The Egyptian Journal of Remote Sensing and Space Sciences (2016) **19**, 195–205

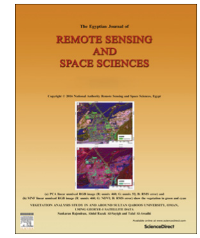
HOSTED BY

ELSEVIER

National Authority for Remote Sensing and Space Sciences

The Egyptian Journal of Remote Sensing and Space Sciences

www.elsevier.com/locate/ejrs
www.sciencedirect.com



RESEARCH PAPER

Spatiotemporal analysis of fine particulate matter ($PM_{2.5}$) in Saudi Arabia using remote sensing data

Said Munir [a,*], **Safwat Gabr** [a,b], **Turki M. Habeebullah** [a], **Mamoun A. Janajrah** [c,d]

[a] *The Custodian of the Two Holy Mosques Institute for Hajj and Umrah Research, Umm Al-Qura University, Makkah, Saudi Arabia*
[b] *National Authority for Remote Sensing and Space Sciences (NARSS), Cairo, Egypt*
[c] *Faculty of Engineering, University of Jeddah, Jeddah, Saudi Arabia*
[d] *Faculty of Engineering, Zarqa University, Zarqa, Jordan*

Received 14 July 2015; revised 2 June 2016; accepted 8 June 2016
Available online 28 June 2016

KEYWORDS

Remote sensing;
Temporal and spatial trend;
Makkah – Saudi Arabia;
Fine particulate matter ($PM_{2.5}$);
MODIS;
Satellite-derived data;
Air quality

Abstract Fine particulate matter ($PM_{2.5}$) can penetrate deeper into the respiratory systems and cause various health problems. In this paper satellite-derived $PM_{2.5}$ concentrations, which provide better spatial coverage in the form of satellite-imageries are used to analyse the spatial and temporal distributions of $PM_{2.5}$ in Saudi Arabia. $PM_{2.5}$ concentrations (μg/m^3) are estimated using the relationship between Aerosol Optical Depth (AOD) and $PM_{2.5}$ concentrations from satellite images, such as those of the Moderate Resolution Imaging Spectroradiometer (MODIS). $PM_{2.5}$ concentrations varied both temporally and spatially and there was a negative south to north trend in $PM_{2.5}$ levels. Dammam showed the highest whereas Tabuk showed the lowest $PM_{2.5}$ concentrations. Temporally all cities demonstrated a positive trend, except At-Taif and Madinah. The positive trend was significant only in Dammam, Hofuf, Khobar, and Nijran. In most of the cities due to lack of data, ground level $PM_{2.5}$ concentrations could not be compared with satellite-derived data, except in Makkah, where a comparison is made between observed and satellite-derived data for years 2001–2007. Both sets of data in Makkah showed positive trends, however satellite-derived concentrations were lower roughly by a factor of 2.5. Remote sensing successfully supplements the ground level air quality monitoring programme and helps better understand the spatial variability of atmospheric pollutants, especially on a large scale, such as regional or global scale. Further comparison between observed and satellite-derived data is required over a larger spatial and temporal resolution.

1. Introduction

Atmospheric particulate matter has been recognised as one of the major environmental problems due to its health and environmental impacts. Particles enter human body during inhalation process and accumulate in the respiratory system, where

* Corresponding author. Fax: +966 2 5564955.
E-mail addresses: saidmunir@yahoo.co.uk (S. Munir), Safwat_gabr@yahoo.com (S. Gabr), t_habeebullah@yahoo.com (T.M. Habeebullah), mjanajrah@kau.edu.sa (M.A. Janajrah).
Peer review under responsibility of National Authority for Remote Sensing and Space Sciences.

http://dx.doi.org/10.1016/j.ejrs.2016.06.001

the particles cause respiratory and cardio-vascular illnesses (COMEAP, 2011). In addition, particulate matter may reduce visibility by scattering and absorption of radiation. Habeebullah (2013) has analysed the levels of particulate matter with aerodynamic diameter of 10 micron or less (PM_{10}) in Makkah and evaluated its potential health impacts. Habeebullah op. cit. reported that Makkah experiences high levels of PM_{10} and often exceed air quality standards (Table 1), which could cause potential health and environmental impacts.

Particulate matter, when breathed in can cause several health problems, which include asthma, rhinosinusitis, chronic obstructive pulmonary diseases and respiratory tract infections (WHO, 2003; Walters and Ayres, 2001). Particulate matter, especially the fine particulate matter ($PM_{2.5}$) is considered the most dangerous atmospheric pollutant in terms of its health effects. Researchers have focused on $PM_{2.5}$ as a metric more closely associated with adverse human health effects than the larger particle size (AQEG, 2012). The UK Committee on the Medical Effects of Air Pollutants (COMEAP, 2009, 2010) has published detailed reports on the impacts of $PM_{2.5}$ on human health, which quantify the potential negative effects of $PM_{2.5}$ and emphasise on taking measures to control its emissions. This shows the importance of characterising the spatial and temporal variability of $PM_{2.5}$ in Saudi Arabia and elsewhere in the world.

Saudi Arabia is located in an arid region, where frequent dust storms take place Alharbi et al. (2013) analysed the impact of dust storms on air quality in Saud Arabia and reported that dust storms caused widespread heavy atmospheric dust load, very low visibility, airport shutdown and damage to vehicles and trees across the Kingdom of Saudi Arabia. In addition to dust storms, other sources of atmospheric aerosols in Saudi Arabia include heavy oil combustion, resuspended soil, industrial emissions, traffic emissions and marine sources (Khodeir et al., 2012). More recently, Munir et al. (2013a) modelled PM_{10} concentrations to investigate the effects of different meteorological factors and road traffic-related air pollutants on PM_{10} in the city of Makkah, Saudi Arabia. They concluded that meteorological variables, especially temperature and wind speed were the major controlling factors of PM_{10} concentrations in Makkah. Topographic map of Saudi Arabia is shown in Fig. 1, showing different regions and their topographical characteristics.

Air quality worldwide including Saudi Arabia is monitored using ground based air quality monitoring stations that monitor various air pollutants at specific points. The continuous monitoring network provides vital information for assessing the levels of air pollutants. The measured data from such monitoring stations are used for various purposes including comparison with air quality standards to determine if the levels are exceeding the limits, determining air pollutant hotspots and evaluating model performances. However, the main drawback is that such continuous monitoring stations provide data only for specific points, where the monitoring stations are installed. To provide a full spatial coverage of a large urban area, there is a need for a vast network, which requires a huge amount of resources. Alternatively, remote sensing tools can be used to supplement the ground based monitoring. Satellite images provide a wide coverage, which can help improve the monitoring programmes. Remote sensing and GIS techniques are also used for total ozone column assessment, flood monitoring and damage assessment, land use and crop rotation

Table 1 Air quality standards of various air pollutants set by WHO and the Presidency of Meteorology and Environment (PME) of the Kingdom of Saudi Arabia.

Air pollutant	Organisation	Criteria based on	Standards (μg/m^3)
SO_2 (μg/m^3)	PME	1 h mean	730
		24 h mean	365
		Annual mean	85
	WHO	24 h mean	20
		Annual mean	50
		10 min	500
CO (mg/m^3)	PME	1 h mean	40
		8 h mean	10
	WHO	30 min	60
		1 h mean	30
		8 h mean	10
NO_2 (μg/m^3)	PME	1 h mean	660
		24 h mean	–
	WHO	1 h mean	200
		Annual mean	40
Ozone (μg/m^3)	PME	1 h mean	289
	WHO	8 h mean	100
PM_{10} (μg/m^3)	PME	24 h mean	340
		Annual mean	80
	WHO	Annual mean	20
		24 h mean	50
$PM_{2.5}$ (μg/m^3)	PME	24 h mean	35
		Annual mean	15
	WHO	24 h mean	25
		Annual mean	10