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Satellite-based remote sensing as a tool to monitor vehicle usage: A case study in Sri Lanka

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ABSTRACT

Vehicle usage monitoring is a widely studied field which is commonly used in optimizing traffic patterns in urban development. Typical methods of vehicle tracking include roadside sensor networks and crowd-sourced GPS based systems. In this study an indirect measurement for vehicle usage is proposed based on atmospheric spatiotemporal changes monitored using satellite based remote sensing. Atmospheric NO_2 and NO variation was extracted using images produced by the Tropospheric Monitoring Instrument (TROPOMI), on-board the Sentinel-5 Precursor satellite. The NO_x variation was studied in Colombo, Sri Lanka (79.45°-80.38° E,6.31°-7.40°N) from July 2018 to December 2020. The average NO_x column density in the study area showed a correlation with ground measurements of particulate matter (PM2.5) published by the Colombo Air Quality Monitor - US Embassy to the World Air Quality index platform and the coefficient of determinant is found to be 0.61. The proposed indirect vehicle usage measurement was evaluated based on local holidays and during the government-imposed lockdown measures in response to the COVID-19 pandemic during the period of March to April 2020. A maximum decrease of 20% was observed in the atmospheric NO_2 column density, compared against the average weekly activity. This showed an agreement with published google mobility data. It was noted that diesel power plants located within city limits causes a significant increase in atmospheric NO_x.

Keywords: Remote sensing, Google earth engine, GEE, NO_2, NO_x,TROPOMI

1 INTRODUCTION

Since the invention of the wheel, inland transportation has come a long way. Modern society heavily relies on road transportation due to its quick turnaround time, high availability, and low cost. Increasing demand for road transportation has caused an unprecedented increase in road and vehicle use. Traffic jams are common occurrences in most major metropolitan cities in the world. Overpopulation, residential and industrial zone placement, availability of mass transport systems and lifestyle are some of the major reasons behind congestion. Road and vehicle usage monitoring is an integral part in analyzing and reducing traffic which is often done during road network development and urban planning.

Road use and vehicle statistics are typically generated using ground-based measurements. Vibration sensor plates, inductive loop detectors and video-based vehicle tracking are commonly used techniques [1]. However, limited coverage and high implementation and maintenance costs when monitoring widespread road networks are some of the main drawbacks in those approaches. Since the public release of GPS in 2000 [2], consumer grade GPS localization and automated navigations systems have been using real time traffic updates in path planning and navigation. Due to data privacy regulations, such information cannot be used for large scale traffic monitoring.

High Resolution aerial image-based vehicle segmentation has been proposed as a solution to large-scale traffic monitoring [3]. Misclassification due to non-uniform lighting, vehicle color, and object shadows have reported increased false positive rates. The high computational costs required in storing and processing high resolution imagery is also another major drawback [3].

During the past decade over 90% of fossil-fuel has been used in industries directly related to transportation [4]. Environmental impact of fossil fuel usage has been a well scrutinized topic. Noise and air pollution due to traffic amounts to a majority of pollution in many densely populated cities. In this study we propose, air quality monitoring as an alternate method to derive national scale vehicle usage.

Air pollution is primarily caused due to the addition of various pollutants into the atmosphere. Road vehicles and fossil fuel-based power generation have been considered as the major pollutant source.

Remote sensing refers to extracting information about an object without being in direct physical contact. Often the intensity of reflected or emitted radiation is used to gain insights into distinct physical objects. Satellite-based remote sensing has been used in a wide variety of fields such as land use classification, weather forecasting, air quality monitoring and soil moisture monitoring which usually involves large scale ground monitoring. It reduces the human costs involved in gathering ground data.

The objective of this study is to develop and implement computational techniques to measure key air quality parameters based on remote sensed observations in Sri Lanka and to derive indirect traffic measurements based on air quality in a wide geological area.

2 METHODOLOGY

2.1 Data sources

Sentinel 5 - Precursor (S5P) mission which was launched in October 2017 is the first mission dedicated to atmospheric monitoring under Copernicus mission and it carries the Tropospheric Monitoring Instrument (TROPOMI) which is considered to be the highest performing sensor to date in-orbit considering sensitivity, spectral resolution, spatial resolution, and temporal resolution. Near real-time and offline data products including NO_2, SO_2 and O_3 column density data were publicly released in mid-2018. S5P is in a Sun-synchronous orbit which allows daily passes and near full-surface coverage daily. TROPOMI consists of four spectrometers covering both ultraviolet and near infrared bands at 270-500 nm and 675-775 nm respectively. The NO_2 column density measurements are done using the 405-465 nm band [5]. This was used as the primary data source during this study.

In addition to remote sensing, ground based particulate matter under 2.5 µm (PM2.5) measurements were used [6]. Google mobility data published during the island wide government-imposed lockdown situation during the COVID 19 outbreak (January-April 2020) was also used for comparison [7].

2.2 Platform

Google Earth engine (GEE), a publicly accessible cloud computing platform was used to analyze remote sensed data. [8] This platform allows the user to select and filter data based on spatial and temporal bounds and allows executing custom algorithms in a cloud based distributed environment. This avoids the high computational requirement typically related to storing and processing remote sensed data. A custom JavaScript API (Application Programing Interface) is available to implement low level manipulation and visualization functions.

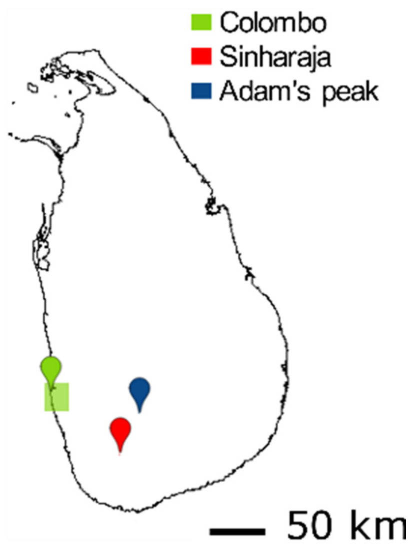

Figure 1 Map of selected locations for NO2 mapping

Figure 1 shows the locations and regions used for further analysis. Colombo (In a 400 km^2 region centering Colombo) and two 10 km^2 areas were selected from the Sinharajaya forest reserve (80.44ºE, 6.41ºN) and Peak Wilderness sanctuary (80.60ºE, 6.76ºN). These were used as background reference locations due to the fact that they have minimal vehicular emissions compared to metropolitan areas

The *NO_2 column number density* provided as a part of the Level 3 data package gives the vertically integrated number of NO_2 molecules per unit area between the surface and the tropopause. This was used to generate averaged activity measures of selected geographical areas. A median filter was used to remove extremes in each image. Image statistics were then generated and exported using Google Earth Engine for further analysis.

Air quality parameters were extracted and compared statistically with each other. To look at the national level trends spatiotemporal maps were created by reducing filtered image collections starting from March 2019 with 10-day intervals to evaluate the effect on air quality due to the reduction in traffic during the lockdown period in March 2020

3 RESULTS AND DISCUSSION

NO_2 emissions were used as an air quality measure because it is one of the main products emitted by combustion engine-based vehicles. S5P data showed a yearly occurring peak and it followed the same variation published by previous ground-based studies. Available ground $PM_{2.5}$ measurements showed a coefficient of determination of 0.61 with remote sensed data and the distribution is shown in Figure 2. This indicates that the proposed measurement can be successfully considered as a viable air quality measurement based on remote sensed observations.

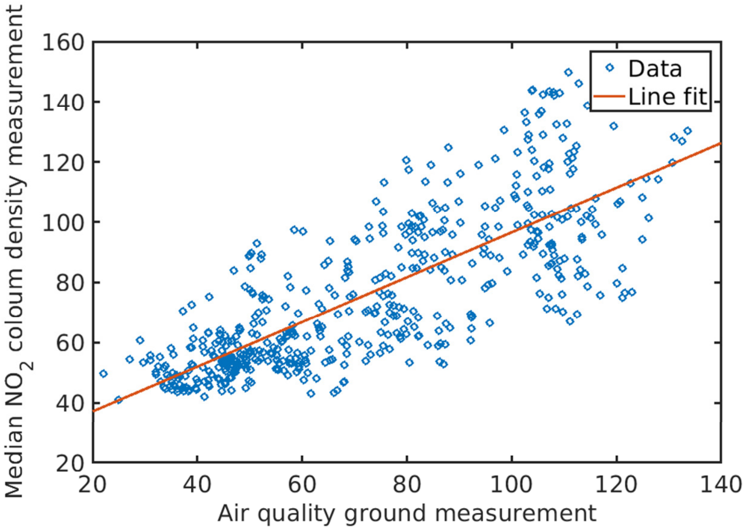

Figure 2: Correlation plot of band medians of NO_2_vertical_density vs corresponding PM2.5 ground measurements at US embassy for Jan-2019 to Jun-2020 (R2 = 0.61)

In order to check the performance of air quality measurements as an indirect traffic measurement, known local socio-economic events were analyzed. NO2 variation from previous years were considered a base line reference.

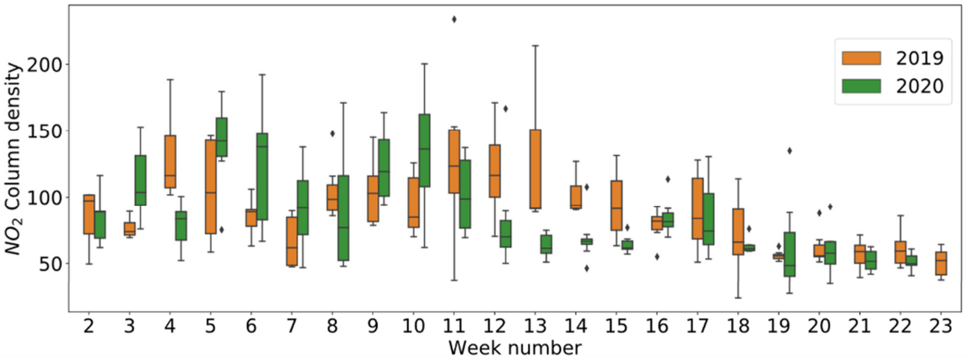

Figure 3: Temporal variation of Colombo during the first 23 weeks of 2019 and 2020

COVID 19 was one of the significant events in 2020 which impacted human activity in a global scale. The local government imposed an island wide curfew starting from 20th March 2020. The initial lock down was extended for two months in Colombo and other identified high-risk zones. A reduction of motor traffic was clearly observed during this period in the Colombo district. The temporal variation of the band-mean of Colombo and selected locations of Sinharajaya forest reserve observed during January to May in 2019 and 2020 is shown in Figure 3.

It can be noted that Colombo shows a significantly higher value compared to Sinharajaya. This indicates that human activity has a direct impact on the NO_x column density and the lockdown period showed a significant decrease compared to the previous year average. This agrees with the published Google mobility data for Sri Lanka as shown in Figure 4

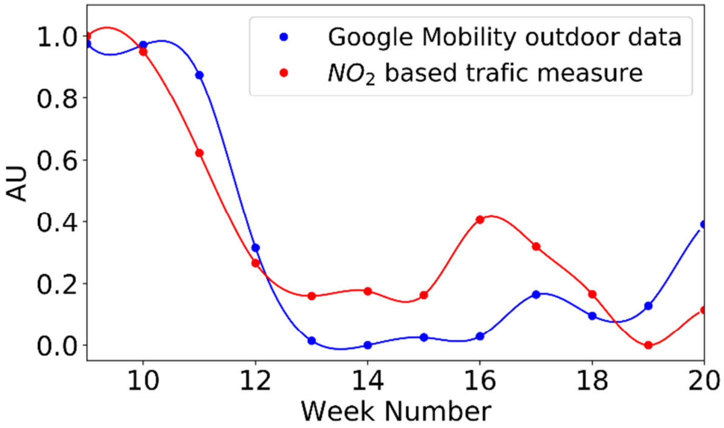

Figure 4 Vehicle activity derived based on remote sensed data and google mobility data

Figure 5 shows the averaged NO_x column density data for periods of 10 days starting from 10th March 2020. The hotspot in and around Colombo show a decreasing size which correspond to the low activity level reported due to the government imposed preventive measure. With the relaxation of curfew, increased air pollutants can be identified around Colombo. Apart from the main hotspot two additional hotspots were detected in Embilipitiya (80.8ºE,6.2ºN) and Puttalam (79.7ºE,8.0ºN). These correspond to the locations of Ace power and Lakvijaya non-renewable power plants.

In our approach industrial zones and fossil fuel-based power plants can also be identified as NO_x hotspots in addition to vehicle emissions due to traffic. Such non transportation related air pollutants sources could be identified as anomalies in this approach. Kelanithissa power-plant, which is located within the Colombo hotspot, cannot be identified as an anomaly due to the increased background level within Colombo.

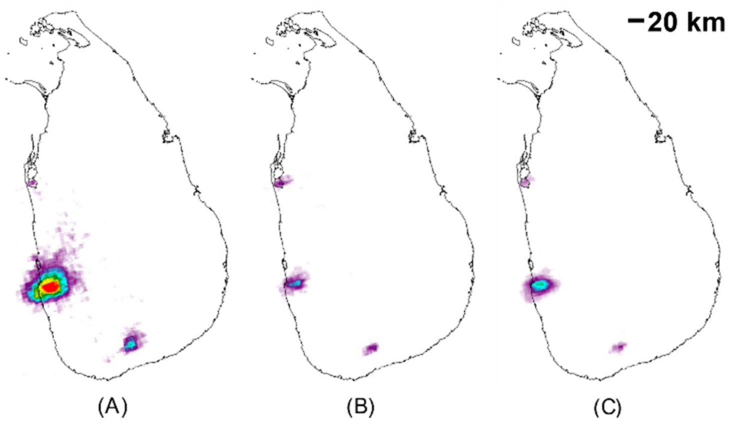

Figure 5 Averaged spatial variation of NO_2_coloum number density in March to April 2020. (A) March 10th to 20th (B) March 20st to 31st (C) April 1st to 10th

In Figure 5-A the Colombo hotspot typically tends to extend further beyond the landmass of Sri Lanka. This could be attributed to the lifespan of NO_2 and wind patterns. Previous Studies have shown NO_2 to have a maximum lifespan of about 7.5 h. Wind conditions and geological barriers could have a significant effect on remote sensed observations.

4 CONCLUSION

Satellite-based remote sensing can be successfully used for large scale air quality monitoring and it shows agreement with ground-based observations. Traffic monitoring can be done as a derived measurement of air quality in a localized area. The presence of external NO_2 sources and wind dependence are the major drawback for traffic monitoring based on air quality. Usually, the external NO_2 sources are stationary entities like diesel power plants and their locations can be masked and removed from any analysis. The spread of NO_2 sources due to wind is a bit of an issue and need to be corrected using wind velocity details from an instrument such as radar scatterometer. However, the wind velocity data at ground level on land is difficult to capture by a satellite-based system. One possibility is to make use of ground-based wind measurements.

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