Atmospheric Environment 179 (2018) 239–249

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Appraising city-scale pollution monitoring capabilities of multi-satellite datasets using portable pollutant monitors

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ARTICLE INFO

Keywords:
Nigeria
Air pollution
Portable monitors
Satellite pollution estimates

ABSTRACT

The retrieval characteristics for a city-scale satellite experiment was explored over a Nigerian city. The study evaluated carbon monoxide and aerosol contents in the city atmosphere. We utilized the MSA Altair 5× gas detector and CW-HAT200 particulate counter to investigate the city-scale monitoring capabilities of satellite pollution observing instruments; atmospheric infrared sounder (AIRS), measurement of pollution in the troposphere (MOPITT), moderate resolution imaging spectroradiometer (MODIS), multi-angle imaging spectroradiometer (MISR) and ozone monitoring instrument (OMI). To achieve this, we employed the Kriging interpolation technique to collocate the satellite pollutant estimations over 19 ground sample sites for the period of 2015–2016. The portable pollutant devices were validated using the WHO air filter sampling model. To determine the city-scale performance of the satellite datasets, performance indicators: correlation coefficient, model efficiency, reliability index and root mean square error, were adopted as measures. The comparative analysis revealed that MOPITT carbon monoxide (CO) and MODIS aerosol optical depth (AOD) estimates are the appropriate satellite measurements for ground equivalents in Zaria, Nigeria. Our findings were within the acceptable limits of similar studies that utilized reference stations. In conclusion, this study offers direction to Nigeria's air quality policy organizers about available alternative air pollution measurements for mitigating air quality effects within its limited resource environment.

1. Introduction

Air quality is undoubtedly a key subject of public concern (Gozzi et al., 2016). Petroleum derivatives and biomass consumption are the major sources of air pollution in developing cities and have been linked to unfriendly respiratory impacts (Marais et al., 2014). Exposure to air pollutants is increasing respiratory and cardiovascular morbidity and mortality (2.8 million deaths), with developing countries still experiencing the worst air pollution (WHO, 2016). With over a decade of global awareness on air pollution, studies are still reporting the effects of criteria pollutants on the human cardiovascular and respiratory systems (Ghozikali et al., 2015; Miri et al., 2016; Ren et al., 2017).

Rapid economic development coupled with scarce administrative policies within the African continent is leading to an increased level of air pollution, thus putting the wellbeing of its major population at risk (Marais and Chance, 2015). In Africa, studies on surface air pollution monitoring are insufficient, with only a few nations having established environmental procedures. South Africa is the only African country that appears to have established well-defined standards and a comprehensive monitoring network (Kgabi, 2014; Hersey et al., 2015).

Nigeria is Africa's most populated country (182 million people as at 2015) and also the largest economy, recently surpassing South Africa (The Economist, 2017; UN, 2017). Nigeria's rapid growth stimulates a variety of environmental worries, most especially air quality. Outdoor air pollution is majorly worsened by inept automobiles, unsystematic road structure leading to traffic obstruction, dependence on power generating sets by commercial outlets due to poor electricity infrastructure and congested road side activities (Adewunmi et al., 2015; Orogade et al., 2016). The measurements of outdoor pollutants are essential for human exposure awareness (Duvall et al., 2012; Bereznicki and Kamal, 2013).

Since urban air pollution undergoes several processes which generates its spatial variable concentrations, a network of pollution station units can be employed to predict concentrations at unmeasured locations and also effectively monitor urban air pollution (Kanaroglou et al., 2005; Adams et al., 2012; Dash, 2016). The density of an urban environment combined with natural variability and unpredictable anthropogenic emission sources, compels for the constant appraisal of

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https://doi.org/10.1016/j.atmosenv.2018.02.034
Received 14 November 2017; Received in revised form 11 February 2018; Accepted 18 February 2018
Available online 20 February 2018
1352-2310/

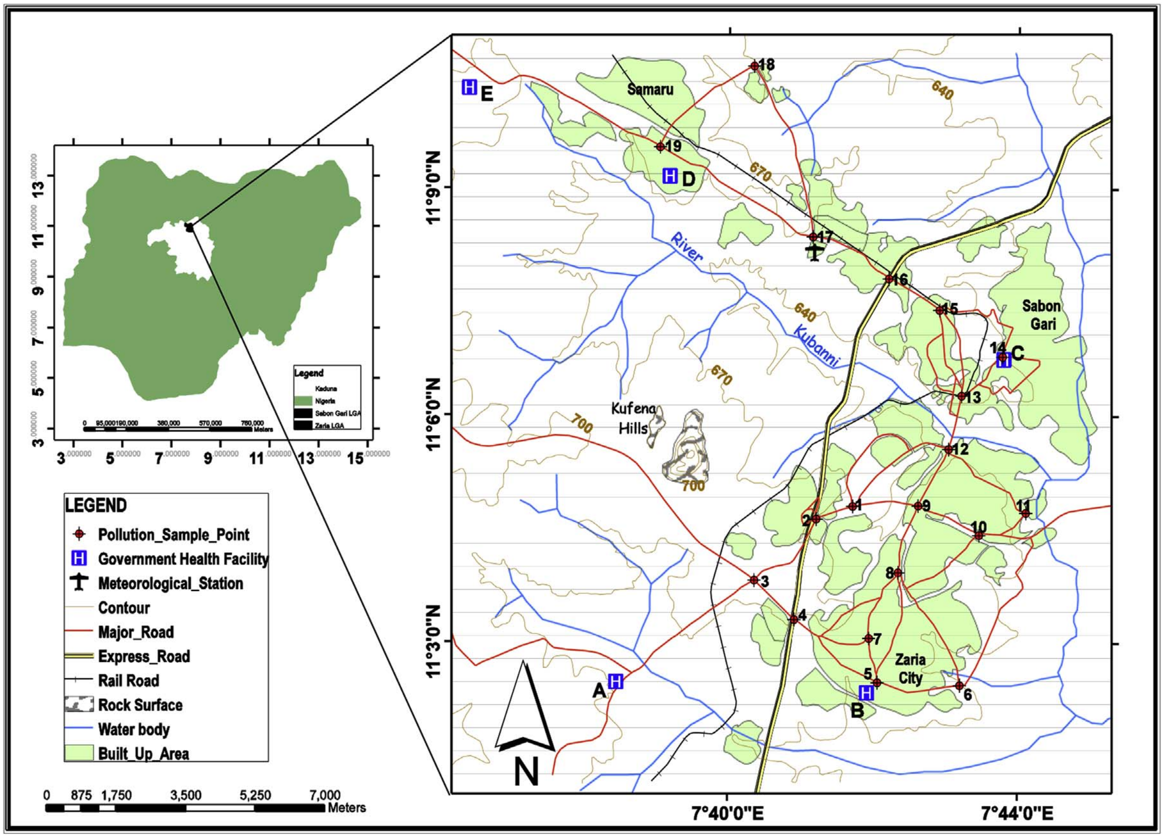

Fig. 1. Study area displaying the Kufena hill, meteorological station and distribution of the 19 sample sites (Sites 3, 6 and 18 are control sites).

pollution models by means of up-to-date datasets (Neophytou et al., 2011).

Low-cost pollutant monitors are getting extra attention in the area of air pollution monitoring, when compared with established reference devices (Kumar et al., 2015). The majority of the lower cost sensors is robustly designed using micro-electro-mechanical techniques and energy efficient sensor circuits. This makes them cost effective, lightweight and compact, thus consuming minimum power for detecting selected toxic gases and particulates in any industrialized environment (Mead et al., 2013). Their user-friendliness enables efficient near real-time resolution data acquisition, thus allowing for larger spatial coverage especially in remote/developing areas (Snyder et al., 2013). The availability of portable pollution monitoring detectors has considerably increased the possibility of identifying pollution hot spots, enriching air pollution maps, evaluating air quality policies and safeguarding public health (Engel-Cox et al., 2013; Gozzi et al., 2016). Cities across the globe are embracing the concept of portable test sites for gathering air quality variability and statistics for mitigation planning. Validated portable pollutant monitors can be adopted as ground-based retrieval stations, as they provide fast and transparent dissemination of observed dataset (Kumar et al., 2015; Gozzi et al., 2016). However, the challenges regarding the deployment of portable sensors for air pollution monitoring are their operational maintenance which in most cases eventually exceeds the actual cost of sensor. The operation maintenance comprises of device stability (such as sensor re-calibration, sensor/battery replacement), data management costs and operational longevity before replacement (Kumar et al., 2015).

Considerable achievements are still being realised in the area of space-based atmospheric pollution monitoring. Satellite pollution sensors have continued to show increased capability of observing chemical species at high 4-D resolutions that can be utilized for a wide range of environmental-friendly atmospheric related applications (Duncan et al., 2014; Zhang et al., 2016). While the particle satellite instruments measure the extinction of light to retrieve the chemical aerosols, the trace gas instruments measures the number density of the trace gas, all in a vertical column of air. This approach is also used to further estimate the chemical particles precisely under that column of air, as long as their movement and chemical conversion are minimally interfered with or compensated for (Streets et al., 2013). The advantage of satellite pollution data is its spatial and temporal coverage. This coverage serves as a surrogate for long-term regional air quality monitoring, as well as development of emission inventories (Engel-Cox et al., 2004; Schaap et al., 2009). The space-based pollution measurements are also being embraced as a distinctive resource for detecting air quality in regions with scarce ground-based information (Marais et al., 2014). The main challenge of satellite pollution instrument is its resolution at low-altitude. The measurements at low altitudes is perceived to be influenced by all kinds of atmospheric attenuations thus generating errors. For this reason, the satellite brochures continue to encourage researches to utilize the retrieved satellite datasets for surface test/validation procedures. Another familiar challenge of the satellite pollution instrument with limited resources establishments, is the technical know-how to access, process and accurate interpret the satellite pollution observational datasets (Duncan et al., 2014).

The dependence on portable monitors for air pollution monitoring is on the rise. There is also no record of Nigeria's air quality planners acknowledging the use of satellite pollution data resources. These are the motivation for the study. Thus we attempt to determine, the level of pollution measurements these satellite pollution estimates represent in a developing Nigerian city. It is on this basis, that this study pilots an approach for appraising city-scale monitoring capabilities of multi-satellite pollution datasets using ground-positioned, portable pollutant monitors.