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Objective:

Your goal is to use space-based satellite data combined with ground observations like air pollution, social-economic activity, traffic or transportation, mobility, industrial activity perform exploratory data analysis, find a correlation between changes in ground activities and their impact on the environment. Compare data across different time periods and geographic regions and explore changes in Earth-related attributes (such as land use, land cover, and other characteristics) in response to COVID-19?

Considerations:

1. Your solution may focus on any type or combination of environmental phenomena (e.g., atmosphere, land, ocean, water, ice, fire), attributes, and locations. You may consider these attributes in your solution (but you are not limited to these examples)
   - Changes in air quality (due to reduced transportation & economic activities)
   - Wildfires events
   - Deforestation
   - Urban growth
   - Water Quality
2. For the solution any type of geographic location is suitable. Clearly define the region of interest for your solution.
3. Make sure to clearly state what data you used and how you used it.
4. For solutions involving machine learning clearly state the evaluation stage, metrics used, and validation set.
5. How would you determine if observed environmental phenomena are impacts of the COVID- 19 pandemics?
6. Which impact dynamics can be discovered on a local or regional basis?
7. Identify links among various environmental and anthropogenic activities in your solution.
8. Present your assumptions, theories, and solution with necessary correlation or causal relationships.

Summary Report

Besides your solution provide a document answering all the below-mentioned questions
1. Summary of your solution.
2. Key outcomes or takeaways from your solutions.
3. How did your solution involve geospatial data?
4. Does your solution require improvements in terms of data or methodology?

Dear humans yes emissions are required to keep me green!

The atmosphere of the Earth is characterized as the layer of gases around the planet that is sustained by the Earth's gravity. The atmosphere of the Earth consists largely of two groupings. The first category comprises gases of almost stable concentrations, whereas the second group includes particles with fluctuating concentrations i.e. aerosols. Although the climate has changed in past years, the study of anthropogenic emissions on climate change is important with a rise in human-produced aerosols. Aerosols from natural and anthropogenic sources are continuously discharged into the atmosphere. The sources of natural aerosols like sea salt, dust, volcanic ash are seas, deserts, volcanic eruptions, etc.; while the sources of man-made aerosols like smoke, polluted continental particles, etc. are vehicular emissions, biomass burning, industries, etc. Over most land surfaces, the atmosphere is loaded primarily by dust and smoke amongst all aerosol types and possesses high variability over space and time. 90 per cent of total aerosols are natural by origin, while 10 per cent of total aerosols are more critical and are of anthropogenic origin. Apart from aerosols the greenhouse gas emission are also now seen to have increasing trend causing further much more unpredictability in understanding the meteorological processes and estimates. These aerosols and greenhouse gas impact public health, visibility, ocean fertilization, Earth energy budgets, cloud formation, climate forcing, radiation flow, and hydrological flow. However Covid-19 gave an opportunity to better study the role of these greenhouse gas emissions in the meteorological processes in other environment indices.

The objective of the assignment is to highlight the changes in other environment variables due to reduced air pollution due to covid-19 lockdown.

1. Domain considered: Land-surface, Air, Water.

2. Variables/Indices: Satellite data, Ground stations (IMD stations data)
   - **Normalised Difference Vegetation Index (NDVI):** NDVI is a dimensionless index that describes the difference between visible and near-infrared reflectance of vegetation cover and can be used to estimate the density of green on an area of land.
   - **Enhanced Vegetation Index (EVI):** The enhanced vegetation index (EVI) is an 'optimized' vegetation index designed to enhance the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences.
   - **Normalised Difference Vegetation Index (NDWI):** The NDWI is a remote sensing based indicator sensitive to the change in the water content of leaves (Gao, 1996).
   - **Aerosol Optical Depth (AOD):** Aerosol Optical Depth (AOD) is the measure of aerosols (e.g., urban haze, smoke. particles, desert dust, sea salt) distributed within a column of air from the instrument. (Earth's surface) to the top of the atmosphere.
   - **Land Surface Temperature (LST):** Land surface temperature (LST) is the radiative skin temperature of the land derived from solar radiation. LST measures the emission of thermal radiance from the land surface where the incoming solar energy interacts with and heats the ground, or the surface of the canopy in vegetated areas.
   - **Surface Soil Moisture (SSM):** Surface soil moisture is the water that is in the upper 10 cm of soil.

- **Evapotranspiration (ET):** Evapotranspiration is the name given to the total water loss to the atmosphere from a land surface, usually expressed in units of depth; it includes the water vapour evaporating from the soil surface and from the liquid water on plant surfaces together with that transpired from within plant surfaces.
- **Latent Heat Flux (LHF):** Latent heat flux is the flux of heat from the Earth's surface to the atmosphere that is associated with evaporation of water at the surface and subsequent condensation of water vapour in the troposphere. It is an important component of Earth's surface energy budget.

3. Region/Locations: New Delhi, Bengaluru, Desert, Agriculture field (Haryana), Forest (Kerala)

   LULC Types (MODIS): Urban build, Desert, Cropland, Broad leaf forests.
   The above regions/ zones are selected based on distribution of aerosols, air pollution homogeneity and meteorological factors. More of distribution of aerosols is discussed in Metha et al., 2021. For example, during summers the north India is dominated by dust while the south India is dominated by smoke type and gas emissions.

4. Dataset Usage:
   Factor of Change: AQI and other indices from IMD station data, Aerosol Optical Depth (AOD).
   Meteorological and surface factors impacted: Latent Heat Flux (LHF), Land Surface Temperature (LST), Precipitation (PPT), Surface Soil Moisture (SSM), Evapotranspiration (ET), Normalised Difference Vegetation Index (NDWI).
   End Factors: Normalised Difference Vegetation Index (NDVI), Evapotranspiration (ET).

   The solar flux is first impacted by AOD and other air pollutants in the atmosphere, which impacts the meteorological factors as described above. Finally these meteorological and surface factors largely decides the NDVI and EVI.

   The study however requires more parameters like humidity, solar radiation, etc to actually predict the NDVI or EVI and crop yield but due to limited computed capability and dataset availability at Google Earth Engine the exploration is done with the above mentioned factors.

5. Observed environmental phenomena, impacts and linkages of the COVID- 19 pandemics.

The mean values of the above mentioned parameters were taken and the percentage change is calculated (2019 data is subtracted from 2020) for different sites selected based on LULC. The changes in covid-19 can be very be seen in Nighttime lights of the cities. The nighttime light reduced in all the regions which is well linked to mass migration of people from big cities to tier two cities or villages. Due to Covid-19 lockdown there were less anthropogenic emission resulting high solar radiation reaching on ground. This is initial input to the microclimate dynamics, following preliminary observations were made due to reduced emissions (sample outputs attached):

- Aerosol Optical Depth (AOD) : Due to reduction in air pollution there is reduction in AOD in all regions except that of in Delhi. The north India region in summers is heavily influenced by dust and smoke from forest fires. The increased AOD during lockdown period could be linked to the smoke from the forest fires in central India and Himalayas started late evening (Mehta and Hooda (2021)). This can be further checked with the VIIRS or MODIS active fire products as well with proper screening of bands. Conversely this could be linked to one of the input to the forest fire among other variables like relative humidity, soil moisture, biomass index, evapotranspiration, NDWI, NDVI, etc. The underlying assumption here in estimating AOD is the satellite retrieval

algorithms and signal to noise ratio of the sensor. To avoid these as well as the cloud mis-classification the conservative/strict quality check parameters can be used to calculate the AOD.

- Air Quality Indices: Significant improvement was observed in air quality in all metro cities and other regions. In majority of the cases PM 2.5, PM10 and ozone found to have high correlation with AOD. For example the South India region which is dominated by anthropogenic smoke and polluted dust aerosols showed sloughy higher correlation of AOD with PM2.5 than PM10. While in North India the correlation of AOD was higher with PM10. The underlying assumption here is that the pollutants are well distributed in the space however, in the current work where the point buffer of 30 km have the high spatial variability. Also, the spatial resolution of AOD and AQI may induce further bias in correlation. This correlation can be improved by taking multiple stations data and applying the kriging technique to interpolate within the zone/buffer.
- Land Surface Temperature (LST): The LST is affected primarily due to the scattering and absorption by the aerosols and and greenhouse gases allowing lower solar flux to the ground. The regions dominated by dust aerosols found to have little reductions in temperature however the region where the smoke aerosols are found to have the heating effect and higher LST. This can again be linked to the AOD and PM2.5 and PM 10 correlation. For example the Delhi region found to have lower day temperature, this is to be linked to comparatively higher presence of dust in atmosphere than smoke when compared to previous years. While in Banglore the similar reduction is primarily due to PM2.5 which could be smoke or polluted dust. Another example is the Desert region which is affected only by dust, during the lockdown period reduction in dust aerosols were reported by many researchers. Similar observation is seen AOD reduction in Desert region as well as PM10 in the bar diagram of Delhi. The quality parameters here is the cloud screening or presence of water vapours.
- Soil Surface Moisture (SSM): During the day time the SSM found to have the negative correlation with LST while during the nighttime the SSM found to have positive correlation. Here, the LST during the day time (Terra (11 AM), Aqua (2:30 PM))and night time (Terra (11 PM), Aqua(2:30 AM)) are compared to the SSM. However further more investigation is required to claim increase or decrease in various location. This also requires the soil type mapping and evapotranspiration rate in the given location.
- Precipitation: Precipitation process is heavily influenced by the micro-climatic conditions. For cloud formation the aerosols are required to act as the cloud seeding points however the mechanism requires further more meteorological processes to calculate the formation of cloud and to precipitate. Precipitation hold a positive correlation with AOD depending upon the region and climate. For example the in North India the cloud formation is heavily dependent on presence of dust particles and altitude while in south India smoke particles helps in tight packing of clouds to form denser cloud and heavy precipitation. This process is further more dependent on smoke injection height. If the smoke particles are present within the Planetary boundary layer height can help in thermal convection and activating cloud formation process resulting good rainfall but of the smoke is injected to free troposphere the actual precipitation will be lower due to reduced radiative forcing. Similar results could be seen in correlation plot where AOD showed strong positive correlation to precipitation with significantly higher values during the lockdown period resulting higher precipitation during the lockdown period. The precipitation is high variable in space and time, therefore downscaling of precipitation data at given spatial resolution is recommended.
- Normalised Difference Water Index (NDWI): NDWI found to have significant negative correlation with Land surface temperature and positive correlation with Evapotranspiration. Over different land topography different observations were observed which is primarily due to the LST. For example, in forest regions where there is very less of change in LST is observed however significant water content is seen in biomass which is primarily linked to higher precipitation rate and lower evapotranspiration process which requires further validation. For other sites the with relatively higher precipitation and higher transpiration process the NDWI found to have reduced

in the regions. The work also requires delineation of waterbodies in the buffer zone. This can be done by keeping the threshold value <0 for better results values less than -0.3 is recommended.

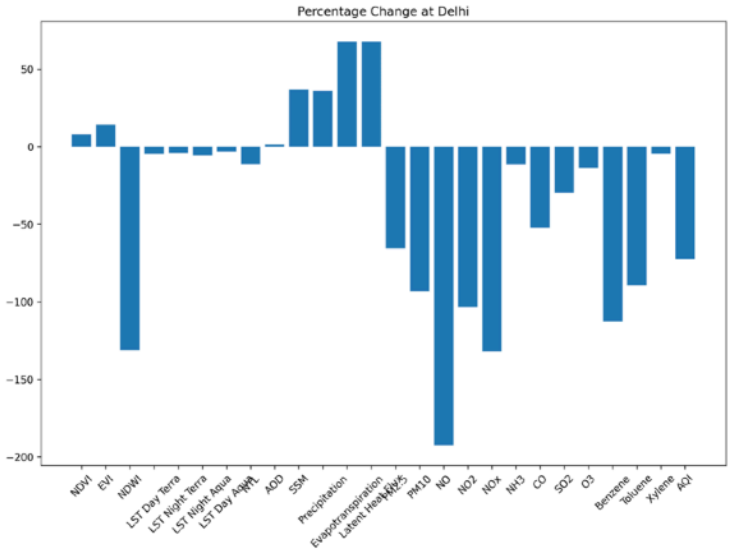
- Evapotranspiration and Latent Heat Flux: During Covid Lockdown the relatively clear skies clean allowed more solar radiation flux however its may also have resulted in the cloud formation depending upon microclimate of the region. These indices have temporal resolution of 8 day in MODIS Google Earth Engine data product however, the process is sensitive on hourly basis. This further require ML model to predict daily values. The same was attempted in current assignment using auto-sklearn however the validation score was lower (~0.20) and MAE was relatively higher (0.80). Calculation is however significant to develop relationship of crop yield or biomass estimation in conjunction with other agri indices.
- Normalised Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI): These variables were taken as the qualitative end result of changes in environment due to Covid-19. NDVI and EVI found to have significant viability over different topography in response to Covid-19. For example in Delhi region there is increase in NDVI values during the lockdown period while in Bangalore region NDVI decreased while EVI increased. Like Bangalore similar observation is seen in forest region. Some parameter that affects NDVI and EVI are soil type, NDWI, humidity, soil moisture, precipitation, solar flux, etc. However, on accounting the correlation of NDVI and EVI with other variables it is found that EVI is highly correlated to Evapotranspiration and correlation further decreased during the lockdown period. Much of variability could also be attributed to the actual harvesting time period. During covid-19 lockdown the late harvesting and shorter growing season of next crop could also induce bias in the correlation between the time period. This need to be further studied with other agro-covariables to verify the changes in the NDVI during the Covid-19 lockdown. This can very well seen with in agriculture field and forest type land use.

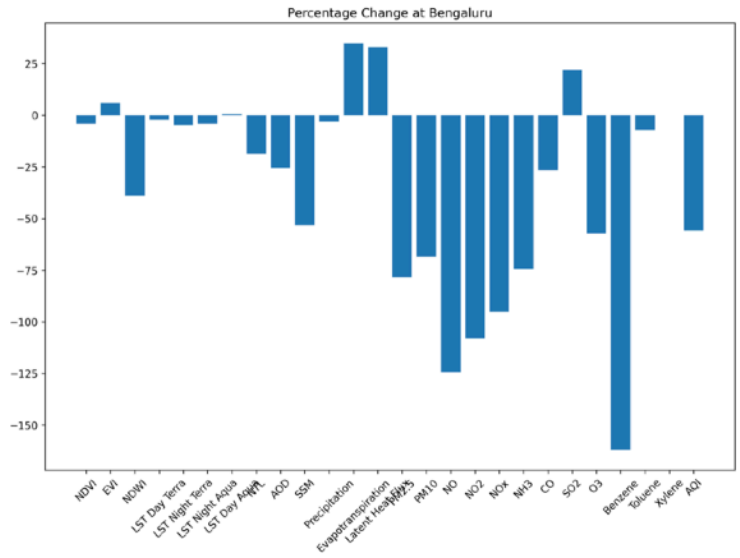
- Other work attempted in the assignment:
  - Water quality indices: NDCI for inland water bodies, Algae bloom in ocean were attempted however due to computation incapability i.e. number of pixels that can be processed at a given time the work was stopped.
  - Machine Learning model for predicting the evapotranspiration and latent heat flux. The validation score was lower and MAE was higher.
  - Deriving other meteorological parameters like humidity, net solar flux, winds were difficult in google earth engine in the given time frame is difficult.
  - Collection of Google covid-19 mobility data, Uber mobility data, electricity consumption data.

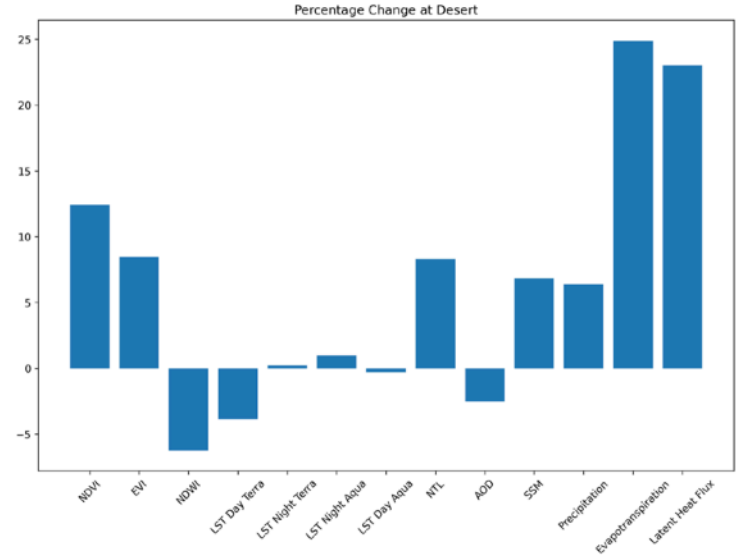
- Skill Growth/Learning:
  - Google Earth Engine
  - ML/Models

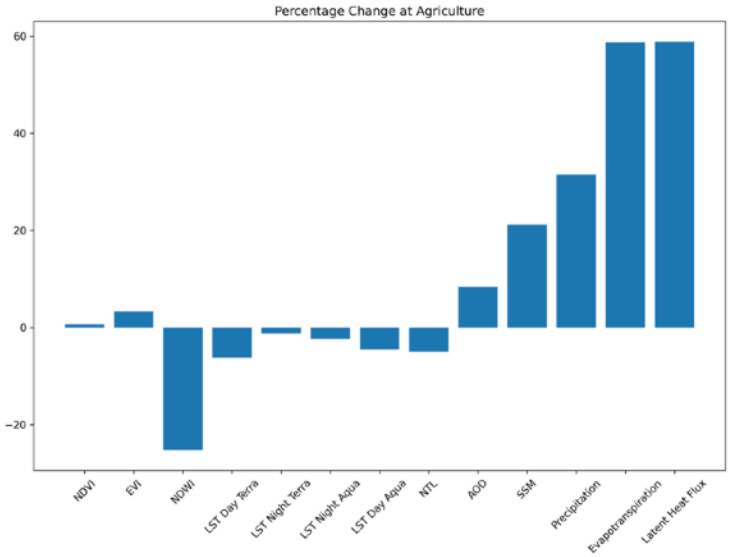
Key outcome/ Takeaways:

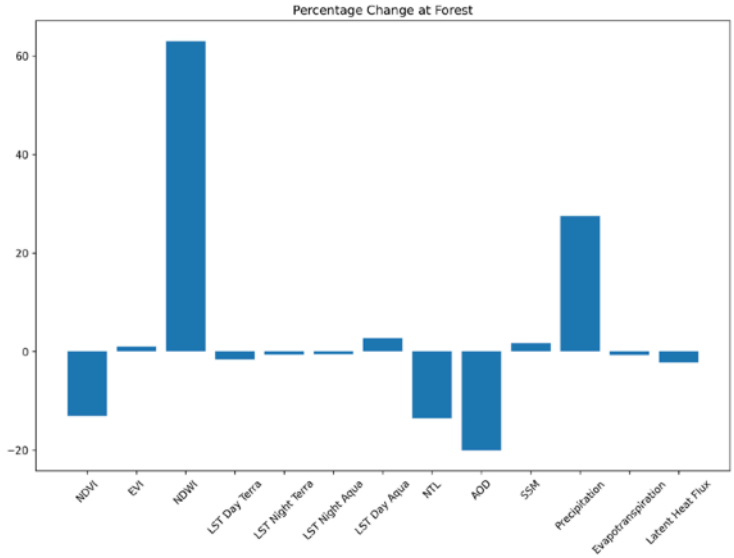
The objective of the assignment was to bring out changes in environment during the lockdown period. For this the changes were first seen through the nighttime lights which was easily noted in terms of reduced radiance values captured by VIIRS sensor. Later changes in AOD and AQI indices as the key first parameter that affect incoming solar radiation is observed. It was found that there is significant reduction in AOD and improvement in AQI indices however exception being North India region where low AOD resulted in forest/ wild fires in the region thus injection of smoke into the atmosphere. Following this changes in other parameters noted wherein high correlation of AOD with precipitation, negative correlation of AOD with LST, etc were noted which clearly indicated that with clear skies more cloud formation or precipitation can be take place in the region however it is closely related to the type of pollutant. All of these together result in green earth i.e. high NDVI or EVI regional variability. One this that is noted here is that with more incoming solar radiation due to absence of emissions resulted more wildfires in North India. Although this was not attempted in the current work but studied in conjunction with some research publications. Apart from this other datasets like evapotranspiration rate, heat flux, humidity etc are also required to better understand the dynamics of environment with less human intervention.


Percentage Change at Delhi
50
0
−50
−100
−150
−200
NDVI
EVI
NDWI
LST Day Terra
LST Night Terra
LST Night Aqua
LST Day Aqua
NTL
AOD
SSM
Precipitation
Evapotranspiration
Latent Heat Flux
PM2.5
PM10
NO
NO2
NOx
NH3
CO
SO2
O3
Benzene
Toluene
Xylene
AQI

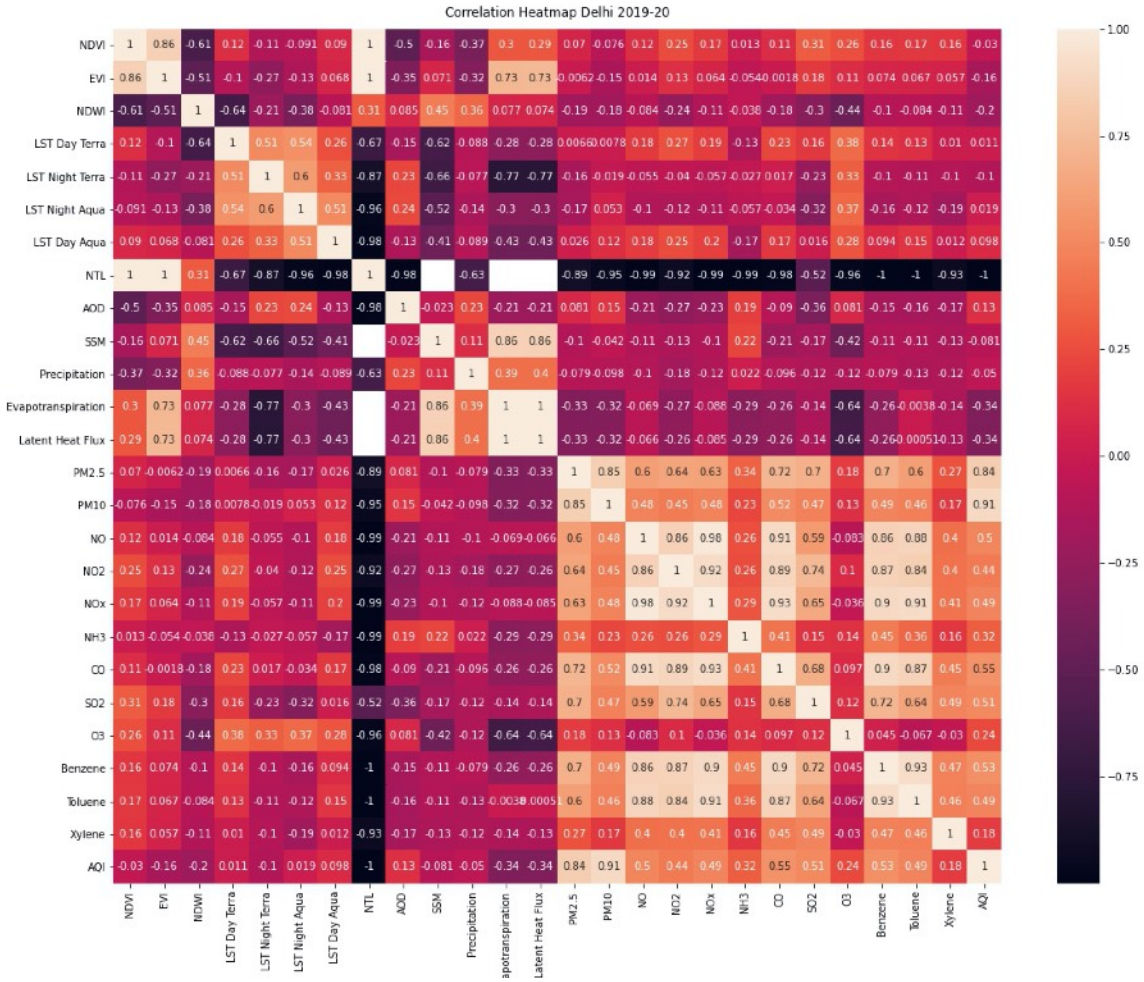

Percentage Change at Bengaluru
25
0
−25
−50
−75
−100
−125
−150
NDVI
EVI
NDWI
LST Day Terra
LST Night Terra
LST Night Aqua
LST Day Aqua
NTL
AOD
SSM
Precipitation
Evapotranspiration
Latent Heat Flux
PM2.5
PM10
NO
NO2
NOx
NH3
CO
SO2
O3
Benzene
Toluene
Xylene
AQI

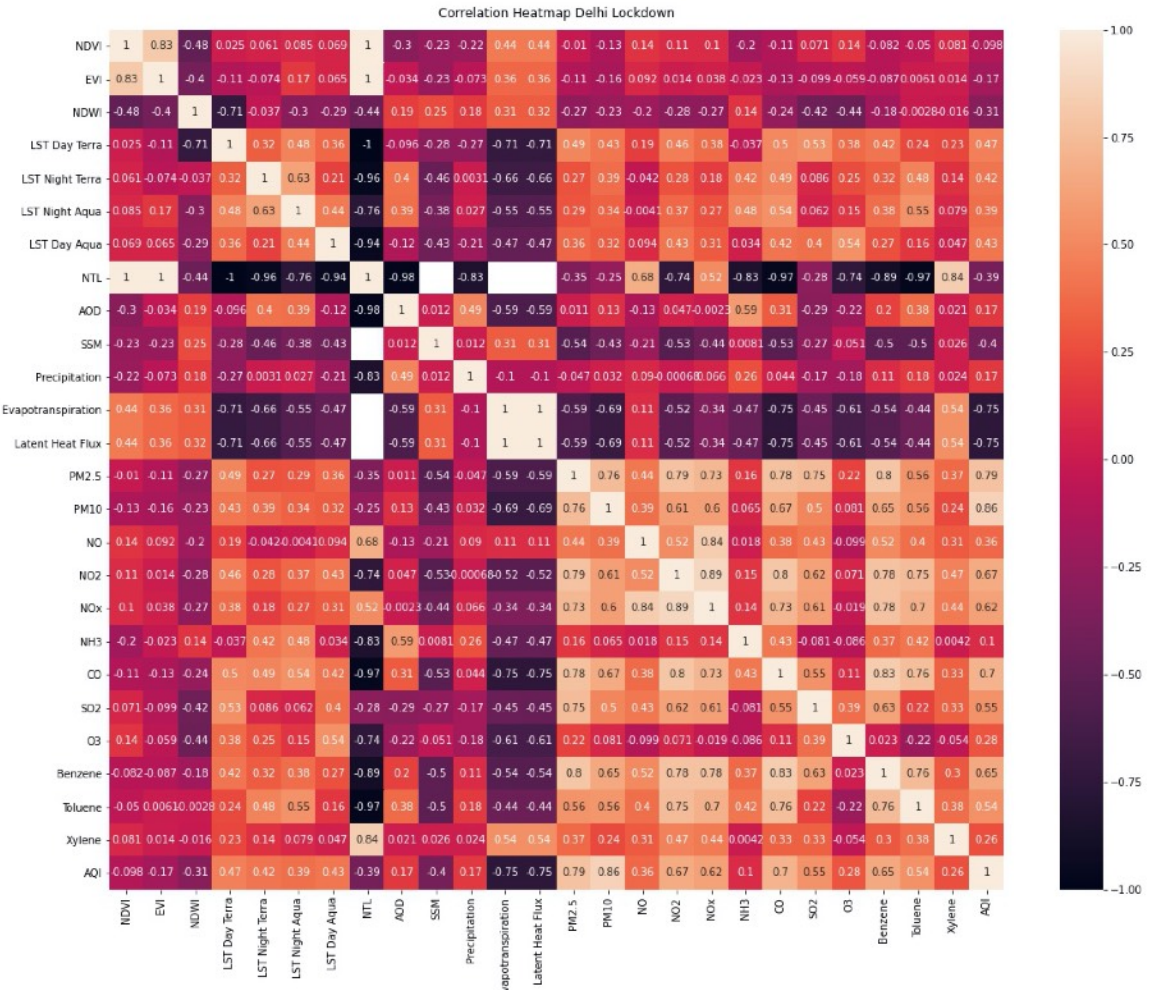

Percentage Change at Desert
25
20
15
10
5
0
−5
NDVI
EVI
NDWI
LST Day Terra
LST Night Terra
LST Night Aqua
LST Day Aqua
NTL
AOD
SSM
Precipitation
Evapotranspiration
Latent Heat Flux

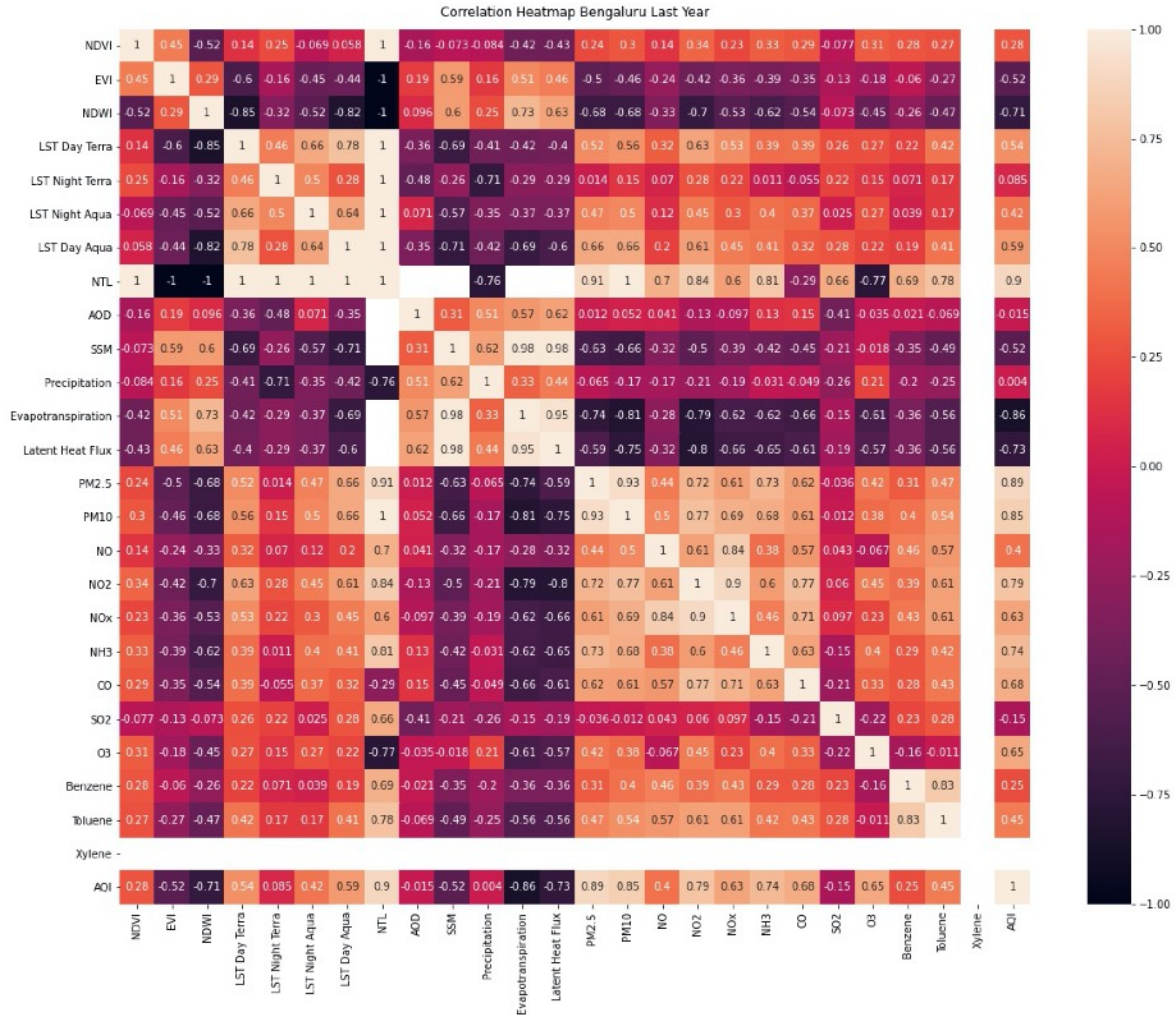

Percentage Change at Agriculture
60
40
20
0
−20
NDVI
EVI
NDWI
LST Day Terra
LST Night Terra
LST Night Aqua
LST Day Aqua
NTL
AOD
SSM
Precipitation
Evapotranspiration
Latent Heat Flux

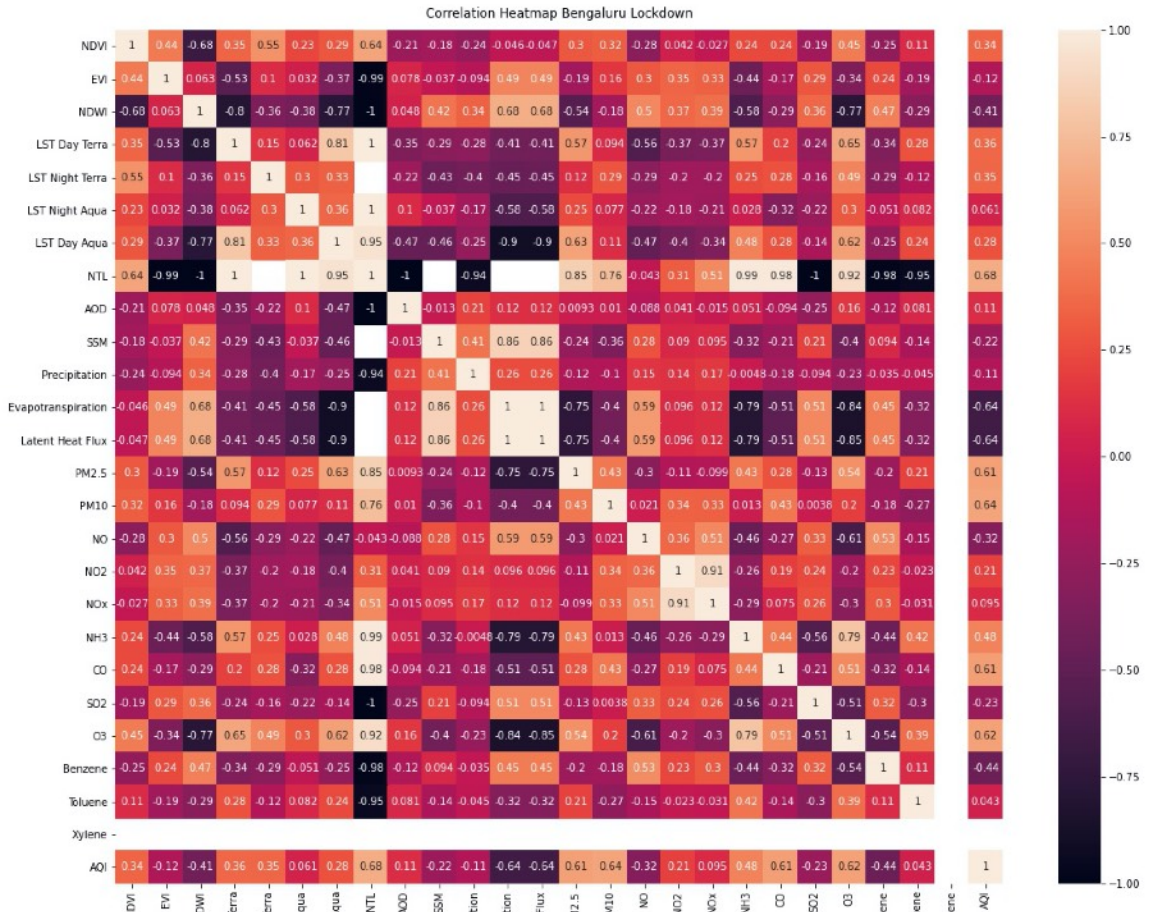

Percentage Change at Forest
60
40
20
0
−20
NDVI
EVI
NDWI
LST Day Terra
LST Night Terra
LST Night Aqua
LST Day Aqua
NTL
AOD
SSM
Precipitation
Evapotranspiration
Latent Heat Flux

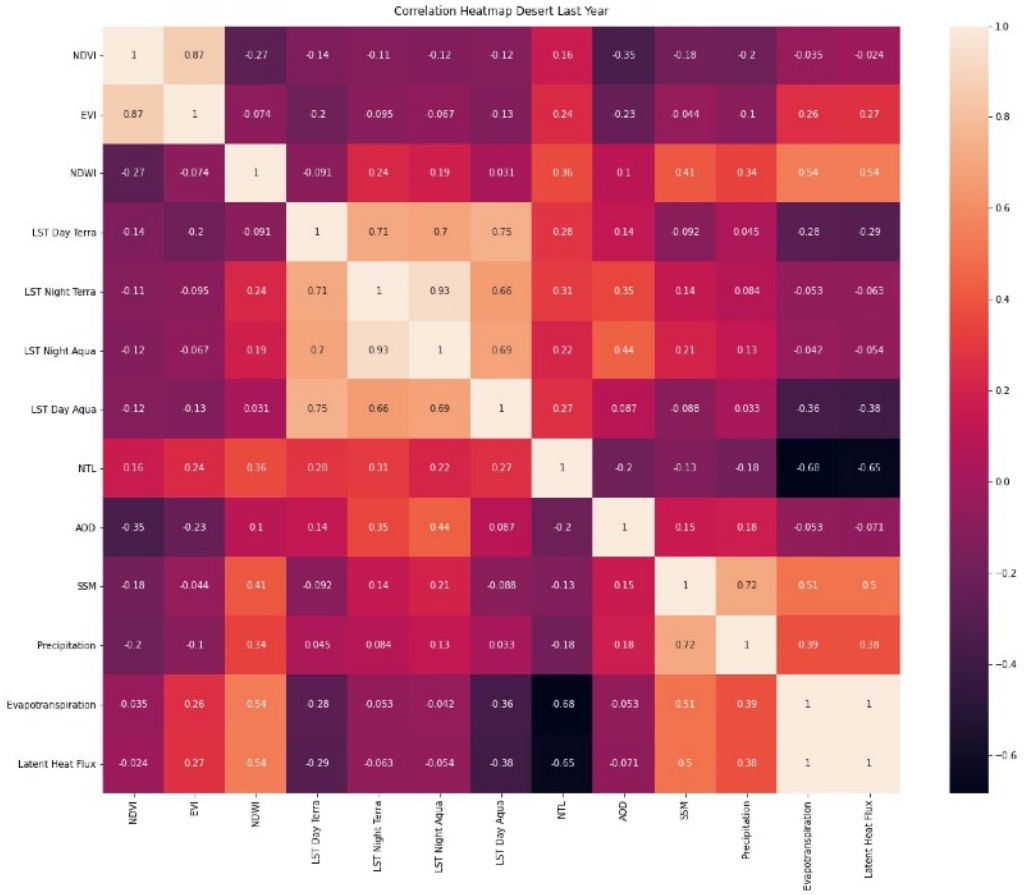
Correlation Plots of Parameters

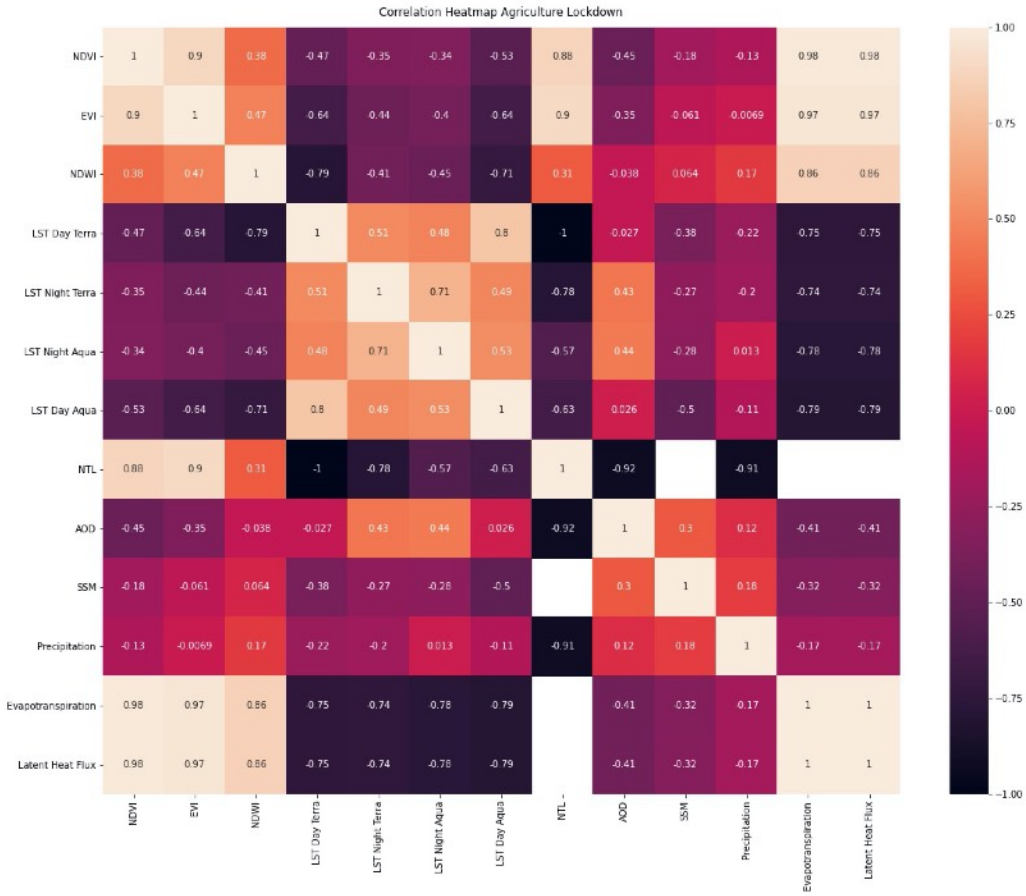





Correlation Heatmap Bengaluru Last Year
NDVI
EVI
NDWI
LST Day Terra
LST Night Terra
LST Night Aqua
LST Day Aqua
NTL
AOD
SSM
Precipitation
Evapotranspiration
Latent Heat Flux
PM2.5
PM10
NO
NO2
NOx
NH3
CO
SO2
O3
Benzene
Toluene
Xylene
AQI
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00


Correlation Heatmap Bengaluru Lockdown
NDVI
EVI
NDWI
LST Day Terra
LST Night Terra
LST Night Aqua
LST Day Aqua
NTL
AOD
SSM
Precipitation
Evapotranspiration
Latent Heat Flux
PM2.5
PM10
NO
NO2
NOx
NH3
CO
SO2
O3
Benzene
Toluene
Xylene
AQI
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00


Correlation Heatmap Desert Last Year
NDVI 1 0.87 -0.27 -0.14 -0.11 -0.12 -0.12 0.16 -0.35 -0.18 -0.2 -0.035 -0.024
EVI 0.87 1 -0.074 -0.2 -0.095 -0.067 -0.13 0.24 -0.23 -0.044 -0.1 0.26 0.27
NDWI -0.27 -0.074 1 -0.091 0.24 0.19 0.031 0.36 0.1 0.41 0.34 0.54 0.54
LST Day Terra 0.14 -0.2 -0.091 1 0.71 0.7 0.75 0.28 0.14 -0.092 0.045 -0.28 -0.29
LST Night Terra 0.11 -0.095 0.24 0.71 1 0.93 0.66 0.31 0.35 0.14 0.084 -0.053 -0.063
LST Night Aqua 0.12 -0.067 0.19 0.7 0.93 1 0.69 0.22 0.44 0.21 0.13 -0.042 -0.054
LST Day Aqua 0.12 -0.13 0.031 0.75 0.66 0.69 1 0.27 0.087 -0.088 0.033 -0.36 -0.38
NTL 0.16 0.24 0.36 0.28 0.31 0.22 0.27 1 -0.2 -0.13 -0.18 -0.68 -0.65
AOD -0.35 -0.23 0.1 0.14 0.35 0.44 0.087 -0.2 1 0.15 0.18 -0.053 -0.071
SSM -0.18 -0.044 0.41 -0.092 0.14 0.21 -0.088 -0.13 0.15 1 0.72 0.51 0.5
Precipitation -0.2 -0.1 0.34 0.045 0.084 0.13 0.033 -0.18 0.18 0.72 1 0.39 0.38
Evapotranspiration -0.035 0.26 0.54 -0.28 -0.053 -0.042 -0.36 -0.68 -0.053 0.51 0.39 1 1
Latent Heat Flux -0.024 0.27 0.54 -0.29 -0.063 -0.054 -0.38 -0.65 -0.071 0.5 0.38 1 1
NDVI EVI NDWI LST Day Terra LST Night Terra LST Night Aqua LST Day Aqua NTL AOD SSM Precipitation Evapotranspiration Latent Heat Flux
1.0 0.8 0.6 0.4 0.2 0.0 −0.2 −0.4 −0.6


Correlation Heatmap Agriculture Lockdown
NDVI 1 0.9 0.38 -0.47 -0.35 -0.34 -0.53 0.88 -0.45 -0.18 -0.13 0.98 0.98
EVI 0.9 1 0.47 -0.64 -0.44 -0.4 -0.64 0.9 -0.35 -0.061 -0.0069 0.97 0.97
NDWI 0.38 0.47 1 -0.79 -0.41 -0.45 -0.71 0.31 -0.038 0.064 0.17 0.86 0.86
LST Day Terra 0.47 0.64 -0.79 1 0.51 0.48 0.8 -1 0.027 0.38 -0.22 -0.75 -0.75
LST Night Terra 0.35 -0.44 -0.41 0.51 1 0.71 0.49 -0.78 0.43 -0.27 -0.2 -0.74 -0.74
LST Night Aqua 0.34 -0.4 -0.45 0.48 0.71 1 0.53 -0.57 0.44 -0.28 0.013 -0.78 -0.78
LST Day Aqua 0.53 -0.64 -0.71 0.8 0.49 0.53 1 -0.63 0.026 -0.5 -0.11 -0.79 -0.79
NTL 0.88 0.9 0.31 -1 -0.78 -0.57 -0.63 1 -0.92 -0.91
AOD 0.45 -0.35 -0.038 -0.027 0.43 0.44 0.026 -0.92 1 0.3 0.12 -0.41 -0.41
SSM -0.18 -0.061 0.064 -0.38 -0.27 -0.28 -0.5 0.3 1 0.18 -0.32 -0.32
Precipitation -0.13 -0.0069 0.17 -0.22 -0.2 0.013 -0.11 -0.91 0.12 0.18 1 -0.17 -0.17
Evapotranspiration 0.98 0.97 0.86 -0.75 -0.74 -0.78 -0.79 0.41 -0.32 -0.17 1 1
Latent Heat Flux 0.98 0.97 0.86 -0.75 -0.74 -0.78 -0.79 0.41 -0.32 -0.17 1 1
NDVI EVI NDWI LST Day Terra LST Night Terra LST Night Aqua LST Day Aqua NTL AOD SSM Precipitation Evapotranspiration Latent Heat Flux
1.00 0.75 0.50 0.25 0.00 −0.25 −0.50 −0.75 −1.00

Percentage change in parameters