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How Much Does Kansas Rangeland Burning Contribute to Ambient $PM_{2.5}$?

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The Concept of TSP, PM_{10}, and $PM_{2.5}$

Particulate matter (PM) measurement in air uses equipment that separates the particles into different sizes (diameter of the particle in micrometers). The concentration (indicating level of pollution) of PM in air is usually given in the unit of $\mu g/m^3$ (micrograms PM per cubic meter of air).

The following terms TSP, PM_{10}, and $PM_{2.5}$ are used in air quality measurement and regulations.

TSP means Total Suspended Particulate, which includes particulate mass of all particles that are suspended in the air.

PM_{10} means particulate mass of particles smaller than 10 micrometers in diameter

$PM_{2.5}$ means particulate mass of particles smaller than 2.5 micrometers in diameter.

The reason for the two size categories (PM_{10} and $PM_{2.5}$) is that particles smaller than 10 micrometers in size are respirable, meaning the particles can be inhaled below the nose and mouth. Particles below 2.5 micrometers in size can travel into the lungs. The fraction of PM_{10} larger than $PM_{2.5}$ is referred to as coarse particles and the $PM_{2.5}$ size and smaller is called fine particles. Particles with diameters less than 0.1 micrometers are often called ultra-fine particles. In recent years this size fraction has come into focus because of the newfound link between these particles and health effects from respiratory problems such as asthma, inflammatory diseases, and reduced oxygen uptake efficiency.

Smoke and $PM_{2.5}$

Rangeland burning is a long-standing practice in Kansas for maintaining the tallgrass prairie ecosystem. The smoke from burning has resulted in air quality concerns and smoke exposure constitutes public health concerns. Smoke is a complex mixture of PM and gases. The PM in smoke is largely composed of elemental carbon, organic compounds, and inorganic ash. The elemental carbon primary particles form as a result of incomplete combustion of carbon-based materials. The organic compounds can be primary particles or secondary particles that are formed through gas-to-particle conversion processes. The hot vapors of low-volatile organic products can either nucleate or condense on the surface of pre-existing particles as the smoke plume cools down, yielding fine particles. Many of the organic compounds are irritants, and some are carcinogens. Trace metal elements are also known to concentrate on fine particles. Smoke PM acts as a vehicle to carry these adsorbed hazardous compounds into the respiratory tract.

Smoke particles are generally very small. About 70 to 90 percent of PM in smoke is $PM_{2.5}$, meaning 2.5 micrometers or smaller in size. Particles of this size range are not easily removed by gravitational settling and therefore can be transported over long distances. The fine particulates in smoke have a size range near the wavelength of visible light (0.4 to 0.7 micrometers) and therefore can efficiently scatter light and reduce visibility (causing haze). The depth of particle penetration into the lungs and the likelihood of particles being exhaled is dependent upon their size. Coarse particles affect the nasopharyngeal region, whereas fine particles such as $PM_{2.5}$ can penetrate the large airways of the trachea, bronchi, and bronchioles, and even reach the alveoli. Inhaled fine particles themselves can cause an inflammatory response in the respiratory system even though the material itself is inherently nontoxic.

The health impacts of fire smoke exposure have been recognized, particularly among children and the elderly (Liu et al., 2016a). In a study of wildfires in California, Wegesser et al. (2009) reported that PM under the influence of fires was about 10 times more damaging to alveolar macrophages than PM collected under normal conditions on an equal-dose basis.

The Ambient $PM_{2.5}$ in Kansas

The standards for $PM_{2.5}$ in the National Ambient Air Quality Standards (NAAQS) are evolving. In 2006, the 24-hour average standard of $PM_{2.5}$ was reduced from 65 to 35 $\mu g/m^3$ (micrograms per cubic meter of air). In 2012, the primary annual average standard of $PM_{2.5}$ was reduced from 15 to 12 $\mu g/m^3$. The current Kansas $PM_{2.5}$ monitoring network includes 10 monitoring sites throughout the state. The monitoring sites in the Kansas City urban area usually have slightly higher $PM_{2.5}$ than other sites. Overall, the $PM_{2.5}$ concentrations across the state are below the NAAQS standard (KDHE, 2015). However, increased $PM_{2.5}$ concentrations were observed around April each year at the Tallgrass site located at the center of the Flint Hills region, indicating the impact of rangeland burning in the region. From 2002 to 2014, the 24-hour average $PM_{2.5}$ concentrations were higher than 30 μg/m^3 on 10 days, and higher than 35 μg/m^3 on five days. All these high $PM_{2.5}$ days were in April or late March, when intensive rangeland burning occurs in the Flint Hills region. The reduced standards, together with the Regional Haze Regulations, have highlighted the need for smoke management to reduce the impact of smoke on air quality.

Source Categories of $PM_{2.5}$

At the Tallgrass monitoring site, research modeling of the long term $PM_{2.5}$ data identified the following five source categories (S1 to S5) that contribute to local ambient $PM_{2.5}$:

- S1-nitrate/agricultural,
- S2-sulfate/industrial,
- S3-crustal/soil,
- S4-primary smoke particles,
- S5-secondary organic particles.

S1 is characterized by high nitrate mainly due to ammonia emissions from agricultural sources. S2 is characterized by high sulfate and represented secondary sulfate from regional SO_2 emissions, including coal-fired power plants and industrial processes. S3 represents re-suspended soil particles.

On annual average, S1, S2, and S3 contributed 66 percent of the total $PM_{2.5}$, and all three source categories demonstrated strong seasonal contribution to air quality as shown in Figure 1. S1 was generally low in summer and high in winter. In contrast, S2 and S3 were generally high in summer and low in winter.

S4 includes mostly primary smoke particles from burning. S5 is composed of secondary organic particles which are particulates formed from atmospheric organic species through gas-to-particles transformation. S5 can be associated with biogenic, mobile, or smoke emissions, such as those from rangeland burning.

Both S4 and S5 were heavily affected by episodic smoke emissions from rangeland burning and had consistent spikes in April. The monthly average contributions of S4 and S5 to $PM_{2.5}$ were 11 percent and 49 percent in April as compared with annual averages of 5 percent and 29 percent respectively. The monthly average $PM_{2.5}$ in April was much greater than in other months (Figure 1). Details on results of the research modeling can be found in Liu et al. (2016b).

At the Kansas City site, traffic, diesel, and copper dominated sources were identified in addition to the above source categories. The average smoke contribution to $PM_{2.5}$ was less than 10 percent. At the Kansas City site, the highest monthly average $PM_{2.5}$ was observed in July instead of April.

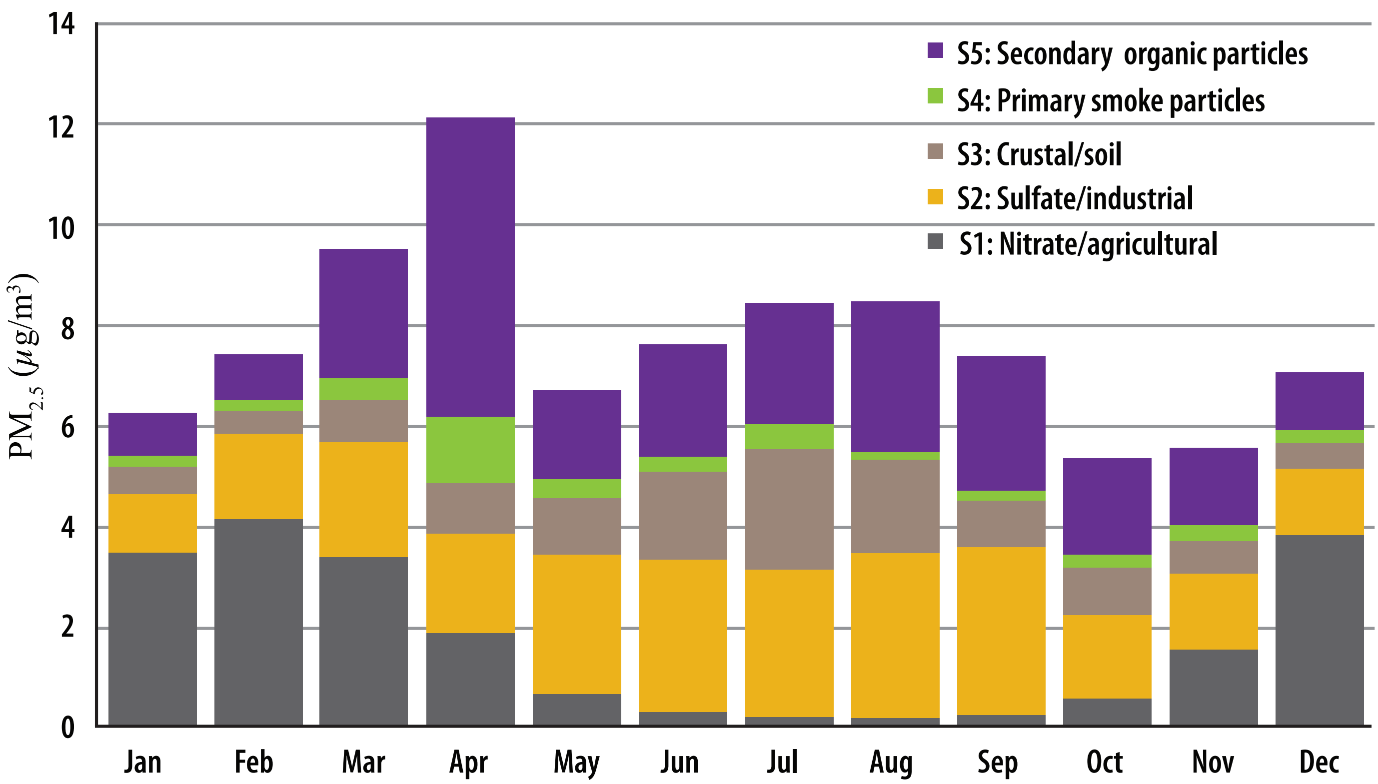

Figure 1. Monthly variation of $PM_{2.5}$ contributions from the five source categories at the Tallgrass monitoring site.

Contributions of Kansas Rangeland Burning to Ambient $PM_{2.5}$ during the Burning Season

Contributions of rangeland burning to ambient $PM_{2.5}$ during the burning season were estimated by comparing the S4 and S5 contributions in April and the average S4 and S5 contributions in other months. This analysis assumes that the S4 and S5 contributions from other sources during April remained near the average level.

In April, around two-thirds of the secondary organic particles (S5) at the Tallgrass site could be attributed to rangeland burning; and the monthly average contribution of April burning was estimated to be 0.93 $\mu g/m^3$ as primary smoke particles and 3.79 $\mu g/m^3$ as secondary organic particles. The average contribution of secondary organic particles was four times higher than that of primary smoke particles, highlighting the importance of secondary particles in air quality.

In the top five high $PM_{2.5}$ days from 2002 to 2014, the 24-hour average $PM_{2.5}$ concentrations were higher than 35 $\mu g/m^3$, and they all occurred in April. The average contribution of secondary organic particles was as high as 41.6 $\mu g/m^3$ or 85% of the total $PM_{2.5}$, while the average contribution of primary smoke particles was 4.4 $\mu g/m^3$, or 9% of the total $PM_{2.5}$.

The impact of rangeland burning in the Flint Hills region on the ambient $PM_{2.5}$ at the Kansas City site was much less due to its distance from the smoke source. During the period when smoke from rangeland burning was influencing the site, the largest daily average contributions of smoke (including both primary smoke particles and secondary organic particles) was 6.5 $\mu g/m^3$ or 25% of the total $PM_{2.5.}$

Source Profile of the Smoke Particles

Primary smoke particles mainly consist of elemental carbon and organic carbon, and also contain a small portion of soil elements entrained into the smoke column as a result of the turbulence and buoyancy generated by the fire. The secondary organic particles mainly consist of various organic compounds and a small portion of sulfate.

For the secondary organic particles at the Tallgrass site, the ratio of total particle mass to organic carbon was as high as 4. In contrast, the general estimate of the average ratio of total particle mass to organic carbon for urban particles is around 1.4 to 1.6 (Turpin and Lim, 2001). The large difference in this ratio indicated that the secondary organic particles generated from smoke could contain much more complex organic compounds with higher molecular weights as compared with normal urban particles, and thus could have a greater impact on health.

References

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MF3358 **June 2017**