NO_2 Correlation Using Sentinel-5P Images and on-site Measurements during the Evolution of COVID-19 and its Influence in the Metropolitan District of Quito, Ecuador

Martha Correa [a,b], Mónica Duque [c], Mauricio Meza [d], Rodolfo Salazar [e,f,*]

[a] *Escuela Técnica Superior de Ingenieros en Topografía, Geodesia y Cartografía, Universidad Politécnica de Madrid, Madrid, Spain*
[b] *Miembro Alterno Comisión de Cartografía del Instituto Panamericano de Historia y Geografía IPGH, Ecuador*
[c] *Gestión de Investigación y Desarrollo, Instituto Geográfico Militar, Quito, Ecuador*
[d] *Consultor Independiente, Quito, Ecuador*
[e] *Departamento de Ciencias de la Tierra y de la Construcción, Universidad de las Fuerzas Armadas ESPE, Quito, Ecuador*
[f] *Grupo de Investigación de Análisis Territorial, Universidad de Santiago de Compostela, Santiago de Compostela, Spain*

*Corresponding author: *rjsalazar@espe.edu.ec*

***Abstract*— Since the first outbreak of coronavirus disease (COVID-19) reported in Wuhan (China) on December 31, 2019, countries all over the world have decreed different security measures such as lockdowns and confinement, resulting in reduced levels of air pollution. The present study explores the correlation of the levels of nitrogen dioxide (NO2) measured using two different source data as Sentinel - 5P images and the on-site database of three monitoring stations belonging to the Environmental Monitoring Network in the Metropolitan District of Quito, within three periods of time during the progression of COVID-19. The result of this analysis shows an overall correlation of ninety-three percent of the levels of NO2 for both measurements in the period January to June 2020. During the lockdown and confinement measures from March to April 2020 a reduction of forty-nine percent was found, but when confinement measures were reduced within the period May to June 2020, an increase in NO2 concentration was again observed and the reduction was only thirteen percent; thus, the reduction in NO2 concentrations may be attributed partly due to the significant reduction in vehicle exhaust gas emissions. From the correlation of the results obtained, it can be concluded that this methodology, using Sentinel-5P image analysis may be used to measure the NO2 concentrations in the atmosphere in cities where there is no on-site air quality monitoring network.**

***Keywords*— COVID19; sentinel-5P; dioxide nitrogen.**

Manuscript received 19 Mar. 2021; revised 4 Sep. 2021; accepted 22 Dec. 2021. Date of publication 30 Jun. 2022.

I. INTRODUCTION

Environmental pollution is the variation in the state of the climate, which can be statistically identified through fluctuations in the mean and/or variability of its properties, persisting for long periods, usually decades or longer periods. Anthropogenic greenhouse gas emissions are the main trigger and contribute to the Earth's energy balance fluctuations by preventing the infrared radiation it emits from dissipating; hence, by changing the temperature suitable for life. The increase in those emissions in the atmosphere has contributed to an imbalance, leading to global warming.

Global warming is directly related to nitrogen oxides because they play an important role in air quality and impact human health. They represent a mixture of gases formed by nitrogen and oxygen: mainly nitric oxide (NO), nitrogen dioxide (NO_2), dinitrogen trioxide (N_2O_3), dinitrogen tetroxide (N_2O_4), and dinitrogen pentoxide (N_2O_5); all included under the NOx formula [1].

Nitrogen dioxide is a gaseous, brown-colored, highly oxidizing agent in the air [2], which is formed when fossil fuels are burned at high temperatures, such as in-vehicle engines and industrial plants. It is harmful to health and a precursor to near-surface ozone that adversely affects health and ecosystems [3]. It is also a short-lived climatic factor.

The impact of alterations derived from climate change is transboundary, causing extreme meteorological phenomena [4] , effects on human health through diseases derived from extreme temperatures, famines, and changes in the distribution of infectious diseases worldwide. An example is an appearance of the coronavirus (COVID-19) outbreak, first reported in the Chinese city of Wuhan on December 31, 2019.

The result of the analysis carried out in the Rajasthan region, one of the most polluted cities of India showed that the most significant dip was observed in the NO_2 concentration, with a maximum decline of less than 64% has being observed in Bhiwadi city of Rajasthan, before and during lockdown duration in 2020 [5].

The World Health Organization (WHO) has been monitoring household air pollution for more than ten years and has an extensive air quality database. This information determines that the main sources of air pollution caused by fine particles are the inefficient use of energy in homes, industrial sectors, agriculture, coal-fired power plants, and mainly transportation [6].

Many studies have shown that the symptoms of decreased lung function, premature death, lung disease, aggravated asthma, irregular heartbeat, and nonfatal heart attacks are due to long exposure to the toxic component as nitrogen dioxide (NO_2). As per those documents, a total of 2.6 million people is significantly affected due to the degradation of air quality.

An example is the appearance of the coronavirus (COVID-19) outbreak. Statistics indicate that COVID-19 has spread worldwide. In June 2020, more than ten million cases [7], and as of August 2020, twenty-five million cases [8]. It has led to the implementation of extreme health measures such as confinement [9], reduction of vehicular traffic, activities productive plants with high energy demand, thus reducing the levels of nitrogen dioxide (NO_2), one of the parameters responsible for air pollution [10].

Because of these measures, the percentage of pollution worldwide was significantly reduced. Studies in countries such as China, Italy, Spain, and Argentina report the air purer, according to the results obtained after analyzing the Sentinel-5P satellite images [11] of the Copernicus program of the European Space Agency (ESA) that reveals key information on the emission of nitrogen dioxide into the atmosphere.

Sentinel-5P images with free and open data access are used to monitor the atmosphere, taking global data on radiance or air quality parameters such as ozone, carbon monoxide, nitrogen and sulfur dioxide, methane, aerosols, formaldehyde. TROPOMI (TROPOspheric Monitoring Instrument) technology is used, which consists of a state-of-the-art multispectral imaging spectrometer that more accurately detects the unique footprint of atmospheric gases with high spatial resolution, measuring air pollution from space [12].

Research conducted by Gautam [13] collected the variation of NO_2 from the satellite (Sentinel – 5P), and it was used to suggest the significant reduction in the level of NO_2 in Asian and European countries due to COVID-19 lockdowns. According to data recently released by the National Aeronautics and Space Administration (NASA) and European Space Agency (ESA), the environmental quality has improved, and there was a 30% reduction observed in the emission of NO_2. Using Sentinel – 5 P satellite images, they realized a variation in the concentration level of NO_2 before and after COVID-19 (March 2019–March 2020). This research concludes that the NO2 reduced 20–30% in European countries (mainly in Spain, Italy, and France) and about 70% in Asian countries due to lockdown applied by respective governments. It was also observed that lockdown is more effective in Asian countries than in European countries because Asian countries placed travel restrictions relatively early, and many states quickly shut off access to public places [7].

In Ecuador, due to the health emergency, industrial production and vehicle restrictions were reduced drastically in the Metropolitan District of Quito. It shows a decrease in air pollution levels by almost 50% [14], [15]. When it was compared to the levels registered in January and February 2020, it reached the status of "desirable level" according to the Metropolitan Network of Atmospheric Monitoring of Quito (Red Metropolitana de Monitoreo Ambiental de Quito), and a study carried out by the University of Las Américas (UDLA) [16].

In this context, the objective of this study was to analyze the correlation of the measured data values of nitrogen dioxide at surface level obtained from on-site stations with the tropospheric data taken by the TROPOMI sensor from the Sentinel 5P air quality images during three selected periods in the Metropolitan District of Quito and thus obtain reliable results to show the reduction the level of environmental pollution as a collateral effect of social isolation, the decrease in industrial activities and vehicle restrictions.

Furthermore, a factor that has been explored in several academic studies is poor air quality. Some conclusions in such studies have identified the significant improvements in air quality that have resulted from COVID-19 lockdowns. In the case of NO_2, there is a positive and statistically significant association with COVID-19. It is also suggested that livestock production could be a major source of emissions in countries where pollution sources do not correlate well with major metropolitan areas. Research can be used to provide early warning for rural areas where health services are less developed [17].

Surface observations of the Copernicus Atmospheric Monitoring Service of the European Union [18] have shown that nitrogen dioxide levels are significantly reducing due to measures of social isolation, restriction of mobility in several countries. In Ecuador, it is also demonstrated through the information obtained from the REMMAQ, such as those of the satellite, showing that the levels of contamination by NO_2 have dropped.

Data for this study were correlated with the information obtained from the Sentinel 5P satellite at selected periods before and during confinement because of the COVID 19 pandemic. The results showed a significant correlation of ninety-three percent between the data obtained on-site and those provided by the satellite, thus verifying the veracity of the same.

II. Materials and Methods

In the case of Ecuador, the city of Quito, located at 2800 meters above sea level, was selected as the area of study. It is at an altitude where the air has less oxygen and produces alterations in the levels of combustion efficiency, which causes equipment that burns fossil fuels, such as industrial generators or incinerators or vehicle engines, to consume greater amounts of fuel and at the same time, generate greater amounts of pollutants [19]. The average concentrations of the environmental pollutant NO2, used as an air quality parameter, were evaluated in three environmental monitoring stations in Quito compared with data obtained from the Sentinel 5P satellite.

Experimental and case study methods were carried out for the development of this work. Different sources of information on monitoring the decrease of NO_2 in several countries were reviewed, and remote sensing technologies for the management of air pollution information. The following (Fig. 1) presents the methodological scheme carried out in this study.

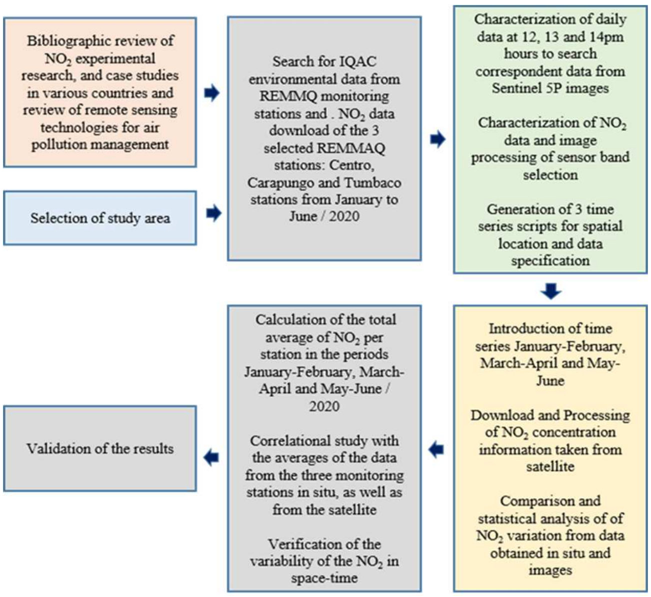


Fig. 1 Methodological scheme of the research

The study area and the nitrogen dioxide (NO2) environmental data from the Air Quality Index of Quito, AQIQ (Índice de la Calidad del Aire de Quito – ICAQ) registered in January to June 2020, in the REMMAQ database were selected. Data from three of the nine sectioned monitoring stations were used considering the high, medium, and low contamination levels registered at the Centro, Carapungo, and Tumbaco stations. The information was downloaded from the Secretary of the Environment of the Municipality of Quito portal [20].

To manage air quality in response to the environmental pollution problem, the Ministry of the Environment of Ecuador used the nine remote stations that are distributed in the urban area of Quito and valleys nearby; these data are related to monitoring the AQIQ of common pollutants: particulate matter (PM2.5), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and ozone (O_2), which report daily information.

NO_2, measured in µg/m3 is one of the atmospheric pollutants produced by vehicular traffic that hurts people's health and the environment. Its emissions directly affect air pollution problems on a local, regional, and global scale. NO_2 as the main pollutant source and its effects on human health are summarized [21](Table 1).

TABLE I

NO_2 AND ITS MAIN SOURCES AND EFFECTS ON HUMAN HEALTH

Pollutant (NO_2)		
Characteristics	**Main Sources**	**Effects on Human Health**
Red-brown gas, strong in color and pungent odor. It can produce nitric acid, nitrates, and toxic organic compounds	Combustion processes (vehicles, industrial plants, thermal power plants, incinerators)	Causes lung irritation, bronchitis, lung, significant reduction in respiratory resistance to infections. Continuous exposure to high concentrations increases the incidence of respiratory diseases in children, worsening of affectations in asthmatic individuals and chronic respiratory diseases

Source: Air Quality Report 2016, Secretary of the Environment [21].

It is quite difficult to obtain periodical satellite images because Ecuador and Quito, located at 0º of Latitude, have very cloudy conditions at hours required for the study, near midday. Other huge cities as Guayaquil or Cuenca can be considered when weather conditions permit acquiring their images.

According to the WHO Air Quality Guide and the Ecuadorian Air Quality Standard, the current guide value is 40 µg / m3 (annual average) and the highest 200 µg / m3 (one-hour average), established to protect the population from the effects of gaseous NO_2 on health [6]. The rationale for this is that, since most concentration reduction methods are specific for NOx, they are not designed to control other accompanying pollutants and may even increase their emissions. However, a lower annual guideline value should be used if NO2 is monitored as a marker of complex mixtures of pollution from combustion [22].

The REMMAQ on-site monitoring stations are detailed with the respective geographic coordinates [23](Table 2) of the Environmental Monitoring Stations in the Metropolitan District of Quito.

TABLE II

ENVIRONMENTAL MONITORING STATIONS IN THE METROPOLITAN DISTRICT OF QUITO

Name	**Height m,a,s,l.**	**Longitude, Latitude (Geographical Location)**
BEL Belisario	2835	78°29'24" W, 0°10'48" S
CAR Carapungo	2660	78°26'50" W, 0°5'54" S
CEN Centro	2820	78°30'36" W, 0°13'12" S
COT Cotocollao	2739	78º29'50"W, 0º6'28" S
CAM Camal	2840	78°30'36" W, 0°15'00" S
GUA Guamaní	2887	78°33'5" W, 0°19'51" S
LCH Los Chillos	2453	78°27'36" W, 0°18'00" S
TUM Tumbaco	2331	78°24'00" W, 0°12'36" S
JIP Jipijapa	2781	78°28'48" W, 0°09'36" S

Source: Air Quality Report 2016, Secretary of the Environment [21].

The spatial location (Fig. 2) presents the special characteristics of the study area.

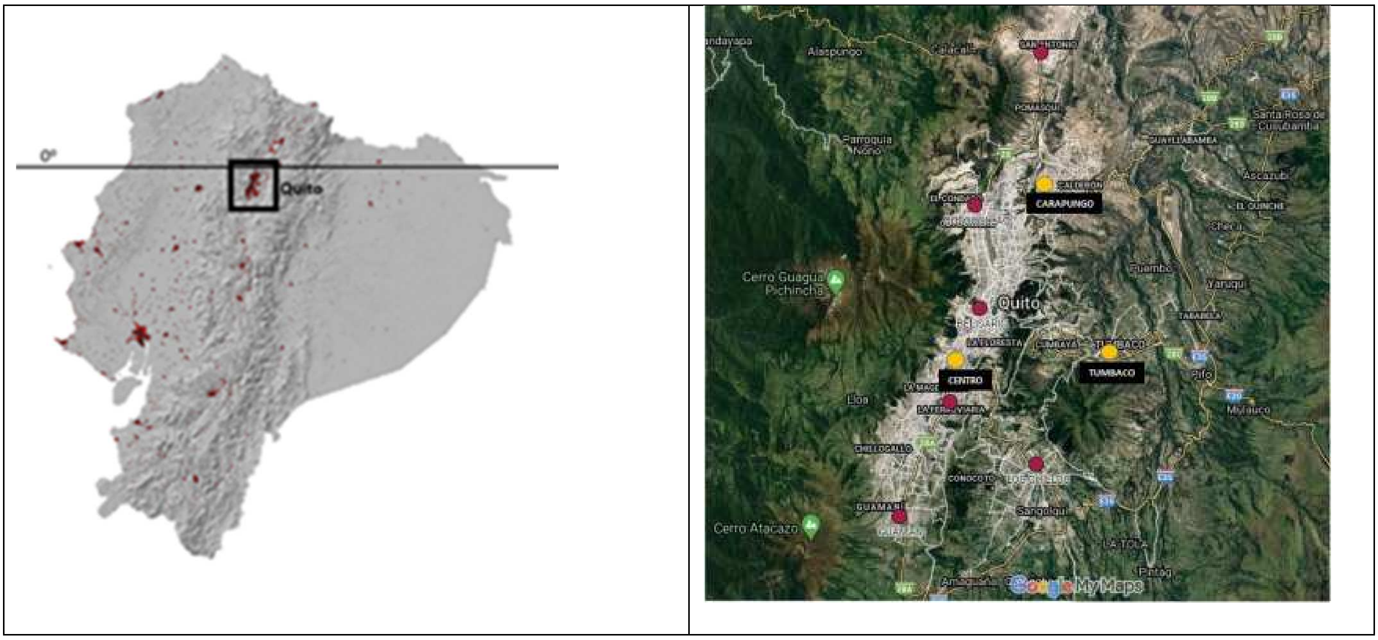


Fig. 2 Spatial location of the Environmental Monitoring Stations

As for the three selected stations, the AQIQ daily reports [20], were obtained from January to June 2020 using the REMMAQ database in its web portal. An example of the 500 values of these data (Fig. 3) used for the selected hours is shown.

Monthly Report

Current Date: 18/06/2020 13:30

Site Name: Carapungo : May 2020 Avg Interval: 1 hour

Parameter: NO2_ug 42602 Units: ug/m3 001 Method:

Hours

Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total General		
																									Max	Avg	RDS
01	6,53	4,35	5,09		3,68	7,20	10,93	13,11	12,05	11,98	12,24	12,95	14,18	8,40	3,68	3,91	4,12	4,52	5,61	5,99	5,95	6,28	4,88	4,94	14,18	7,50	23
02	5,52	2,63	2,00	2,21	4,33	9,87	13,31	10,29	9,63	6,02	4,69	3,99	4,26	3,41	3,83	3,02	3,13	3,56	3,86	4,20	4,86	3,56	2,69	2,85	13,31	4,90	24
03	3,59	3,11	2,40		4,03	7,23	7,88	8,11	8,04	6,58	4,09	4,64	3,51	3,55	3,05	2,41	2,03	2,65	3,60	4,55	5,88	8,18	6,06	8,04	8,18	4,92	23
04	7,50	6,84	5,45	3,67	5,16	11,32	14,70	13,06	14,48	14,61	12,19	5,56	5,34	6,17	5,07	4,65	4,56	4,53	6,70	8,66	6,76	7,47	7,18	7,51	14,70	7,88	24
05	5,07	7,95	8,16		15,00	20,37	22,66	23,96	21,82	19,90	9,82	9,48	8,79	7,81	5,65	4,35	5,26	7,64	7,04	10,06	8,83	8,50	10,22	9,09	23,96	11,19	23
06	9,07	9,50	12,46	8,71	8,91	15,97	17,17	22,44	19,84	11,84	10,62	10,57	8,94	6,33	7,42	4,23	2,83	5,11	7,71	7,22	7,88	8,73	7,56	7,80	22,44	9,95	24
07	6,80	9,40	8,99		11,98	13,99	18,12	16,70	11,13	4,86	7,31	7,20	7,63	7,35	4,83			5,27	5,37	8,07	10,99	8,96	5,75	4,91	18,12	8,83	21
08	5,58	4,87	4,54	11,75	13,95	14,21	21,55	17,83	24,53	17,45	9,12	9,28	7,99	8,00	5,87	4,74	3,22	4,70	7,12	8,78	7,81	8,35	6,22	7,11	24,53	9,77	24
09	3,92	6,04	7,57		7,38	10,53	13,43	7,78	5,87	4,88	5,04	4,25	4,01	4,78	3,41	3,11	2,37	3,54	4,13	6,37	7,47	7,83	7,99	9,85	13,43	6,15	23
10	10,17	9,37	6,91	3,07	5,46	8,25	10,54	10,40	10,53	7,53	6,65	3,98	5,19	5,95	4,47	2,94	2,47	2,84	4,78	5,04	4,14	5,42	4,51	3,97	10,54	6,02	24
11	4,32	3,90	3,32		4,23	5,95	14,80	14,98	13,04	14,69	8,76	6,93	6,59	7,56	5,64	5,50	5,54	6,06	6,96	6,75	4,71	4,61	4,98	4,34	14,98	7,13	23
12	2,59	1,80	1,29	2,05	3,89	13,21	19,35	17,09	14,49	10,75	14,09	12,36	7,98	5,81	4,08	2,67	6,18	14,25	13,30	7,29	7,03	4,75			19,35	8,46	22
13										16,66	18,12	15,46	18,82	15,78	9,48	7,05	9,22	12,92	14,07	12,74	7,75	7,60	12,91	12,96	18,82	12,76	15
14	13,04	15,04	17,61	18,95	21,93	23,42	40,20	42,47	32,83	36,57	34,42	16,43	10,24	9,47	7,49	6,07	4,37	6,01	10,30	10,44	10,04	8,96	7,81	4,61	42,47	17,03	24
15	3,91	7,06	6,86		7,21	18,53	18,02	16,80	16,27	12,19	11,05	11,43	9,70	8,77	5,97	4,73	3,86	4,72	8,27	8,56	7,10	7,51	8,41	10,39	18,53	9,44	23
16	11,62	14,76	14,60	12,68	11,18	19,33	22,57	22,11	19,83	10,41	6,65	8,48	6,40	5,74	5,51	3,48	3,51	5,05	6,64	10,78	11,68	8,13	8,12	7,69	22,57	10,70	24
17	5,74	5,74	7,83		13,49	19,08	22,47	8,27	5,11	3,39	4,44	3,57	5,25	4,35	3,36	2,78	2,76	4,25	4,81	5,65	5,16	5,33	5,61	4,12	22,47	6,63	23
18	4,17	2,76	2,69	2,59	3,42	7,18	15,78	12,48	13,13	9,98	10,48	9,04	7,79	5,92	5,09	4,13	3,81	4,13	6,10	7,96	8,08	10,43	15,14	12,38	15,78	7,69	24
19	7,21	12,32	15,37		17,70	26,10	24,37	23,95	14,95	14,91	15,12	7,99	7,27	7,38	4,83	3,17	3,28	3,94	4,83	6,09	6,99	6,38	5,60	7,92	26,10	10,76	23
20	9,45	7,00	5,20	4,25	4,97	10,49	17,58	12,45	9,28	12,52	9,22	7,99	10,88	9,41	7,00	4,11	3,68	5,71	8,65	9,92	7,52	10,35	5,71	4,86	17,58	8,25	24
21	6,84	10,43	11,20		15,64	21,14	28,79	33,41	19,43	17,11	10,71	9,95	9,73	8,22	6,42	4,24	5,53	5,66	10,49	10,15	8,88	8,03	7,97	9,33	33,41	12,14	23
22	9,18	10,11	13,51	16,17	16,10	19,33	29,67	38,31	13,40	10,78	13,89	10,17	11,98	8,62	7,17	4,97	4,02	5,36	11,06	12,95	13,75	16,97	10,88	10,35	38,31	13,27	24
23	7,93	8,24	12,35		9,98	18,01	22,10	15,14	8,46	7,77	7,07	7,86	9,04	4,98	4,70	3,36	4,80	5,56	7,47	8,67	10,37	8,09	5,58	8,38	22,10	8,95	23
24	11,34	13,68	6,67	9,89	10,63	5,27	5,30	6,32	4,52	5,46	5,53	4,50	4,82	6,14	3,83	2,34	2,73	3,58	5,53	8,13	6,65	9,29	6,11	7,43	13,68	6,48	24
25	6,75	6,37	9,54		15,46	24,64	23,69	18,79	11,83	8,38	8,44	7,92	8,28	7,06	5,60	5,07	4,82	6,50	6,83	11,79	13,64	11,27	12,78	18,91	24,64	11,06	23
26	14,78	9,11	4,26	5,44	11,41	21,19	30,88	19,58	13,81	9,24	7,45	9,68	7,06	7,32	7,25	6,24	5,82	5,60	9,63	7,84	9,50	8,81	5,81	5,73	30,88	10,14	24
27	3,96	5,04	7,15		11,51	18,84	23,82	19,89	16,91	11,75	9,91	10,51	8,53	6,11	4,76	3,72	4,05	4,29	8,36	8,20	7,66	7,35	4,54	3,04	23,82	9,12	23
28	2,96	2,68	2,51	2,62	2,89	9,43	17,97	14,06	13,66	13,67	15,55	7,40	6,68	7,56	5,11	4,00	3,59	5,15	7,89	7,50	6,32	4,28	3,77	2,77	17,97	7,08	24
29	2,72	2,68	3,63		5,66	8,73	19,77	19,31	20,03	15,98	15,21	10,72	7,59	8,16	7,29	4,69	4,18	5,65	10,23	9,71	9,24	5,90	4,48	5,30	20,03	8,99	23
30	4,39	4,42	4,75	5,50	5,48	6,67	16,95	22,10	16,97	16,98	15,85	15,95	10,13	6,81	5,02	4,57	4,89	6,88	8,53	7,71	6,69	6,19	4,41	3,16	22,10	8,79	24
31	2,59	3,46	2,68		2,33	3,84	7,15	12,25	9,80	6,66	6,42	3,94	3,90	5,20	4,36	3,26	3,30	5,41	8,97	7,75	6,54	9,06	4,45	4,91	12,25	5,57	23
Max	14,78	15,04	17,61	18,95	21,93	26,10	40,20	42,47	32,83	36,57	34,42	16,43	18,82	15,78	9,48	7,05	9,22	14,25	14,07	12,95	13,75	16,97	15,14	18,91	42,47		
Avg	6,64	7,02	7,21	7,30	9,16	13,97	19,05	17,78	14,18	11,98	10,65	8,71	8,01	7,03	5,39	4,11	4,13	5,51	7,57	8,24	7,93	7,82	6,93	7,15		8,91	
Cuenta	30	30	30	15	30	30	30	30	30	31	31	31	31	31	31	30	30	31	31	31	31	31	30	30			716

Fig. 3 Example of REMMAQ monthly reports used

With the data obtained on-site from the three monitoring stations, Centro, Carapungo, and Tumbaco, specific hours of high vehicular traffic [24] of each day were selected (Table 3). These specific hours of high vehicular traffic were: 12:00, 13:00, and 14:00 hours of each day/month, which were classified in two-month intervals from January to June, corresponding to three periods: January-February, March-April, and May June.

TABLE III
GLOBAL DATA FOR THE CENTRO, CARAPUNGO, AND TUMBACO STATIONS

Time	Number of datasets of the three stations
12:00	152
13:00	152
14:00	152
Grand Total	456

The other resource used in the study was the images of the Sentinel 5P satellite by the European Space Agency Copernicus Program. It allows mapping pollutants based on atmospheric concentration levels worldwide, monitoring air quality, mapping planetary environmental situation as well as analyze and create air quality maps using the Tropomi Sensor, which is a passive detection multispectral nadir vision imager onboard the satellite, which takes, among others, the values of the tropospheric column of NO_2 in mol/m^2.

The analysis of the fluctuation of nitrogen dioxide concentrations was carried out by selecting the air quality data recorded on-site by the monitoring stations of the city of Quito (Centro, Carapungo, and Tumbaco), with a total sample of 456 data values in the same temporal spaces of the tropospheric data from the Sentinel 5P satellite that crosses Ecuador between 13:00 and 13:30 local time, whose characteristics (Table 4) were considered [25].

TABLE IV
SATELLITE SENTINEL-5 P (PRECURSOR)

MISION	From the Copernicus Program, in charge of monitoring air pollution. Released 10/13/2017. Use a spectrometer in the ultraviolet, visible, near-infrared wavelengths called TROPOMI
DESIGN	The hexagonal shape on an Astrobus L 250 and equipped with antennas in the S and X bands, three folding solar panels that generate power of 1500W, and hydrazine propellants to maintain the orbit.
FEATURES	It uses a high tilt orbit (approximately 98.7 °). The inclination of the orbit is the angular distance of the orbital plane from the equator.
ORBIT	The orbit is nearly polar, synchronous with the sun, with an ascending node equatorial crossing at 1:30 PM local mean solar time. Synchronous with the sun, the surface is always illuminated at the same solar angle.
ORBITAL CYCLE	The orbital cycle is 16 days (14 orbits per day, 227 orbits per cycle). The orbit cycle is the time it takes for the satellite to pass through the same geographic point on the ground.
ALTITUDE	The reference altitude of the orbit is approximately 824 km.
VISIT PERIOD	1 day
RESOLUTION	7 – 68 Km
MISION INSTRUMENT TROPOMI	Passive Mesh Imaging Spectrometer Projection on Earth: 2,600 km Spatial sampling: 7x7 km2 Spectral: 4 spectrometers, each electronically divided into two bands (2 in UV, 2 in VIS, 2 in NIR, 2 in SWIR) Radiometric Accuracy (absolute): 1.6% (SWIR) to 1.9% (UV) of the measured terrestrial spectral reflectance.

Source: ESA [12]

Through Google's cloud-based free scientific analysis platform Google Earth Engine (GEE) [26], data from satellite images released from SENTINEL 5P were accessed, and the script [27] was parameterized to analyze the offline high-resolution image collections "COPERNICUS/ S5P/ OFFL/ L3_NO_2" in the study area.

The TROPOMI sensor data characterize the distribution and concentration of NO_2, using the vertical column density (VCD) in real-time to obtain column density values of environmental contaminants. For the case study, the "tropospheric_NO_2_column_number_density" band was selected and a script was generated for each period of the date ranges: January-February, March-April, and May-June using the geographic location data (longitude and latitude, [23] Table 2) of the three on-site monitoring stations, obtaining as a result three (3) interactive maps of the NO_2 fluctuations in those periods [28].

The objective of obtaining NO_2 data from a sensor through satellite images and those obtained from terrestrial on-site monitoring stations was to compare the results of two different technologies, whose common purpose is to measure air quality analyzing the changes in NO_2 concentrations in the study period because of the health emergency generated by COVID 19.

Subsequently, the statistical analysis of the data was carried out. The partial average of each station was calculated in the previously selected hours and thus calculated the total average of each station in the periods between January-February, March-April, and May-June. With the averages of the data from the three monitoring stations on-site and the satellite, a correlational study was carried out to demonstrate a relationship between what the satellite captures in space and the monitoring instruments of each on-site selected station measures.

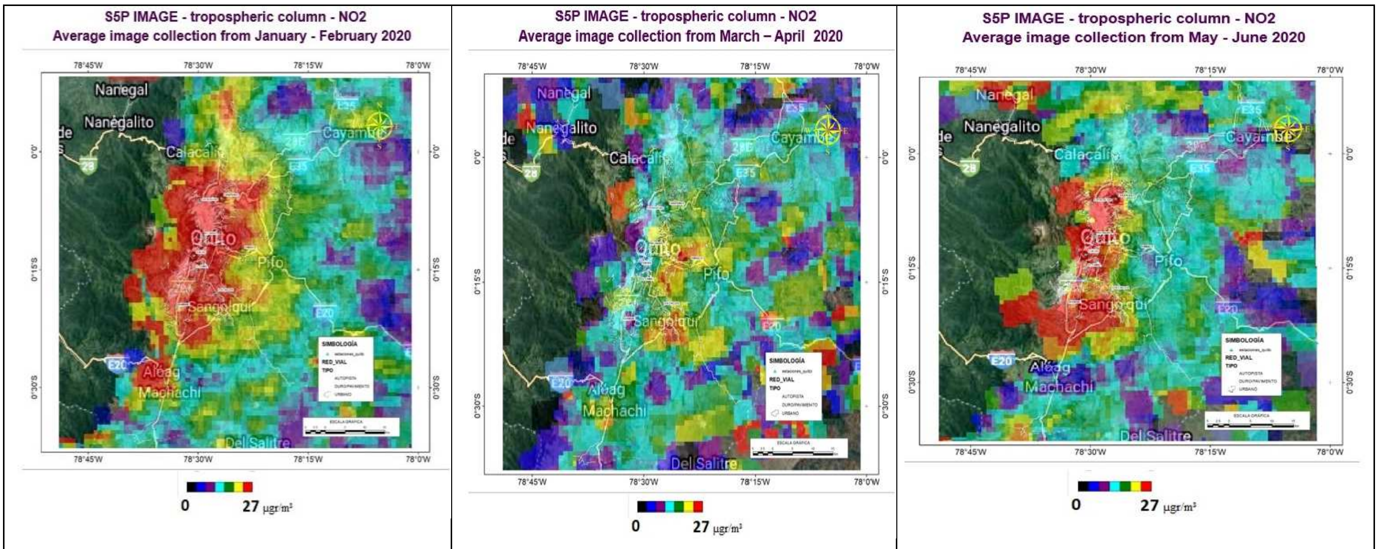
III. Results and Discussion

This study evaluated the strength of the results of the correlation of nitrogen dioxide as one of the environmental pollutants through the data monitored by the Centro, Carapungo, and Tumbaco stations of the REMMAQ environmental monitoring network of the city of Quito and those obtained from satellite images using the TROPOMI instrument, with a spatial resolution of 7 km X 3.5 km and temporal resolution of 1, as parameters for measuring the air quality and characterizing the spatial-temporal variability of NO_2 concentration.

The stations selected in the study areas were chosen for their high average presence and low environmental pollution for the study period from January to June 2020. After analyzing the scripts generated with the Sentinel-5P image collections, three graphs corresponding to the periods January-February (Fig. 4a), March-April (Fig. 4b), and May-June (Fig. 4c) were obtained, with the values corresponding to the NO_2 levels at the spatial location of the Centro, Carapungo and Tumbaco stations.

In the sequence of satellite images, the spatial-temporal changes of nitrogen dioxide are evident; in each image, it can be seen how the level of nitrogen dioxide has changed over time during the study period. The colors from red, yellow, green, blue, purple, and black tones represent a continuation of high, medium, and low NO_2 concentration values in descending order.

In the image corresponding to the period January-February, (Fig. 4a), a high level of nitrogen dioxide (NO_2) contamination is observed before the health emergency and confinement in the Metropolitan District of Quito, represented by the reddish color. In the March - April period, a notable decrease in nitrogen dioxide (NO_2) can be seen, showing a scarce reddish coloration during confinement (Fig. 4b). While in the period May - June, it is seen that the reddish color of nitrogen dioxide (NO_2) has increased (Fig. 4c); due to the new measures taken by the authorities in the city of Quito to resume gradually economic and productive activities.



a. January – February | b. March – April | c. May – June

Fig. 4 NO_2 pollution in the periods a. January-February, b. March-April and c. May-June 2020. Source: S-5P images extracted from GEE

During the evolution of COVID-19 in the Metropolitan District of Quito, there were several effects on the health of the capital´s citizens; for this reason, the authorities have been decreeing different measures to safeguard people's lives, one of these was the full confinement in March, April, and mid-May. In the March-April period, the authorities decided to establish confinement as a preventive measure to deal with the coronavirus. This resulted in an overall reduction of (47.86% - in satellite data and 50.87% - in on-site data) in the levels of pollution of the capital and specifically of nitrogen dioxide (Table 5). The reduction was due to the paralysis of transport [29], factories, businesses, etc., preventing nitrogen dioxide from being emitted into the atmosphere in such a way that the city's air quality became poor. Regarding May and June, the pollution reduction was only (5.08% - in satellite data and 11.70% - in on-site data) (Table 5). The corresponding authorities decreed that the traffic light be switched to yellow, meaning that the confinement and industrial transport activities gradually normalize over time.

TABLE V
Reduction of the Levels of Pollution According to AQIQ

	Satellite			**On-site**		
	Jan Feb	**Mar-Apr**	**May Jun**	**Jan Feb**	**Mar-Apr**	**May Jun**
Centro	27.27	7.92	22.95	25.75	8.56	20.31
Carapungo	20.59	11.05	24.00	19.11	9.83	16.42
Tumbaco	18.27	15.51	14.10	17.36	12.18	13.79
Total	66.13	34.48	61.05	62.22	30.57	50.22
Mean	22.04	11.49	20.35	20.74	10.19	16.84
Difference		31.65	5.08		31.65	11.70
Percentage		47.86	7.68		50.87	18.80
Mean Percentage					49.36	13.24

The overall reduction for the three on-site stations changed (Fig. 5) from the 49.32% less concentration of NO_2

considering the period January – February to 13.24% in the period May – June.

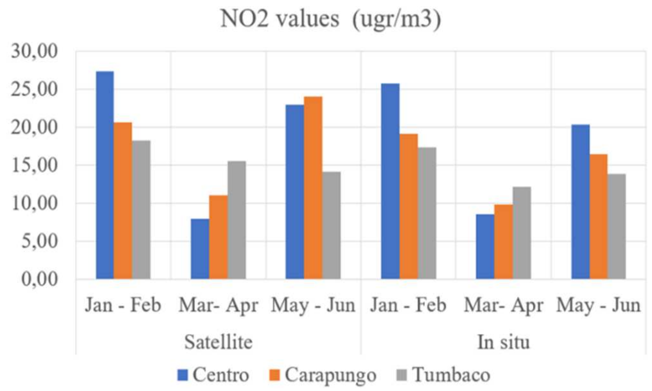


Fig. 5 Overall reduction of NO_2 level in the three stations

The correlational analysis [30] shows the increase and decrease of the NO_2 values of the environment in the Metropolitan District of Quito using the sentinel-5P images. The data from the monitoring of the ground stations resulted in 93% assertiveness (Fig. 6). The data shows that the atmospheric instruments of each monitoring station of the city take correct and real data of the concentration of nitrogen dioxide on-site, compared to the measurements with state-of-the-art technology of the Sentinel-5P satellite in space.

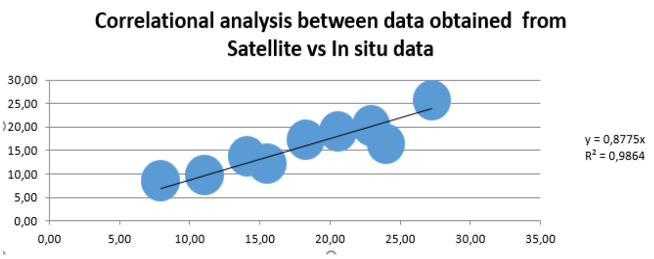


Fig. 6 Correlational analysis between data obtained from the satellite and on-site data

Additionally, it can be seen how the NO_2 trend has been according to the data obtained from the stations on-site in the Metropolitan District of Quito from January to June 2020 (Fig. 7). The trend in nitrogen dioxide pollution levels has been variable. It can be seen how it has been evolving before, during, and after quarantine (Table 5), (Fig. 6).

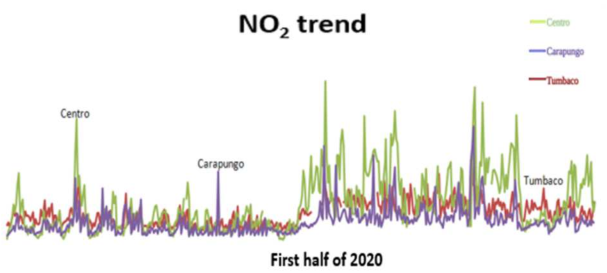


Fig. 7 NO_2 trend during the first half of 2020

The monitoring station Centro presents the highest trend because even though not many people live in that sector, due to its commercial land use, most people did not respect the quarantine. The Carapungo station is the second on the list, as it is a strategic point in the city, where traffic is essential since it connects with the market throughout the north of the country and is an area of high population density. Finally, the Tumbaco station presents the lowest trend of all because it is a residential area with high added value, and most people did not travel to Quito because they started teleworking.

Another additional result is that the Central sector is the one with the highest contamination, followed by the Carapungo and Tumbaco sectors, as shown in (Fig. 5 and 7).

IV. CONCLUSION

With the Quito Air Quality Index of Quito, AQIQ obtained from both the 3 monitoring stations of REMMAQ and Sentinel 5P, the variations of NO2 contamination were evaluated in the study areas. The correlation of the data gives an average of 93% of assertiveness, which determines a correlation between the satellite information and the measurements taken in the selected stations on-site. Management measures by the competent authorities will contribute to the continuous reduction of various pollutants, and in the future to improve the health and quality of life of citizens. The use and access to open data make it easier to have crucial information in real-time for analysis and timely decision-making to manage the right measures that improve the quality of life and reduce the impact of environmental pollution that influences the health and well-being of the population.

The containment measures and the reduction in economic and industrial activity have generated positive side effects, due to the pandemic, with a clear decrease in atmospheric pollution in Quito. The President of the Republic of Ecuador decreed the state of exception, given the spread of the coronavirus. It has allowed a reduction in environmental pollution due to the effects of NO2 in the city of Quito, so the air quality has improved in different values during the study periods March-April and May-June.

The Sentinel 5P Satellite that monitors the atmosphere on the planet, through the TROPOspheric Monitoring Instrument (TROPOMI) sensor of the higher special resolution, allows showing a decrease in the concentrations of nitrogen dioxide (NO2), one of the main harmful substances that emit vehicles and industry in the city of Quito, coinciding with the adoption of quarantine measures, because of the pandemic.

The discharge of atmospheric data on concentrations, nitrogen dioxide from the Sentinel 5P satellite from the Google Earth Engine platform allowed them to be applied to the study area in the city of Quito, obtaining a significant correlation with the data obtained on-site through the monitoring stations of Centro, Carapungo, and Tumbaco. Cloud platforms allow us to develop custom scripts to manage geospatial information on various topics.

The city of Quito, being at an approximate height of 2800 meters above sea level, causes the concentration of oxygen in the air to decrease, which threatens the efficiency of combustion by causing equipment that burns fossil fuels such as engines of vehicles, consume more fuel and generate more pollutants in the air with adverse results to human health.

There is a first approach to conclude that the increase-decrease of NO2 contamination is related to land use. Central and commercial areas may be affected than those of residential use. This conclusion matches the conclusion that the link between the infection and air pollution in environments with a high density of population and high industrialization (vehicle emissions), and some special characteristics [7] (volcanic ashes in the case of Andean cities) may have a strong impact in the high rate of infection and mortality.

While concluding this study, many studies have been conducted to find a relationship between concentrations of the tropospheric NO2 extracted from the Sentinel-5P satellite and the spatial variation of fatality cases in four European countries and show two main NO2 hotspots: in Northern Italy and Madrid metropolitan area [31]. This approach also can be conducted with the data used in this study.

Finally, it can be concluded that the reduction in NO2 concentrations in Quito is attributed, among others, to the containment measures that resulted in a significant reduction in vehicle exhaust gas emissions; and that the measurements obtained from the Sentinel 5-P images are of great and timely importance for decision-makers in the improvement of air quality.

ACKNOWLEDGMENT

We are very grateful to our college Lino Verduga Moreira MSc. for his input in the methodological aspects.

REFERENCES

[1] L. Fernández, "El papel de los óxidos de nitrógeno en el Cambio Climático," pp. 1–20, 2015, [Online]. Available: http://147.96.70.122/Web/TFG/TFG/Memoria/LAURA FERNANDEZ RIVAS.pdf.

[2] GreenFacts, "La Contaminación del Aire Dióxido de Nitrógeno." https://www.greenfacts.org/es/dioxido-nitrogeno-no2/index.htm (accessed Apr. 08, 2020).

[3] K. Wark, *Contaminación del aire: su origen y control, tercera edición*.

[4] WMO, "Climate | World Meteorological Organization." https://public.wmo.int/en/our-mandate/climate (accessed Apr. 21, 2020).

[5] M. Sharma, S. Jain, & Bhawna, and Y. Lamba, "Epigrammatic study on the effect of lockdown amid Covid-19 pandemic on air quality of most polluted cities of Rajasthan (India)," doi: 10.1007/s11869-020-00879-7/Published.

[6] WHO, "Guías de calidad del aire de la OMS relativas al material particulado, el ozono, el dióxido de nitrógeno y el dióxido de azufre," *2005*. https://apps.who.int/iris/bitstream/handle/10665/69478/WHO_SDE_PHE_OEH_06.02_spa.pdf;jsessionid=217875A942155B81F9AE066738D59B30?sequence=1 (accessed Mar. 04, 2020).

[7] A. Frontera, L. Cianfanelli, K. Vlachos, G. Landoni, and G. Cremona, "Severe air pollution links to higher mortality in COVID-19 patients: The 'double-hit' hypothesis.," *J. Infect.*, vol. 81, no. 2, pp. 255–259, Aug. 2020, doi: 10.1016/j.jinf.2020.05.031.

[8] JHU, "COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU)." https://coronavirus.jhu.edu/map.html (accessed Jun. 04, 2020).

[9] Primicias, "La contaminación del aire de Quito disminuyó por la emergencia sanitaria." https://www.primicias.ec/noticias/sociedad/contaminacion-aire-quito-coronavirus/https://www.primicias.ec/noticias/sociedad/contaminacion-aire-quito-coronavirus/ (accessed Mar. 21, 2020).

[10] V. M. Cevallos, V. Díaz, and C. M. Sirois, "Particulate matter air pollution from the city of Quito, Ecuador, activates inflammatory signaling pathways in vitro," *Innate Immun.*, vol. 23, no. 4, pp. 392–400, 2017, doi: 10.1177/1753425917699864.

[11] ESA, "Sentinel-5P - Misiones - Sentinel Online - Sentinel." https://sentinel.esa.int/web/sentinel/missions/sentinel-5p (accessed Apr. 05, 2020).

[12] ESA, "Sentinel-5 precursor. Data access and products." https://sentinel.esa.int/documents/247904/1848259/Sentinel-5P_Data_Access_and_Products (accessed Apr. 29, 2020).

[13] S. Gautam, "COVID-19: air pollution remains low as people stay at home," doi: 10.1007/s11869-020-00842-6/Published.

[14] S. Roa, "Medidas para enfrentar al Covid-19 mejoran calidad del aire en dos ciudades ecuatorianas." https://es.mongabay.com/2020/04/menor-contaminacion-del-aire-por-coronavirus-en-quito-y-cuenca-ecuador/ (accessed May 03, 2020).

[15] C. Rivas, "Impact of Covid 19 on Ecuadorian tour guides," *Ecuadorian Sci. J.*, vol. 4, no. 2, pp. 1–6, 2020.

[16] Ambientum, "Reducción de NO2 debido al COVID-19." https://www.ambientum.com/ambientum/contaminacion/reduccion-de-no2-debido-al-covid-19.asp (accessed Apr. 18, 2020).

[17] M. Cole, C. Ozgen, and E. Strobl, "Air Pollution and COVID-19 in Dutch Municipalities," *2020*. https://ideas.repec.org/a/kap/enreec/v76y2020i4d10.1007_s10640-020-00491-4.html (accessed May 11, 2020).

[18] J. P. Veefkind *et al.*, "TROPOMI on the ESA Sentinel-5 Precursor: A GMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications," *Remote Sens. Environ.*, vol. 120, no. SI, pp. 70–83, May 2012, doi: 10.1016/j.rse.2011.09.027.

[19] S. Peña Murillo, "Impact of Atmospheric Contamination in Two Main Cities of Ecuador," Accessed: May 05, 2020. [Online]. Available: https://www.researchgate.net/publication/335032934_Impact_of_atmospheric_contamination_in_two_main_cities_of_Ecuador.

[20] Secretaría del Ambiente - Quito, "Indice Quiteño de la Calidad del Aire (IQCA)," 2020. http://www.quitoambiente.gob.ec/ambiente/index.php/indice-quiteno-de-la-calidad-del-aire (accessed Jun. 25, 2020).

[21] Distrito Metropolitano de Quito, "Informe de la Calidad de Aire -2016," *2017*, 2017. http://www.quitoambiente.gob.ec/images/Secretaria_Ambiente/red_monitoreo/informacion/Informe_Calidad_Aire_2016.pdf.

[22] R. Parra, "Efecto Fin de Semana en la calidad del aire de la ciudad de Cuenca, Ecuador," *ACI Av. en Ciencias e Ing.*, vol. 9, no. 15, Dec. 2017, doi: 10.18272/aci.v9i15.291.

[23] Secretaría del Ambiente - Quito, "Red de Monitero Atmosférico." http://www.quitoambiente.gob.ec/index.php/carapungo (accessed Jun. 02, 2020).

[24] USFQ, "Conexiones USFQ - Una radiografía al tráfico de Quito." https://conexiones.usfq.edu.ec/index.php/369-una-radiografia-al-trafico-de-quito (accessed Jun. 25, 2020).

[25] ESA, "Sentinel-5P muestra la contaminación del aire," 2017, [Online]. Available: https://www.esa.int/Space_in_Member_States/Spain/Sentinel-5P_muestra_la_contaminacion_del_aire#:~:text=Sentinel-5P aloja el sensor,que respiramos y a nuestro clima.

[26] O. Mutanga and L. Kumar, "Google earth engine applications," *Remote Sensing*, vol. 11, no. 5. MDPI, p. 591, 2019.

[27] GEE, "Sentinel-5P OFFL NO2: dióxido de nitrógeno fuera de línea." https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S5P_OFFL_L3_NO2 (accessed Apr. 12, 2020).

[28] G. A. Perilla and J. F. Mas, "Google Earth Engine - GEE: A powerful tool linking the potential of massive data and the efficiency of cloud processing," *Investig. Geogr.*, no. 101, pp. 0–2, 2020, doi: 10.14350/rig.59929.

[29] E. Paredes and A. B. Álvarez, "Situación actual del Sistema de transporte en la ciudad de Quito, Ecuador: una propuesta de mejora," *TRIM. Tordesillas, Rev. Investig. Multidiscip.*, no. 16, pp. 5–40, Jul. 2019, doi: 10.24197/TRIM.16.2019.5-40.

[30] G. Martínez, E. Cortés, and A. Pérez, "Metodología para el análisis de correlación y concordancia en equipos de mediciones similares," *Univ. y Soc.*, pp. 65–70, 2016, [Online]. Available: http:rus.ucf.edu.cu/.

[31] Y. Ogen, "Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality," *Sci. Total Environ.*, vol. 726, Jul. 2020, doi: 10.1016/j.scitotenv.2020.138605.