Effects of San Diego Wildfire on Ambient Air Quality and Health of San Diego Residents

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ABSTRACT

Gaseous and particulate pollutants emitted by the wildfire of October 2003 on ambient air quality and health of San Diego residents before, during, and after the fire are analyzed using data available in San Diego County Air Pollution Control District and California Air Resources Board. It was found that $PM_{2.5}$ levels exceeded the federal daily 24-hour average standard during the fire. Although there was a slight increase in some of the gaseous pollutants, none exceeded federal standards. Ozone precursors, such as total hydrocarbons and methane gasses, experienced elevated concentration during the fire. However, the absence of sunlight due to the cloud of thick smoke that covered most of the county during the fire appear to have not allowed photochemical conversion of the precursor gasses to harmful concentration of ozone. The increased particulate matter concentration above the federal standard resulted in significant increase in hospital emergency room visits for asthma, respiratory problems, eye irritation and smoke inhalation.

Background

San Diego, county encompasses 4300 square miles and includes a mixture of urban and rural communities, from coast to mountains and desert. San Diego County has been successful in achieving federal air quality standards for criteria pollutants for majority number of days for the past seven years. Around October, the region experiences persistent dry weather and low moisture that create conditions conducive for fire that are reinforced by Santa Ana winds, This weather pattern prevails throughout much of the southwestern part of the country during the beginning of the fall thereby creating condition for wildfires. In October 2003 alone, Southern California was besieged by the most disastrous wildfires in the state's history; the fires that occurred in San Diego, mainly, took place in three different locations. The Santa Ana winds took the fires towards the west directly into wild vegetations and the residential areas. San Diego fire consumed an area of over 390,000 acres, burned 5,597 homes, commercial and accessory buildings, and destroyed 3,773 automobiles, trucks and boats (County of San Diego, 2003) and caused 16 deaths directly attributable to the fire (Downey, 2003). The Fire released approximately 300,150 tons of particulate matter and other pollutants to the atmosphere (Clinton et al, 2003). The purpose of this research project is to

evaluate the amounts and effects of major gaseous pollutants and particulate matter emitted into the ambience of San Diego County by the wildfire of October 2003 and establish correlations between pollutant levels in the region and resultant health problems experienced by the county citizenry using the medical surveillance report compiled in collaboration with area hospitals.

Literature Review

Biomass burning and wildfires emit a substantial amount of gaseous pollutants and particulate matter to the environment, and is responsible for respiratory illnesses if exposed to certain concentration levels depending upon individual sensitivity, physiological characteristics and susceptibility. There have been growing concerns about the adverse effects of air pollution on birth outcomes, such as low birth weight (LBW), intrauterine growth retardation (IUGR), preterm births and birth defects (Bobak and Leon, 1992; Dejmek et al., 1999; Bobak, 2000; Ritz et al., 2002). PM_{10} exposure in the second and fourth months has been associated with LBW (Ha et al., 2003). Particulate air pollution has been associated with both acute and chronic exacerbation of childhood asthma. More chronic symptoms of bronchitis have been observed in previous cross-sectional studies of children with asthma exposed to PM (Heinrich et al., 2000; Dockery et al., 1996; Dockery et al., 1989; Braun-Fahrlander et al., 1997; McConnell et al., 1999; Jedrychowski and Flak, 1998). Wildfire smoke is comprised of a complex mixture of particles, liquids, and gaseous compounds. These include particulate matter (PM_{10}), carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2), oxidants that may include small amounts of ozone (O_3), and polycyclic organic material (Ward and Smith, 2000) and toxic pollutants.

Particulate matter is the pollutant that has most consistently been associated with short-term effects on mortality (Le Tertre et al., 2002). Recent findings tend to relate particulate pollution to an increased plasma viscosity (Peters et al., 1997), increased risks of heart rate (Pope et al., 1999), electro-cardio-graphic changes in humans (Pope CA III et al., 1999; Liao, 1999; Gold, 1999) and the triggering of myocardial infraction (Peters et al, 2001). Several studies have indicated that the smaller particles, which are less than 2.5 micrometer in diameter, are mainly responsible for the above effects (Le Tertre et al., 2002). Each 10 microgram per cubic meter increase in fine particulate air pollution is associated with approximately a 4%, 6%, and 8% increased risk of, cardiopulmonary and lung cancer mortality, respectively (Pope et al, 2002).

Time series and panel studies have shown acute increases in ambient PM to be associated with increases in emergency room visits (Norris et al., 1999) and hospital admissions for asthma (Pope, 1991; Atkinson et al., 2001), and acute symptoms (Pope et al., 1991; Romieu et al., 1996; Delfino et al., 1998; Vedal et al., 1998; Yu et al., 2000) and medication use (Pope et al., 1991; Delfino et al., 1998), and a decline in PEF rates (Pope et al., 1991; Romieu et al., 1996; Vedal et al., 1998). On average, there was a 1-1.5 day lag between the fire event and the increased emergency room (ER) visits and in-patient admissions for asthma (Zweiman, 2001).

CO emission from fires coupled with carbon dioxide and methane has been found to be a significant source of greenhouse gases. Besides CO, nitrogen oxides (NOx) can also form at lower temperatures though the amount primarily depends on the nitrogen content of the fires burnt. Fires also emit a large amount of semi volatile organic compounds, which are partitioned between the gaseous and liquid or solid phase at ambient temperatures, and some VOCs are carcinogenic, and can condense or be adsorbed into the surface of the particulate. Particulate matter comprises of a complex mixture of soot, tars, and volatile substances (Ward and Smith, 2000). $PM_{2.5}$ is becoming more commonly measured during fire related incidents because since the fine fraction predominates in the smoke and haze and it is thought to be more responsible than larger particles for the observed health effects (Zhang and Morawska, 2001, Chow et al., 2002).

Methodology

San Diego Air Pollution Control District (APCD) has established nine air monitoring stations strategically located to evaluate pollution levels that affect the county residents (Figure 1). Each station monitors specific pollution levels borne by sources pertaining to the area, such as stationary and mobile sources (Table 1).

Figure 1. San Diego Air Pollution Control District Chosen Monitoring Stations

STATION	POLLUTANT MEASURED
Alpine – Victoria Drive	Ozone, Nitrogen Dioxide, Nitric Oxide, Nitrogen Oxides, PM_{10}
Camp Pendleton	Ozone, Nitrogen Dioxide, Nitric Oxide, Nitrogen Oxides

Chula Vista	Ozone, Nitrogen Dioxide, Nitric Oxide, Nitrogen Oxides, PM_{10}, $PM_{2.5}$
Del Mar – Mira Costa College	Ozone
El Cajon – Redwood Avenue	Ozone, Nitrogen Dioxide, Nitric Oxide, Nitrogen Oxides, PM_{10}, $PM_{2.5}$, Methane, Non Methane Hydrocarbon, Total Hydrocarbon
Escondido – East Valley Parkway	Ozone, Nitrogen Dioxide, Nitric Oxide, Nitrogen Oxides, Carbon Monoxide, $PM_{2.5}$
Otay Mesa – Paseo Internacional	Ozone, Nitrogen Dioxide, Nitric Oxide, Nitrogen Oxides, Carbon Monoxide, Sulfur Dioxide, PM_{10}
San Diego – Twelfth Avenue	Ozone, Nitrogen Dioxide, Nitric Oxide, Nitrogen Oxides, Carbon Monoxide, Sulfur Dioxide, PM_{10}, $PM_{2.5}$
San Diego – Overland Avenue	Ozone, Nitrogen Dioxide, Nitric Oxide, Nitrogen Oxides, Methane, Total Hydrocarbon, PM_{10}, $PM_{2.5}$

Table 1. Pollutants monitored by the nine monitoring stations in the San Diego APCD.

To assess the impact of the pollutants emitted by the San Diego Wildfire, a four-week baseline surveillance period before the start of fire (October 25, 2003), a ten-day period of fire, and a four-week period immediately after the fire was established for post-fire surveillance. For the purpose of analysis, data was primarily obtained from two urban and one remote monitoring locations: Downtown San Diego, Escondido, and Alpine. Downtown San Diego and Escondido are heavily urbanized with a high density of vehicular population. Alpine is a remote city in a mountainous location about 50 miles east of the city of San Diego. Average daily, one- hour maximum and eight-hour maximum readings were referenced for analyzing the resultant effects of gaseous pollutants while standard and local conditions for particulate matter was noted for the purposes of this study. Contributions by ozone precursors, such as total hydrocarbons (THC), methane (CH_4), non-methane hydrocarbons (NMHC) were analyzed to determine the behavior of the major pollutants.

Before October 1, 2003, San Diego APCD was using the Federal Reference Method (FRM) samplers to collect $PM_{2.5}$ data for forecasting and recording purposes. The FRM is based upon statistical analyses of filter samples collected at the five monitoring stations located throughout the county. These five stations are located in downtown San Diego (Twelfth Street), Chula Vista, El Cajon, Kearny Mesa (Overland Avenue), and Escondido. When San Diego APCD became part of the national forecasting program on October 1, 2003, district meteorologists rely on data collected from the two $PM_{2.5}$ Beta Attenuation Monitors (BAM) samplers for real-time data reporting and forecast verification. Statistical analysis of the FRM data did not show sharp gradients across the county or radical departures from mean conditions. As a result, the two BAM samplers were thought to be adequate for ambient conditions expected in the county. These two BAM samplers are located at the downtown San Diego and Escondido monitoring stations. The only real time PM_{10} Tapered

Element Oscillating Microbalance (TEOM) sampler is located in Alpine monitoring station. Meteorological data were provided by the District's Radar Wind Profilers (RWP) and the Radio-Acoustic Sounding Systems (RASS) located in Miramar and Point Loma areas.

Medical Surveillance Methods

Health effects to county residents were assessed through the efforts of San Diego County Public Health and Human Services. On Tuesday, October 28, 2003, in response to the fires, smoke and circulating ashes, a fire related surveillance process was developed and by Thursday, October 30, 2003, each of the 19 emergency departments in the county (2 Navy Hospitals were excluded from this surveillance) were asked to participate in this fire-related surveillance. A three-week surveillance period was established, including one week of baseline (pre-event), and two weeks following the fires. Since this surveillance was conducted during the fires, the intent was to capture critical information from a limited time period to quickly assess the impact of the fires. A number of potential fire related indicators were identified as categories including asthma, bronchitis or emphysema, other respiratory conditions with no fever, eye irritation, smoke inhalation, burns, chest pain or cardiac arrests, diarrhea. The total number of visits made by patients to the hospital was also considered. Each hospital was asked to provide necessary data to support these surveillance activities.

Results

Data on pollutants between the period of September 28 and December 6, 2003 from Escondido, Downtown (Twelfth Avenue), Kearny Mesa (Overland Avenue), and Alpine Monitoring Stations were analyzed. The Escondido and Downtown Stations provided gaseous pollutants and $PM_{2.5}$ data. The PM_{10} data from Alpine Station and gaseous pollutant data from Kearny Mesa Station along with meteorological data recorded by San Diego APCD's Radar Wind Profilers and Radio Acoustic Sounding Systems located in Miramar and Point Loma were anlayzed. Statistical analysis of medical surveillance data compiled by San Diego County Health and Human Services Agency in collaboration with area hospitals was utilized to establish correlations between pollutant levels in the region and resultant health problems experienced by the county citizens.

Particulate Matter

Particulate Matter, 2.5 μ ($PM_{2.5}$)

The $PM_{2.5}$ trend during the observation period is shown in Figure 1. In the Escondido Station during the fire, the $PM_{2.5}$ Federal EPA limit of 65μg/m^3 was exceeded on October 27, 2003. This measurement was recorded by Federal Reference Method (FRM) monitor. The recorded readings during the time period before and after the fire episode did not exceed the Federal EPA limit. The data plot before and after the fire episode reveals a consistent trend.

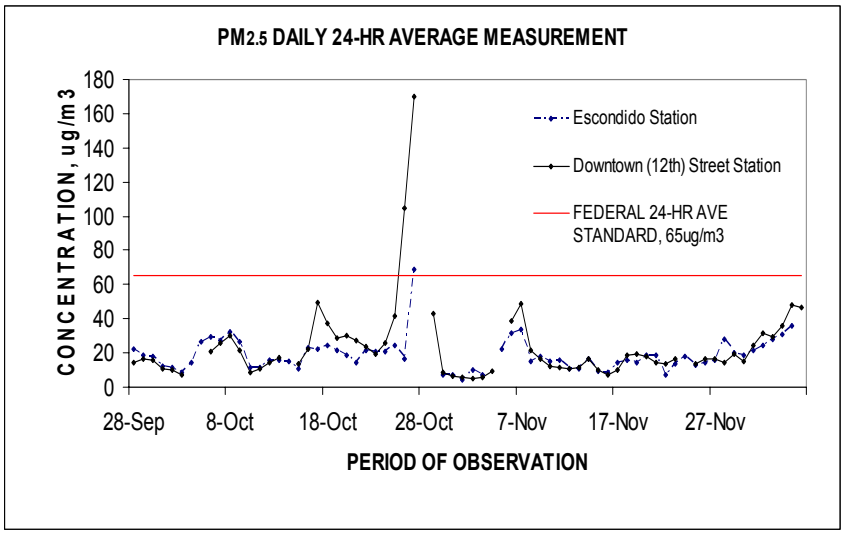

Figure 1. $PM_{2.5}$ measurements during the surveillance period.

The $PM_{2.5}$ trend during the observation period in the Downtown Station is shown in Figure 1. During the fire episode on October 26, 2003, the first full day of the fire, $PM_{2.5}$ daily 24-hour average measurement rose sharply to 104.6µg/m3. On October 27, 2003, $PM_{2.5}$ daily 24-hour average measurement recorded was more than 2.5 times the Federal EPA limit at 170µg/m3. However, similar to the Escondido Station, the Federal limit was not exceeded during the surveillance period, the period before and after the fire episode. The data plot revealed consistent trend before and after the fire episode.

Particulate Matter, 10 µ (PM_{10})

The Alpine Station monitors real time PM_{10} particulate matter using the Tapered Element Oscillating Microbalance (TEOM) monitor. Based on the PM_{10} trend measurement for the Alpine Station it was evident that there was no real time measurement recorded between October 27 and November 2, 2003 because power supply to the Alpine monitoring station was interrupted by the fire. Just before data recording was lost the trend was steadily increasing although it did not reach the maximum 24-hour average Federal standard of 150µg/m^3. However, Federal Reference Method (FRM) PM_{10} measurement from the Escondido Station recorded 179 µg/m^3 on October 29, 2003. This level exceeded the Federal maximum 24-hour average limit. Therefore, it could be inferred that if the Alpine real time monitor was functional at that time it would have recorded a much higher concentration due to its close proximity to the fire. Real time measurement indicated unusually high concentration of PM_{10} particulate matter on November 23 and 27, 2003 at 294µg/m^3 and 184µg/m^3, respectively. This was due to the Santa Ana wind condition during that time frame. The strong offshore wind direction stirred and carried the ashes deposited in the burned areas.

Gaseous Pollutants

Three gaseous pollutants namely ozone (O_3) carbon monoxide (CO) and nitrogen dioxide (NO_2) were analyzed in Escondido and Downtown (Twelfth Street) Stations based on data recorded by the stations' monitoring equipment. No data were available between October 25 to 28, 2003, the period when the fires were burning.

Ozone (O_3)

Ozone trend during the observation period is shown in Figure 2. Throughout the surveillance period the Federal 1-hour ozone concentration of 0.12 ppm was not exceeded. The trend showed a relative decrease in concentration after the start of the fire and continued until the end of the surveillance period.

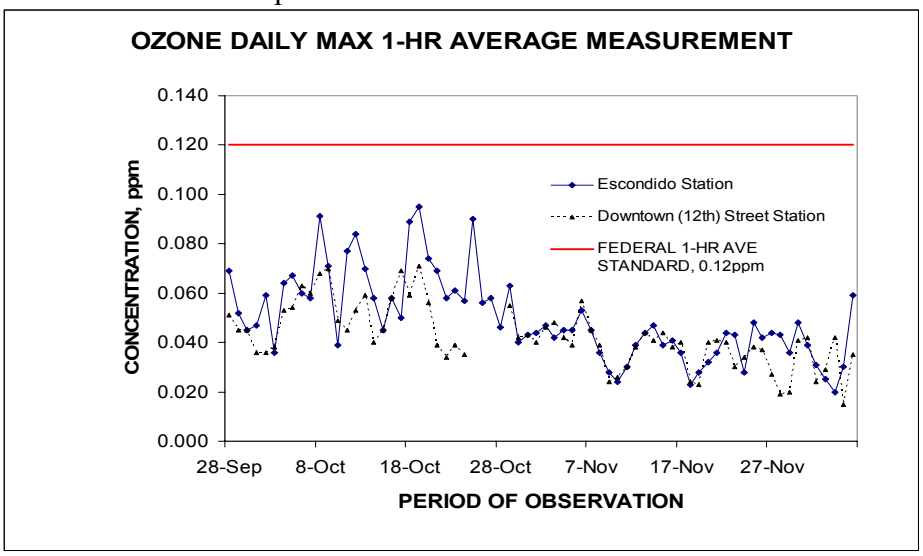

Figure 2. Ozone measurements during the surveillance period.

Carbon Monoxide (CO)

Carbon monoxide trend during the surveillance period in Escondido and Downtown Stations showed that CO concentrations before, during, and after the fire were well below and did not exceed the Federal 1-hour standard of 35 ppm.

Nitrogen Dioxide (NO_2)

Nitrogen dioxide trend during the surveillance period showed did not exceed the State of California mandates a 1-hour maximum concentration level for NO_2 of 0.25 ppm before, during, and after the fire in both Escondido and Downtown Stations.

Methane and Total Hydrocarbons (THC)

Methane and Total Hydrocarbons (THC) trend during the surveillance period were well below all applicable standards.

Meteorological Influence

The San Diego Air Pollution Control District (APCD) air quality forecasted for a moderate level of $PM_{2.5}$ throughout the county from Saturday, October 25, 2003 through Sunday, October 26, 2003 due to Santa Ana winds. Although on October 26, 2003, the fire was driven in the southwest direction by the Santa Ana winds, there was no significant surface smoke impact except in the areas immediately around the fire. Wind condition near the coast was not strong. The meteorological station recorded a shallow mixed layer during the morning followed by a weak neutral atmosphere later in the day. These conditions were not conducive to heavy smoke impacts at the surface level from a lofted plume of smoke. This was the general situation over the coastal populated area of the county. As the first full day of the fire progressed on October 26, 2003, conditions in the close proximity of the fire recorded a different result. Throughout the morning, the fire advanced rapidly in a southwesterly direction and burned the heavily populated communities. Flames and vortex of heavy smoke prevailed in the vicinity of the fire particularly downwind and on the leading edge of the fire. There was a localized turbulent condition as the wind fanned the fire. In addition, the intense fire produced its own circulation, an indication of a firestorm.

The Santa Ana wind condition deceased in strength towards the end of the day on October 26, 2003. At dawn of October 27, 2003, the fires' progression was shifted to easterly direction away from major population centers and into the mountain communities. Data recorded on October 27, 2003 showed offshore winds aloft during the first half of the day followed by a turning of the winds to weak onshore in the early afternoon and then general stagnation conditions during the evening and night time. At the same time the data recorded showed an isothermal atmosphere during the early morning with surface-based inversion forming later in the day. These meteorological conditions were more conducive to trapping smoke in the surface layer. On October 28, 2003, the data recorded showed wind conditions becoming stagnant during the day with low level winds becoming southerly in the evening. The data also showed a surface-based inversion during most of the day. These stable conditions were conducive for trapping the smoke in the surface layer. Even as the fires continued burning eastward into the more rural areas of the county, satellite photograph taken by the National Oceanographic and Atmospheric Administration (NOAA) showed an abrupt stop and slow smoke movement offshore. Data recorded on Wednesday, October 29, 2003 showed southerly winds in the low levels during the early morning hours, turning to offshore during the day, and south-southwest and southerly winds at night. For the same day, the recorded data showed a shallow marine layer capped by an inversion that lifts during the day and dissipates at night. These conditions were consistent with air mass change and improved air quality conditions. Although the fires continued to burn in the inland, mountain areas of the county, similar meteorological conditions continued until the fire was out on November 4, 2003.

Medical Surveillance

During the surveillance period, 15 (79%) of the 19 hospitals participated by providing the following surveillance information from October 18 through November 8, 2003:

- Number of patients admitted to the hospital
- Date of Admission
- Type of medical problems encountered (asthma, bronchitis, emphysema, other respiratory problems, chest pain)

The participating hospitals represented geographic diverse locations and included several hospitals near the fire-impacted areas. As seen in Figure 3, several of the surveillance indicators increased significantly during the periods of the fire. The most dramatic increase was among asthma and other respiratory complaints with no fever. Each of the surveillance indicators is further described below.

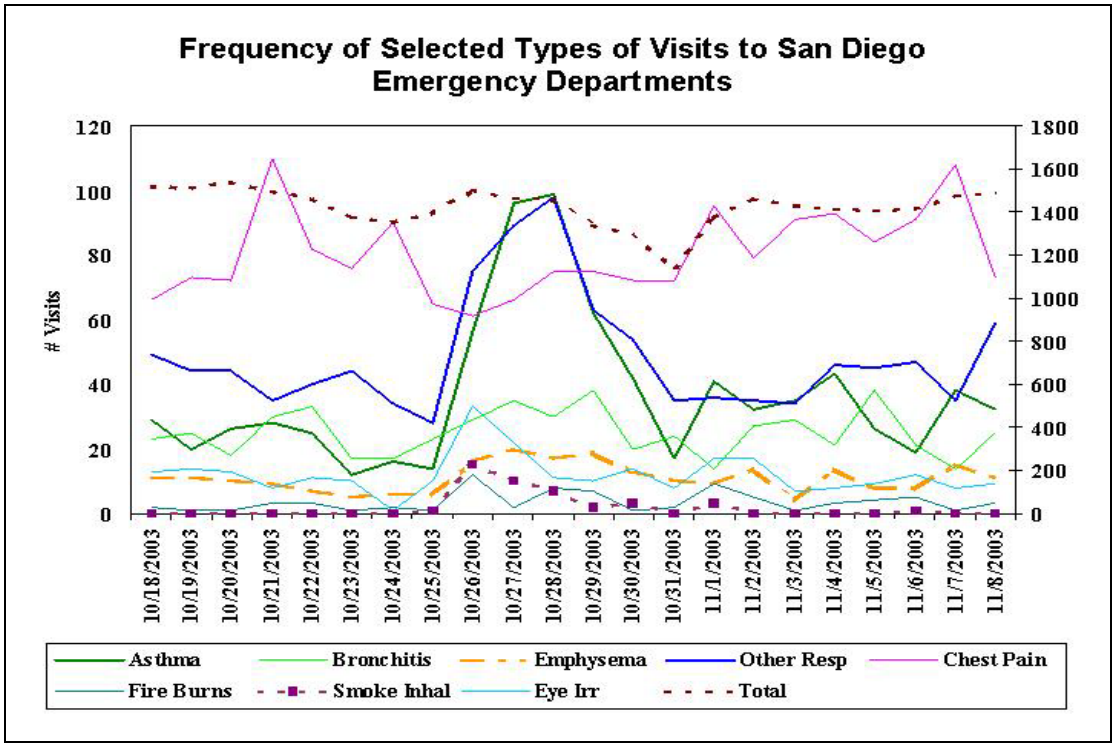

Figure 3. Frequency of selected types of visits to San Diego emergency departments.

Total Visits

The impact of the fires on area emergency department visits varied across hospitals. In total, information on 31,321 visits were recorded and analyzed. For the surveillance time period, the mean number of cases was 1,423 visits per day among 15 hospitals. In general, the total number of emergency department visits declined during selected periods of the fire. The day with the minimum number of total visits was October 31, 2003. The period of

greatest decrease in total volume of patients corresponds with the days that the schools and employees were asked to remain at home (October 27-31, 2003). When the total visits were analyzed using the EWMA method, the mean number of total visits continued to remain lower at lower levels for over a week after the fires began. During this period, the moving average decreased substantially.

Asthma

Several respiratory indicators were monitored at emergency departments throughout the county and related visits were assessed. In general, each of the respiratory indicators demonstrated significant increases during the fire period with expected post-fire levels approaching pre-fire levels with the decline in the fires and subsequent improvement in air quality. Figure 4 describes the general characteristics of asthma related visits.

Asthma related visits increased significantly, particularly during the days of greatest fire burn and unhealthy air quality. Both the total number of asthma visits and the proportion of asthma visits increased. These increases correspond well with the increases in air quality index. Figure 5 displays the number of asthma related visits over time with the days of greatest number of asthma related visits occurring on Tuesday, October 28. Controlling for the total number of visits, Figure 6 includes the proportion of asthma related visits during the surveillance period. Additional information about the asthma related results are detailed in Figure 7 and Figure 8.

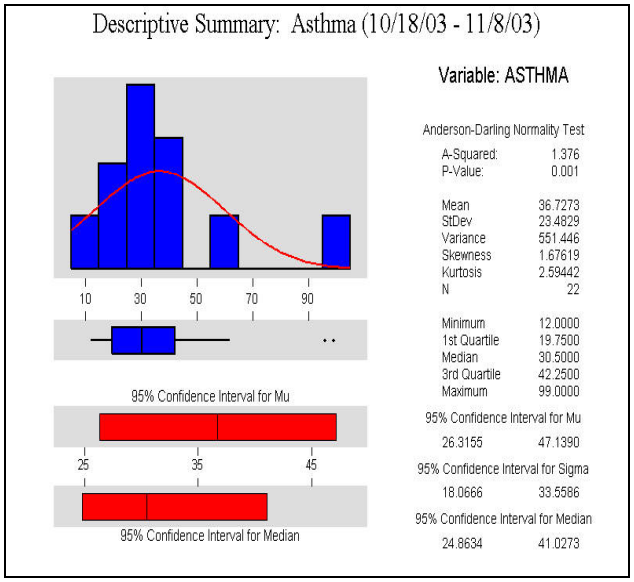

Figure 4. Descriptive analysis plot for Asthma

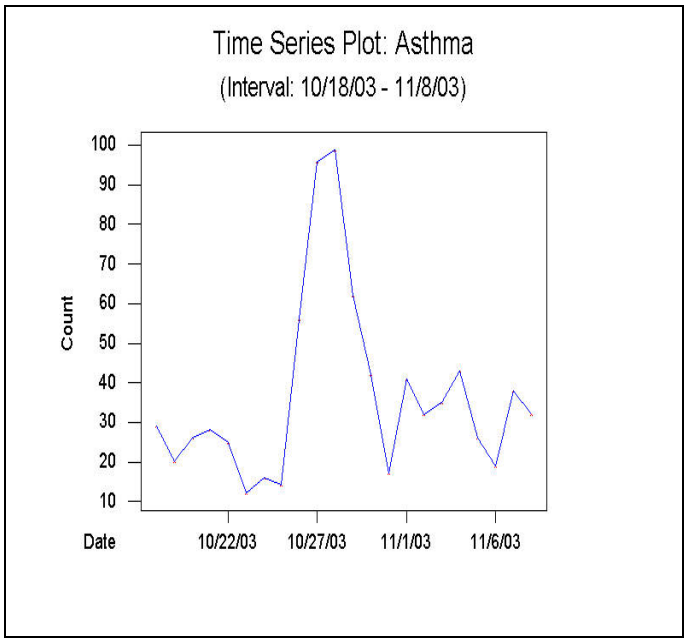

Figure 5. Time series plot for Asthma

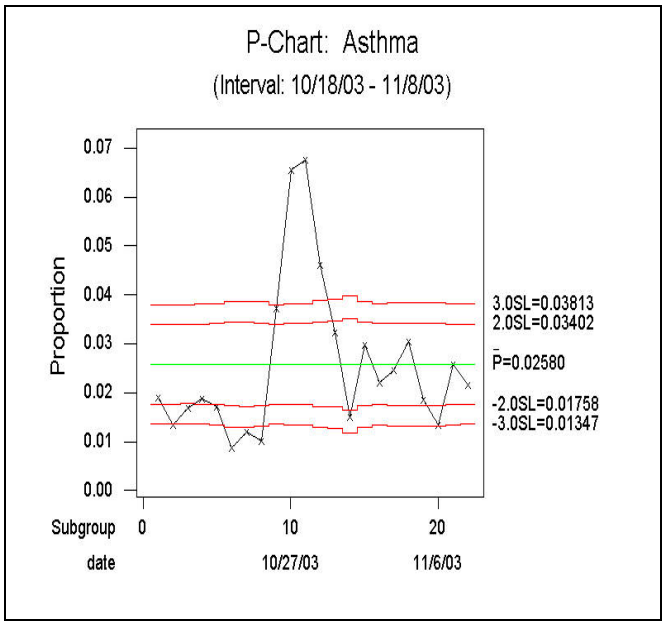

Figure 6. p-chart plot for Asthma

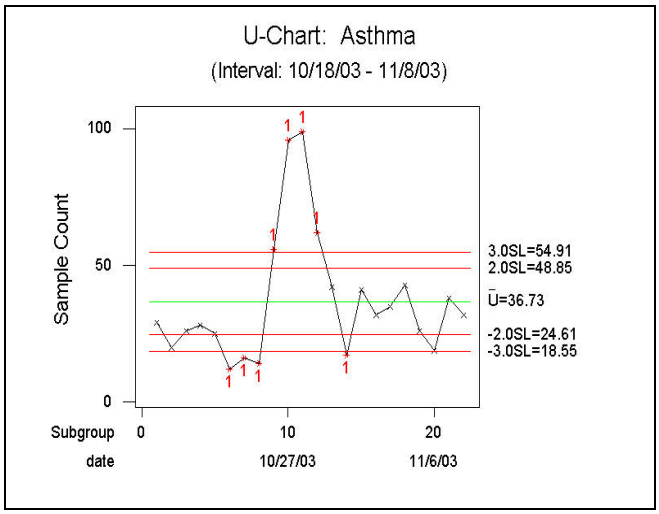

Figure 7. U-chart plot for Asthma

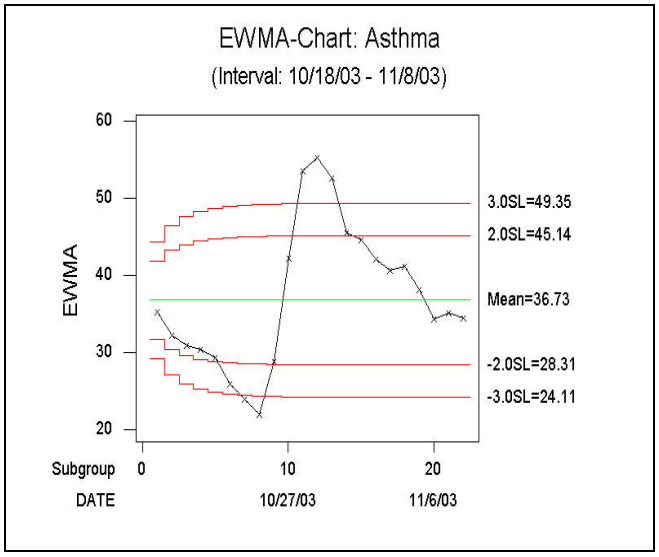

Figure 8. Exponentially Weighted Moving Average plot for Asthma

Bronchitis

Bronchitis related visits were monitored and increased slightly during the surveillance period. The mean number of cases across all participating hospitals was 25 per day. A slight increase in bronchitis related visits was noted. However, the increase was neither significant nor sustained.

Other Respiratory With No Fever

The surveillance category for other respiratory with no fever related visits were analyzed. The intention of this indicator is to track people with a multitude of respiratory related symptoms not previously identified as asthma, bronchitis or those respiratory infections typically presenting with fever (influenza like, pneumonia, etc). A dramatic increase in visits with chief complaints associated with the other respiratory with no fever visits seen following the beginning of fires on October 25, is likely a direct result of the increasingly poor air quality. Analysis of this indicator reveals that both the total number of visits and the proportion of visits increased significantly particularly during the days of greatest fire burn and ash fallout.

Smoke Inhalation

Because of the large area of fire burn in both densely and rural populated areas, it was expected that hospitals would experience a number of patients with smoke inhalation. Although the overall number of smoke inhalation related visits across participating hospitals was small each day during the surveillance period, smoke inhalation related visits increased markedly.

Eye Irritation

Due to several days of large ash fall throughout San Diego County, it was expected that a number of patients would seek treatment for eye irritation at emergency departments. Although very few patients experiencing eye irritation problems were reported during the pre-fire period, a brief increase of those with eye irritation occurred during the days of greatest fire burn and ash fallout.

Chest Pain/Cardiac Arrest

Due to the uncertainty of determining how the fire and air quality would impact patients' suffering from chest pain or cardiac arrest, an indicator was selected to assess the same during the surveillance period. The number of chest pain and cardiac arrest visits seemed to have no noticeable increase as a result of the fire. Although, the time period is limited to about three weeks, it is difficult to determine if this pattern is typical during non-fire periods.

Diarrhea/Gastroenteritis

During the fires, selected parts of the county were without power for several days. Because of the potential for consumption of spoiled food or contaminated water, an indicator for diarrhea/gastroenteritis was monitored. In general, diarrhea related visits during this surveillance period did not increase or decrease from the usual trend.

Recommendations

The following recommendations are made in the event of future similar events:

- Improve the capability of accurate real-time monitoring of particulate matters as it is the pollutant of concern that has immediate impact on health of county residents. Mobile monitoring capability is an added resource because it can better assess the actual condition independent of prevailing meteorological condition.
- Prepare hospitals and other emergency medical facilities to deal with medical conditions caused by airborne particulate matters such as asthma, other respiratory with no fever, eye irritation and smoke inhalation.
- Employ all available meteorological forecasting resources including real-time satellite imaging assets to accurately forecast air quality, assist firefighting efforts, and mobilizing emergency service providers.

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