated urban areas arising from waste transfer sites. While a case study in London is presented, this is a potential problem across the industrialised world. A drive to increase the recycling rates of both domestic and construction materials means that such transfer stations are common across Europe and North America. Their relatively small size means that they are often located within residential areas of towns and cities[19], leading to potentially harmful public exposure of PM_{10} concentrations well above those recorded at busy roadside locations[4,5].

6. Conclusions

The case study presented in this paper demonstrates that, with a relatively limited monitoring regime, advanced analysis techniques can evaluate the impact of air quality management activities at waste transfer stations and similar facilities. It should be stressed that the source signals were relatively large in this study, with a strong relationship between particulate emissions and meteorological. However, weaker signals should be identifiable with more extensive and targeted monitoring.

Analysis techniques to identify the impact of particulate mitigation interventions developed in this study will also be applicable to other high dust generation activities in sensitive areas, such as medium to large construction and demolition sites. Such techniques should empower licensing authorities to more effectively characterise and mitigate PM emissions and in turn, reduce the risk of a detrimental health impact on surrounding residents.

Such evaluation will assist in the creation of evidence based best practise procedures for controlling dust emissions from such processes. The implementation of proven and effective procedures will be essential if the UK, and other EU Member States are to meet Limit Values for PM_{10} and avoid fines for breaching environmental laws. to more effectively characterise and mitigate PM emissions and in turn, reduce the risk of a detrimental health impact on surrounding residents.

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8. Notes

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Figure 1: GIS map showing the location of the EA8 monitoring site on Horn Lane and the industrial area to the south west. Monitoring locations are shown as dots.
353x236mm (72 x 72 DPI)

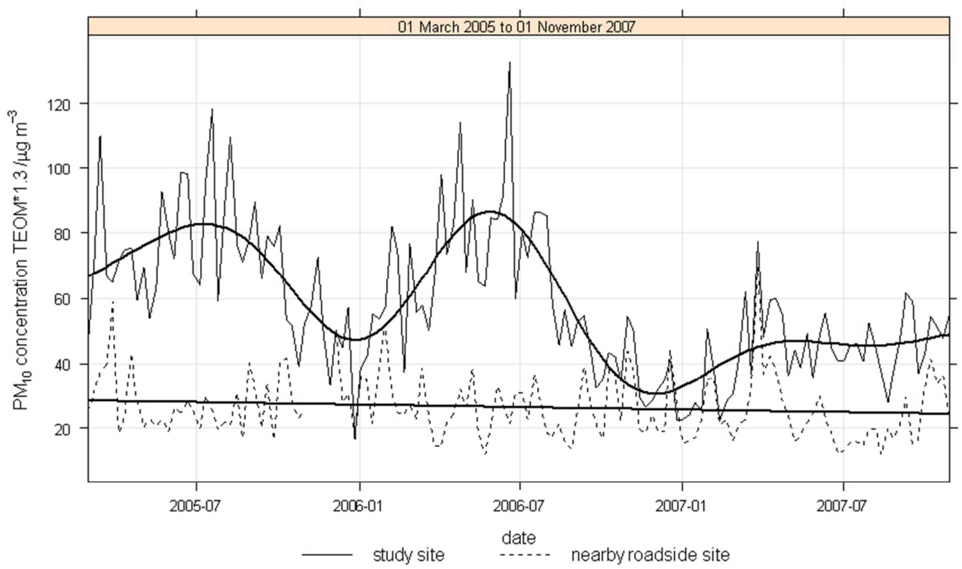

Figure 2: Weekly mean time series plot of PM10 concentrations with smoothed trend line at the EA8 monitoring site. Concentrations from a nearby roadside site ('EA2') are shown for comparison (also with smoothed trend line).
313x195mm (72 x 72 DPI)

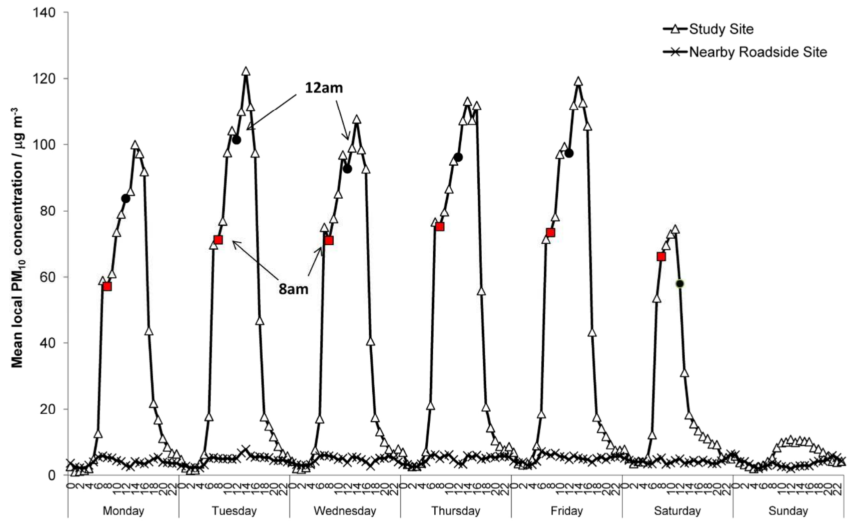

Figure 3: Diurnal variation in hourly mean local PM10 at the EA8 monitoring site, 1st Mar 2005 to 1st Nov 2007. Dips at 8am (squares) and noon (circles) have been highlighted. Local PM10 concentrations from a nearby roadside site ('EA2') are included for comparison.
209x148mm (300 x 300 DPI)

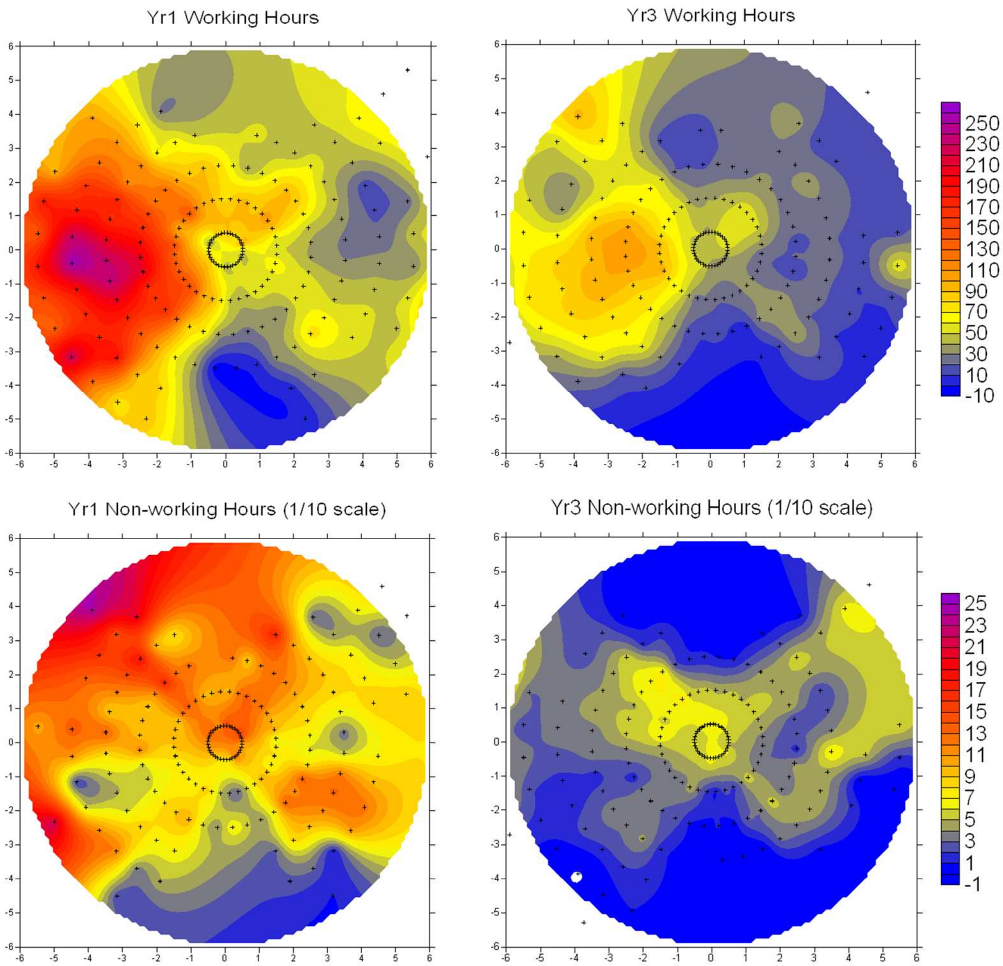

Figure 4: Bivariate polar plots showing mean local PM10 concentrations at the EA8 monitoring site. Wind speed in m s^{-1} is shown on the radial axis (0-6 m s^{-1}), wind direciton on the polar axis (0 to 350 decrees, 0 representing north), the colour scale indicates PM10 concentration in μg m^{-3}, grid points with available data are indicated with '+' symbols. Regions where no data are available, e.g. southerly winds >3 m s^{-1}) should be interpreted with caution.
466x452mm (72 x 72 DPI)

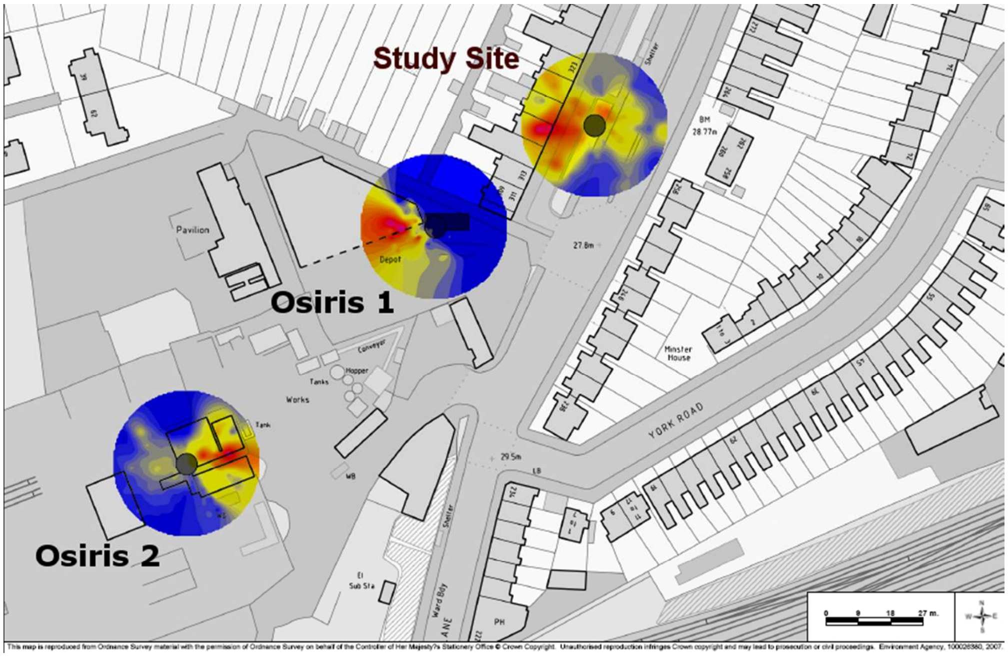

Figure 5: Polar plot results from the three monitoring datasets overlaid on area map. Note: for qualitative analysis only – monitoring methods, analysis periods and concentration scales differ between sites. Only 52 days data available from 'Osiris 1', therefore some wind conditions may be under represented.
321x208mm (72 x 72 DPI)

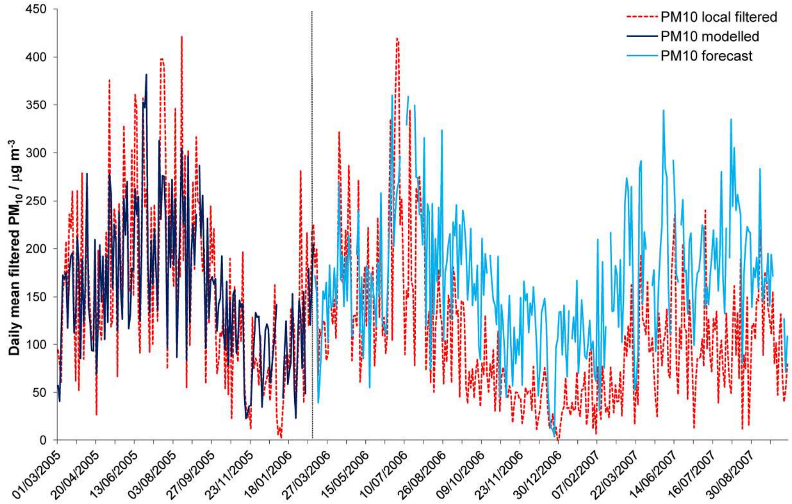

Figure 6: Measured, modelled and forecast local filtered PM10 concentrations at the EA8 monitoring site.
209x148mm (300 x 300 DPI)

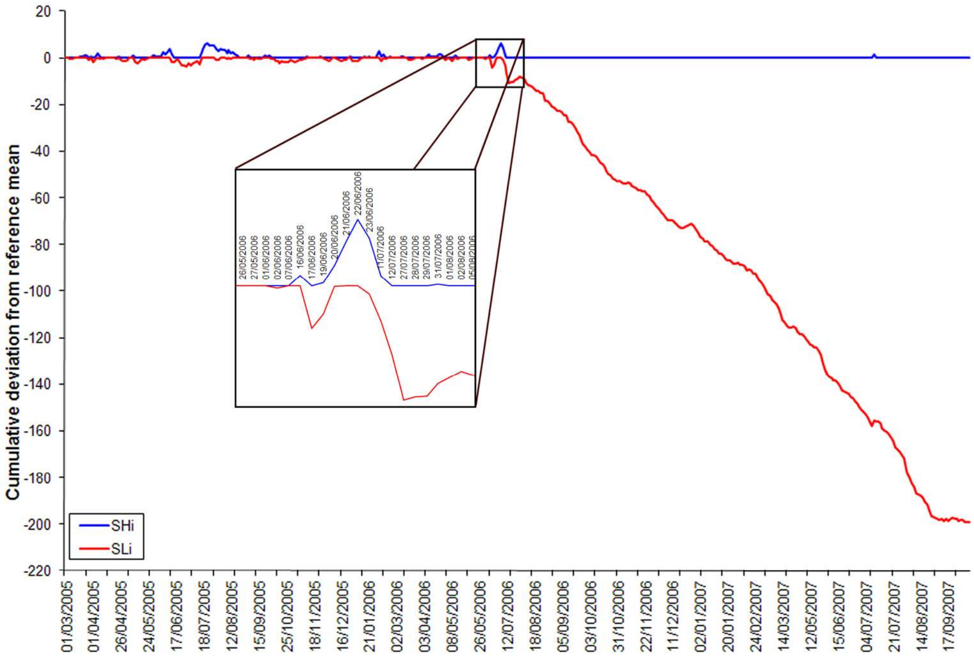

Figure 7: CUSUM plot of deviation from forecast filtered daily mean local PM10 at the EA8 monitoring site. SHi represents positive deviation, SLi represents negative deviation from the reference mean. Inset shows change point detail.
637x433mm (72 x 72 DPI)