Exploring the Air Quality of Gilgit City through Ground and Satellite-Based Observations

By

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THESIS ACCEPTANCE CERTIFICATE

It is certified that the contents and forms of the thesis entitled **"Exploring the Air Quality of Gilgit City through Ground and Satellite-based Observations"** submitted by **Mr. Suhaib Malik**, Registration No. **00000273499** has been found satisfactory for the requirements of the degree of Master of Science in Environmental Science.

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Declaration

I **Suhaib Malik** certify that this research work titled "**Exploring the air quality of Gilgit city through ground and satellite-based observations**" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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بسم الله الرحمن الرحيم

“In the name of Allah, the most merciful and the most Beneficent”

This MS thesis work is dedicated to the

ALLAH Almighty

Who made it possible only with his mercy

&

To my beloved

parents and siblings

who have been a source of inspiration for me throughout my life.

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Suhaib Malik

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List of Abbreviations

Abbreviation	Description
AI	Aerosol Index
AOD	Aerosol Optical Depth
ASL	Above Sea Level
BLH	Boundary Layer Height
COVID-19	Corona Virus Disease 2019
CPEC	China–Pakistan Economic Corridor
DALY	Disability-adjusted life years
EOS	Earth Observing System
EPA	Environmental Protection Agency
GB	Gilgit-Baltistan
GB-EPA	Gilgit-Baltistan Environmental Protection Agency
GLOF	Glacial Lake Outburst Flood
GOME	Global Ozone Monitoring Experiment
HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectory model
KKH	Karakoram Highway
KPK	Khyber Pakhtunkhwa
MODIS	Moderate Resolution Imaging Spectroradiometer
MOPITT	Measurements Of Pollution In The Troposphere
NASA	The National Aeronautics and Space Administration
NCP	Non-Custom Paid
NEQS	National Environmental Quality Standards
NOAA	National Oceanic and Atmospheric Administration
OMI	Ozone Monitoring Instrument
Pak-NEQS	Pakistan National Environmental Quality Standards
PBL	Planetary Boundary Layer
PEPA	Pakistan Environmental Protection Act
PHQ	Provincial Headquarter
PM	Particulat Matter
RHQ	Regional Headquarter

RH	Relative Humidity
SCIMACHY	SCanning Imaging Absorption spectroMeter for Atmospheric CartograpHY
TROPOMI	TROPOspheric Monitoring Instrument
UV	Ultraviolet
WHO	World Health Organization

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ABSTRACT

Air Pollution has emerged as a challenging issue and threat to many countries that are undergoing rapid economic development and urbanization. In developing countries like Pakistan, there is a lack of continuous ground monitoring of air pollutants. This study aims to assess both the ground-based and satellite-based air pollutants in Gilgit City. Both types of these observations are compared with each other. The ground-based results show that NO_2 concentration exceeds the permissible limit of 80 μgm^{-3} for 24 hours for 28 days out of 38 days observations according to Pak-NEQS. This represents 73% days of the total observations. While CO concentrations are well below and within permissible limits of 5 mg/m^3 averaged for 8 hours. The NO_2 concentration shows a good Pearson's Correlation of r = 0.84 with satellite-based data from the TROPOMI instrument for the tropospheric NO_2 column. The Monthly mean tropospheric NO_2 from OMI (2005-2020) shows that the NO_2 column reaches a maximum during summer while minimum during winter which is directly link and attributed to tourism inflow in the Gilgit-Baltistan area. The daily tropospheric NO_2 column of the TROPOMI instrument shows a Pearson Correlation of 0.505 with the OMI instrument. During the COVID-19 lockdown period, a significantly decreasing trend of NO_2 tropospheric column is observed from TROPOMI data. A total of 44.09% decreasing trend in the NO_2 column is observed in Gilgit City. While CO concentration shows a negative Pearson's Correlation of r = 0.44 with the Total CO column from TROPOMI. The monthly mean of the Total CO column from the TROPOMI instrument shows that it reaches the maximum in January followed by May, March, April, and February, respectively.

MODIS Aerosol Optical Depth is analyzed for two decades (2000-2020). The monthly and seasonal mean are extracted and found that AOD is high during spring followed by winter, summer, and autumn. AOD value ranges from 0.348 maximum in summer to 0.113 minimum in autumn. The Seasonal (Monthly) 3 days backward HYSPLIT trajectory frequencies are analyzed at 1000m above ground level to identify the pathway and frequency of air masses reached to the receptor site and it is found that during summer and autumn the major fraction (>90%) of air masses are localized and coming from KPK and through Karakoram Highway while a small fraction is coming from India, Afghanistan, and Nepal. During Winter and Spring, the major fraction (>90%) of air masses reached the receptor site from the Indian Occupied Kashmir site while a small fraction reached from Afghanistan, China, Tajikistan, Kyrgyzstan, and Uzbekistan. Therefore, in order to have an efficient abatement strategy for various air pollutants, trans-regional cooperation is mandatory.

Chapter 1

Introduction

1.1 Background

Air pollution is the contamination of the indoor and outdoor air by various gases and solids that change its natural characteristics. The most harmful health pollutants include particulate matter ($PM_{2.5}$ and PM_{10}), Nitrogen Oxides (NO_x), Carbon monoxide (CO), Ozone (O_3), Sulfur Dioxide (SO_2), and Black Carbon (BC) (WHO., 2018). The sources and composition of a complex mixture of particles and gases vary temporally and spatially. It is a serious problem in different countries and megacities around the world, especially in areas where transportation, urbanization, and industrialization are growing more rapidly. Moreover, air pollution is being linked with global warming and various case studies have found that an increase in air pollutants jeopardizes public health. According to WHO, 4.2 million premature deaths per year globally are assigned to air pollution. The Global Burden on Diseases study (Forouzanfar et al., 2016) found that Air Pollution was listed fourth on the global mortality risk factor. Furthermore, by 2050, the global mortality burden due to outdoor air pollution was expected to double. While in Asia, 3.3 million premature deaths are attributed to outdoor air pollution and the major contributor is $PM_{2.5}$ (Lelieveld et al., 2015).

To indicate the quality of air, the United States Environmental Protection Agency (US EPA) labeled 6 pollutants as criteria air pollutants under the Clean Air Act 1970. These criteria pollutants include Particulate Matters (PM_{10} and $PM_{2.5}$), Carbon Monoxide (CO), Sulphur dioxides (SO_2), Nitrogen Oxides (NO_x), Tropospheric Ozone (O_3), and Lead (Pb). The topography, meteorology, and anthropogenic activities of a region also contribute to the air quality of a region. Metrological parameters like temperature, relative humidity

(RH), wind direction, wind speed, play a crucial role in determining the ambient air quality of a region. Additionally, meteorological parameters influence direct and indirect emissions; along with the formation, transport, and deposition of different air pollutants (Zhang et al., 2015).

Around the world, the study of air pollution is difficult because of the complex nature of the medium, the spatially and temporal variation of various pollutants, and the poorly understood physical and chemical processes taking place between pollutants and the atmosphere. Even with these limitations, various air quality studies have been conducted around the world. Most cities of the world have continuous air quality monitoring stations indicating the air quality of the city. However, In Pakistan, this is not the case with no air quality monitoring infrastructure available and very few studies available on air quality. Most if not all these studies are limited to the major cities i.e. (Islamabad, Lahore, Faisalabad, Peshawar, Quetta, Karachi).

In the context of air quality, the region of Gilgit-Baltistan is one of the most understudied regions in Pakistan. Gilgit-Baltistan is a unique mountainous region and home to the world's 3 largest mountainous ranges including the Karakoram, the Himalayans, and the Hindukush. The ecosystem of this region is very fragile, there are over 7,000 glaciers and around 3,044 lakes and because of the increasing anthropogenic activities, it is believed that the ecosystem has is under tremendous stress. 36 out of 3044 lakes are vulnerable to GLOF (Glacial Lake Outburst Flood). Many of the glaciers are melting and the air quality (indoor and ambient air quality) is deteriorating day by day due to the increased influx of Non-Custom Paid (NCP) Vehicles and the frequent use of fossil fuel in winters for cooking and heating (Agency, 2012). And with the inclusion of the China-Pakistan Economic Corridor (CPEC), these impacts are probably going to increase.

1.2 Study Area

Gilgit is the capital of Gilgit Baltistan which is at 35.8819° N, 74.4643° E in the North of Pakistan. The elevation is about 1500 m (4900 ft) above sea level. The Gilgit covers an area of 14,672 km^2 and the population is about 222,000. The winds in Gilgit are predominantly westerlies. The maximum temperature is observed at 34.93°C in summer (Zeb et al., 2019). Gilgit River and Hunza river are confluence in the capital city (Nasir., et al 2019). The population and urbanization are increased over the last decade drastically and dramatically. Similarly, the use of transport and vehicles especially non-custom paid (NCP), is increasing simultaneously which leads to the emissions of hazardous gases which deteriorate the quality of air and caused severe public health issues. Moreover, there is no exhaust system in the region because there is no wind corridor for the transportation of Gases due to the high mountain ranges and narrow valleys.

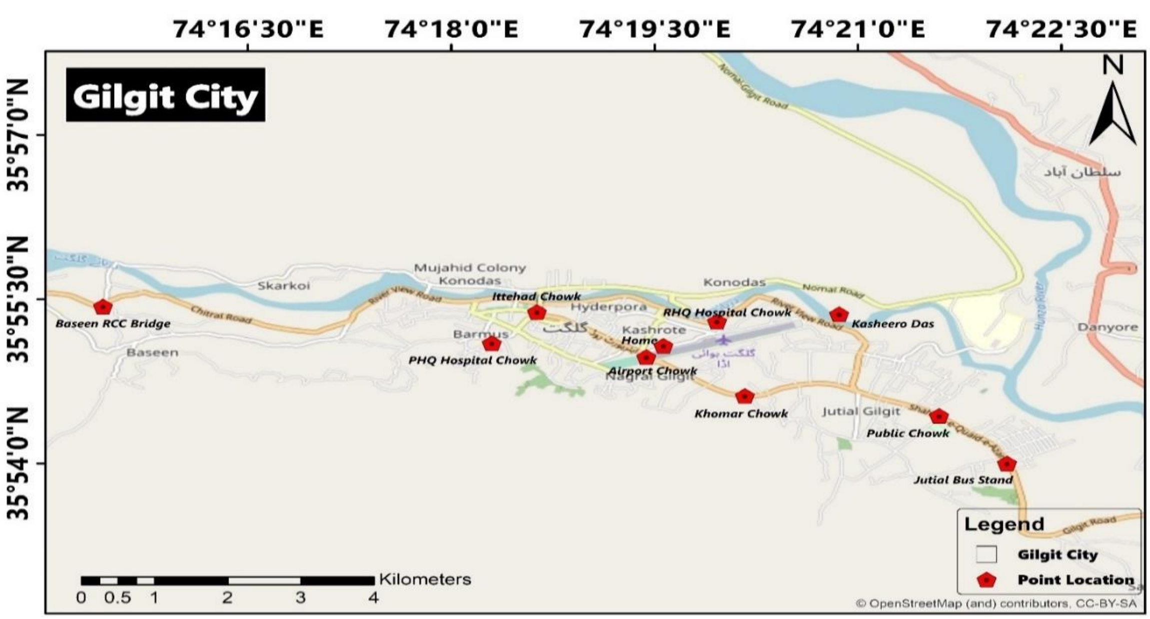


Figure 1. 1. Gilgit City - A Study Area

1.3 Objectives

This study was designed to achieve the following objectives:

1) Ground-based monitoring of criteria air pollutants in different sites using Haz-Scanner.

2) To compare the results of satellite-based observation for various criteria air pollutants concentration with ground-based observations.

1.4 Expected Outcomes of Study

This study will provide a baseline for the air quality of Gilgit City. The main area of this study is Gilgit city which is the capital and major hub of transport and commerce. The major goal of this study is to determine and quantify the criteria pollutants along with other parameters including AOD to determine the air quality of the city and Gilgit-Baltistan province. This study will provide the current and past scenarios of air pollution levels in Gilgit-Baltistan province.

Chapter 2

Literature Review

2.1 The Earth's Atmosphere:

The Earth's atmosphere is comprising and surrounding by several different gases. Which are responsible for sustaining life on earth. Each gas in the atmosphere exhibits a specific quality in response to the atmosphere, life, and environment. The atmosphere has oxygen for supporting life, Ozone in Stratosphere for absorbing UV radiations coming from the sun and other gases which regulates and sustain the various climatic system and maintain Earth energy Budget.

The primary composition of the earth's atmosphere is nitrogen (78%), oxygen (21%), and argon (1%). The abundance of these gases over geologic timescales is controlled by the biosphere, degassing of the interior, and the uptake and release from crustal material. The next most abundant constituent mainly found in the lower atmosphere is the water vapor, whose concentration is highly variable (highest is 3%) and is controlled by evaporation and precipitation. The remaining constituents are the trace gases, representing less than 1% of the total atmosphere but these trace gases play a fundamental role in the chemistry of the atmosphere and the radiative balance of the Earth. Moreover, an extraordinary pace of increase in the abundance of these traces gases is noticed over the last two centuries as compared to the levels of the distant past. The presence and abundance of these species can be traced to various chemical, biological, geological, and anthropogenic processes (Seinfeld and Pandis, 2016).

2.2 Layers of Atmosphere:

The earth's atmosphere is varied with temperature and pressure with respect to altitude. Which server as the basis for differentiating the atmospheric layers. Fig 2.1 illustrates the layer earth atmospheric, which are comprised of Troposphere, Stratosphere, Mesosphere, Thermosphere, and Exosphere.

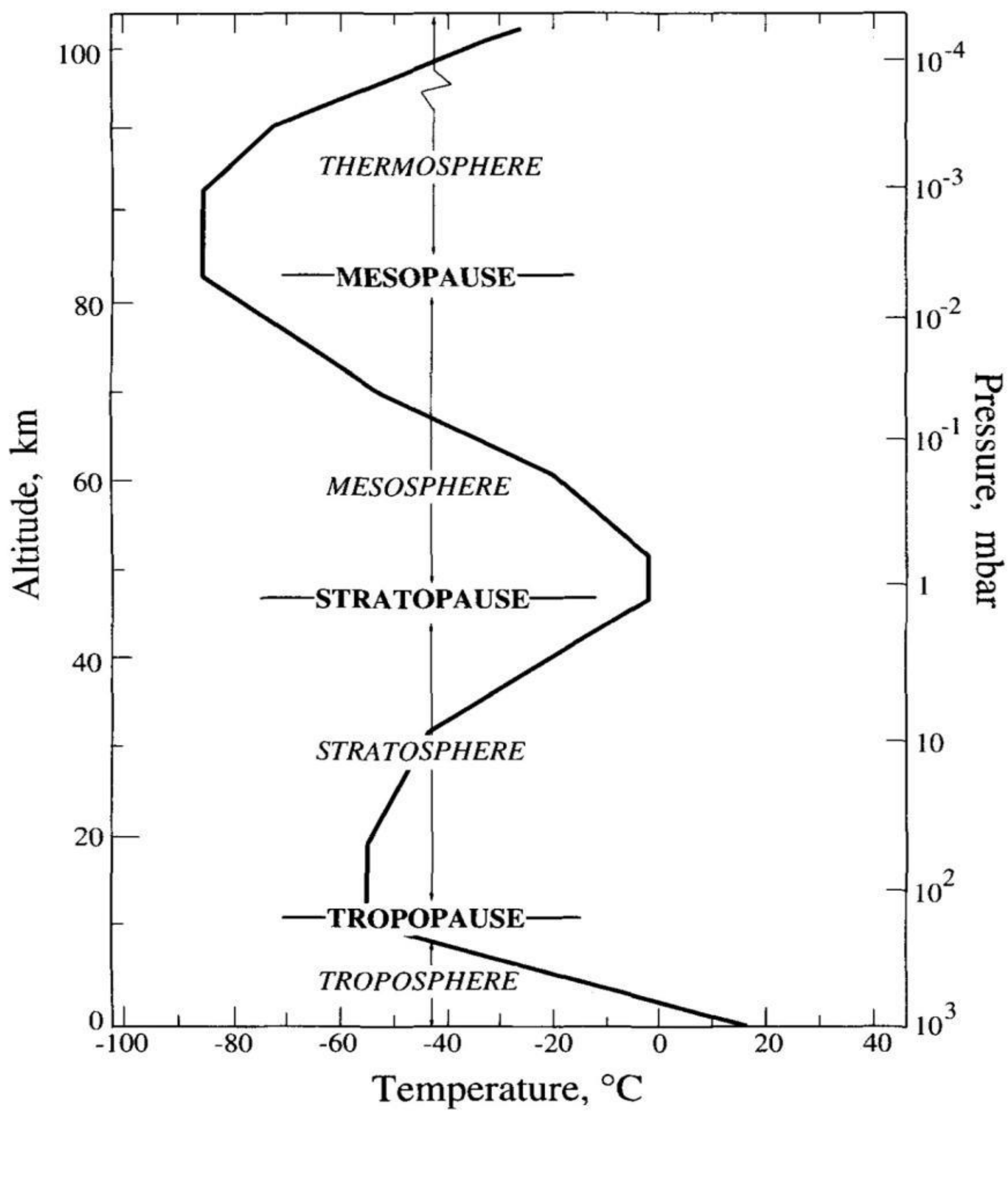


Figure 2. 1 Earth Atmospheric Layers (Seinfeld and Pandis, 2016)

The lowest layer of the atmosphere above ground level is the Troposphere which ranges up to around 10 to 15 km altitude and extends from the surface of the Earth to the tropopause. The height of the troposphere depends on latitude and time of the year. Temperature decreases with height while the vertical mixing is rapid in this layer. The stratosphere ranges almost 45 to 55 km altitude extending from the tropopause to the stratopause. The temperature of the stratosphere increases with altitude and the vertical mixing is slow in it. The mesosphere ranges approximately 80 to 90 km altitude and extends from the stratopause to the mesopause. It is the coldest point in the atmosphere and the vertical mixing is rapid. The thermosphere is the region above the mesopause with rapid vertical mixing and has high temperatures due to the absorption of short-wavelength radiation by O_2 and NO_2. The exosphere is the outermost layer of the atmosphere above 500 km altitude. It is the region where gas molecules having sufficient energy can escape from the gravity of the Earth (Seinfeld and Pandis, 2016). The major concern of spheres in terms of air pollution is the troposphere and stratosphere.

2.3 Air Pollution:

Air pollution is the contamination of both indoor and outdoor air by various solids and gases that modify its natural characteristics. The most harmful health pollutants include particulate matter ($PM_{2.5}$ and PM_{10}), Nitrogen Oxides (NO_x), Carbon monoxide (CO), Ozone (O_3), Sulfur Dioxide (SO_2), and Black Carbon (BC) (WHO., 2018). The presence of any contaminants that can overwhelm the natural cleansing capacity of the atmosphere, cause adverse effects to the environment, and results in changes to natural processes is air pollution (Cerbu et al., 2019). Atmospheric Pollutants are released into the environment through Natural and Anthropogenic sources. Which not only disrupt the natural cycle but also cause and harm to human health. Pollutants such as Oxides of Nitrogen (NO, NO_2), Particulate matterS ($PM_{2.5}$ and PM_{10}) which differ in their composition and structure, spatial and temporal distribution, and decomposition can cause, damage to human health and the environment. (Gaffney & Marley, 2003). According to the Global Burden on Diseases study (Forouzanfar et al., 2016), Air Pollution listened fourth on the global mortality risk factor. Furthermore, By 2050, the global mortality burden due to outdoor air pollution was expected to double. While in Asia, globally 3.3million premature deaths are attributed to outdoor air pollution and the major contributor is $PM_{2.5}$. (Lelieveld et al., 2015).

(Lelieveld et al., 2015) also found that emissions from residential energy usage for cooking and heating, more prevalent in China and India have the largest contributor to the global premature mortality rate. In Pakistan, from outdoor air pollution, the annual burden of diseases has been estimated to be liable for around 22,000 premature adult deaths and the loss of around 163,432 DALY. (Disability-adjusted life years). Pakistan ranked third on mortality rate due to air pollution attributed to Aerosols Mass concentration (PM2.5) which is consistently increasing and exceeding WHO Air Quality Guidelines (AQG) (Bilal et al., 2021).

2.4 Criteria Pollutants:

Criteria pollutants are a set of pollutants first regulated by the US Environmental protection Agency to define the Clean Air Act. They include Ground-level Ozone (O3), Particulate Matters (PM_{10}, $PM_{2.5}$), Nitrogen oxides (NO_x), Carbon Monoxide (CO), Sulphur Dioxide (SO_2), and Lead (Pb). They were defined and regulated as Criteria Pollutants because they have hazardous impacts on humans, an environment in the form of acid rain, smog, and other health-related issues. The word Criteria for these pollutants because it gives science base guideline to regulate human base health and environment-based criteria for setting the permissible limit. Today, these criteria pollutants are used to identify and quantify the quality of air.

2.4.1 Nitrogen Dioxide:

Nitrogen dioxides (NO_2) is one of the major and important criteria air pollutant in the atmosphere, belong to the high reactive group of gases known as oxides of Nitrogen (NOx). NO_2 gets into the air mainly from the burning of fossil fuels. It is formed from the emissions of cars, trucks, buses, and other vehicles and power plants. It plays an important role in the chemistry of the atmosphere, more prominently in the formation of acid rain and photochemical smog which is a secondary air pollutant (Khokhar et al., 2015)

Nitrogen dioxide (NO_2) is one of the criteria pollutant and ambient trace-gas which is produced from both anthropogenic and natural processes. Prolonged exposure to NO_2 may cause wide and severe health issues such as heart and cardiovascular diseases, hypertension, diabetes, and even death (Ogen, 2020). It is an important air pollutant that causes direct harm to the environment and human health. (Wu et al., 2021).

2.4.1.1 Impacts of Nitrogen dioxide:

Nitrogen Oxides affect life, both aquatic and terrestrial. When Nitric oxide gets to mix with ozone, it initiates the catalytic conversion of nitrogen dioxide into nitric oxide. This cycle continues naturally and maintains a balance. Due to anthropogenic activities, this cycle gets disturbed. Due to the vehicular emissions and burning of fossil fuels in large quantities, habitat is adversely affected. Conditions turn worse when NO_2 is converted into nitric acid and settles down in the form of acid rain (Seangkiatiyuth et al., 2011). However, when NO_2 accumulates in urban areas, in certain meteorological conditions, pollution episodes are likely to happen like that of smog which not only affects the lungs, eyes, and skin of exposed humans but also affects the economic activities of the affected area.

2.4.1.2 Studies and Findings on NO_2 Pollution:

Nitrogen Dioxide is one of the criteria pollutants that has been monitored within major cities of Pakistan. In Pakistan, the sectors which are contributed more than 70% of NO_2 pollution are transportation, industries, and power plants. (GOP/IUCN, 1992). From 1995 to 2005 the growth rate for all motor vehicles in Pakistan has been increased 33.61% annually (Ilyas et al. 2007), which has worsened the ambient air quality in the country.

Ul-Haq et al in 2014 measured spatio-temporal patterns of NO_2 over Pakistan using ozone monitoring instrument (OMI) between 2004 and 2008. (Renuka et al., 2014) also analyzed temporal variations of tropospheric NO_2 over South India using OMI and GOME instruments during (1996– 2014). These authors found the decreasing trend between western and eastern Ghats associated with changes in land use thus limiting the soil emissions of NO_2.

COVID-19 pandemic halted the socio-economic activities all over the world, as a result, the emission sources of pollutants were also shut down. (Sulaymon et al., 2021) found a significantly decreasing trend of Pollutants during the lockdown period in Wuhan, China. A lockdown was enacted in Wuhan from January 1^{st} to April 5th, during this period they studied the criteria pollutants including NO_2, $PM_{2.5}$, PM_{10}, CO, and O_3. A sharp decreasing trend of 50.6%, 41.2%, 33.1, and 16.6% for NO_2, $PM_{2.5}$, PM_{10} and CO respectively. While Ozone shows an increasing trend of 149%.

2.4.2 Carbon Monoxide (CO):

Carbon monoxide (CO) being one of the criteria and primary air pollutants has an important role in atmospheric chemistry and it is a key tracer in climate change (Worden et al., 2013; Yoon & Pozzer, 2014). It is different from most of the other pollutants because it has a long life and can persist in the atmosphere for almost a month. It can be transported to long distances by winds due to long life but not long enough to mix uniformly throughout the atmosphere (Voiland, 2015).

CO is a primary toxic gas and is taken as a major precursor of the toxic pollutant 'tropospheric ozone' (TO3). CO being an indirect greenhouse gas has global warming potential and affects the lifetime of several greenhouse gases resulting in poor quality ambient air (Park et al., 2009). Inadequate processes of combustion (Worden et al., 2013) including biomass burning and fossil fuel consumption are the major sources of CO (Yoon & Pozzer, 2014). It is a key tracer gas in climate change and has a significant role in atmospheric chemistry (Yoon & Pozzer, 2014). It also has detrimental effects on human health and animals (Seinfeld and Pandis, 2016; (Girach & Nair, 2014)

2.4.2.1 Studies and Findings on CO Pollution:

(Girach & Nair, 2014) carried out a comprehensive study on tropospheric carbon monoxide (CO) over the Indian landmass and surrounding oceanic region from the year 2000 to 2014. They emphasized the lower-tropospheric, upper-tropospheric, and CO total column using MOPITT retrievals. They observed decreasing trend of about 2.0 to 3.4 ppb per year (1.1-2.0% per year) in lower-tropospheric CO and related it to reduced anthropogenic and biomass burning activities, strong convective activity, monsoonal circulation, and vertical uplifting of CO to higher altitudes.

2.5 Aerosol Optical Depth:

A complex mixture includes both liquid and solid particles suspended in the air are known as aerosols. They are also demonstrated as particulate matter (PM) and can be responsible for poor air quality and populations exposed to higher levels of aerosols can experience negative and serious damage to their health (Gupta et al., 2013; Evans et al., 2013; (Kumar et al., 2018).

Aerosols or particulate matter is an element of air pollution that is most certainly associated with adverse health outcomes (Anderson et al., 2012)

Smaller particles have a more severe effect on health as they tend to reach the alveoli without any obstruction while larger particles get trapped in the upper respiratory tract. Therefore, epidemiological studies have reported that particles that have an aerodynamic diameter of less than 2.5 microns have greater effects on health (Schwartz et al., 1996; (Franklin et al., 2007). The entire population in Pakistan is exposed to a high concentration of particulate matter ($PM_{2.5}$) for several years with an annual mean value is 54.7 µg/m3 from 2003 to 2020. (Bilal et al., 2021)

2.6 Methods and Techniques for Ground and Remote Sensing Based Observations:

Several methods and techniques are used to quantify the ground-based and remote sensing satellite-based observation of pollution and their concentration, Following are the most useful methods, instruments and sensors used to find the ground-based concentration:

- **Electrochemical Sensors**
- **Chemiluminescence Methods**
- **Colorimetric Methods**
- **Passive Samplers**
- **Satellite Observations**

2.6.1 Electrochemical Sensors:

Electrochemical sensors are portable, cost-effective sensors used to measure the concentration of trace gases in ambient air. Because of their high sensitivity, low costs, and long sample retention time these sensors are ranked among the best of all sampling techniques. The instrument's working is based on the electrochemical reduction of agas between electrodes, dipped in an electrolyte. The gas contained in the sample makes its way into the reaction chamber of a cell through diffusion, where it is reduced at the electrode. Because of this reduction, a potential difference is created, which produces current proportional to the concentration of gas in the sample. These instruments can be used to find NO_2, CO concentrations in ambient air directly and are used in studying exposures from an occupational health and safety perspective. (Mijling et al., 2018)

2.6.2 Satellite Observations

Satellite observations are the most useful tool for assessing spatially and temporally throughout the world. The importance of satellite observations as effective tools for qualitative and quantitative evaluation of the distribution of several atmospheric gases have been cited by various studies (Beirle et al, 2003; Martin, 2008, Burrows, Platt, & Borrell, 2011; Lee et al., 2011; Lin, McElroy, & Physics, 2011). Although satellite observations have limitations such as coarse resolutions, coarse spatial resolutions, requiring frequent ground-based validation and intermittent observations, and to improve the accuracy of retrieved information. But marked improvements have been seen, the TROPOspheric Monitoring Instrument (TROPOMI) instrument has been launched aboard the Sentinel 5P satellite. Because of its high spatial resolution, it can detect local NO_2 pollution more clearly than its predecessors such as OMI, GOME, GOME-2, and SCIAMACHY. NO_2 concentrations retrieved from TROPOMI (TROPOMI filter 50) in southern China has a higher columnar value than OMI. TROPOMI expresses high quality and presents a significantly better performance of representing spatial variability. (Wang et al., 2020). MOPITT instrument which is abord on EOS-Terra satellite is widely used for CO dataset.

2.7 Pakistan National Environmental Quality Standards

Pakistan Environmental Protection Agency (PEPA) has formulated standards for all the major air pollutants (Table 2.1) to curtail the levels of air pollution in the country:

Table 2. 1 List of NEQS for ambient air in Pakistan (The gazette of Pakistan, 2010)

Pollutants	Time-Weighted Average	Concentrations in Ambient Air	Method of Measurement
Sulphur Dioxide (SO_2)	Annual Average	80 µg/m³	Ultraviolet Fluorescence Method
	24-Hour Average	120 µg/m³	
Oxides of Nitrogen as (NO)	Annual Average	40 µg/m³	Gas Phase Chemiluminescence
	24-Hour Average	40 µg/m³	
Oxides of Nitrogen as (NO_2)	Annual Average	40 µg/m³	Gas Phase Chemiluminescence
	24-Hour Average	80 µg/m³	
Ozone (O_3)	1-Hour Average	130 µg/m³	Non-Dispersive UV Absorption Method
Suspended Particulate Matter (SPM)	Annual Average	360 µg/m³	High Volume Sampling (Average flow rate not less than 1.1 m3/minute
	24-Hour Average	500 µg/m³	
Respirable Particulate Matter (PM 10)	Annual Average	120 µg/m³	-β Ray Absorption Method
	24-Hour Average	150 µg/m³	
Respirable Particulate Matter (PM 2.5)	Annual Average	15 µg/m³	-β Ray Absorption Method
	24-Hour Average	35 µg/m³	
	1-Hour Average	15 µg/m³	
Lead (Pb)	Annual Average	1 µg/m³	ASS Method after sampling using EPM 2000 or equivalent Filter Paper
	24-Hour Average	1.5 µg/m³	
Carbon Monoxide (CO)	8 Hours Average	5 mg/m³	Non-Dispersive Infrared (NDIR) Method

Chapter 3

Data and Methodology

3.1 Ground-Based:

In this study, a field campaign was conducted to retrieve the ground-based data using the following instruments.

3.1.1 HAZ-Scanner (HIM-6000):

The HAZ-Scanner (model HIM-6000) is a portable and easy to deploy ambient air quality monitoring station, capable of measuring several EPA-criteria pollutants and atmospheric constituents. It can carry out simultaneous monitoring of $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, and up to 14 critical air parameters. In this research, only NO_2, CO, and Particulate matter (PM_{10} and $PM_{2.5}$) were studied. The Haz-Scanner used in this study has the following specification as mentioned in table 3.1 below.

Table 3. 1 Instrument specifications for Haz-Scanners used in this study

Specifications			
Sensor	**Technology**	**Range**	**Features**
$PM_{2.5}$	Gravimetric $PM_{2.5}$ impactor	2.5 µm	Yes
PM_{10}	Gravimetric PM_{10} impactor	10 µm	Yes
Carbon Monoxide (CO)	Electrochemical	0 to 10 ppm	Yes
Nitric Oxide NO	Electrochemical	0 to 5000 ppb	Yes
Nitric Dioxide (NO_2)	Electrochemical	0 to 5000 ppb (0 to 5 ppm)	Yes
Ozone (O_3)	Metal Oxide Semiconductor	0 to 150 ppb (0 to 0.15 ppm) or 0 to 500 ppb (0 to 0.5 ppm)	Yes
Sulphur Dioxide (SO_2)	Electrochemical	0 to 5000 ppb (10 to 500 ppb for ambient applications)	Yes

In this study, the Haz-Scanner was deployed in several different locations throughout the study area. The main aim of this study was to identify and quantifying pollutant concentrations across different sites of Gilgit city i.e., around major traffic intersections (Chowks), near hospitals, residential areas, and low-traffic areas. The sampling was carried out for 38 days across Gilgit city starting from 19-July-2019 to 6-September-2019. Each site was sampled for around 16 hours daily starting from 6 am, for major traffic hotspots. the Haz-Scanner was deployed for consecutive two days on a single location. The timeline for sampling, across each selected site, is mentioned in table 3.2 below:

Table 3. 2 Timeline of Haz-Scanner-based Field Campaign across Gilgit city.

Day	Location	Date
1	Site A	(19-07-2019) - (26-07-2019)
2	Airport Chowk	(28-07-2019) & (29-07-2019)
3	Ittehad Chowk	(30-07-2019) & (31-07-2019)
4	PHQ Hospital Chowk	(01-08-2019) & (02-08-2019)
5	RHQ Hospital Chowk	(04-08-2019) & (05-08-2019)
6	Baseen RCC Bridge	(07-08-2019) & (08-08-2019)
7	Kasheero Das	(09-08-2019) & (10-08-2019)
8	Jutial Bus Stand	(17-08-2019) & (18-08-2019)
9	Public Chowk	(19-08-2019) & (21-08-2019)
10	Khomar Chowk	(23-08-2019) & (25-08-2019)
11	Site A	(24-08-2019)
12	Site A	(26-08-2019) - (06-09-2019)

3.1.2 Meteorological Data:

The metrological data set for temperature was obtained from the Gilgit Meteorology station. The temperature data was filtered from 2010 to 2020 and the dry bulb temperature was selected. The temperature data set was used to correlate with the OMI tropospheric mean NO_2 data product.

3.1.3 Tourist Data:

Gilgit-Baltistan is home to beautiful landscapes, natural beauty, mighty mountains, mesmerizing lakes, and historical places. Tourists throughout the world visited Gilgit-Baltistan every year to experience such natural beauty. The tourism industry has a direct impact on air quality by the transportation and vehicular emissions. So, monthly tourist data from 2007 to 2017 was correlated with OMI Tropospheric NO_2 data.

3.2 Satellite-based Data:

In this study, different datasets were obtained from various satellite-based instruments. The specifications, working principles, and limitations of these satellite-based instruments are mentioned below:

3.2.1 Ozone Monitoring Instrument (OMI):

The OMI instrument is located aboard the Aura satellite, which was launched in July of 2004, it is a NADIR-viewing instrument capable of measuring solar backscattered irradiance and has a swath width of 2600 km and a spatial resolution of 13 x 24 km^2. OMI covers the globe in a single day and its measurements cover a spectral region of $264 - 504\, nm$ (for $UV\ 264 - 383\, nm$ and, $VIS\ 349 - 504\, nm$) and with a spectral resolution between $0.42\, nm\ and\ 0.64\, nm$.

The OMI instrument can measure multiple different trace gases, clouds, and aerosols, However, in this study, only the Tropospheric NO_2 data product has been used (from 2005 to 2020). The OMI Tropospheric NO_2 is a level 2 data product, which is 30% cloud screened. This data product was retrieved from NASA's open-access web portal https://giovanni.gsfc.nasa.gov/giovanni/.

The OMI instrument can provide good quality data, however beginning from 2008 a physical defect in the OMI instrument has appeared called the row anomaly, this anomaly has significantly decreased the spatial resolution of the instrument and long-term record of aerosol products.

3.2.2 TROPOspheric Monitoring Instrument (TROPOMI):

The TROPOspheric Monitoring Instrument (TROPOMI) is an instrument aboard the Copernicus Sentinel-5 Precursor satellite. The Copernicus Sentinel-5 Precursor (S5-P) mission is the first-ever Copernicus mission which is dedicated to monitoring the atmosphere. The main objective of this mission is to perform atmospheric measurements with a high spatio-temporal resolution, for use in air quality, ozone & ultraviolet radiation, and climate monitoring & forecasting. The Sentinel-5 Precursor (S5P) was launched on 13 October 2017, and the data products were first released in mid-July 2018. While more data products were released in 2018 and early 2019.

The TROPOspheric Monitoring Instrument (TROPOMI) observes backscattered sunlight on the space by the atmosphere and surface of the earth. It identifies the unique fingerprints of gases in different parts of the spectrum. It operates in the push broom Configuration with a swath width of $2600\ km$ on the surface of the earth. It measures in the UV and visible $(270 - 500\ nm)$, NIR $(675 - 775\ nm)$, and SWIR $(2305 - 2385\ nm)$ spectral bands. This means that pollutants of a wide range such as Nitrogen Dioxide (NO_2), Ozone (O_3), Formaldehyde (HCHO), Sulphur Dioxide (SO_2), methane (CH_4), and Carbon

Monoxide (CO) can be monitored more precisely than ever before with a resolution as high as $7 \times 3.5\ km^2$. The TROPOMI Spectral range is highlighted in figure 3.1 below:

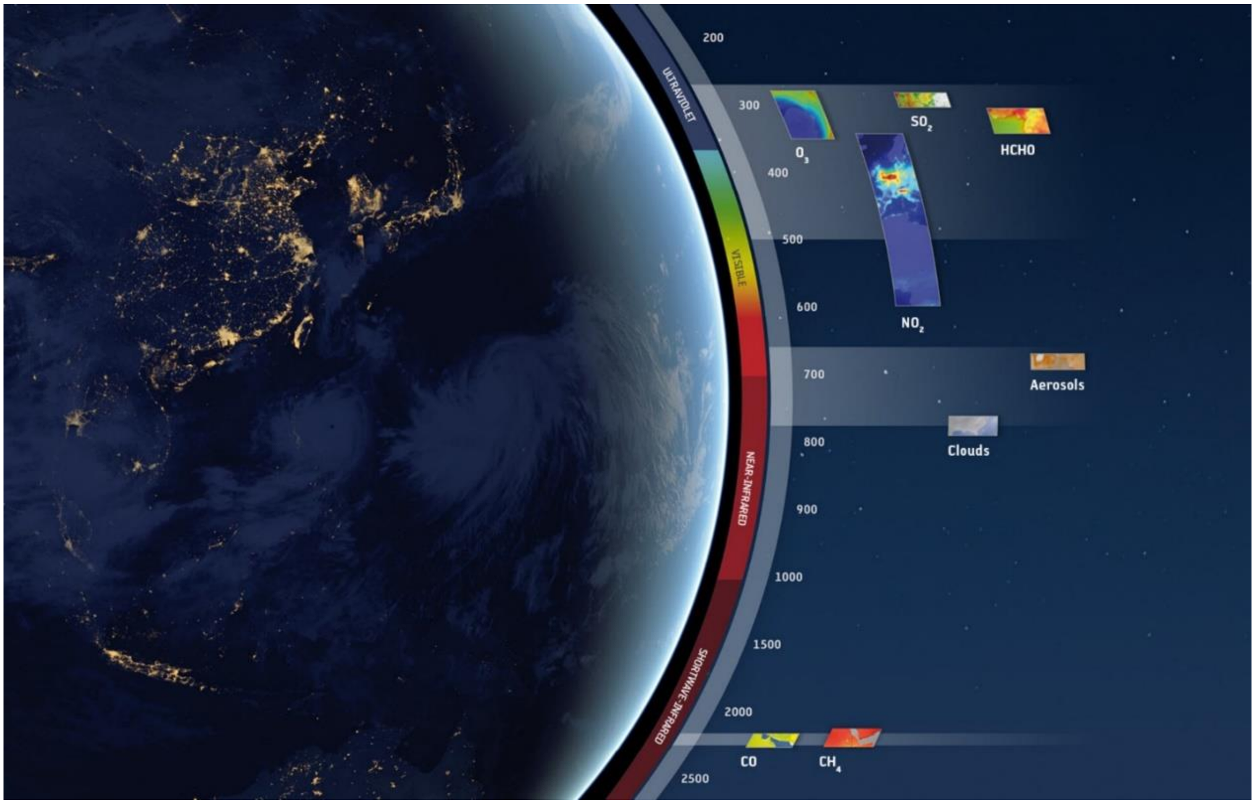


Figure 3. 1 TROPOMI Spectral Range
(Source: https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Tropomi)

The tropospheric NO_2 data product has a good quality assurance value (qa value > 0.75). It is good and has the recommended pixel filter. In which cloud-covered scenes is removed ($cloud\ radiance\ fraction > 0.5$), partially snow/ice-covered scenes, errors, and problematic retrievals. (Eskes et al., 2019).

In this study, tropospheric NO_2 and total CO columnar data was retrieved from TROPOMI Instrument. For the retrieval of the above gases, the Google Earth Engine (GEE) code editor was used, which provided geospatial processing services. The data was then processed and correlated with the available ground-based data.

Both the OMI and TROPOMI instruments have their unique configurations, spatial and spectral resolutions, and their own data processing algorithms. However, in general, the TROPOMI instrument has a significantly better spatial resolution (6x times higher) than the OMI instrument. This is highlighted in figure 3.2 below:

Figure 3. 2 Comparison of TROPOMI and OMI instruments
(Source: https://www.tudelft.nl/en/2017/citg/grs/what-makes-tropomi-special/)

3.2.3 MODIS Aerosol Optical Depth:

The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor is currently onboard two satellites, Terra (launched December 1999) and Aqua (launched May 2002) Earth observation System (EOS) satellites. This instrument provides multispectral data of 36 bands spanning the visible, near-infrared, and far-infrared portion of the spectrum. It has 1 km, 500 m, 250 m multi-resolution sensors and covers the entire globe. It circumnavigates the globe in 12 hours and has a swath width of 705 Km (Jensen, 2009). Terra passes over the equator at 10:30 am morning in descending mode while aqua passes over the equator at 01:30 pm in the daylight in ascending mode. For the sake of this study, the AOD is retrieved from Moderate Resolution Imaging Spectroradiometer (MODIS) which is onboard on Both Aqua and Terra Satellite. The MCD19A2 data product is used which is a combined product of Aqua and Terra Satellite observations with Multi-angle Implementation of Atmospheric Correction (MAIAC) for retrieval of Land-based Aerosol Optical Depth (AOD). To download the Data product, the Google Earth engine was used. The data was then processed over the study area and the time series and seasonal trends were obtained.

3.3 Hybrid Single Particle Lagrangian Integrated Trajectory (NOAA HYSPLIT):

The National Oceanic and Atmospheric Administration (NOAA), Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) models, backward trajectory analysis was used to analyze/backtrack the origin of air masses reaching the study area at the coordinates of 35.9166 N, 74.3237 E. This model was used to identify the plausible linkages and pathways for the transportation of pollutants from the surroundings to the receptor site. Trajectories were calculated at different altitudes and the direction and frequency of air masses were calculated.

For the determination of air parcels reaching the study site, the Frequency type trajectories were used at 1000 m Above Ground Level (AGL). The model was run for 72 hours and the number of trajectories was calculated for 30 days. To distinguish between the seasons, the 30 days (One Month) frequency was analyzed for the whole seasons (Summer, Winter, Autumn, Spring).

The model was run also for 72 hours and the number of trajectories was calculated for 3 days too at 1000 m above ground level.

3.4 Boundary Layer Height:

The planetary boundary layer (PBL) height is the fundamental character of the earth atmosphere characterized by the vertical extent of the earth atmosphere mixing near the earth's surface. It is defined as “It is the altitude of transition layer where temperature, air, or humidity gradient are most significant. It lies in the lowest atmosphere and between 1-5 kilometers”. It plays a fundamental role in air quality prediction, weather forecasting, climate modeling, and pollution transport processes. (Allabakash & Lim, 2020).

The National Oceanic and Atmospheric Administration (NOAA), Climate Forecast System Reanalysis (CFSR) model was used to execute the Planetary boundary layer height. Which was used in the correlation process with satellite-based data products to get in the same units.

3.5 Impact of Socio-Economic Lockdown Period on Air Quality:

By the end of 2019, an infectious disease belongs to a family of coronaviruses was discovered in Wuhan, Hubei province of China. The Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was named COVID-19 by the World Health Organization (WHO). On March 11, 2020, WHO declare COVID-19 as a Pandemic, and it spreads most rapidly through the world. COVID-19 affects worldwide, and Pakistan confirmed its first case on 26 February 2020.

To halt the spread of COVID-19, a lockdown was enacted thorough out the world, the Government of Gilgit-Baltistan enacted the Socio-Economic Lockdown period on the 22nd of March 2020 and Name as Home Lockdown. Due to the imposition of lockdown, the socio-economic activities in Gilgit-Baltistan were halted and the impact of Lockdown on

NO_2 was studied and compare with Before, and During the first strict lockdown period. The strict lockdown period was enacted in two phases started from the 23rd of March till the 15th of April 2019.

3.6 Operating tools and Software:

In this research different operating tools and software was used to processes, analyses, and retrieval and mapping of the different dataset. Following is the tools and software which are used are mentioned below;

Table 3. 3 Operating Tools and Software

Sr. No.	Software	Purpose
1	**Haz Scanner (v7_7_7)**	For the retrieval of ground-based Haz-Scanner measurements
2	**Google Earth Engine (GEE)**	For retrievals of satellite data products, such as NO_2, CO, SO_2, and time-series from TROPOMI and PBL from NOAA CFSR
3	**Giovanni (NASA Portal)**	For retrieval of satellite-based data product, such as time series of OMI tropospheric NO_2 measurements
4	**ArcGIS (v 10.3.1)**	Interpolation of satellite data, representation, and comparison of field campaigns, generation of maps
5	**Microsoft Excel (v 365)**	For calculation of various statistical analyses and making graphs of data.

3.7 Methodology Hierarchy Flow Chart:

This research was carried out by using the following hierarchy flow chart mentioned in figure 3.3 below;

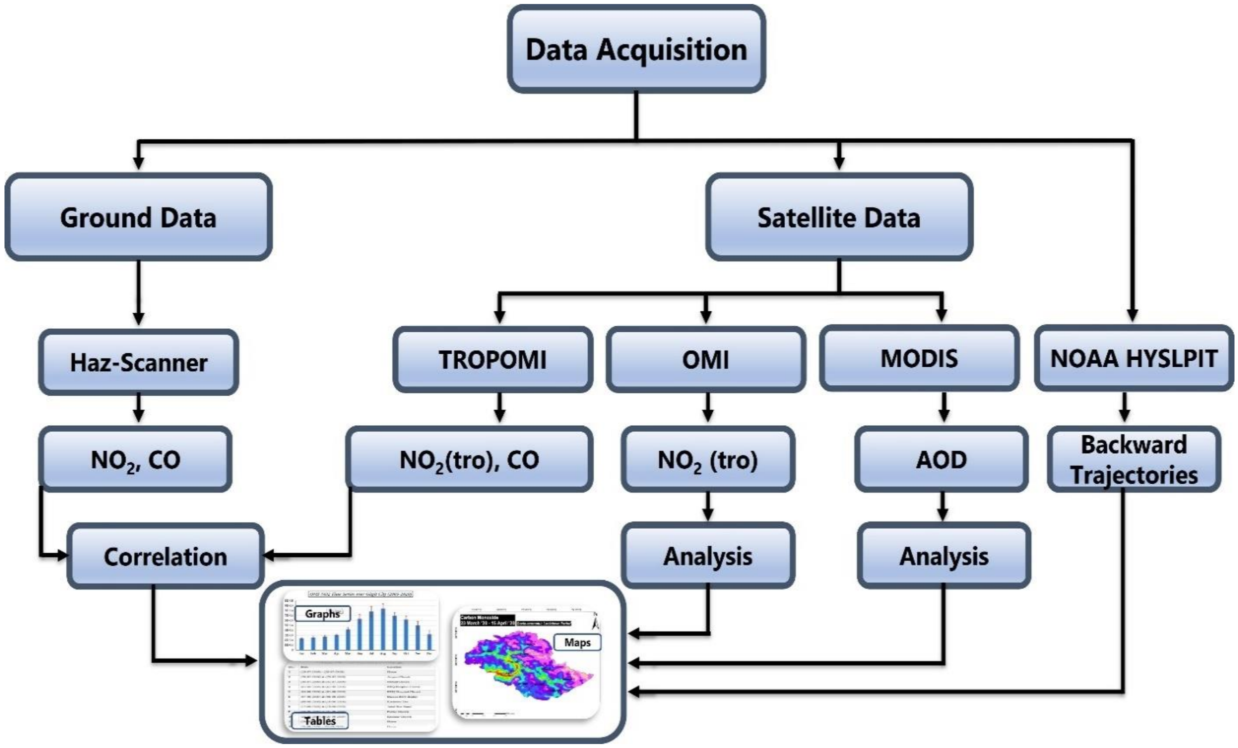


Figure 3. 3 Methodology Hierarchy Flow Chart

Chapter 4

Results and Discussion

4.1 Nitrogen Dioxide (NO_2):

4.1.1 Monitoring by Haz-Scanner:

Haz-Scanner is used for Ground-based NO_2 observations. The Haz-Scanner was deployed on different locations in Gilgit City from 19th April to 06th September 2019. The average total observation is for 16 hours daily, and the Haz-Scanner is deployed in each location in the early morning (6 am).

4.1.2 NO_2 Observations and Pak-NEQS:

Daily mean NO_2 values are represented in the bar graph in figure 4.1. The graph shows that NO_2 exhibits a minimum concentration of 8.32 μgm^{-3} during the first day at home while a maximum concentration of 427.46 μgm^{-3} was also observed at Site A on the 24th of July 2019. The high concentration of NO_2 is most likely because of the low boundary planetary layer, which decreased substantially from 2.21 km to 0.15 km during nighttime and the meteorology supported the pollutant accumulation. The major high peaks observed at Site A can be attributed to the pollution emitted from residential areas using wood stoves and natural gas as fuel for cooking and heating purposes. Furthermore, Site A is located adjacent to the main road (near the only airport in the city) and high traffic flow is observed at different periods throughout the day. This variability in traffic loads could be the reason for the irregularity in pollutant loads observed at the Site. NO_2 values also exceeded the Pak-NEQS prescribed limits at Kasheero Das, Baseen RCC Bridge, Airport Chowk, RHQ Hospital Chowk, Khomar Chowk, Public chowk, PHQ Hospital Chowk, and Jutial Bus Stand sites with concentrations of 405.802 μgm^{-3}, 164.006 μgm^{-3}, 162.4969 μgm^{-3}, 139.435

µgm^{-3}, 131.638 µgm^{-3}, 92.829 µgm^{-3}, 87.932 µgm^{-3}, 80.618 µgm^{-3} respectively. Figure 4.2 elaborates point NO_2 Concentration with respect to point area.

A total of 28 out of 38 days exceeded the Pak-NEQS prescribed limit of 80 µgm^{-3} for 24 hours. This represents 73% days of the total observations.

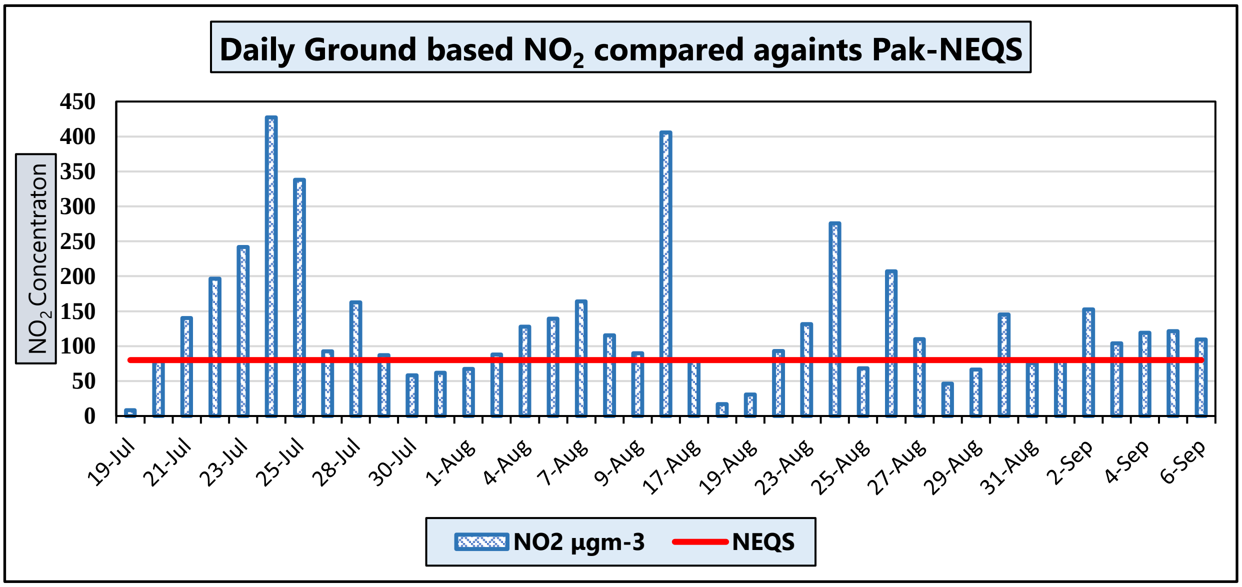


Figure 4. 1 Daily Ground-based NO_2 compared against Pak-NEQS

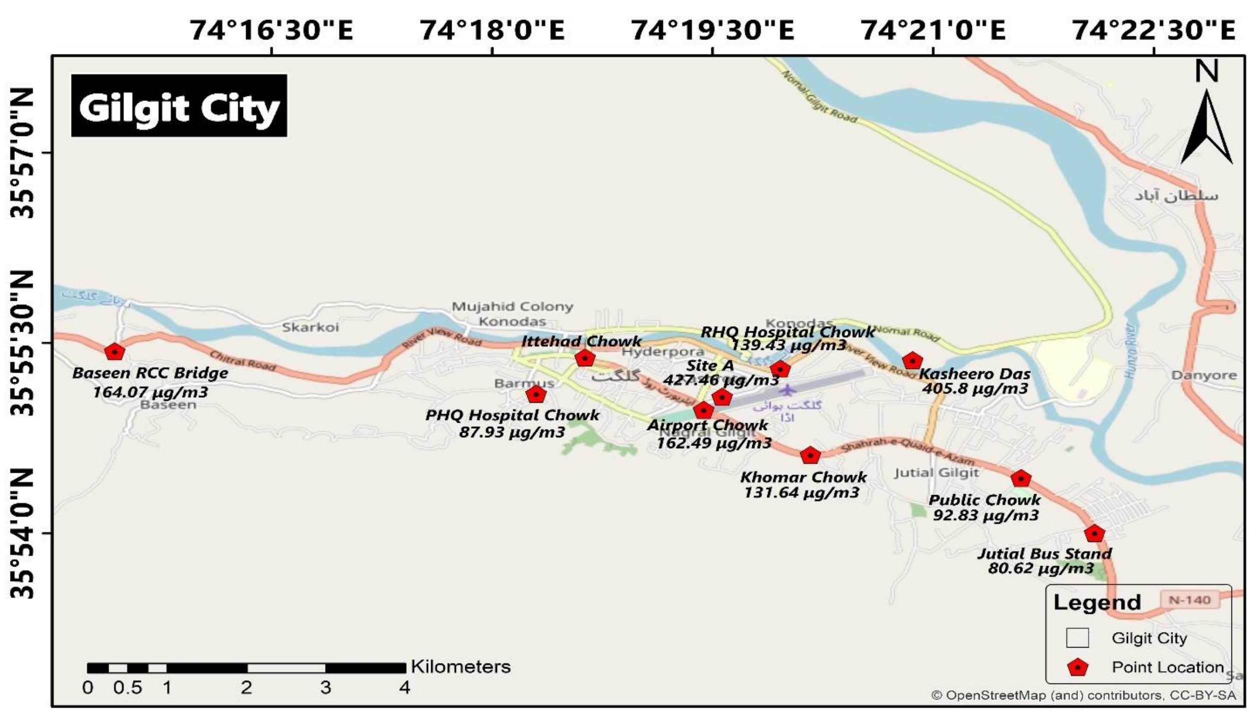


Figure 4. 2 Haz-Scanner based daily mean NO_2 point location concentration

4.1.3 NO_2 observation from OMI and TROPOMI:

The daily comparison of both satellite-based instruments TROPOMI and OMI are presented in Fig 4.3 below. The TROPOMI NO_2 dataset is available from July 2018 so the data is selected from July 2018 for both instruments. The figure shows a good comparison between the two instruments. The figure shows high values during summer and low values during the winter season. The OMI underestimates some values because it has a coarse spatial resolution (13 x 24 km^2) as compared to TROPOMI (7 x 3.5 km^2).

A relative change for both the data product from June 2018 to June 2019 is calculated. OMI shows an increased Relative change of 74.43% while TROPOMI shows an increased Relative change of 19.25%.

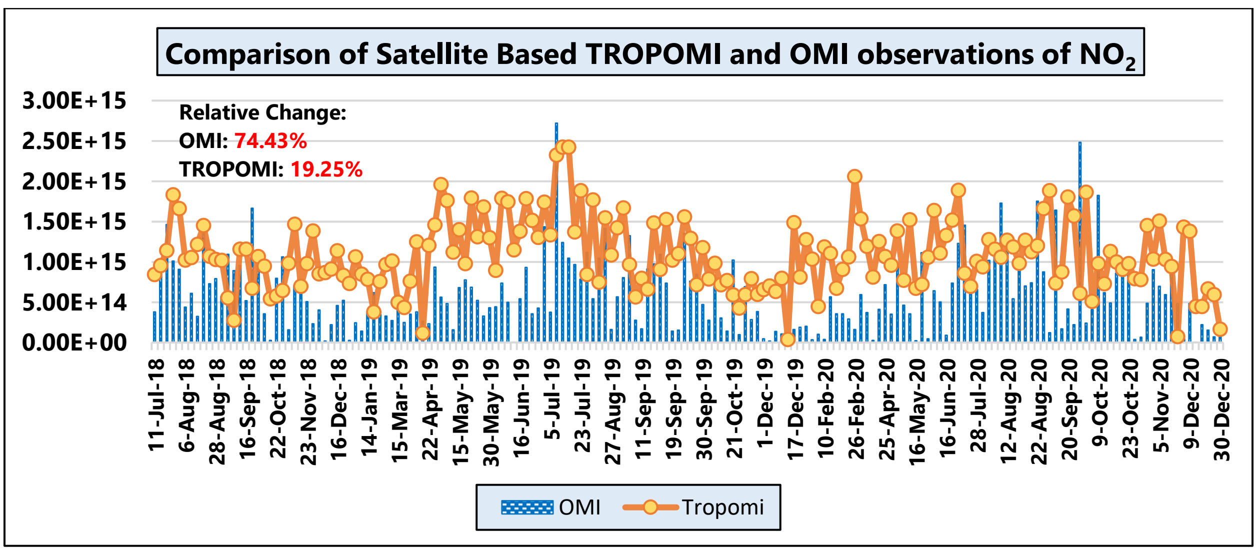


Figure 4. 3 Comparison of Satellite-Based TROPOMI and OMI observations of NO_2 Columns

The below figure 4.4 shows the correlation between the daily OMI and TROPOMI tropospheric NO_2 data set, which exhibits a Pearson's correlation value of r = 0.505 (R^2 = 2.554). The difference in measured NO_2 values between both instruments can be due to the presence of cloud fractions in the study area and the difference in resolution of both instruments. As Gilgit city is nestled between two mountains, the coarse resolution of OMI instrument might not be able to distinguish between the city and the surrounding regions and thus give a lower NO_2 value as compared to the high-resolution TROPOMI instrument.

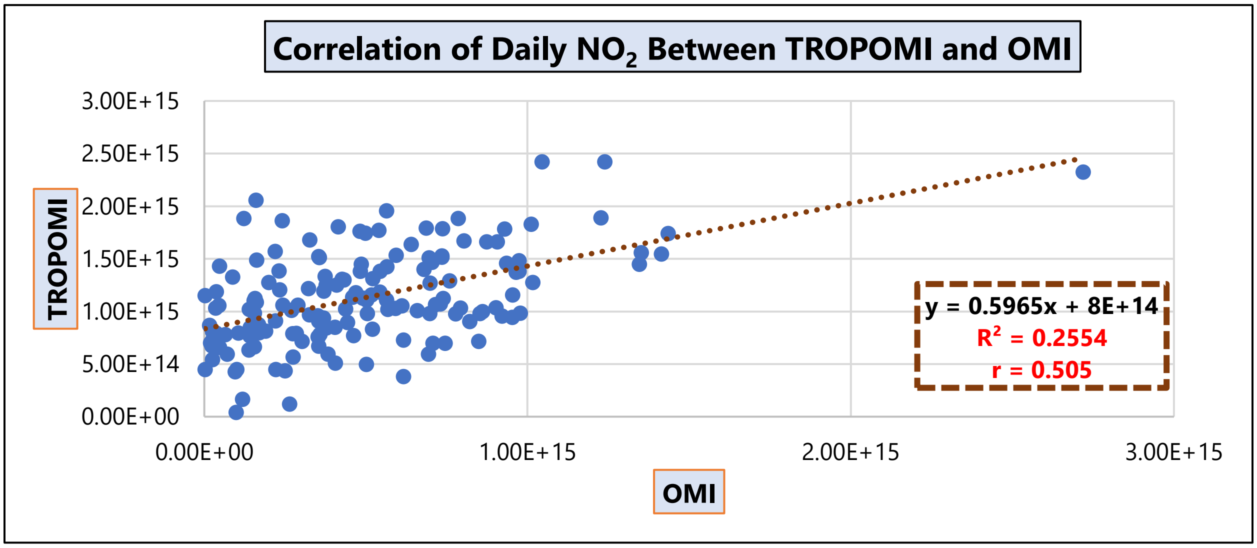


Figure 4. 4 Correlation of Daily NO_2 Between TROPOMI and OMI

4.1.4 Correlation between ground and Satellite-based NO_2 observations:

Figure 4.5 Illustrate the correlation of ground-based NO_2 from Haz-Scanner and satellite-based TROPOMI instrument measurements. In this study, the Haz-Scanner NO_2 data product is selected and extracted from 11 am to 04 pm only over the points.

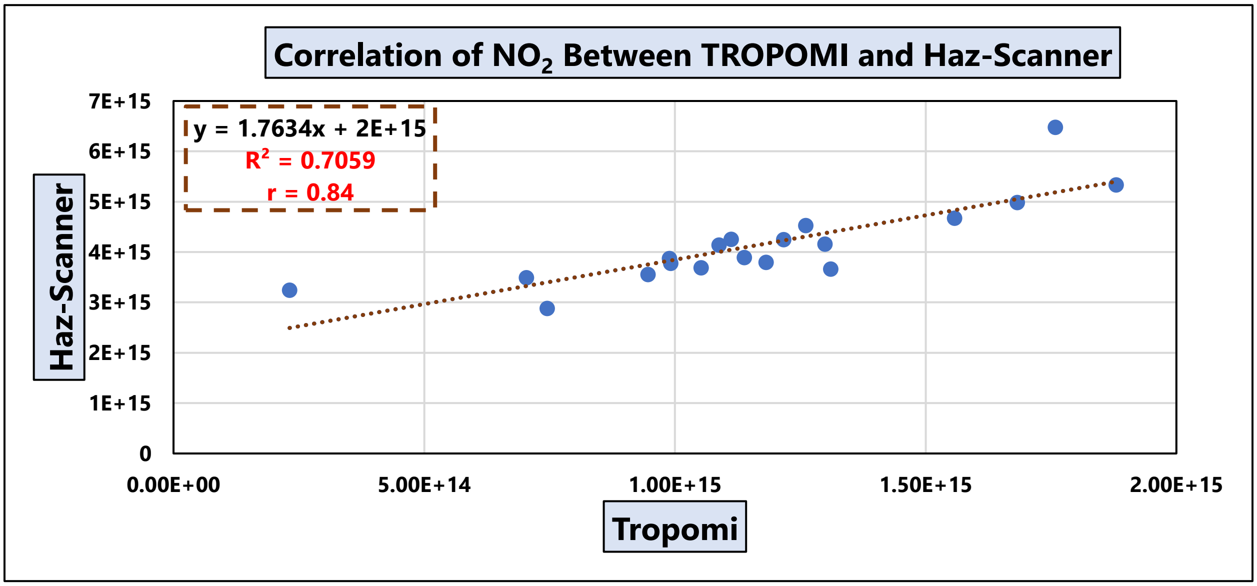
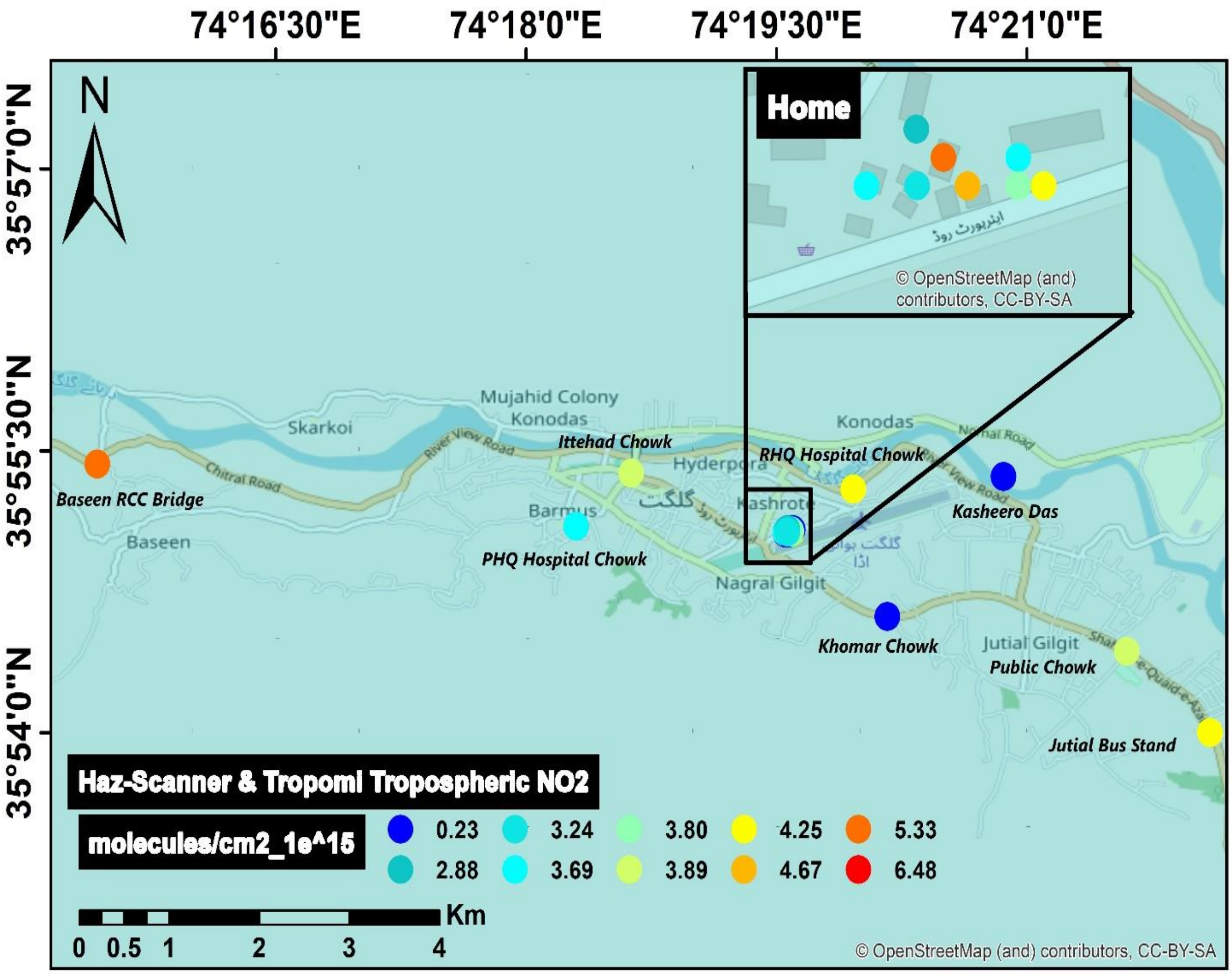


Figure 4. 5 Correlation of NO2 Between TROPOMI and Haz-Scanner

During the mid-day photolysis activity occurs and breaks down of NO_2 into NO. Therefore, for better understanding and representation of NO_2 on the ground this 6-hour data is selected.



On the other hand, the daily mean values of planetary boundary layer (PBL) height are selected to convert NO_2 concentrations into columns and correlate the ground-based NO_2 with satellite-based NO_2. A significant correlation of r = 0.84 (R^2 = 0.705) is observed between ground and satellite-based NO_2.

Figure 4. 6 Graphical correlation of NO_2 Between TROPOMI and Haz-Scanner

Figure 4.6 shows that the background ground color scheme is for OMI mean tropospheric NO_2 from 19th July to 6th September 2019 which is $3.24x10^{15}$, while the point location color scheme represents the daily concentration of NO_2 through Haz-scanner.

The figure shows that the Haz-Scanner exhibits high concentration because it is a ground-based instrument and it covers near ground level concentration.

4.1.5 Seasonal Analysis of tropospheric NO_2:

The daily tropospheric NO_2 data product from Ozone Monitoring Instrument (OMI) is available since 1st of October 2004. It has a Spatial resolution of 0.25º x 0.25º. In this study, the daily tropospheric NO_2 from 2005 to 2020 is taken. The data is then processed and take monthly mean from 2005 to 2020. Figure 4.7 shows the monthly mean tropospheric NO_2 values with standard deviation. The figure shows a high concentration in summer while minimum in winter. A reason for the high values of NO_2 in summer could be because high tourism activities take place during summer in Gilgit city which is accompanied by heavy traffic loads and therefore results in a higher level of pollutions.

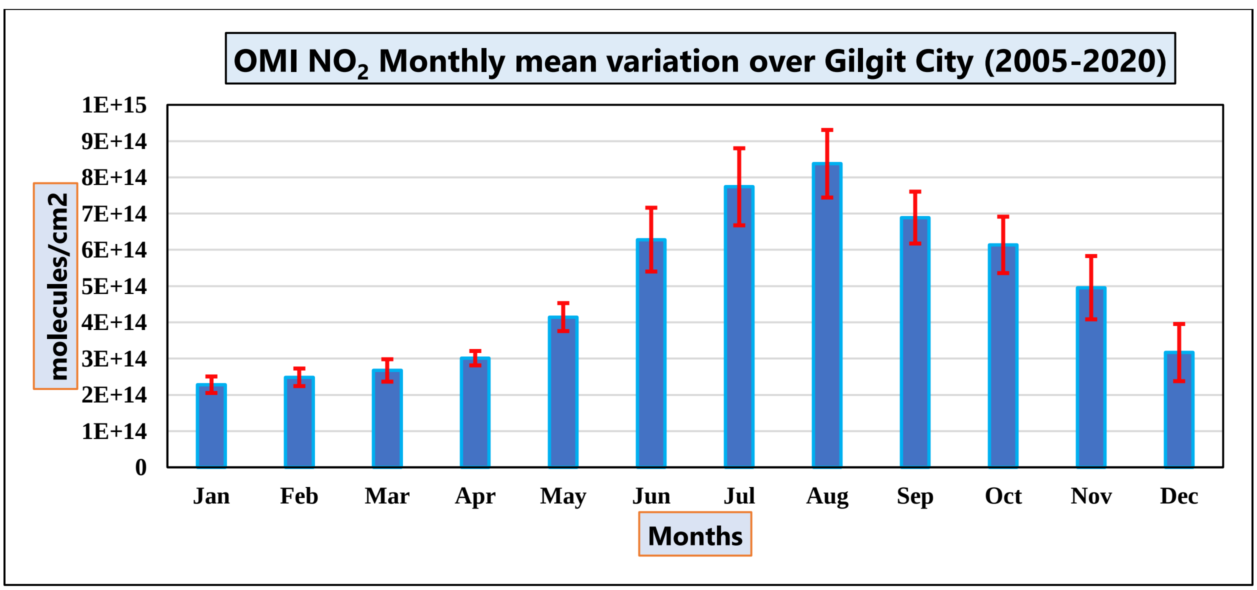


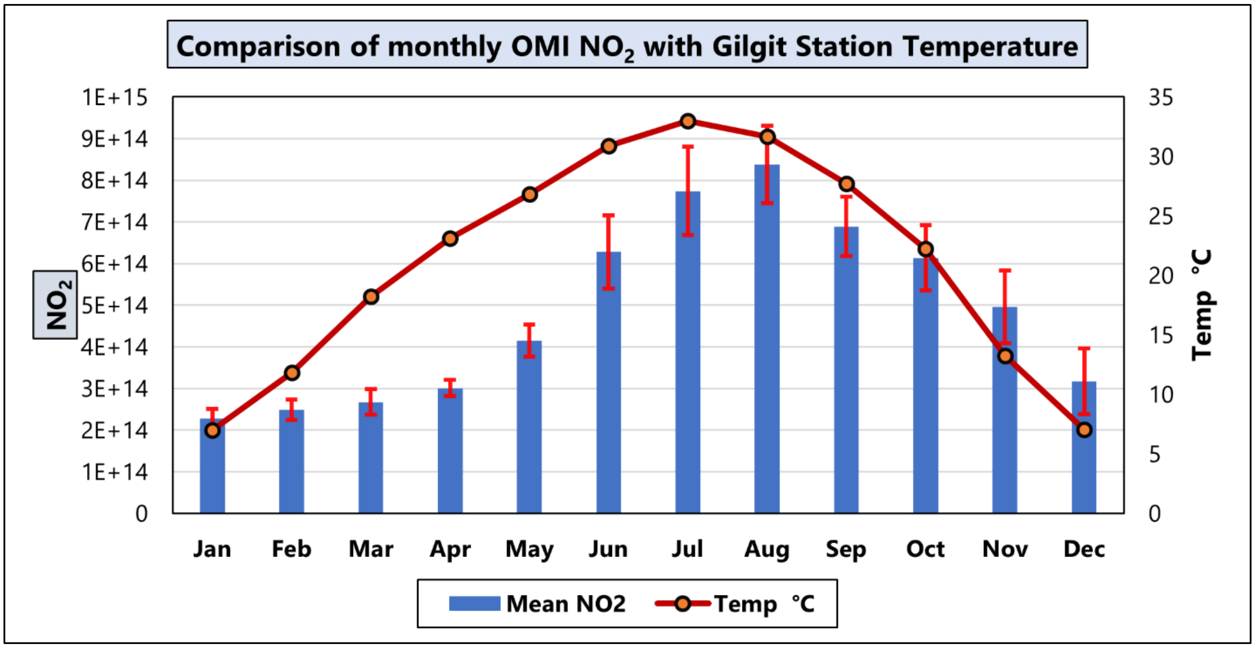
Figure 4. 7 OMI NO_2 Monthly mean variation over Gilgit City (2005-2020)

4.1.6 Comparison of NO_2 with Temperature and tourist inflow:

Figures 4.8a and 4.8b show the comparison between monthly OMI tropospheric NO_2 values (2005 – 2020), with temperature (2010-2020), and tourism (2007-2017). According to results, values of NO_2 exhibit maximum value in July which can be a result of a high rate of tourism. Tourism is heavily influenced by the temperature of the area. The maximum tourism activities in Pakistan occur from March-August (before this the major routes and tourist destination points are closed off). The maximum flow of tourists in Gilgit is in the summer reason and mostly in June, July, and August to September too. The high values of NO_2 observed in figure 4.8 emphasize the role of tourist activities in the deterioration of the air quality of Gilgit city. The graphs categorically show the increasing trend of tropospheric NO_2 after May and the maximum peak is observed in August month. The maximum value is recorded as 8.37×10^{14} in August. And after August the tourist inflow is gradually declining, as a result, the columnar value of NO_2 starts gradually decreasing too.

The verticle yellow and red lines in Figure 4.8 show the standard deviation of the monthly means. The yellow line shows the standard deviation of the total number of tourist inflow from 2007 to 2017 while the red line shows the standard deviation of monthly OMI NO_2 from 2005 to 2020.

The number of tourists in Gilgit city is very well correlated with the tropospheric NO_2 column. However, relatively higher NO_2 during winter months is attributed to low planetary boundary layer (PBL), use of biomass burning activities for open heating, cooking, and other domestic purposes.



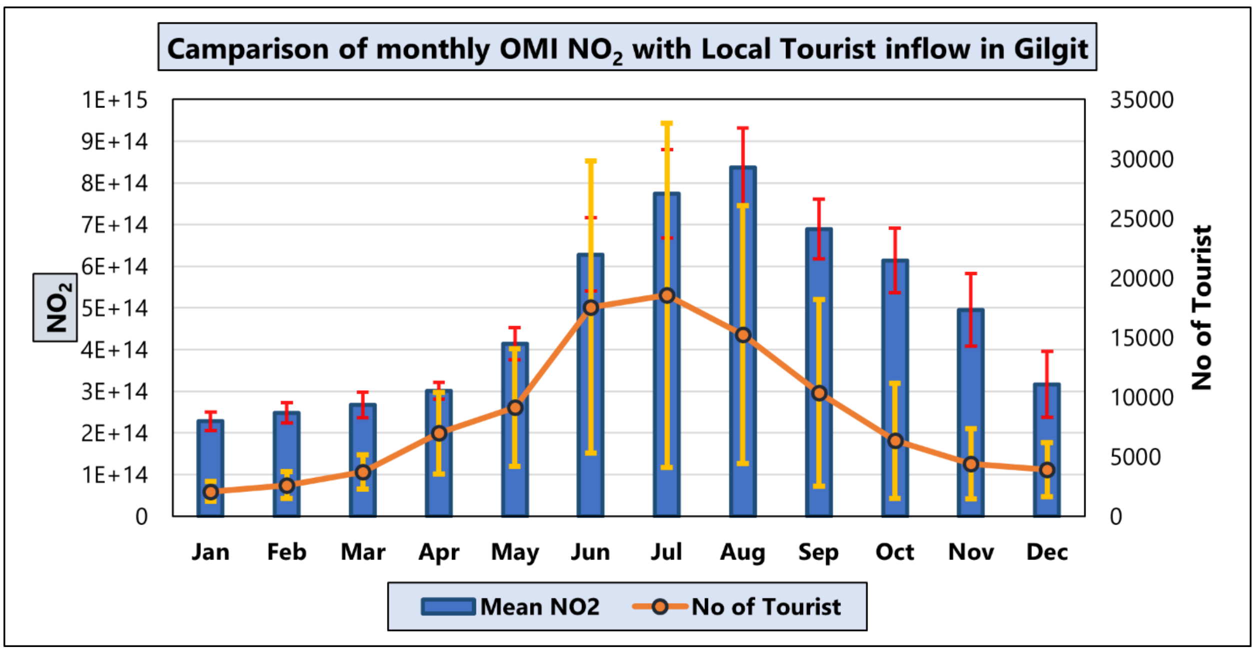


Figure 4. 8 Comparison of monthly OMI NO_2 with Temperature and Local Tourist inflow in Gilgit

4.1.7 Comparison of this study with EPA study for 2010:

A study was conducted by Gilgit-Baltistan Environmental Protection Agency (GB-EPA) in 2010 entitled as Air and Noise Pollution Monitoring in Seven Urban Centers of Gilgit-Baltistan. During their study, they monitored air and noise pollution levels in 7 Urban districts of Gilgit-Baltistan including the Gilgit District. During their study, they monitored NO_2, CO, SO_2, PM_{10} and compare them with the Pak-NEQS concentration.

4.1.8 Comparison of NO_2 between Haz-Scanner with EPA data:

In EPA's study, they monitored NO_2 at 4 main sites of Gilgit-City which are Airport Chowk, Ittehad chowk, PHQ hospital chowk, and Khomar chowk in July 2010. Figure 4.9 shows the comparison between the two studies. During the EPA study, they monitored the gases and pollutants for 8 hours. In this research, the Haz-Scanner data (8 hours) is compared with the sites which were monitored by EPA. The Concentration of NO_2 recorded high during EPA's study as 590 µg/m^3, 590 µg/m^3, 580 µg/m^3, and 380 µg/m^3 in Ittehad chowk, PHQ Hospital chowk, Airport chowk, and Khomar chowk, respectively. While in 2019 field campaign with Haz-Scanner Airport chowk and PHQ Hospital chowk exceeds the Pakistan National Environmental Quality Standard (Pak-NEQS) only.

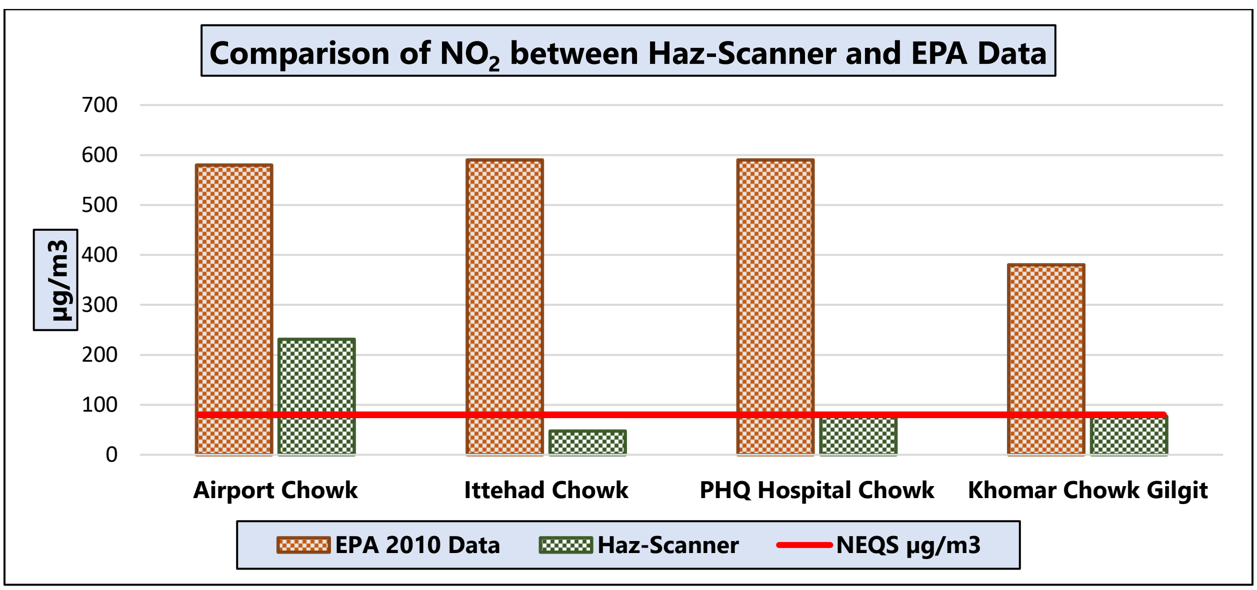


Figure 4. 9 Comparison between NO_2 of Haz-Scanner with EPA Data

4.2 Carbon Monoxide:

Carbon Monoxide (CO) is a common criterion Air Pollutant. It produces due to incomplete combustion of fossil fuels, like Natural gas, Petrol, oil, gas, wood-burning, etc.

4.2.1 Comparison between Haz-Scanner CO Observation with Pak-NEQS:

The portable Haz-Scanner instrument is also used to measure the concentration of CO in the same location which are mentioned earlier.

Figure 4.10 shows the relationship of ground-based CO observation with Pak-NEQS. The Pak-NEQS for CO is 5 mg/m^3 for 8 hours. In this study, the concentration of Carbon Monoxide Figure 4.10 is well below the Pak-NEQS, and they are not exceeding the Pak-NEQS Prescribed limits.

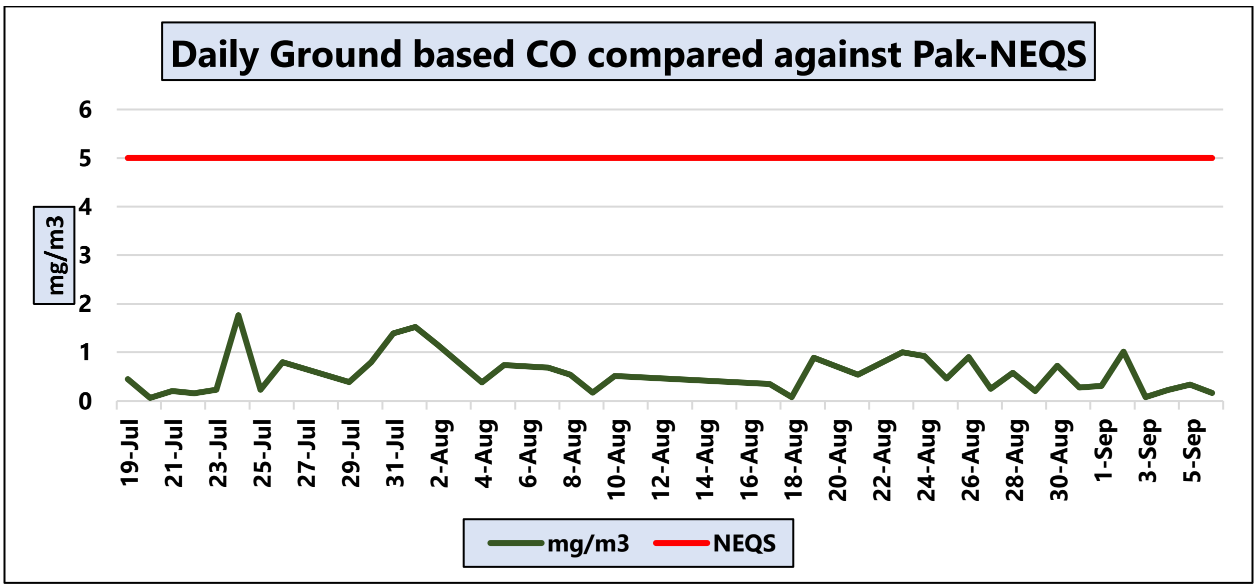


Figure 4. 10 Comparison of Daily Ground-based CO with Pak-NEQS

4.2.2 CO observations from TROPOMI.

Figure 4.11 shows the daily variation and time series of CO from TROPOMI. The data is available from July 2018, and it is a Total Column Density. In this research, the data product of CO is retrieved from July 2018 to December 2020. The result shows that the CO column is maximum in winter and minimum in summer. The highest Column of CO is recorded as 2.28 x 10^{18} molecules/cm^2 in November (16th Nov) 2020 followed by the 2nd highest column observed as 2.0 x 10^{18} in winter (3rd January) 2019 while the minimum column is observed in September 2018 and October 2019 as 9.635 x 10^{17}. The high concentration in winter is most likely due to the burning of wood and natural gas in winter for heating and cooking purposes. Figure 4.12 shows the monthly mean averages of TROPOMI from July 2018 to December 2020. The figure shows the highest value recorded in January. The relative change from July 2018 to July 2020 is recorded as 22.72%. which means that the sources and emissions of CO are increasing over the study area.

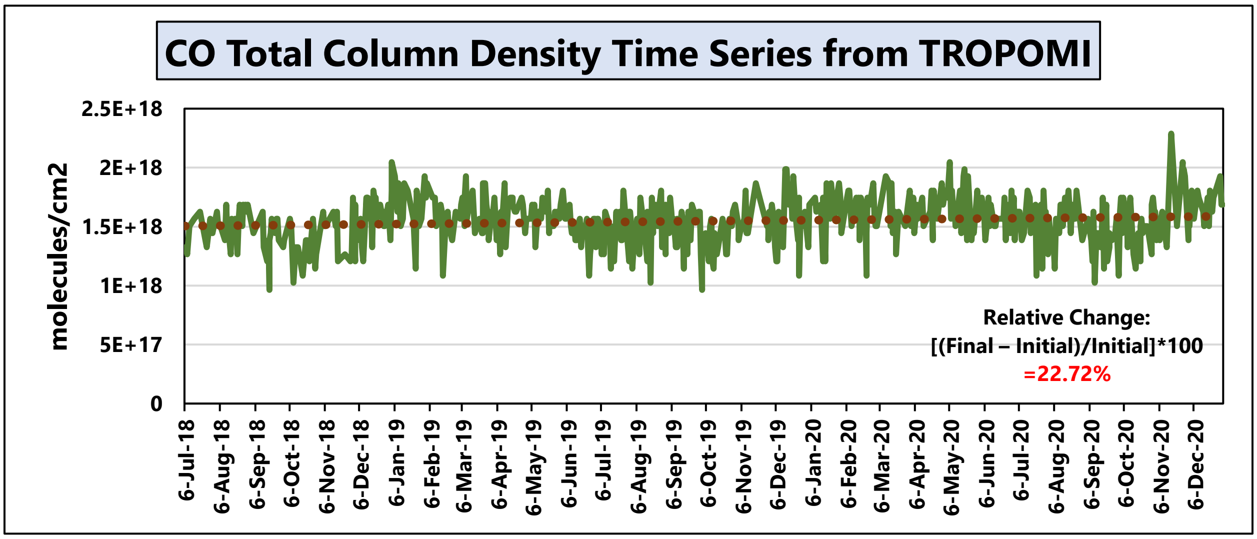


Figure 4. 11 CO total column density time series

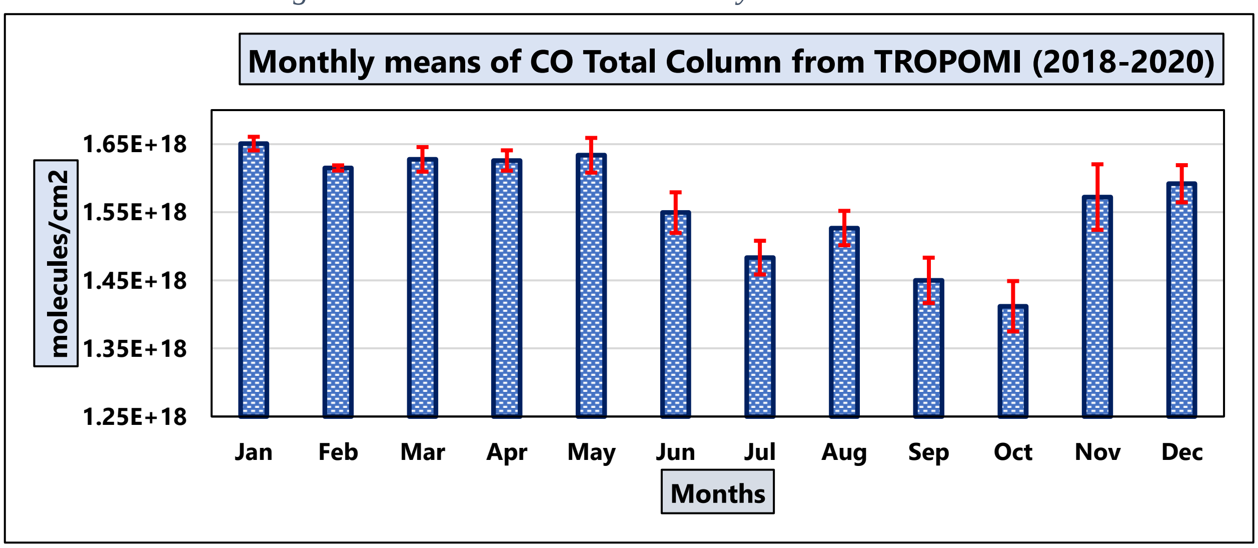


Figure 4. 12 Monthly means of CO Total Column from TROPOMI

4.2.3 Comparison between CO of Haz-Scanner with EPA data:

Figure 4.13 shows the comparison between the Haz-Scanner CO of the current field campaign with the EPA 2010 data. The result shows that the CO concentration in the current field campaign is high as compared to 2010 EPA data. However, it is under Pak-NEQS which is 5 mg/m^3 for 8 hours. In this study, 8 hours of CO concentration data is compared. The highest concentration is recorded in Khomar chowk as 2.401 mg/m^3.

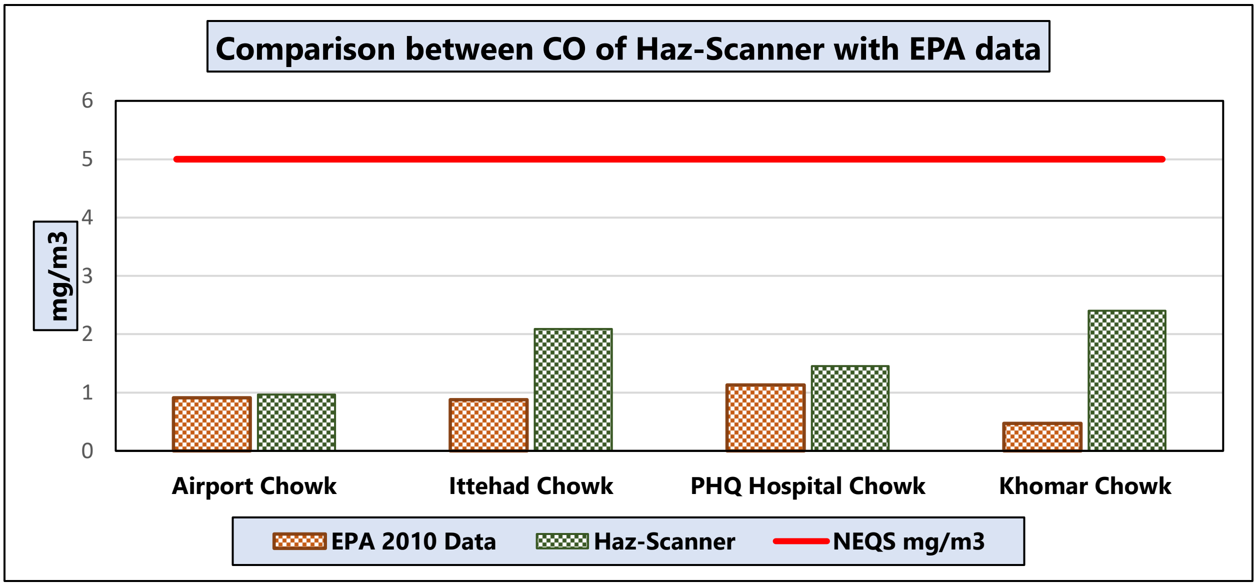


Figure 4. 13 Comparison between CO of Haz-Scanner with EPA data

4.2.4 Correlation of CO of Haz-Scanner with Total CO column of TROPOMI:

The ground-based CO concentration is monitored with Haz-Scanner and the Total CO Column is retrieved from the TROPOMI instrument. Figure 4.14 shows the correlation between Haz-Scanner and TROPOMI Total CO Column. The results show a negative Pearson correlation r = -0.44. The negative correlation is most likely due to the TROPOMI instrument which measures the CO Total Column of atmosphere, while the Haz-Scanner measures the only point location concentration which shows adiabatic results due to the ground-based pollution. The ground concentration changes from time to time.

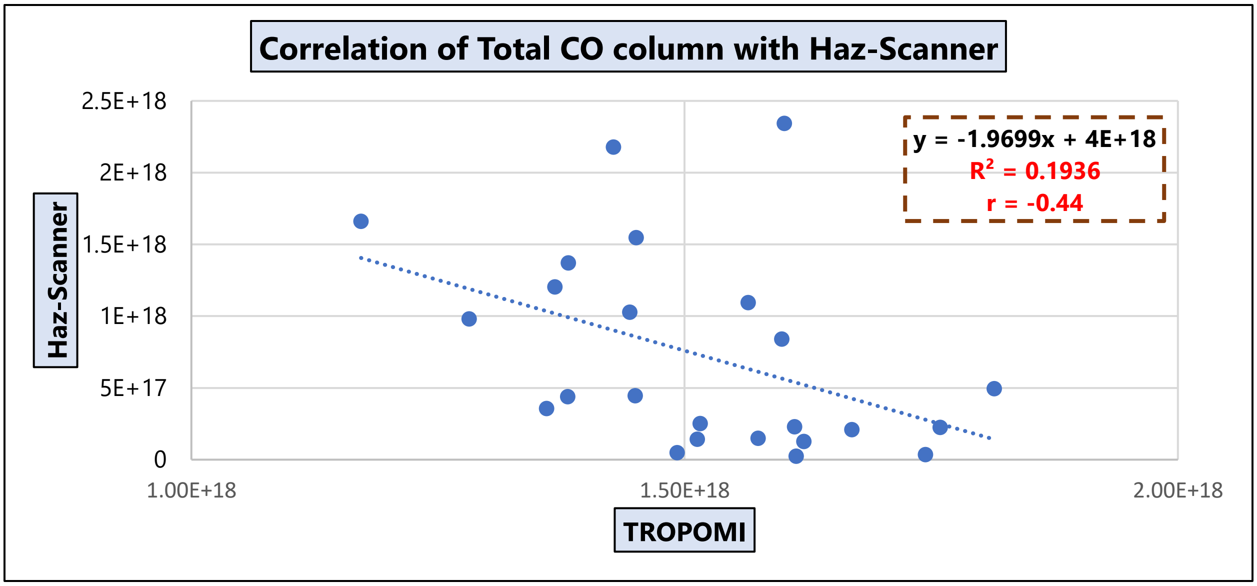


Figure 4. 14 Correlation of Total CO column with Haz-Scanner

4.3 Comparison of Particulate matters (PM_{10} & $PM_{2.5}$) with Pak-NEQS:

The daily Haz-Scanner retrieved Particulate matters including both PM_{10} and $PM_{2.5}$ are compared against Pak-NEQS. The data is selected from the 19th of July to the 6th of September. Figure 4.15 shows a comparison of particulate matters with Pak-NEQS. The graph shows that both PM_{10} and $PM_{2.5}$ are well below the prescribed limit of Pakistan National Environmental Quality Standards throughout the field campaign.

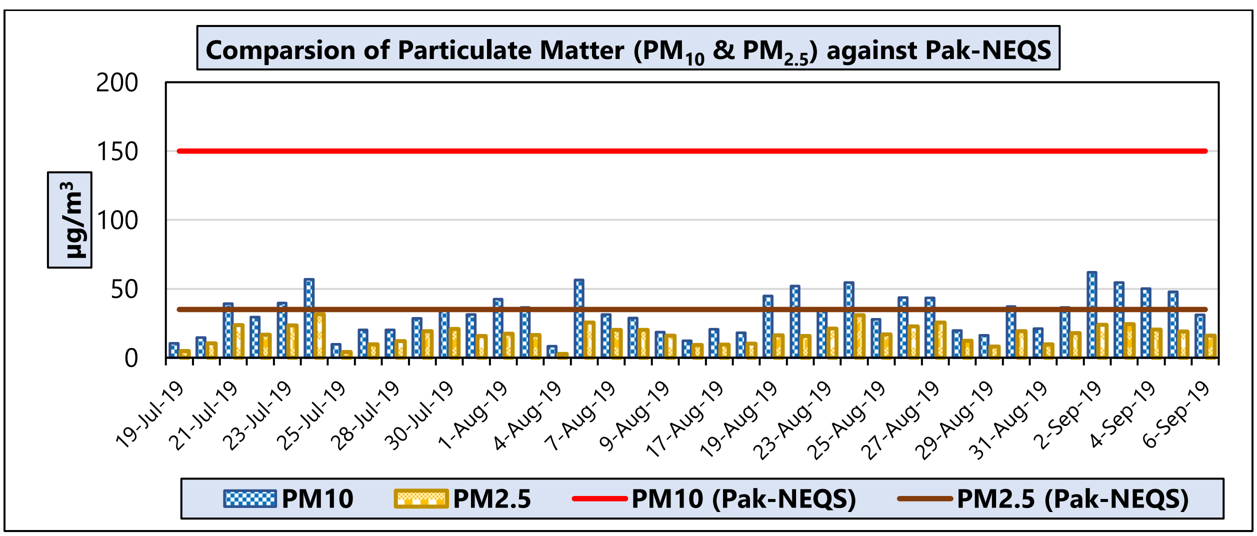


Figure 4. 15 Comparison of Particulate matters (PM_{10} with $PM_{2.5}$) against Pak-NEQS

4.4 Air Quality during COVID-19:

4.4.1 Impact of lockdown on NO_2 variation in Gilgit:

Tropospheric NO2 column from TROPOMI Instrument (Sentinel 5-p) available at 7 x 3.5 km^2 spatial resolution has been analyzed. The data product of tropospheric NO_2 is retrieved from 2019 and 2020. Temporally averaged NO_2 column for the pre-lockdown period (01 march – 22nd of march) and Lockdown Period which was named as Home Lockdown (23rd march – 15th April) has been analyzed and the corresponding time for the year of 2019 also retrieved as shown in Table 4.1 below.

Table 4. 1 Timeline and mean concentration changes in NO_2

S. No	**Date**	**Tropospheric NO_2**	**Mean Change in NO_2**
1	1st March 2019, to 22nd March 2019 (Pre-lock down period for 2019)	6.247E+14	-40.83%
2	1st March 2020, to 22nd March 2020 (Pre-Lockdown period)	9.310E+14	-11.82%
3	23rd March 2020, to 15th April 2020 **(Socio-economic lockdown period)**	5.903E+14	**-44.09%**
4	23rd March 2019, to 15th April 2019 (Lockdown period for 2019)	1.056E+15	***(Reference Point)***

The point was selected is Airport Chowk, Kashrote Gilgit (35.9166° N, 74.3237° E). In 2019 the same period of lockdown (23rd march – 15th April), the tropospheric NO_2 over the site was analyzed and averaged tropospheric NO_2 shows 1.056E+15 molecules/cm^2. In contrast to this much lower NO_2 and a significant reduction in ambient tropospheric NO_2 is observed during the 2020 Home Lockdown period as 5.903E+14. This means a total of 44% reduction of Tropospheric NO_2 is observed during the Home Lockdown period as compared to the same period of last year (2019). Figure 4.16 shows the total comparison between the pre-lockdown and lockdown period of 2019 and 2020

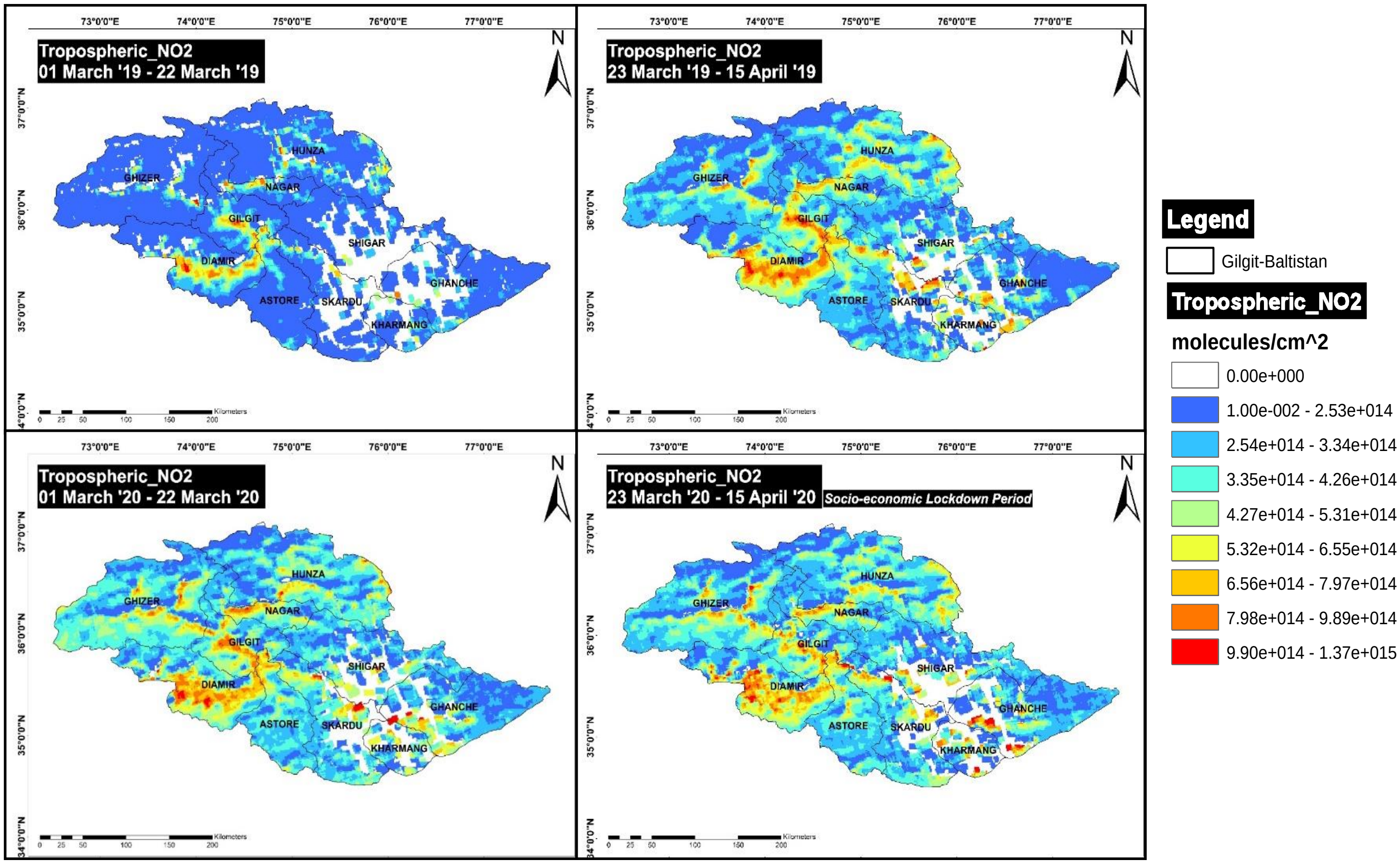


Figure 4. 16 Impact on NO_2 Tropospheric Column during Socio-Economic Lockdown period in COVID-19

4.5 Variation in Aerosol Optical Depth (AOD):

In this study, the MCD19A2 V6 of MODIS (Aqua and Terra) Land AOD daily with a spatial resolution of 1 km is analyzed both seasonally and monthly. The daily data product is analyzed for two decades (2000-2020). The Figure 4.17. (a and b) shows the Monthly and seasonal variation of AOD over Gilgit city (35.9166° N, 74.3237° E). The 4.17a figure shows that the AOD exhibits maximum mean value during March as 0.29 while minimum values show 0.13 in October.

The seasonal values as shown in figure 4.17b reveals that the AOD is high during spring followed by winter, summer, and autumn. During spring and winter, the AOD value ranges from 0.348 to 0.101 and 0.279 to 0.132 respectively. Similarly, during summer and autumn, the AOD value ranges from 0.256 to 0.151 and 0.189 to 0.113 respectively. The maximum value is spring is mainly due to the transport and vehicular emissions, biomass burning, local pollutants, and dust due to soil erosion. The high AOD in spring is also due to westerlies in which the long-range winds brought dust from several different regions like West Asia, Thar desert, Sahara desert, and the middle east (Zeb et al., 2019; Nasir et al., 2019) The air masses cross through the Indo-Gangetic region and Himalayans (Kant et al., 2015). The prominent aerosol found during Winter is due to dust. (Zeb et al., 2019)

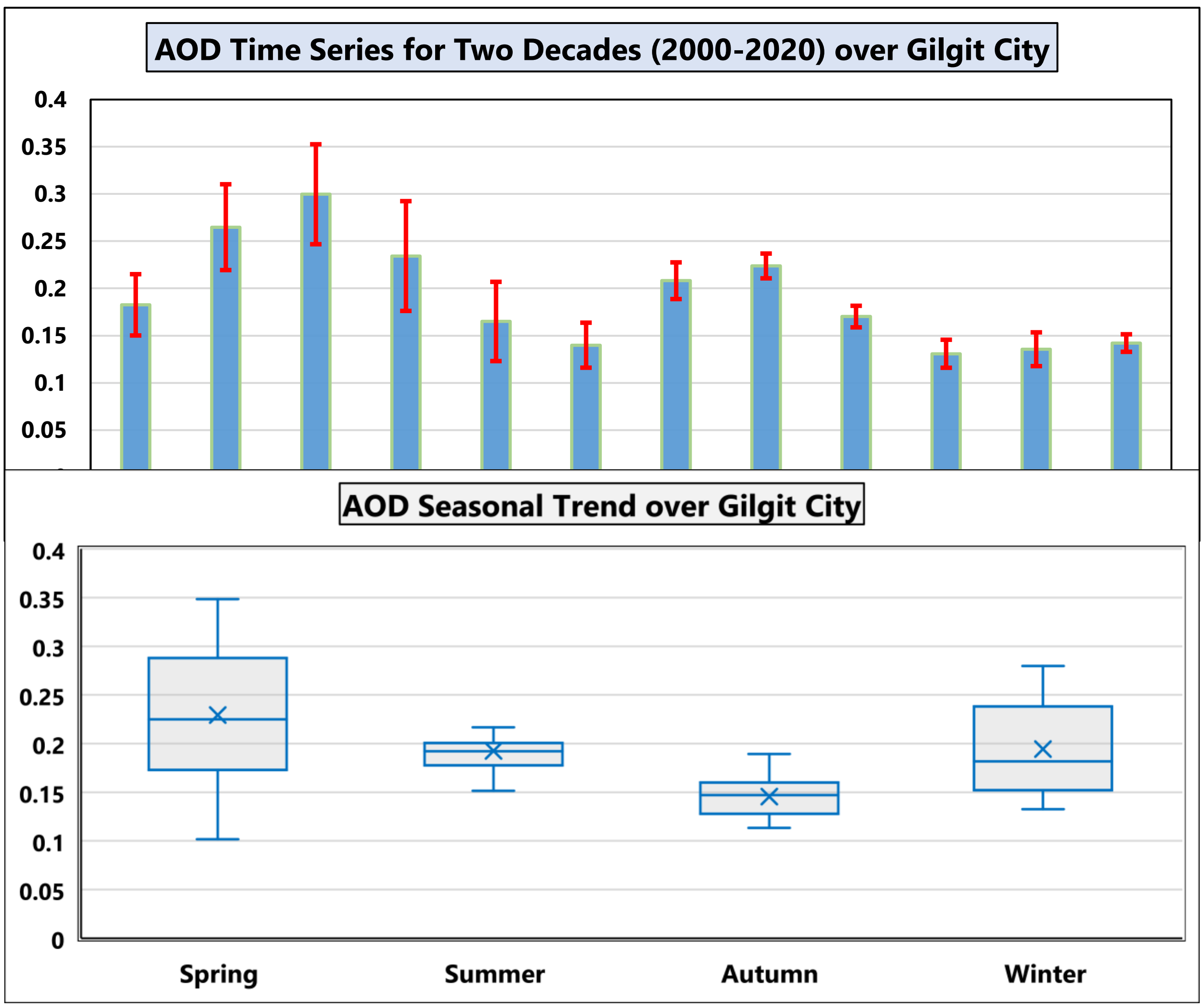


Figure 4. 17 Monthly and Seasonal Trend of AOD over Gilgit

4.6 HYSPLIT Trajectory Analysis:

To find the pathway, origin, and frequency of air masses reaching the receptor site (Airport Chowk), the National Oceanic and Atmospheric Administration (NOAA), Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) models was used. To find the backward trajectory frequency matric the model was run for 72 hours, and the number of trajectories was calculated for 30 days at 1000 m above ground level. To distinguish between the seasons, the 30 days (One Month) frequency was analyzed for the whole seasons (summer, winter, autumn, spring). Figure 4.18 illustrates the Trajectory Frequencies, which shows that the major fraction of air masses which are more than 90% during summer and autumn Season (July & October 2020) are localized. The 90% of air masses reach to the receptor site are mostly coming from KPK province and through Karakoram Highway (KKH). A small fraction of Air mass frequency is reaching the receptor site from Afghanistan and India while a small fraction frequency is reaching from Nepal in autumn. During the winter and spring seasons (January & April), the major fraction of air mass frequencies, more than 90%, are coming from the Indian Occupied Kashmir to the receptor site. A small fraction of air mass frequency is reaching the receptor site from Afghanistan. For the spring season, a small fraction is also coming to the study site is from China, Tajikistan, Kyrgyzstan, and Uzbekistan.

At 1000 m, 72 hours backward trajectory frequencies were calculated for 3 days too. The model was run for 3 days to identify the frequency of air masses reaching the study site. Figure 4.19 illustrates the 3 days trajectory frequencies. Showing almost a similar trend as the above monthly frequencies.

The origin of air masses for long-range black carbon are identified by (Nasir et al., 2019) and they found that during summer (May/June, August/September) air masses originate from the Caspian Sea and the Black Sea and they reach the receptor site from over eastern Europe and central Asia. While during winter (November/December) Mediterranean sea and the middle east are major sources of westerlies wind which are pass through Iran, Afghanistan and reach the study site.

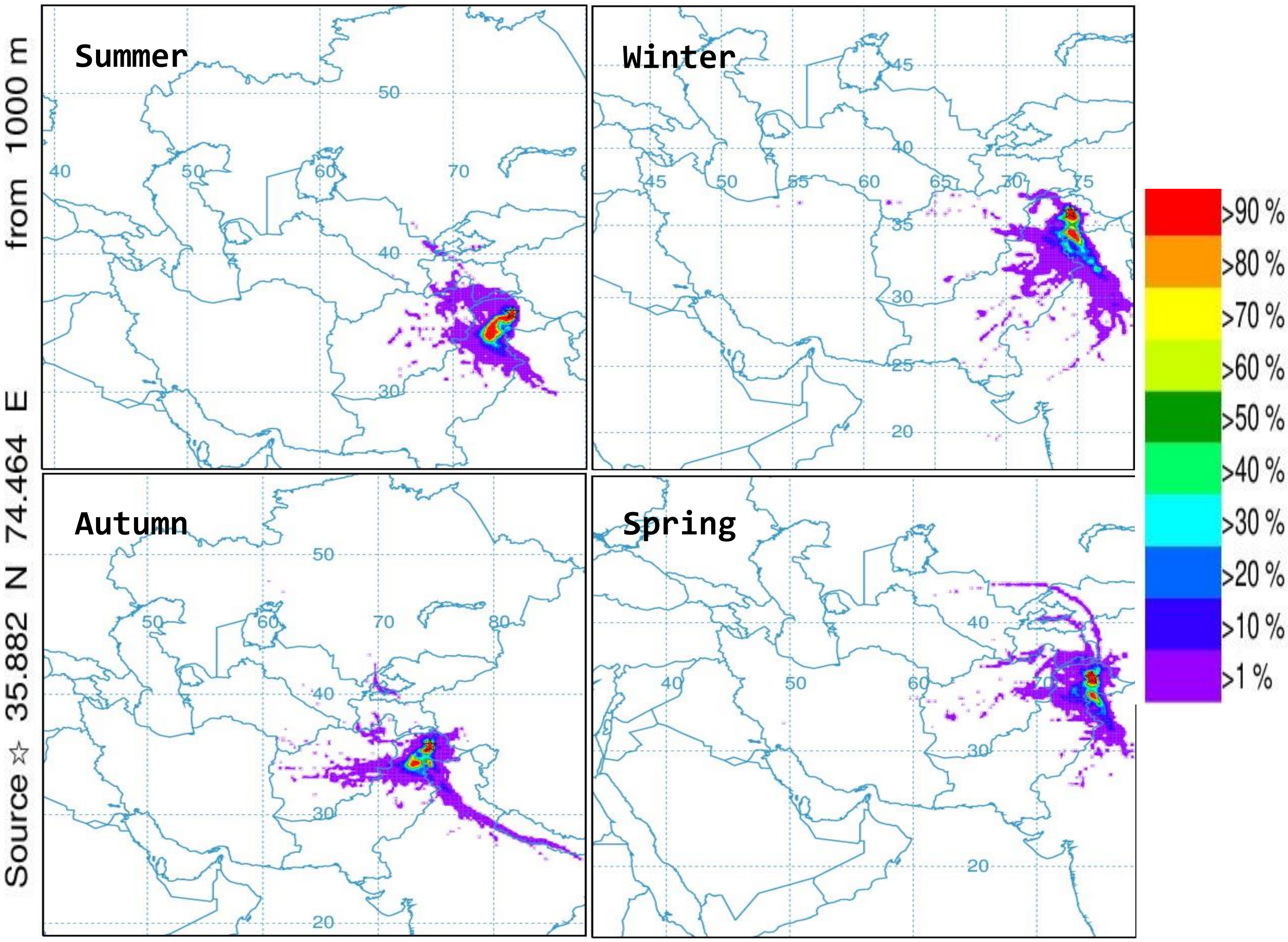


Figure 4. 18 Seasonal (Monthly) NOAA HYSPLIT Backward Trajectories

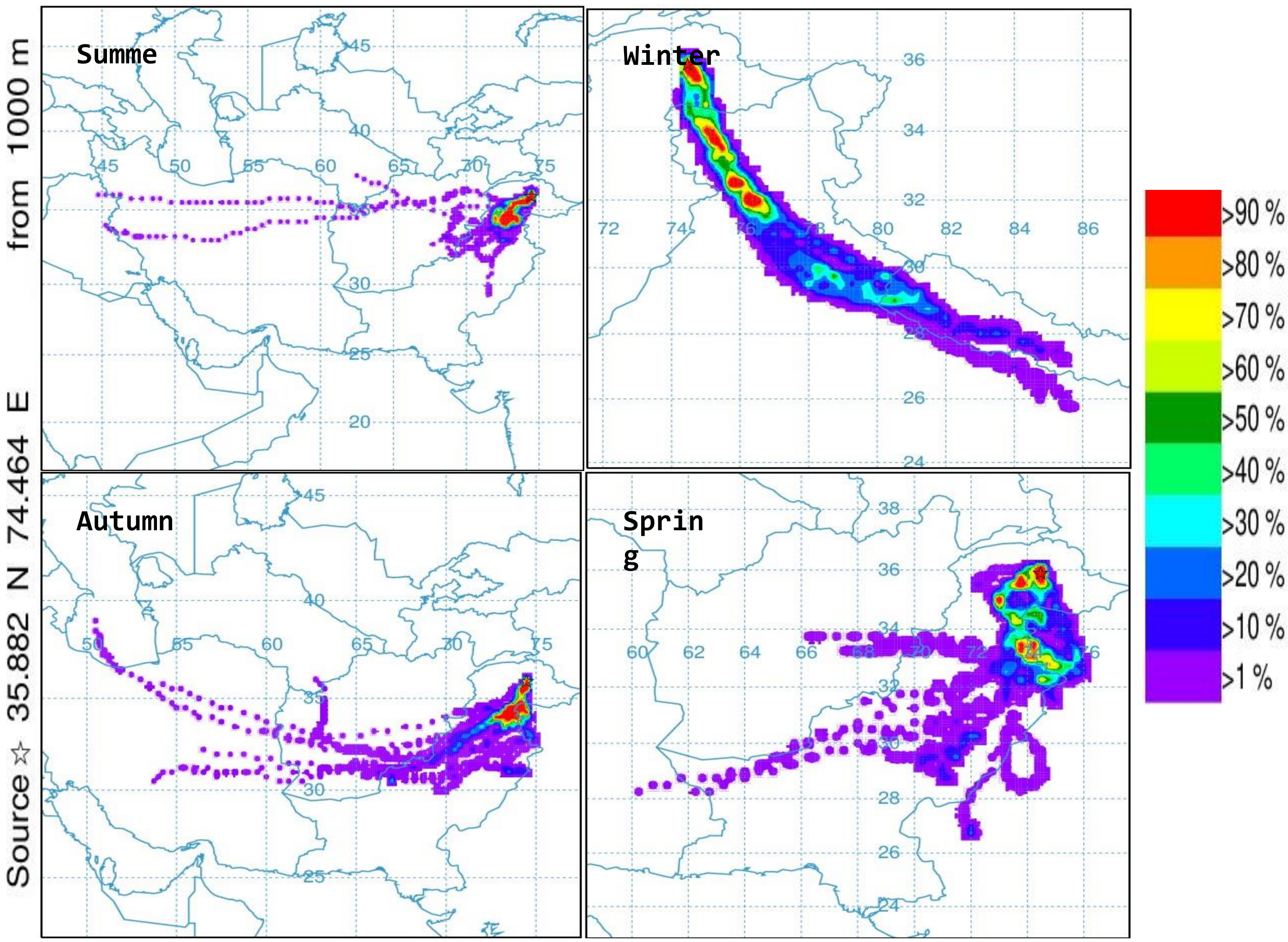


Figure 4. 19 NOAA HYSPLIT 3 Days Backward Trajectories

Chapter 5

Conclusion and Recommendation

5.1 Conclusion:

The air quality of Gilgit city has been identified by exploiting ground and satellite-based observations. The major conclusions drawn from this study are:

- ❖ NO_2 concentration is observed through ground-based Haz-Scanner for 38 days at different sites in Gilgit City and it is found that for 28 days it exceeds the Pak-NEQS permissible limit which is 80 μgm^{-3} for 24 hours. It represents 73% of total observations.
- ❖ NO_2 columns are observed with two satellite instruments (TROPOMI and OMI). They both show a good Pearson correlation value of 0.505. While the ground-based NO_2 concentrations Haz-Scanner show a good Pearson correlation value of 0.84 with satellite-based tropospheric NO_2 from the TROPOMI instrument.
- ❖ The monthly mean tropospheric NO_2 column from OMI is in good agreement with tourism inflow. OMI NO_2 column and tourist inflow high in summer and low in winter.
- ❖ CO concentration is well below the Pak-NEQS permissible limit during the ground-based observation. While CO total Column is high during winter and low in summer through observation from TROPOMI. A relative change of 27.72% increase in CO Total column from TROPOMI is observed.
- ❖ Ground-Based CO concentration shows a negative Pearson Correlation of 0.44 with Total CO Colum from the TROPOMI instrument. This is mainly because TROPOMI gives us total columnar values while ground-based Haz-Scanner gives point data concentration.
- ❖ During COVID-19 lockdown Period, a significant reduction of 44% tropospheric NO_2 column is observed in Gilgit City.

- ❖ MODIS AOD is high during spring which is mostly due to dust particles followed by decreasing trends during winter, summer, and autumn.

5.2 Recommendation:

Based on findings from this study, the following are some recommendations that should be carried out to combat and tackle Air Quality issues in Gilgit-Baltistan in the future:

- Further spatio and temporal research need to be carried out to establish the relationship between ground base pollutants with satellite observations.
- As vehicular emissions are the major contributor to deteriorating the air quality, effective measure, and control techniques such as Portable Emissions Measurement System (PEMS), new technology (Euro 6), alternative fuel, improved combustion, and the catalytic converter is highly recommended.
- The region is very fragile and susceptible to climate change. Long-term ground-based monitoring of pollutants must be carried out to develop an air quality baseline database.
- Inventories of pollutants must be developed for each city in the whole region to identify the susceptibility to climate change.
- More robust pollution regulations are recommended for the safe health and human and environment.
- Effective media campaigns for educating the general public and other stakeholders, to improve their understanding and raising air quality concerns.

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