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Forecasting Emergency Paediatric Asthma Hospital Admissions in Trinidad and Tobago: Development of a Local Model Incorporating the Interactions of Airborne Dust and Pollen Concentrations with Meteorological Parameters and a Time-Lag Factor

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Abstract

Respiratory diseases such as asthma and rhinitis are multifaceted disorders which are exacerbated by various factors including: gender, age, diet, genetic background, biological materials, allergens (pollen and spores), pollutants, meteorological conditions and dust particles. It is hypothesized that, the number of valid physician diagnosed cases of paediatric asthma, which has resulted in emergency room visits in Trinidad can be expressed as a function of the magnitude of pollen counts, particulate matter (PM10), and selected meteorological parameters. These parameters were used to develop a 7-day predictive model for paediatric asthma admittance. The data showed no obvious, strong correlations between paediatric asthma admissions and dust concentrations, and paediatric asthma admissions and pollen concentrations, when considered in isolation or in a linear fashion. However, using polynomial regression analysis, which looked at combinations of interactions, a strong 7-day predictive model for paediatric asthma admissions, was developed. The model was tested against actual data collated during the study period and showed a strong correlation ($R^2 = 0.85$) between the regression model and the actual admissions data.

Keywords

Pollen, Asthma, Paediatric, Saharan Dust, Asthma Forecast Model, Trinidad and Tobago

1. Introduction

Respiratory diseases such as asthma and rhinitis are multifaceted disorders that are exacerbated by interactions between several intrinsic and extrinsic factors. Intrinsic factors include: gender, age, diet, and genetic background, while extrinsic factors include exposure to environmental triggers such as: biological materials or allergens (pollen, and spores), air pollutants, meteorological conditions, dust particles and tobacco smoke [1] [2].

The prevalence of asthma in the Caribbean has reached epidemic levels, affecting as much as 30% of the population of some countries [3]. Increased incidence of asthma has been reported in Trinidad and Tobago [4] and Barbados [5]-[7], with a high prevalence of asthmatic symptoms among primary and secondary school students (13% - 25%) [5] [6] and rhinitis in more than 30% of the student population [4] [8]. This high prevalence is poorly understood, though it has been suggested that environmental factors may influence the development of allergic diseases in genetically predisposed individuals. Preliminary data from Trinidad have hinted at a higher prevalence among students attending schools in urban areas [4], which can be linked to deteriorating air quality in heavily trafficked urban areas [9].

Various studies have suggested that the prevalence of Saharan Dust and certain meteorological parameters, together with biological materials such as pollen and microorganisms may be major contributing factors to increased incidences of asthma [10]-[12]. Meteorological conditions may also contribute to the effect of aeroallergens on health with the abundance and specific types of spores and pollen differing according to meteorological conditions [2]. Moreno-Grau *et al.* (2000) [13] reported that high temperature, increased wind speed and more sunshine increase pollen release and dispersion, while high humidity decreases pollen counts. In Trinidad, Ivey *et al.* (2003) [12] also reported that asthma admissions increased during the rainy season (June to December). Although previous studies noted that atmospheric pollen concentration is reduced by precipitation, it was suggested that the increase in the admissions of asthma patients recorded during these wetter periods may be attributed to increased precipitation leading to hydration and subsequent rupturing of pollen grains. Airborne pollen itself can aggravate and exacerbate asthma and other respiratory diseases through the inhalation of the cytoplasm fragments which are released when the pollen grains become hydrated and rupture [14]-[20].

Regression models based on meteorological factors and dust as the predicators have been previously proposed for paediatric asthma. However, the predictability of these models based on R-squared values is generally low, averaging about 20 percent. This low predictability may be due to the influence of other factors such as environmental pollution, socioeconomic factors, genetic predisposition, pollen, and indoor pollutants such as dust mites and molds [1] [21]. In addition, the models proposed have focused on temperate areas and no models have yet been proposed for tropical regions. This study was therefore designed to examine the hypothesis that the number of cases of paediatric asthma in Trinidad is some function of the magnitude of local pollen counts,

dust (particulate matter 10 microns in diameter or less), and meteorological parameters. The model proposed in this study focused on some of the triggers known to influence asthma in the Caribbean.

2. Methods

Pollen samples were collected daily using a Burkard 7 Day Recording Volumetric Spore Sampler (Burkard Manufacturing Co., Rickmansworth, Hertfordshire, England) at St. Augustine and at a reference site on the east coast of Trinidad between March 2006 and November 2007 (Figure 1). Samples were collected 20 m above ground, with an air intake rate of 10 L/min, and within an arc from North East to South East, which represented the general wind direction for about 75% of the year [22] [23]. Melinex tape coated with silicone grease was used to trap pollen on the rotating drum of the Burkard sampler. After seven days, the tape was removed and segmented so that daily pollen counts could be made. Each section was mounted on a glass slide and Calberla's Stain was added, which is specific for staining pollen exine [22]. Pollen grains were
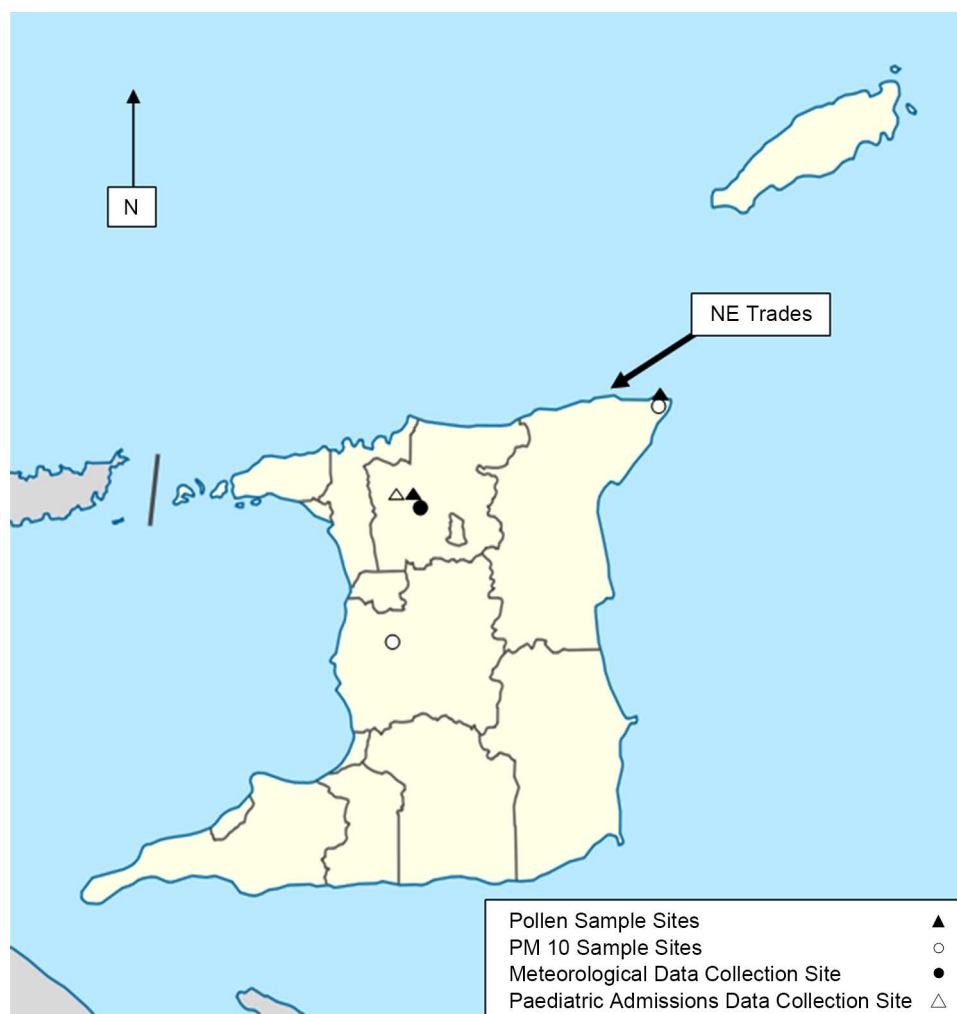
Figure 1. Pollen, Dust, Paediatric asthma admissions and meteorological data sample sites.

counted using a twelve transverse strip counting method, and pollen density was recorded as pollen grains/m^3/day [23]. Meteorological data (rainfall, relative humidity, temperature, and barometric pressure) were provided by the Trinidad and Tobago Meteorological Service located approximately 2 kilometers east of the sample site at St. Augustine. Dust data (PM10) was obtained from a national air monitoring station south of the sample site.

Paediatric asthma admission data for the period March 2006 to November 2007 were obtained from records at the Accident and Emergency Unit of the Eric Williams Medical Sciences Complex, St. Augustine. The population studied consisted of children between the ages 0 and 15 years who had been clinically diagnosed with mild, moderate, or acute asthmatic attacks, or acute bronchospasms. It was hypothesized that the number of valid Physician diagnosed cases of paediatric asthma, resulting in emergency room visits in Trinidad, is some function of the magnitude of pollen counts, particulate matter (PM10), and selected meteorological parameters.

Data Analysis

Paediatric asthma admissions, pollen, meteorological variables, and dust (PM10) were analyzed using the SYSTAT statistical package (version 12). Correlation analyses and time series plots were done to observe trends and relationships between the variables during the study period. Analyses of paediatric asthma admissions were conducted using the total data set, which was disaggregated by age group, sex, area, time of admission, and season. The combined effects of pollen, PM10, and meteorological predictors were examined using multiple regression analysis [24]-[26]. The model used was a seven-factor polynomial:

$$Y = constant + L + S + M + H + P + T + L^2 + S^2 + M^2 + P^2 + H^2 + T^2$$
$$+ LS + LM + LP + LH + SM \left(second\ order \right)$$

where the linear effects were represented by: L = Pollen counts, S = PM10, M = Wind Speed, H = Relative Humidity, P = Barometric Pressure, T = Difference between maximum and minimum temperature; L^2, S^2, M^2, P^2, H^2 and T^2 = the respective quadratic interaction effects; and LS, LM etc. represent the respective linear X interactions. Also included in the regression analysis were day of year and a three day moving average of asthma admissions [27]. Since predicator variables can be extensive and vary between patients, the forecast model focused on a few of the important, measurable predictors.

Individual data points were used to fit the model, by the polynomial regression procedure in the General Linear Model (GLM) module of the SYSTAT statistical package [28]. Checks were made for multicollinearity and residuals were examined for violations of the assumption of homogeneity of variances.

3. Results and Discussion

The association between meteorological variables, dust and airborne pollen concentrations and respiratory disorders such as asthma, can help to effectively manage the dis-

ease. The development of models therefore seeks to improve the prediction of increased occurrence of asthma by taking into account the fluctuations which may occur in pollen concentrations and climatic variables.

The concentration of pollen at the sample site in St. Augustine ranged between 6 to 520 pollen grains/m^3/day with an average of 69 pollen grains/m^3/day. Monthly averages typically ranged between 27 and 122 pollen grains/m^3/day. These values are higher than those reported by Negrini *et al.* (1992) [29] for *Parietaria* pollen count that resulted in allergic symptoms of rhino-conjunctivitis; Mild symptoms were registered with concentrations above 10 - 15 pollens/m^3/day while severe symptoms were reported when pollen count exceeded 80/m^3/day. Similarly, Rapiejko *et al.* (2007) [30] reported that grass pollen concentrations of 20 pollen grains/m^3 resulted in early allergic symptoms in patients. According to the asthma center [31], the values reported in this study can be classified as "very high" and may result in moderate to severe symptoms in persons with allergic responses.

Seasonal variation in pollen concentration was also observed. Significantly higher (p < 0.05) levels were detected in the wet season (June - December) (82 pollen grains/m^3/day) compared to the dry season (January - May) (53 pollen grains per cubic meter /day). Most of the pollen identified belonged to the families Pinaceae, Poacaeae, Asteraceae, Leguminosae and Urticaceae [32]-[34]. Pollen concentrations followed an annual cyclical pattern, with distinct peaks occurring during the wetter months of the year (from July to December) (**Figure 2**), which were consistent with reports by Blades *et al.* (2001) [10] who recorded peak pollen counts from September to October in Barbados, and Hurtado and Riegler-Goihman (1984) [35] who reported pollen peaks in November in Venezuela. However, it has also been suggested that pollen concentration may actually
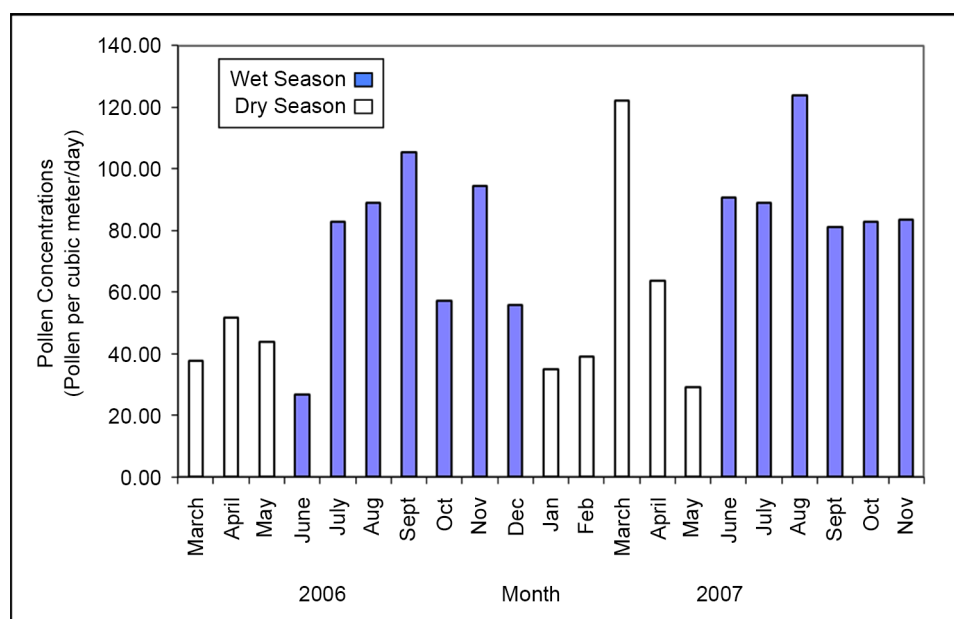
Figure 2. Pollen Concentration at the sample site in St Augustine showing peak levels July - November 2006 and June - November 2007.

decrease as rainfall and relative humidity increases [13] [36] [37]. During the wet season in Trinidad, there are occasional dry periods which may encourage anthesis of pollen. During these dry spells pollen may be released and remain suspended in raising warm air. As the air cools, the suspended pollen becomes grounded, increasing chances of exposure in persons predisposed to respiratory ailments.

Cecropia sp pollen was observed throughout the entire sample period and concentrations increased during the months which showed higher than normal total pollen counts (July - November). The correlation between pollen concentration at the St. Augustine site and wind direction (r = 0.03, p = 0.043), and inland (UWI) pollen and wind speed (r = −0.18, p = 0.001) was very low but statistically significant. Pollen concentration at the St. Augustine sample site was significantly higher than at the east coast reference site, where the mean pollen concentration was 2.6 pollen grains/m^3/day in the dry season and 10.2 pollen grains/m^3/day in the wet season. This would suggest that there was no additional significant contribution to pollen loads from other sources such as Saharan dust which influences the southern Caribbean annually.

Although pollen is often regarded as a major trigger for asthma, it is not the only contributing factor. During this study, it was observed that on days in which paediatric asthma admittance exceeded 10 cases, there was either dust present at concentrations of 30 μg/m^3 or higher during the preceding 0 to 5 days, or pollen at a level of 30 pollen grains/m^3/day or more during the preceding 0 to 4 days, or both, in the atmosphere. It is therefore possible that some threshold value exists for both variables, above which symptoms of asthma begin to appear. This is supported by Rapiejko *et al.* (2007) [30] who reported that the first symptoms in patients allergic to grass pollen became visible during exposure to a concentration of 20 pollen grains per cubic meter. The existence of a threshold level of dust that triggers emergency room visits has also been reported in Taiwan by Chan *et al.* (2007) [38].

Dust concentrations (measured as PM10) ranged between 0.5 and 467 μg/m^3, but was generally lower than the EPA's 24 hr criterion of 150 μg/m^3, for the maximum safe level of exposure (**Figure 3**). The highest dust levels generally occurred during the dry season (January - May) which coincided with the period of high influx of Saharan dust. Wind direction varied from the northeast to the southeast for more than 90% of the study period, and wind speed ranged between 1 to 13 km/h. Mean daily temperatures ranged from 25˚C to 29˚C, humidity from 60% to 97%, and barometric pressure from 1008 to 1017 mmHg. There was a low positive correlation between dust levels and meteorological parameters such as barometric pressure (R^2 = 0.02) and temperature (R^2 = 0.3). However, for humidity (R^2 = −0.37) and rain fall (R^2 = −0.11) there was a negative correlation, suggesting that both of these reduced the level of dust in the atmosphere. Weak positive correlations were also observed for other parameters including: wind speed (R^2 = 0.18), maximum temperature (R^2 = 0.19) and minimum temperature (R^2 = 0.19).

A total of 87,116 paediatric patients were admitted to the Eric Williams Medical Sciences Complex during the study period, about 9% of these were paediatric asthma
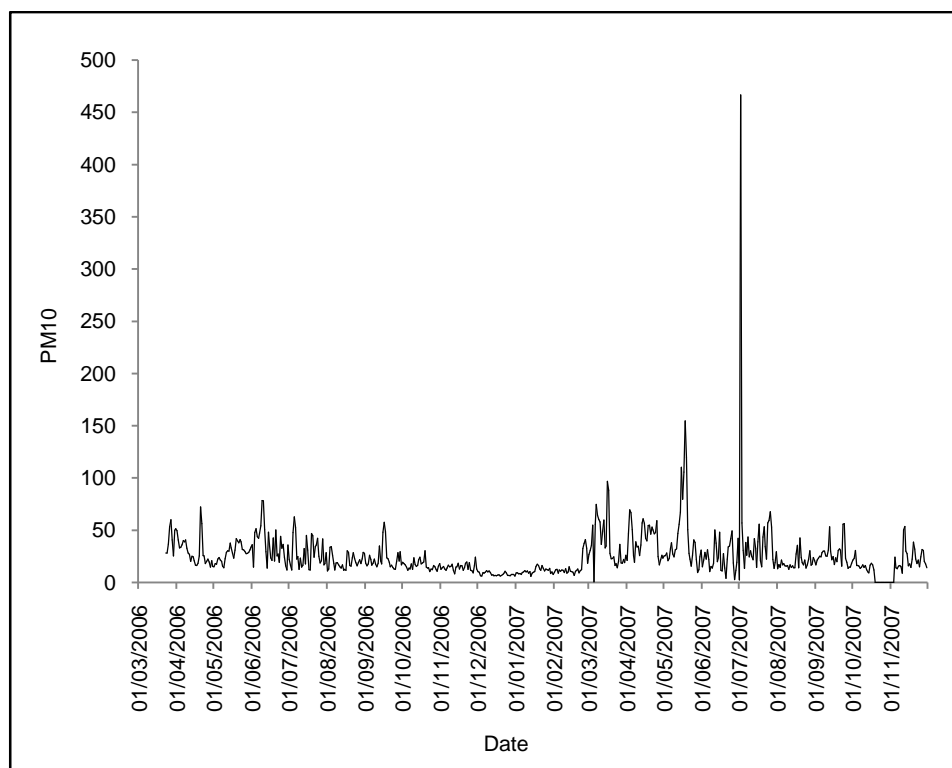
Figure 3. PM10 concentration throughout the study period.

patients. The total asthma admission rate ranged from 72 to 349 cases per month, with peak admissions occurring between September and November and January and March (**Figure 4**). The population cohort for this study consisted of children between the ages of 0 and 15 years. Generally, there was a decrease in paediatric asthma admittance with increasing age, in both the wet ($R^2 = 0.83$) and dry seasons ($R^2 = 0.89$). The percentage of male patients (63.6%) was significantly higher than that of female patients (36.4%) with an overall sex ratio of 1 female to 1.75 males. This gender bias was also evident across both seasons, with males accounting for 63.4% of the patients admitted in the dry season and 63.7% in the wet season. A linear decrease in admission with increasing age was also evident for both males ($R^2 = 0.87$) and females ($R^2 = 0.80$).

A time series plot by day for the relationship between pollen concentrations and paediatric asthma admissions is shown in **Figure 5**. It is evident that a short lag exists between the peak pollen concentration and peak asthma admissions. Further examination of the dust levels, local pollen concentration, and paediatric asthma admittance data, suggested that the lag period in paediatric asthmatic response was not fixed. Paediatric asthma admissions generally showed a low positive linear correlation with airborne pollen concentration ($R^2 = 0.05$) and a low negative correlation with dust concentration ($R^2 = -0.1$), though peak admissions usually coincided with periods of peak pollen (**Figure 4**). No significant correlations were found with individual meteorological parameters such as; humidity, pressure, temperature and rainfall. The low correlations may be due to the influence and interactions of all factors and a time lag which is not
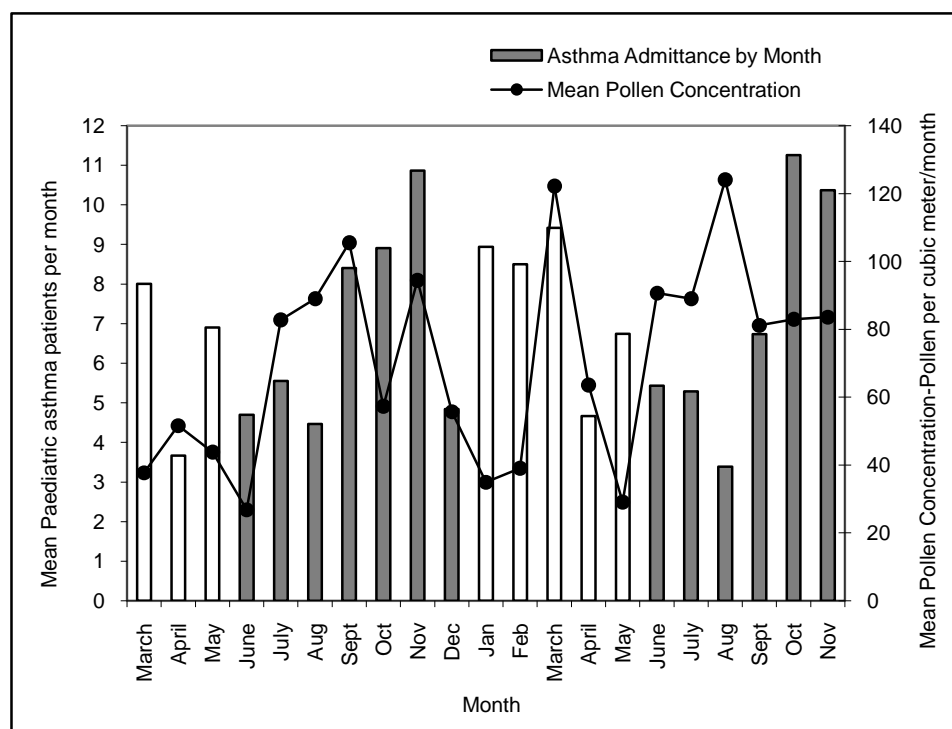
Figure 4. Mean monthly asthma admissions and pollen concentrations.
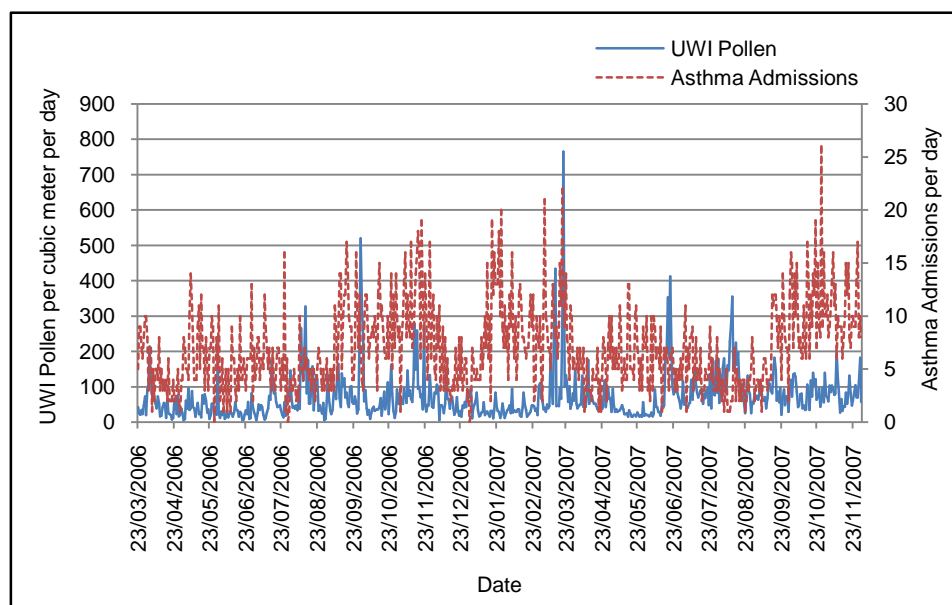
Figure 5. Time series by day of effect of UWI pollen concentrations on paediatric asthma admissions.

captured by a simple linear correlation. When paediatric asthma admissions exceeded 10 cases, the lag period between exposure to the dust and/or pollen irritants varied from 0 to 10 days, and this lag period decreased in the latter period of the year. On days in which paediatric asthma admittance exceeded 10 cases, there was either dust present

in concentrations of 30 µg/m³ or more in the preceding 0 to 5 days, or pollen was present at a level of 30 pollen grains/m³/day or more in the preceding 0 to 4 days, or there were high levels of both in the atmosphere. This suggested that these variables may influence the incidence of paediatric asthma, and also suggested the existence of a threshold level and a lag between exposure to the irritants and the onset of asthmatic symptoms. During the months of September, October and November, when daily admissions increased to more than 10, the pollen concentration in the preceding 0 to 2 days was always greater than 30 pollen grains/m³/day, even when dust was not present. Strong correlations between paediatric asthma admissions and dust level and individual variables were not observed when considered in isolation and in a linear manner. Therefore, a combination of factors including meteorological, pollen concentration, and dust concentration, together with a time variable, were included in the development of the predictive seven day forecast model for paediatric asthma admissions.

Peak asthma admissions do not always correspond directly with peaks in dust and pollen levels, but only became evident after a lag period. Mohammed *et al.* (2005) [39] previously reported a possible 5 to 7 day lag period in asthma admissions following periods of high Saharan dust influxes in Trinidad. During this study, the lag period appeared to be variable (1 to 10 days), suggesting that the sensitivity of patients may differ and the time taken between exposure and hospital admission may vary among patients. This lag may also be due to other factors such as social, economic, or personal choices. During October to December, there appeared to be a reduction in the lag period to between 1 and 4 days, which may be related to the higher levels of pollen detected during this period, and its interaction with the meteorological factors including rain fall, humidity, temperature and barometric pressure.

A weak but significant correlation exists between paediatric asthma admissions and the variables dust concentration, pollen concentration, and the metrological parameters, suggesting that the interaction between the variables may be complex and does not follow a general linear model. There were no strong positive correlations between meteorological variables and pollen concentration. However, various authors [12] [15] [36] have reported interactive associations between temperature and pollen concentration. This formed the justification for modeling the interactions using General Linear Model—Multiple Regression to include only variables showing significant correlations. This study reports a complex linear and quadratic interaction, between paediatric asthma admissions and various predictor variables including pollen, dust concentrations, and meteorological factors.

3.1. Regression Model for Paediatric Asthma Admissions

Asthma admittance (seven day moving average) was represented as a quadratic function of pollen counts, dust, temperature difference, minimum temperature, wind speed, relative humidity, barometric pressure, and the three day moving average of asthma admittance. Several combinations of interactions between the predictors and the response (paediatric asthma admissions 7 day moving average) were chosen based on the

literature [2] [12] [15] [16] [27] and the possible effect the predictor may have had on paediatric asthma admittance, as a single interaction, a quadratic interaction, and in combination with other predictors. The variables used as predictors and response variables included: PM (μg/m^3)—particulate matter 10 microns of less in diameter; WS (knots)—wind speed; T Diff (°C)—temperature difference; RH (%)—relative humidity; BP (hPa)—barometric pressure; U (pollen/m^3/day)—inland (UWI) pollen count; D—day of the year; A3 (paediatric asthma admissions/day)—represented paediatric asthma admissions with a three day moving average; A7 (paediatric asthma admissions/day), represented paediatric asthma admissions with a seven day moving average; U3 (pollen/m^3/day)—represented inland (UWI) pollen with a three day moving average; and U7 (pollen/m^3/day), represented Inland (UWI) Pollen with a seven day moving average.

A three day moving average was used to accommodate a lag in admissions. A three day moving average was also included as a predictor variable on the assumption that the effect on paediatric asthma admissions on the seven day moving average would be an additive effect on present paediatric asthma occurrence. This is because persons would take some time to exhibit symptoms after exposure to the antigen, and also the decision to be admitted to hospital would be after the person was perceived to be ill enough to require emergency treatment. The combinations of interactions used in the Stepwise Multiple Regression included the following (Equation (1)):

$$
\begin{aligned}
A7 = {}& PM + PM * PM + U + U * U + WS + WS * WS + T\,Diff + TDiff * TDiff \\
& + BP + BP * BP + RH + RH * RH + U * PM + U * WS + U * TDiff \\
& + U * BP + U * RH + PM * WS + D + A3
\end{aligned}
\tag{1}
$$

The model derived (Table 1 & Table 2) is given by Equation (2):

$$
\begin{aligned}
A7 = {}& PM3.60 - 0.15PM - 0.5WS + 0.82A3 + 0.02TDiff - 0.11RH * RH \\
& - 0.23BP * U + 0.32RH * U + 0.08WS * U + 0.07WS * PM
\end{aligned}
\tag{2}
$$

$$
S = 0.16; \; R^2 = 84.7\%; \; R^2(adj) = 84.5\%
$$

The model was tested against the actual data collated during the study period and showed a strong correlation ($R^2 = 0.85$) between the regression model and the actual admissions data (Figure 6).

3.2. Regression Model for Inland Pollen

In the formulation of a regression model for pollen concentration, the three day moving average was also included as a predictor variable on the assumption that the seven day moving average of pollen concentration in the atmosphere would be an additive effect of present pollen concentrations in addition to it being a function of other factors. The combinations of interactions used included pollen concentration with a moving average of three days as well as linear and quadratic combinations of meteorological variables derived from the literature. A three day moving average was used to accommodate a lag in pollen concentrations in the atmosphere because there would be a time delay between anthesis, and the effect of the meteorological variables, on the pollen

Table 1. Table showing general linear model determination for 7 day forecast paediatric asthma admissions model. Regression Coefficients B = (X'X)$^{-1}$X'Y.

Effect	Coefficient	Standard Error	Std. Coefficient	Tolerance	t	p-value
CONSTANT	3.62	0.93	0.00	.	3.87	0.000
PM 10 (μg/m^3)-particulate matter	−0.15	0.06	−0.24	0.03	−2.58	0.010
WS (knots)-wind speed	−0.53	0.17	−0.63	0.01	−3.65	0.000
A3	0.82	0.02	0.90	0.92	53.65	0.000
T DIFF*T DIFF (˚C)	0.02	0.01	0.04	0.64	2.16	0.032
RH*RH (%)	−0.11	0.04	−0.19	0.05	−2.60	0.010
BP(hPa)*U (pollen/m^3/day)	−0.23	0.06	−3.07	0.00	−3.56	0.000
RH (%)*U (pollen/m^3/day)	0.32	0.10	2.79	0.00	3.30	0.001
WS (knots)*U (pollen/m^3/day)	0.08	0.02	0.42	0.02	3.28	0.001
WS (knots)*PM 10 (μg/m^3)	0.07	0.03	0.38	0.01	2.63	0.009

Table 2. Analysis of variance for 7 day forecast paediatric asthma admissions model.

Source	Type III SS	df	Mean Squares	F-ratio	p-value
Regression	78.97	9	8.78	361.01	0.00
Residual	14.24	586	0.02		
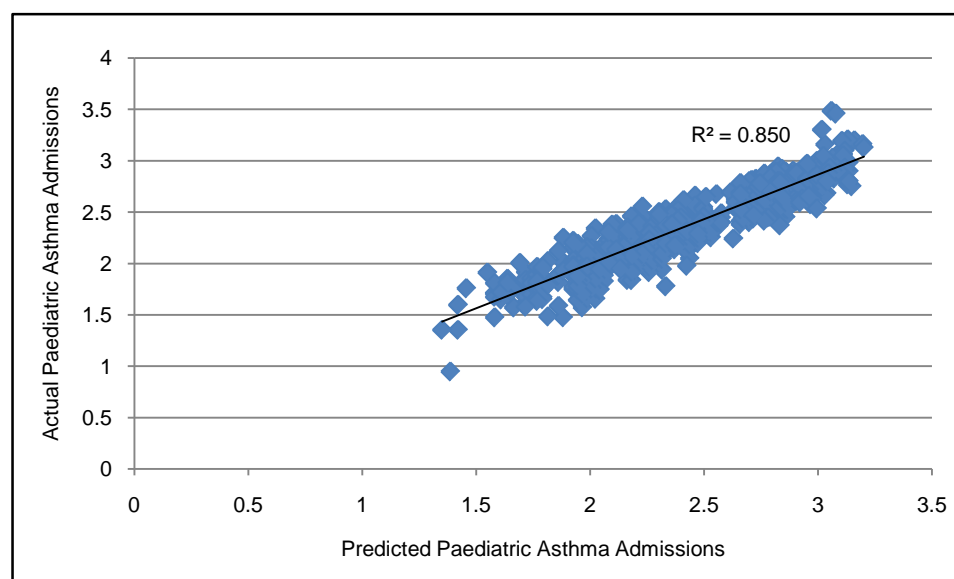
Figure 6. Graph showing seven day forecast model for paediatric asthma admissions actual vs. predicted values.

becoming suspended in the atmosphere. The combinations of interactions used in the Stepwise Multiple Regression included the following (Equation (3)):

$$U7 = \text{Day of the year} + U3 + MaxT + MaxT * MaxT + MinT + MinT * MinT$$
$$+ AvT + AvT * AvT + WS + WS * WS + R + R * R + RH + RH * RH \qquad (3)$$

The model derived is given by Equation (4):

$$U7 = 1.94 + 0.73MinT - 0.93AvT + 0.74U3 - 0.03WS * WS \qquad (4)$$

$$S = 0.27; \ R^2 = 77.0 \ \%; \ R^2(adj) = 76.9\% \ P = 0.000$$

where: PM ($\mu g/m^3$)—particulate matter 10 microns of less in diameter; R (mm)—rain fall; WS (knots)—wind speed; TDiff (˚C)—temperature difference; RH (%)—relative humidity; BP (hPa)—barometric pressure; U (pollen/m^3/day)—inland (UWI) pollen count; D—day of the year; A3 (paediatric asthma admissions/day)—represented paediatric asthma admissions with a three day moving average; A7 (paediatric asthma admissions/day), represented paediatric asthma admissions with a seven day moving average; U3 (pollen/m^3/day)—represented inland (UWI) pollen with a three day moving average; and U7 (pollen/m^3/day), represented Inland (UWI) Pollen with a seven day moving average. All outliers identified by SYSTAT were removed in the development of the model. The model was tested against the actual data collated during the study period and showed a strong correlation ($R^2 = 0.75$) between the regression model and the actual pollen concentrations (Figure 7).

The regression models developed for paediatric asthma and pollen concentration were designed to forecast future levels of both atmospheric pollen concentrations and paediatric asthma admissions. The variables selected for the forecast models are consistent with triggers responsible for exacerbating paediatric asthma [12]. High temperature and wind could increase concentrations of atmospheric pollen, because temperature affects the dehiscence of the anthers, and wind aids in the dispersal of the pollen. Wind is also an important contributor to increased asthma admissions as it aids in the
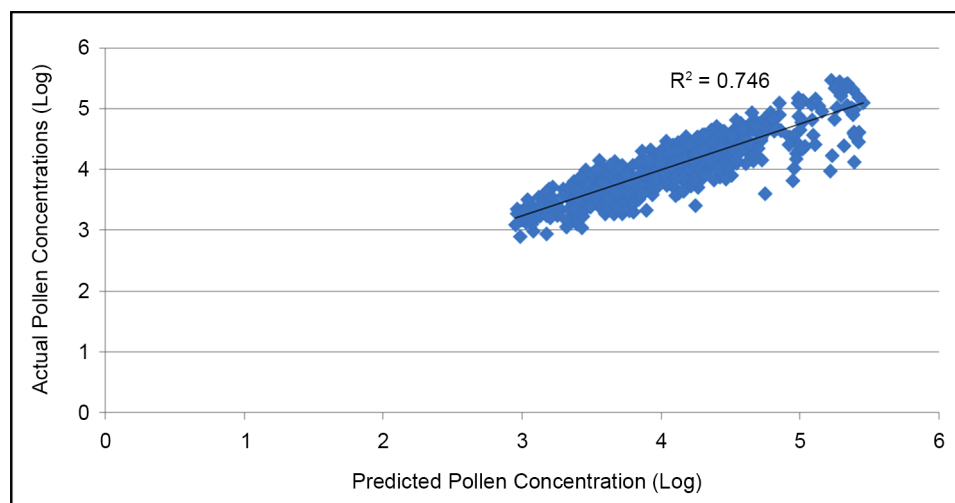
Figure 7. Graph showing seven day forecast model for inland (UWI) pollen concentration actual vs. predicted values.

dispersal of pollen in the atmosphere. The model suggests the interaction of wind speed, barometric pressure and relative humidity, with pollen concentration, and high wind speed and dust, may result in higher airborne concentrations of these irritants, further enhancing the effect of these irritants on the asthmatic patient.

Regression models which use meteorological factors, and dust to determine paediatric asthma occurrence have been proposed by other researchers. However, the predictability of these models was less than 20 percent, because they often did not take into consideration the complex interaction between variables and the influence of other contributing factors [1] [21]. It is difficult for a forecast model to fully capture all variables because these are extensive and vary between patients, hence the proposed model focused on only a few measurable predictors. The proposed 7-day paediatric asthma admittance model (Equation (2)) considered the predicator variables: pollen concentration, dust concentration, day of year, temperature difference, wind speed, barometric pressure, relative humidity, and the three day paediatric asthma lag in the transformed state, which seemed to enhance its predictability (R^2 = 0.85). This was based on the assumption that future paediatric asthma occurrence is a cumulative effect of the present state of paediatric asthma occurrence, in combination with external factors. Lag periods were also included in the model to take into account the incubation time before the onset of symptoms.

$$A7 = 3.60 - 0.15PM - 0.5WS + 0.82A3 + 0.02TDiff - 0.11RH * RH$$
$$- 0.23BP * U + 0.32RH * U + 0.08WS * U + 0.07WS * PM \tag{2}$$

The paediatric asthma admittance for 85% of the variance expressed as a seven day lag prediction is an interaction of a constant minus 0.15 of the dust concentration minus 0.5 of the wind speed plus 0.82 of the three day lag of paediatric asthma admissions, plus 0.02 of the temperature difference minus 0.11 of the square of the relative humidity minus 0.23 of the interaction between barometric pressure and pollen plus 0.32 by the interaction between relative humidity and pollen plus 0.08 by the interaction of wind speed and pollen plus 0.07 by the interaction of the wind speed and dust.

The pollen forecast model (Equation (4)) included predicators maximum temperature, minimum temperature, average temperature, wind speed, rainfall, relative humidity, day of year and a three day pollen moving average in a transformed state

$$U7 = 1.94 + 0.73MinT - 0.93AvT + 0.74U3 - 0.03WS * WS \tag{4}$$

Present pollen concentrations were included in the model with the rationale that future pollen concentration will have an additive effect on the present concentrations, in combination with external factors such as meteorological factors. In the pollen forecast model the relationship between the individual variables and pollen concentration was both linear and quadratic. The pollen concentration for 77% of the variance expressed as a seven day lag prediction is an interaction of a constant plus 0.734 of the minimum temperature, and 0.741 of the three day moving average of paediatric asthma admissions, minus 0.933 of the average temperature and 0.027 of the square of the wind speed. Wind speed is a quadratic variable which shows that two consecutive days of

high winds enhances atmospheric pollen concentration. The meteorological predictors of minimum temperature, average temperature, and wind speed in the forecast model are consistent with literature that shows that temperature and wind play a key role in the release of pollen. Temperature is related to the anther dehiscence which expels pollen into the atmosphere. Wind is an important mechanism for the pollen to be wafted from the anther into the atmosphere [16]. The association between asthma, dust and other triggers builds on previous work by Gyan *et al.* (2005) [11]; however, it is not consistent with work in Barbados by Prospero *et al.* (2008) [40] who found there were no substantial changes in paediatric asthma admittance that could be linked to short term increases in dust concentration. However, they suggested that African dust may constitute a health threat of a different nature, producing symptoms less obvious than those of asthma. Prospero *et al.* (2008) [40] may not have found an association since they did not take into consideration thresholds or a lag phase that may be associated with dust and asthmatic symptoms as noted by Chan *et al.* (2007) [38] in Taiwan. Prospero *et al.* (2008) [40] also excluded the interaction of dust with other existing asthma triggers such meteorological parameters and pollen.

Paediatric asthma also seems to be influenced by age and gender, with the highest incidences in the early paediatric years followed by a linear decrease with age in both males and females. Males also had a higher admittance rate than females, which is consistent with previous work in Trinidad [11]. It was also interesting to note that peak admissions occurred during the time period from 6 am to 12 noon followed by the period from 6 pm to 12 midnight. Admittance to hospital is a function of a number of factors including locality, severity of the attack, convenience, and time of day. These, together with the time taken for symptoms to become apparent, contribute to the lag period between a peak event and peak admissions. Peak paediatric asthma admittance was highest during September to November, which was also consistent with data from Monteil *et al.* (2000) [41]. They noted that apart from the association between dust level and asthma admissions, there were increases in asthma admissions during the non Saharan dust periods of the year, specifically in the latter part of the year during September to December. They also suggested it is likely that Saharan Dust cover does not have a role in this large increase in asthma admittance. This unexplained peak in asthma reported by Monteil *et al.* (2000) [41] which occur during September to November corresponds to the peak in pollen levels during the wet season from June to December. This, together with the thresholds observed and the lag period discussed earlier, suggest that local pollen levels play a role in the exacerbation of paediatric asthma symptoms during September to November. Paediatric asthma admissions also showed a sharp increase during December to January, April to May, and August to September. December, April and August are periods of vacation from school for children. Schools reopen in the months of January, late April/early May and September respectively. This suggests that the spikes observed in paediatric asthma admissions, apart from being influenced by the environment, also have a social component. Chavarria (2001) [42] also reported an increase in asthma admissions in Costa Rica in March and August imme-

diately after children returned to school. They suggested that students are more exposed to viral illnesses when in contact with larger student populations, and therefore viral illnesses, which may act as an asthmatic trigger, increase at the start of the new school term, and consequently asthma admissions also increase. The impact of stress on asthmatic patients may also be associated with increases in asthma admittance. As the new school term begins, children are placed under higher levels of stress, which may act as a further trigger for asthma symptoms. This suggestion requires further study to accurately interpret these trends.

4. Conclusion

The predictors in the forecast models are consistent with the literature which shows that dust pollen and meteorological factors play a role in exacerbating paediatric asthma. The model suggests that parameters such as wind speed, barometric pressure and relative humidity, may result in higher airborne concentrations and dispersal of irritants such as pollen and dust which can further exacerbate asthma. Furthermore, asthma studies cannot focus on a single trigger, but rather take into consideration the interactions between multiple parameters.

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