Report on Internal Industrial Based Learning (IBL) of Term 4 of Year 2022/2023 for the duration July – August, 2023

By

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Bapp (Geoinformatics)

ESEQ/2019 Cohort

Presented to

Dr. Francis Oloo

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1. Introduction

Industrial exposure is an important aspect of training while pursuing a course in Geoinformatics. At the Technical University of Kenya this is achieved through industrial based learning (IBL) which is offered in two forms including internal and external IBL sessions. Internal IBL session is provided within the university setup and aims to provide students with the technical aspects of the theoretical work that they have previously covered. This report details the activities that we covered during the July-August 2023 session. In particularly this IBL covered the following sessions;

- Calculating NDVI using Google Earth Engine
- Laser Scanning
- Surface Modelling
- Academic writing/ proposal writing
- Project

The objectives of the IBL were outlined as follows:

- Remote Sensing – specifically focusing on Google Earth Engine
- Surface Modelling
- Cartography
- Programming- Data mining
- Project Writing/ Academic writing

The approach adopted included face to face guided sessions, field work and online sessions.

A summary of the sessions, the proposal and the project report are provided in chapters 2, 3 and 4 of this report

2. Session Summaries

2.1 Session one Summary: Google Earth Engine

1. Introduction

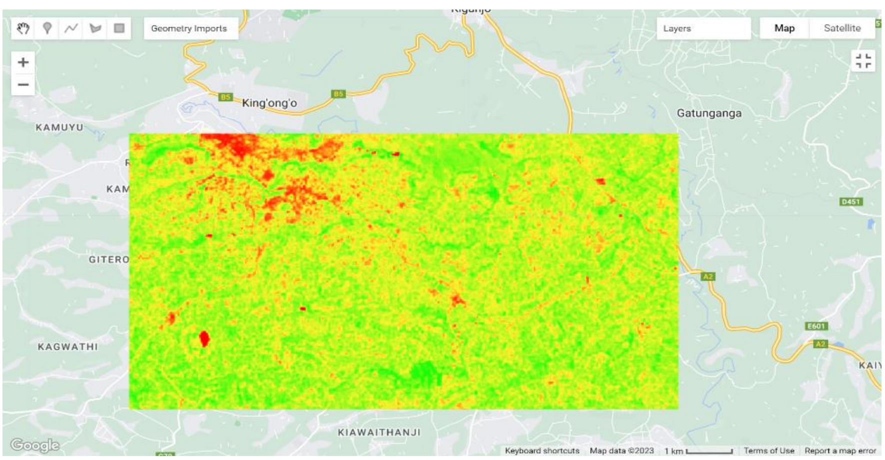
Google Earth Engine is a cloud-based platform developed by Google that allows scientists, researchers, developers and other users to analyze and process vast amounts of satellite imagery and geospatial data. It provides an environment for conducting advanced geospatial analysis, remote sensing, and earth observation tasks at scale.

During this session, we specifically focused on calculating Normalized Difference Vegetation Index (NDVI) in Google Earth Engine using Landsat 8 imagery.

```
//creating a function to calculate NDVI
var ndviCalc=function(image){
  var ndvi=image.normalizedDifference(["B5",'B4']).rename('NDV
  image=image.addBands(ndvi);
  return image;
};

//creating ndvi as a separate image
var ndviCalc2=function(image){
  var ndvi=image.normalizedDifference(['B5','B4']).rename("NDV
  var ndviImage=ee.Image(ndvi);
  return ndviImage
}
```

And later on, mapped the generate NDVI layer.



As a way of practicing what was taught in class, students were required to calculate Normalized Difference Water Index (NDWI) for Lake Nakuru between January 2015 and June 2023.

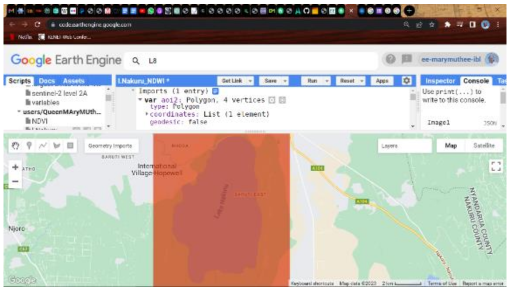
The Normalized Difference Water Index (NDWI) is a remote sensing index that is widely used to detect and assess the presence of water bodies and moisture content in vegetation. It's particularly useful for analyzing changes in surface water bodies, monitoring drought conditions, and studying hydrological processes.

Methodology

The main steps followed for the NDWI calculation were as follows;

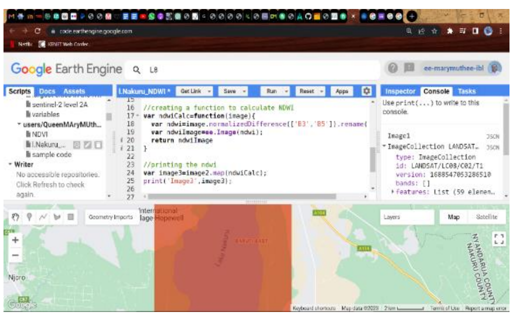
1. **Creating Area of interest boundary**

Here we create a boundary around Lake Nakuru which is to serve as our area of interest boundary

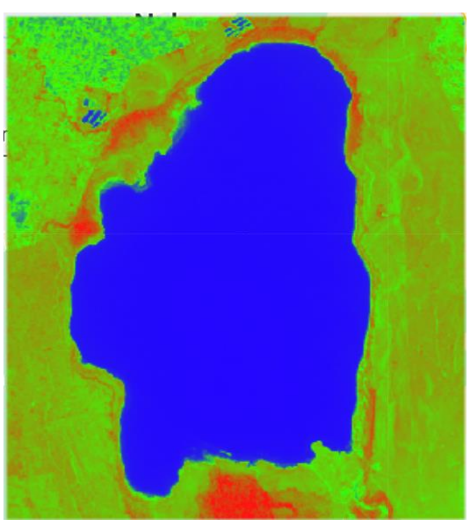


2. **Importing the Landsat 8 image collection**

We then created and image collection from the Landsat 8 and defined parameters such as filter date, cloud cover filter and filtered it to our area of interest. Finally, we generated a function that was used to calculate the NDWI for the years given



Results



Lake Nakuru NDWI

2.2 Session Two Summary: Laser Scanning

Laser scanning combines controlled steering of laser beams with a laser rangefinder. By taking a distance measurement at every direction the scanner rapidly captures the surface shape of objects, buildings and landscapes. There are varieties of laser scanner but for this session we specifically focused on a 3D laser scanner that has been manufactured by Geoslam. This session was led by **Surveyor Peter Ndirangu**. The session was face to face guided and also incorporated a field work.

GeoSLAM's 3D laser scanners typically utilize lidar technology, which involves emitting laser pulses and measuring the time it takes for the pulses to return after reflecting off surfaces in the environment. These measurements are used to create a point cloud, representing the 3D coordinates and reflectivity information of various points in the scanned area.

The main objectives of the day were;

- Learning how the 3D scanner works
- Scan S block and the car park
- View the data collected on the GeoSLAM's Desktop software

How the Scanner works

GeoSLAM scanners are designed to be easily carried and operated by a single person, allowing for flexible and efficient data collection in various environments. It offers real-time data visualization, allowing users to see the scanned data as it's being captured, enabling immediate feedback on the quality and coverage of the scan. GeoSLAM scanners can be used for both indoor and outdoor applications, making them versatile tools for mapping complex environments. For this case, we specifically scanned the inside of S block and the outside which included the car park. The captured data from GeoSLAM's scanners can be processed and analyzed using their proprietary software or other compatible third-party software for further post-processing and analysis.

After having scanned the intended areas, we were able to view the 3D image using the GeoSLAM desktop software. The software which is also designed by the GeoSLAM helps one to view the captured data either in the 2D or 3D form.

Scanner

The resulting images from the scanned S block and car park are shown below

From this IBL session, we were able to learn on how the GeoSLAM 3D scanner works. This a good way of learning that the school has brought to us, as technology is facing to such directions.

2.3 Session Three Summary: Surface Modelling

A surface model is a representation of geographic information phenomena that can be measured continuously across some part of the earth surface e.g., elevation. Some common surface models include:

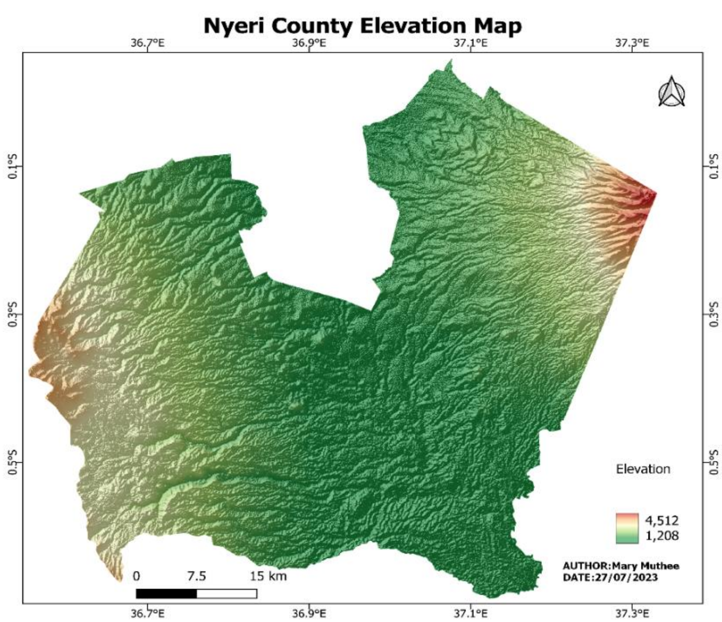
- Digital Surface Model (DSM)- Describes the terrestrial surface including the objects covering the surface.
- Digital Elevation Model (DEM)- A representation of the terrain which filters out and excludes terrain vector features.
- Digital Terrain Model- A 3D bare earth representation of the terrain of the surface topography.

For this session we specifically focused on DEM. My Area of Study was Nyeri County. The main objectives were as follows;

- Downloading DEM data
- Generating Contours
- Creating random points from our data
- Performing Interpolation (IDW and Spline)
- Creating a slope map

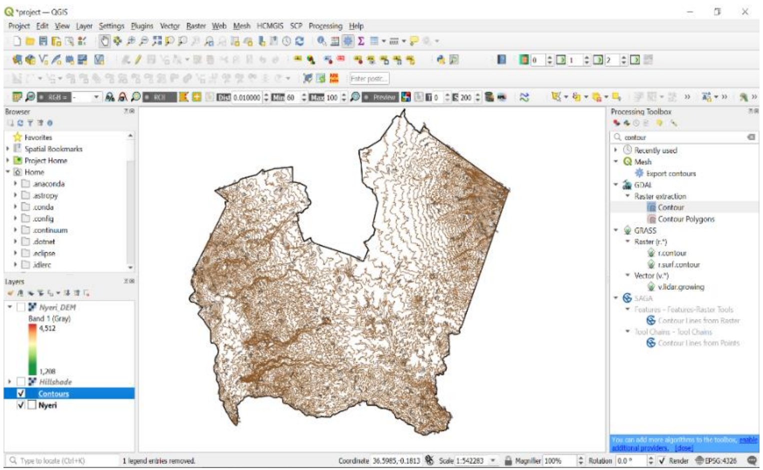
Downloading DEM data

The DEM data was downloaded from the Google Earth Engine. I used the NASA SRTM Digital Elevation 30m dataset which I clipped to Nyeri County. Later on, symbolized the elevation data for the county using QGIS



Generating Contours

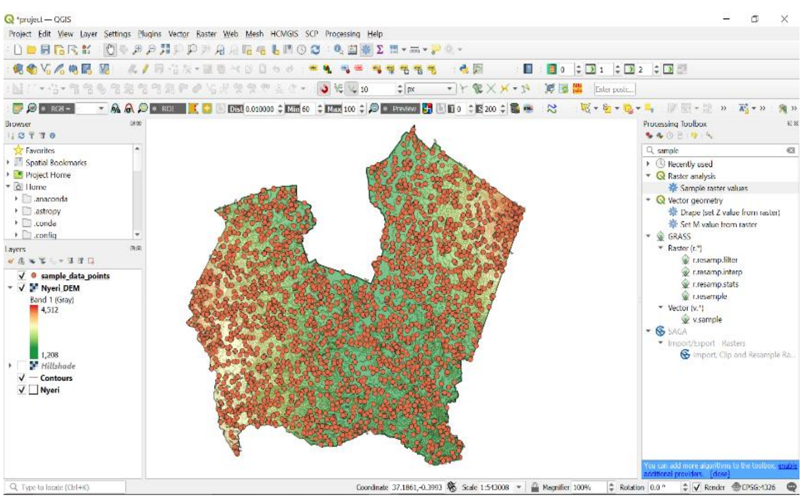
Contour lines are lines that connect points of equal elevation on a surface, allowing one to understand the topography of the region. I used the contour tool under the GDAL tools to generate the contours from the Elevation data. The contours were at an interval of 50.



Creating random points

I created 4000 points within my area of study using the Random Points in Extent tool under the research tools and afterwards performed sampling using the sample raster values tool. Sampling helps us to extract the pixel values of our generated points from the DEM. Through this we are able to attain the elevation of each point which shall later on be used to perform interpolation.

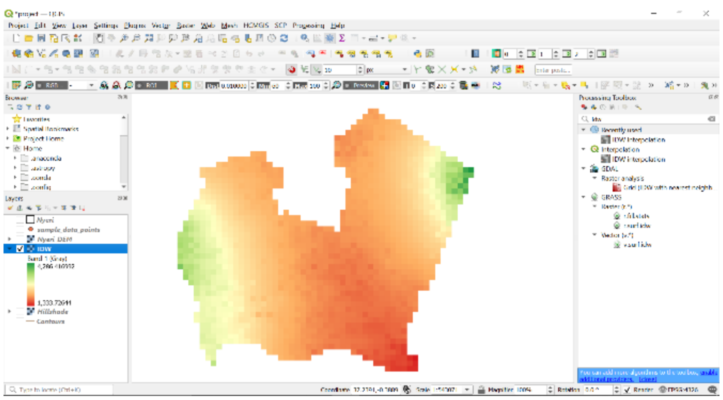
We later on extract only those points with elevation value and exclude the null values. This helps us to only remain with points that fall within our county boundary.



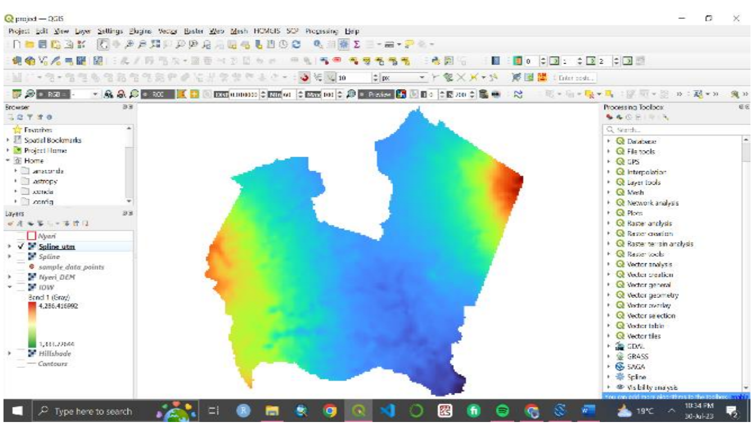
Interpolation

This is the process of estimating the value of a variable at locations where it has not been directly measured, based on the known values at surrounding sample point. We use the sample points generated to perform interpolation using IDW and Spline.

The main principle behind IDW is that the influence of a known data point decreases with increasing distance from the unmeasured location. In other words, nearby points impact the estimated value more than points farther away. This is achieved by assigning weights to the known data points based on their distance from the unmeasured location. We use the IDW interpolation tool to interpolate our sample points and later on clip the raster to our county boundary.


IDW

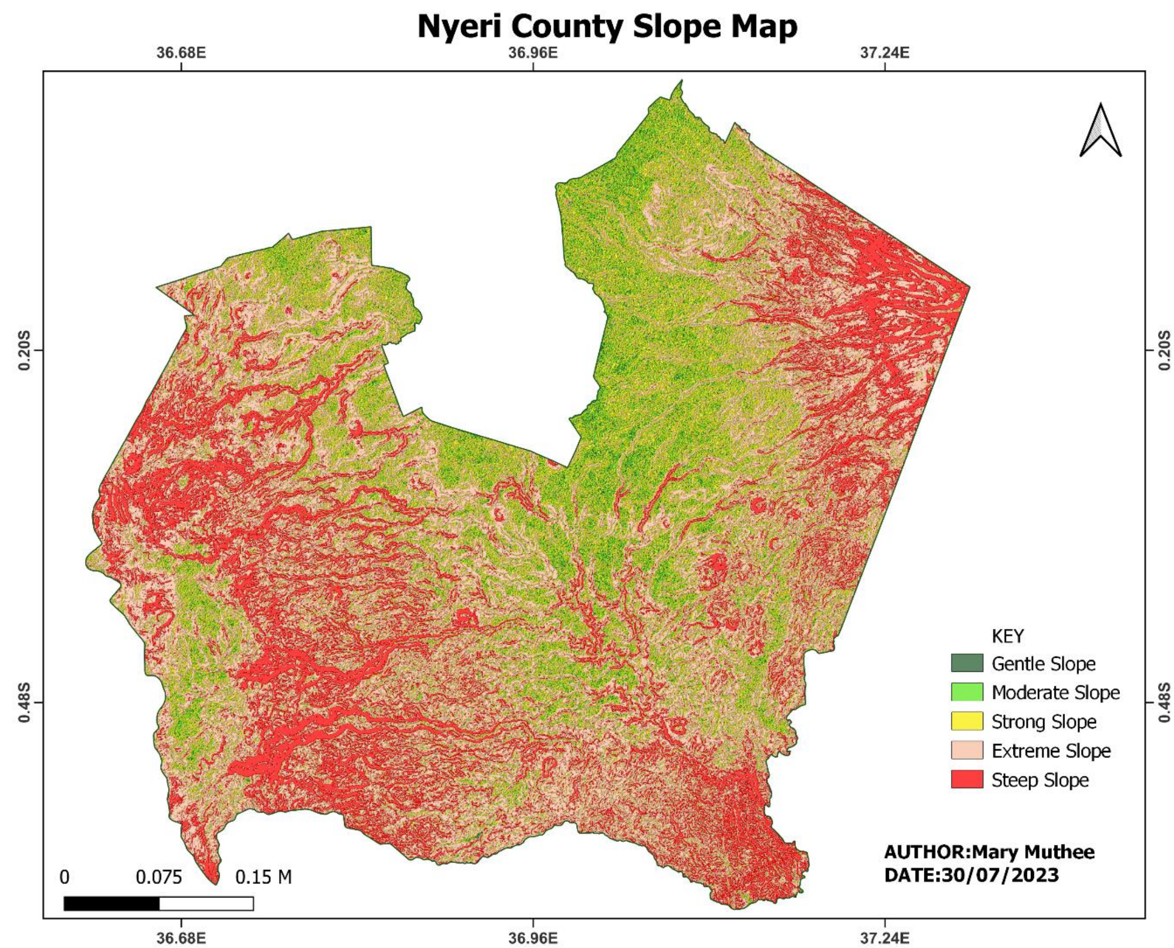
Spline uses mathematical functions called splines to estimate the value of a continuous surface at unsampled locations based on the values of surrounding sample points. Using Saga in Qgis could not produce the expected outcome, therefore I opted to use the Saga GIS software itself.


spline

Slope

Slope refers to the steepness or inclination of the land surface at a specific location. It represents how much the elevation changes over a given horizontal distance. Slope is a crucial aspect of topography and is used in various fields such as geography, geology, hydrology, and land planning. For this case study, I used the elevation data that we had earlier to create the slope

After generating the slope, I reclassified the layer using the “reclassify by table” tool. Reclassification refers to the process of altering the values of a raster dataset based on specific criteria. This process is used to transform the original data into a new representation, often to simplify or categorize the data for further analysis or visualization.



Surface modelling techniques are essential for representing and analyzing terrain data, and they find numerous applications across different domains. Some of the applications are Hydrological analysis, Water resource management, Engineering and infrastructure design, Solar energy studies etc.

3. Proposal Writing

Proposal for developing a high-resolution topographical map of the electricity grid from Thika to Juja

Submitted to

Kenya power and lighting company (KPLC)

Proposal by

G Earth organization

P.O BOX 621-00100

https://www.gearth.org

Contact person

Mary Muthee

0727069128

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To

Kenya Power and Lighting Company

www.kplc.co.ke

RE: Proposal for Developing a High-Resolution Topographical Map of Electricity Lines from Thika to Juja and Web-Based Platform.

I am writing to present a comprehensive proposal on behalf of G Earth, an innovative organization dedicated to leveraging modern technology for sustainable solutions. We are excited to propose a project that aims to develop a high-resolution topographical map of electricity lines spanning from Thika to Juja. This project also includes the creation of a web-based and mobile-accessible platform for data visualization, employing drone technology as the primary method for data acquisition.

The objective of the Project is to produce an accurate and up-to-date topographical map of electricity lines in the Thika to Juja region, aiding in efficient infrastructure management and maintenance. The project tasks involve data acquisition through drones, map generation, and the creation of a user-friendly web-based platform to visualize the collected data.

Team Expertise consists of highly skilled professionals with complementary expertise:

Maxwell: Web Developer and Team Leader

Ian: Drone Pilot

Mary: GIS Analyst

Victor: Researcher

Enock: Cartographer

Profile of G Earth Organization:

G Earth represents a group of geoinformation specialists who are deeply passionate about leveraging technology to foster sustainability. The organization's diverse strengths and collaborative approach position us to tackle intricate challenges and drive transformative change. we're primed to make a lasting impact in the geospatial arena, one innovative solution at a time.

Mission: To utilize cutting-edge technology for environmental and infrastructural sustainability.

Vision: Empowering informed decision-making through accurate and accessible data.

Core Objective: Innovating solutions for a smarter and more sustainable world.

Organizational Capacity:

Our organizational structure is designed to ensure seamless collaboration and task distribution. Team members are assigned duties according to their respective expertise:

Maxwell - Web Developer and Team Leader

Maxwell is a highly skilled software developer with over a year of experience in both front-end and back-end development as well as database management. He has honed his expertise through active involvement in volunteering positions, contributing his talents to various participatory software development programs. Professionally, Maxwell has undergone training as a geoinformation expert and is currently in his penultimate year of studying the BAPP geoinformation course at TUK.

Maxwell's strengths lie in his coding prowess, spatial analysis capabilities, and his proficiency in designing web maps. Not only is he a technical powerhouse, but he also excels in collaborative environments, displaying exceptional teamwork skills. In this project, Maxwell will assume the role of the primary web developer, leveraging his proficiency in web development to build the project's web-based platform. His extensive knowledge and leadership skills will also be harnessed as he takes on the role of team leader, ensuring the coordination and success of the project.

Ian - Drone Pilot and Remote Sensing Expert

Ian is an accomplished drone and remote sensing specialist, amassing over a year of experience in executing successful drone operations. He has primarily acquired his expertise through volunteering positions he actively contributed to piloting participatory programs. Similar to his peers, Ian also holds a background in geoinformation, presently in the penultimate year of his BAPP geoinformation course at TUK.

His capabilities encompass unmanned aerial vehicle flight operations and spatial analysis. Ian is recognized for his indispensable role as a team player, which significantly contributes to the collaborative spirit of the project. His central responsibility in the project will be serving as the chief drone pilot, directing the data acquisition efforts. His proficiency in remote sensing and geoinformation is expected to add valuable insights to the project.

Mary - GIS Analyst and Spatial Data Expert

Mary stands as an adept GIS analyst with substantial experience exceeding a year, particularly in spatial data mining and remote sensing data analysis. Her proficiency has been demonstrated through voluntary participation in various mapping programs, including the OSM participatory mapping initiatives. In her educational journey, Mary has pursued geoinformation studies and is currently in the penultimate year of her BAPP geoinformation course at TUK

Her strengths encompass coding, spatial analysis, and the intricate art of map design. Alongside her technical abilities, Mary is highly regarded for her teamwork aptitude. In this project, Mary will serve as the primary GIS analyst, utilizing her skillset to process and analyze the collected data. Her contributions are anticipated to bring depth and precision to the spatial aspects of the project.

Victor - <u>Research Communication Specialist and Planner</u>

Victor is a versatile specialist in research communication and planning, driven by an eagerness to diversify across various environments. His prowess has been cultivated through extensive volunteering engagement in research and planning capacities. Victor's academic journey aligns with geoinformation studies, and he is currently in the penultimate year of his BAPP geoinformation course at TUK.

His proficiencies encompass pre- and post-project assessments, as well as viability analysis. Victor's role as a pivotal team player shines through in his contributions. In the project, Victor will serve as the lead researcher and planner, utilizing his skills to assess and strategize for the project's success. His broad perspectives and planning acumen are expected to contribute significantly to the project's overall coherence and strategic direction.

Enock - <u>Digital Cartographer and Mapping Specialist</u>

Enock stands as a seasoned expert in digital cartography, showcasing experience exceeding a year in topographical map design, spatial data mining, and remote sensing data analysis using tools like Google Earth Engine. He has actively participated in mapping initiatives such as the OSM participatory mapping programs. Enock's academic journey reflects a pursuit of geoinformation studies, and he is currently in the penultimate year of his BAPP geoinformation course at TUK.

His core strengths encompass spatial analysis and meticulous map design. As a collaborative team player, Enock is known for his effective teamwork. In the project, Enock's principal role will be that of the lead cartographer, leveraging his skills to craft accurate and visually appealing maps. His adeptness in spatial data analysis is anticipated to enhance the project's cartographic outputs significantly.

Technical Aspect:

<u>Problem Statement</u>: The lack of an accurate and updated topographical map of electricity lines hinders effective maintenance and planning of the power grid.

<u>Objectives:</u>

Create a detailed topographical map of electricity lines.

Develop a user-friendly web-based platform for visualizing collected data.

Proposed Work Plan:

1.Data Acquisition: Deploy drones equipped with suitable payloads to gather high-resolution imagery.

2.Data Processing: Employ GIS techniques to transform raw data into comprehensive maps.

Web Platform Development: Develop an interactive platform for data visualization.

3.Quality Assurance: Ensure accuracy and reliability through rigorous data validation.

Proposed Methodology:

1.Study Design: Cross-sectional spatial study.

2.Study Area: Thika to Juja region, focusing on power grid supply and sub-station locations.

3.Target Power Grid Supply: Identifying key power supply lines.

4.Data Collection Tools: Drones equipped with high-resolution cameras and LiDAR technology for accurate terrain mapping.

5.Data Analysis, Interpretation, and Presentation: Utilize GIS software for spatial data analysis, enabling clear interpretation of electricity line distribution, elevation changes, and potential obstacles.

Spatial data analysis will involve overlaying electricity line data onto elevation models, identifying potential hazards and optimizing infrastructure placement.

Deliverables for High-Resolution Topographical Map and Web-Based Platform Project

Documentation of the process used to validate the accuracy and completeness of collected data.

Topographical maps, elevation models, and GIS data layers generated from the collected data.

Overview of the methodologies, software used, and transformations applied to process the data.

Fully functional web-based platform and mobile application for visualizing and interacting with the topographical map and electricity line data.

<u>Project Timeline:</u>

Phase	Tasks	Timeline
Phase1: Project preparation and planning	-Hold kick off meeting -Define scope, objectives and deliverables -Review schedule and milestones -Break down tasks -Assign responsibilities	Week 1-2
Phase 2: Data Acquisition	-Purchase/hire equipment -Configure drones -Capture data along electricity lines -Review data accuracy -Address data gaps	Week 3-6
Phase 3: Data Processing and Analysis	-Clean and organize data -Convert data formats -Process data using GIS -Generate maps and overlays	Week 7-10
Phase 4: Web Platform and mobile application development	-Gather platform requirements -Create wireframes and mockups -Build the platform -Implement data visualization -Develop the mobile application for iOS and Android platforms -Implement data visualization features in both the web platform and mobile app.	Week 11-16

	-Conduct usability testing on the web platform and mobile app interfaces. -Debug and resolve any issues discovered during testing - Provide user training and documentation for navigating the web platform and mobile app	
Phase 5: Project Closure and Reporting	-Compile project documents -Prepare project report -Present completed project to stakeholders	Week 17-18

Financial Aspect:

Budget Summary:

Budget Category	**Description**	**Amount**
Equipment Procurement	Procure drones, cameras, LiDAR technology, and other necessary hardware	Ksh 1,200,000
Personnel Expenses	Cover salaries, travel expenses, and training for team members	Ksh 1,000,000
Software Licenses	Acquire GIS software licenses for data processing and analysis	Ksh 80,000
Web Platform and mobile app Development	Fund the development and maintenance of the web-based data visualization platform	Ksh 90,000
Miscellaneous	Account for unforeseen expenses and contingencies	Ksh 80,000
Total		**Ksh 2,450,000**

4. Project

TITLE: MONITORING NITROGEN DIOXIDE (NO_2) CONCENTRATIONS IN NYERI COUNTY FROM 2019 TO 2022

4.1 Introduction

After high blood pressure and smoking, air pollution is the third-largest risk factor for death globally (Murray et al. 2020). Air pollution can therefore be described as a global "pandemic" that should arguably be monitored and addressed. Remote sensing and cloud computing technologies allow us to do so.

Pollutants that are of primary concern for public health include Nitrogen Dioxide (NO_2) particulate matter with diameter less than 2.5 µm ($PM_{2.5}$), carbon monoxide (CO), ozone (O_3), NO_2, and sulfur dioxide (SO_2). Globally, chronic exposure to air pollution results in greater loss of life than HIV/AIDS, malaria, and tuberculosis combined, and more than an order of magnitude more deaths than all forms of violence (Lelieveld et al. 2020). Exposure to NO_2 may result in 4 million new pediatric asthma cases annually (Achakulwisut et al. 2019).

The main anthropogenic sources of air pollution are industries, motor vehicles, power generation, agricultural activities, and household combustion, while non-anthropogenic sources include desert dust, biogenic emissions, forest fires, and even volcanoes. The reduction in transport and industrial activity during the COVID-19 lockdowns significantly reduced global air pollution levels, thereby highlighting the significance of anthropogenic emissions (Venter et al. 2020).

There are a range of satellite-based datasets on air pollution to choose from in the Earth Engine Data Catalog. The main datasets relevant to air pollution include the Moderate Resolution Imaging Spectroradiometer and Advanced Very-High-Resolution Radiometer for monitoring aerosol optical depth (a proxy for $PM_{2.5}$); the Total Ozone Mapping Spectrometer Ozone Monitoring Instrument for monitoring O_3; and more recently the TROPOspheric Monitoring Instrument (TROPOMI) on board the Sentinel-5 Precursor (Sentinel-5P), which monitors a range of air pollutants. To monitor Nitrogen dioxide for my study I used the Sentinel-5p imagery.

Nyeri County is a county located in the central region of Kenya. Its capital and largest town is Nyeri town. It has a population of 759,164 and an area of 2361 km^2. It is currently under the leadership of H.E. Governor Mutahi Kahiga. Nyeri County comprises of 6 sub-counties namely; Nyeri, Kieni, Tetu, Mathira, Othaya and Mukwereni. It is situated between longitudes 36° 38' East and 37°20' East and between the equator and latitude 0°38° South. It borders Laikipia County to the north, Kirinyaga County to the east, Murang'a County to the South, Nyandarua County to the West and Meru County to the North east.

4.2 Objectives

- Understanding sentinel-5P data
- Quantifying changes in Nitrogen Dioxide concentrations over time.
- Performing zonal statistics
- Visually representing the pollutant changes over time

4.3 Data Sources

Data	Format	Source	Resolution
Tropospheric Nitrogen Dioxide	Raster	Google Earth Engine	7km
Administrative Boundaries (Subcounty)	Vector	Humanitarian Data Exchange (HDX)	

Although Sentinel-5 was launched in October 2017, the data available for analysis in Earth Engine are from July 2018 onward. TROPOMI, the sensor on board the satellite, is a spectrometer sensing ultraviolet, visible, near-infrared, and shortwave infrared wavelengths to monitor NO_2, O_3, aerosol, methane (CH_4), formaldehyde, CO, and SO_2 in the atmosphere. The swath width of TROPOMI is approximately 2,600 km on the ground, resulting in a global daily coverage with a spatial resolution of 7 x 7 km. All of the Sentinel-5P datasets, except CH_4, have two versions: Near Real-Time (NRTI) and Offline (OFFL); CH_4 is available as OFFL only. The NRTI assets cover a smaller area than the OFFL assets but appear more quickly after acquisition. The OFFL assets have a delayed availability, but each asset contains data from an entire orbit and is arguably easier to work with for retrospective analyses. We will use the OFFL NO_2 product in this study.

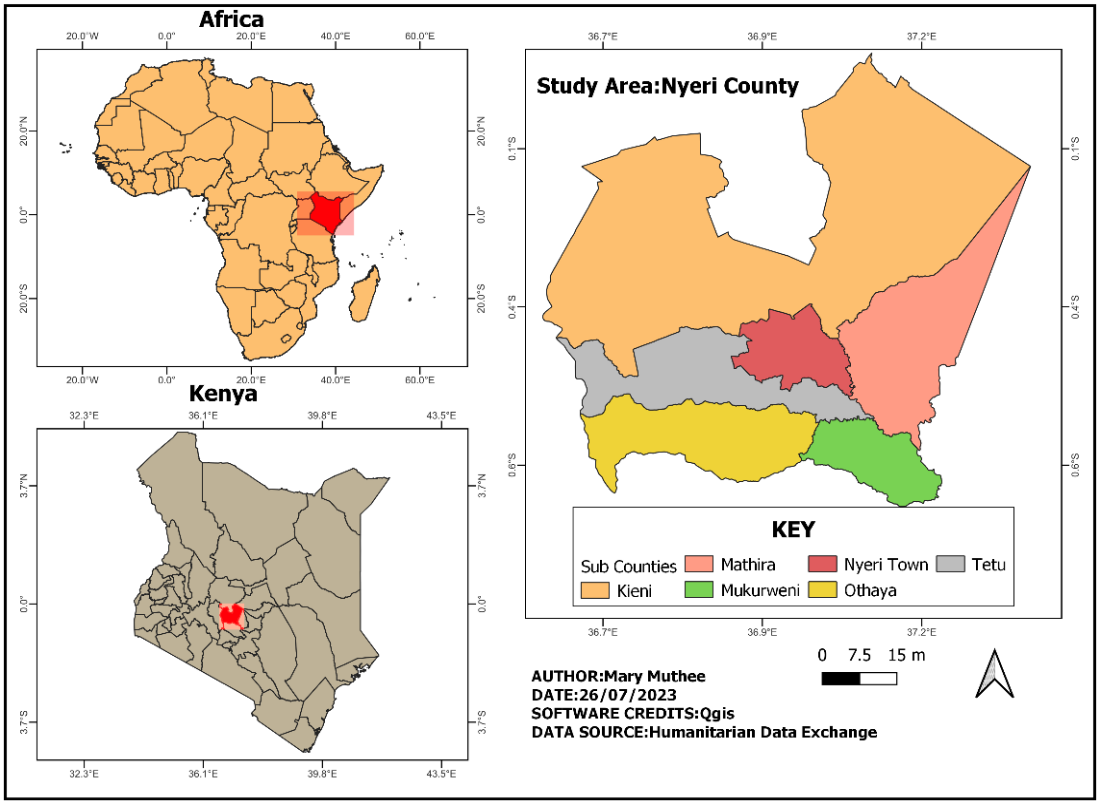
4.4 Methodology

4.4.1 Area of Study

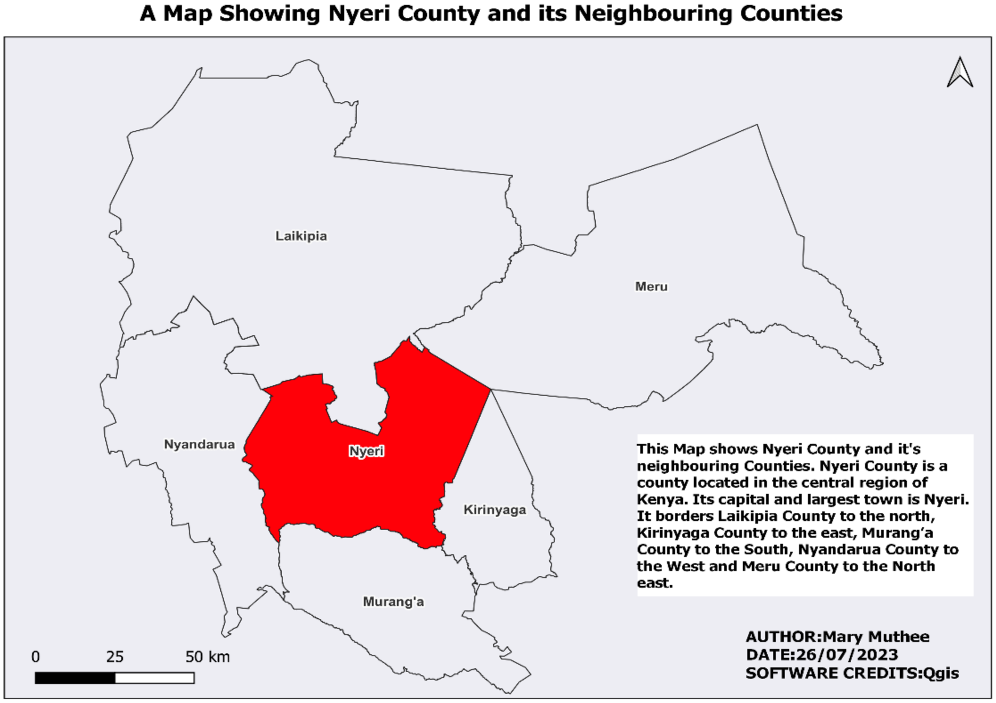
Nyeri County is a county located in the central region of Kenya. Its capital and largest town is Nyeri. It has a population of 759,164 and an area of 2361 km^2. It is currently under the leadership of H.E. Governor Mutahi Kahiga. Nyeri County comprises of 6 sub-counties namely; Nyeri, Kieni, Tetu, Mathira, Othaya and Mukwereni. It is situated between longitudes 36° 38’ East and 37°20’ East and between the equator and latitude 0°38° South. It borders Laikipia County to the north, Kirinyaga County to the east, Murang’a County to the South, Nyandarua County to the West and Meru County to the North east.

Below maps show the location context Map of the county and its neighbouring counties respectively.

Location Context Map



A Map Showing Nyeri County and its Neighbouring Counties



4.4.2 Steps

1. Downloading Data from GEE

I first imported the Nyeri County shapefile to the Google Earth engine. The Sentinel-5p offline product collection was imported and the following parameters were assigned: filtered the dates to our specific years of study, filtered and clipped the dataset to Nyeri Boundary, selected the tropospheric vertical column of NO2 band.

```
var Nyeri: Table projects/ee-mutheemary/assets/Nyeri
/// air polution and population exposure for Nyeri Couty
//import sentinel-5 No2 offline product
//2019
var no2019=ee.ImageCollection("COPERNICUS/S5P/OFFL/L3_NO2")
    .filterDate('2019-01-01','2019-12-31')
    .filterBounds(Nyeri)
    .map(maskClouds)
    // Select the tropospheric vertical column of NO2 band.
    .select('tropospheric_NO2_column_number_density')
    .median().clip(Nyeri);
```

This was repeated for all the years, 2019, 2020, 2021 and 2022

2. Exporting the data

The images were imported from the Google Earth engine to google drive for further analysis.

```
//2019 image export
Export.image.toDrive({
  image: no2019,
  description: 'NO2_2019',
  scale: 10,
  folder:"GEE",
  crs: 'EPSG:4326',
  fileFormat: 'GeoTIFF',
  formatOptions: {
    cloudOptimized: true
  },
  maxPixels: 1e13,
  region: Nyeri
});
```

3.Importing the data to R

The data was imported to R for further analysis and visualize. The images were stacked together.

```
#importing data
Nyeri<-st_read("Nyeri.shp")
No2_2019<-raster("NO2_2019.tif")
No2_2020<-raster("NO2_2020.tif")
No2_2021<-raster("NO2_2021.tif")
No2_2022<-raster("NO2_2022.tif")

#stacking them together
NO2_stack<-stack(No2_2019,No2_2020,No2_2021, No2_2022)

#rename the layers
names(NO2_stack)<-c("NO2_2019","NO2_2020",
                    "NO2_2021","NO2_2022")
```

4. Visualizing the NO2 total concentrations

Using the ggplot, I visualized the total Nitrogen Dioxide concentrations for the whole county from the year 2019 to 2022.

```
#visualize the tropospheric No2
gplot(NO2_stack )+
  geom_raster(aes(x=x, y=y,fill=value))+
  scale_fill_distiller(palette="YlOrRd",
                       direction = 1,
                       name='Tropospheric_NO2')+
  facet_wrap(~variable, ncol = 2, nrow = 2)+
  coord_quickmap()+
  ggtitle('Nyeri County Tropospheric No2 ')+
  xlab("Longitude")+
  ylab("Latitude")+
  theme_classic()+
  theme(text = element_text(size=7),
        axis.text.x = element_text(angle = 90, hjust = 1)) +
  theme(plot.title = element_text(hjust = 0.5))
```

5.Zonal statistics

Performed zonal statistics to determine the mean NO2 concentrations for each sub county in Nyeri County over the given years.

```
#perfoming zonal statistics
zonals<-as.data.frame(cbind(Nyeri,
                            exact_extract(NO2_stack,Nyeri,
                                          c("mean"))))
```

6. Creating maps and charts

Later on, maps were created to visually represent the change in the NO2 concentrations over the given years. A boxplot was also created to show how mean No2 has varied in the entire county during those years.

```
#plotting the mean ndvi
ggplot()+
  geom_sf(Nyeri_stats,
          mapping=aes(fill=Mean_No2))+
  scale_fill_distiller(palette = "Reds",
                       direction = 1, name="Mean No2")+
  facet_wrap(~Year, ncol = 2, nrow = 2)+
  coord_sf()+
  ggtitle("Nyeri County Mean Tropospheric No2")+
  theme_gray()+
  xlab("Longitude")+
  ylab("Latitude")+
  theme(text = element_text(size=7)) +
  theme(plot.title = element_text(hjust = 0.5))+
  geom_sf_text(Nyeri_stats,mapping=aes(label=Name), size=2,
               hjust=0.4,color="black")
```

```
#boxplot
ggplot(Mean_long, aes(x = factor(Year), y = Mean_No2)) +
  geom_boxplot(fill="red") +
  ggtitle("Mean Troposperic No2") +
  xlab("Year") +
  ylab("No2")+
  theme(plot.title = element_text(hjust = 0.5))+
  theme(text = element_text(size=8))
```

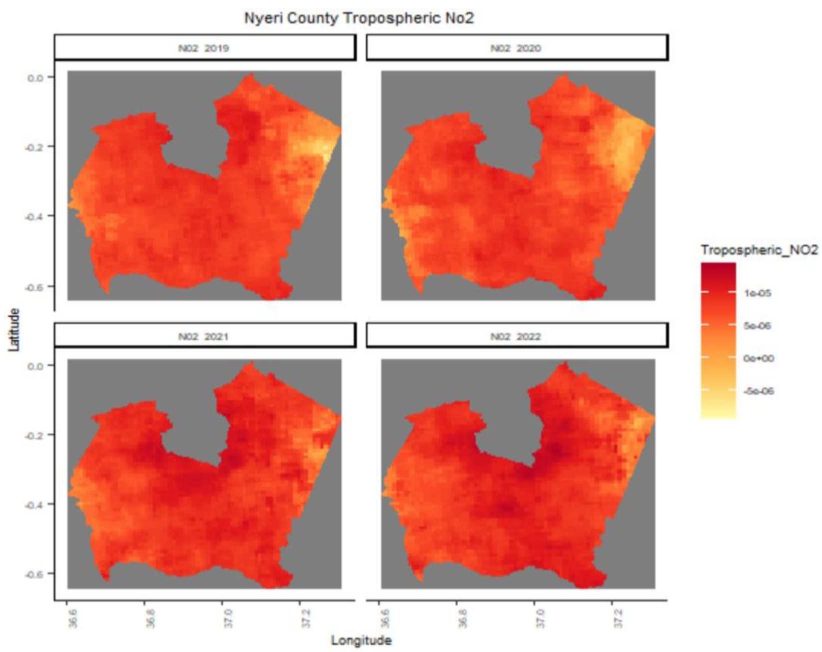
4.4.3 Results

From the above analysis, the following outputs were generated

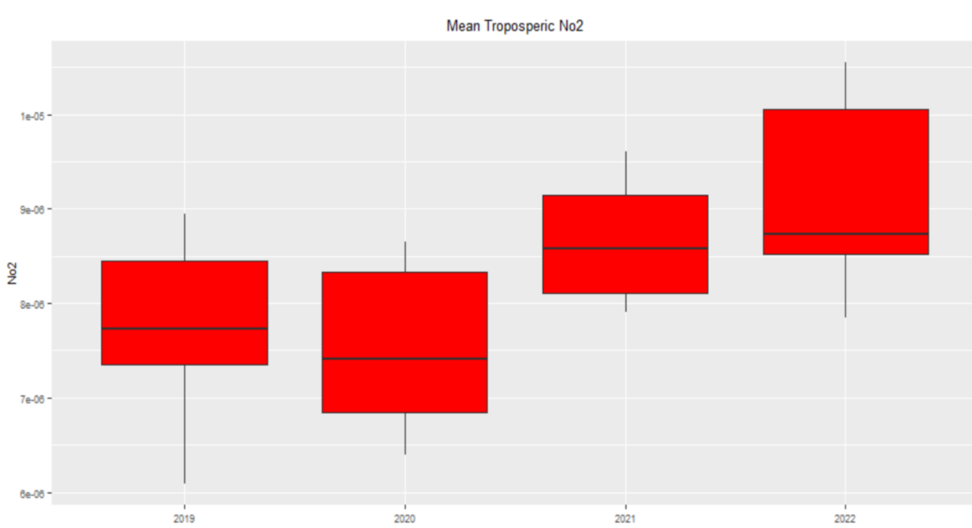
1. **Mean No2 for each subcounty**

	A	B	C	D	E	F	G
1		Name	mean.N02_2019	mean.N02_2020	mean.N02_2021	mean.N02_2022	
2	1	Kieni	7.3338E-06	6.75E-06	8.87E-06	8.82E-06	
3	2	Mathira	6.0886E-06	6.39E-06	8.05E-06	7.85E-06	
4	3	Mukurwei	8.57305E-06	8.66E-06	9.24E-06	1.05E-05	
5	4	Nyeri Tow	8.94864E-06	8.56E-06	9.61E-06	1.06E-05	
6	5	Othaya	8.06917E-06	7.67E-06	8.28E-06	8.64E-06	
7	6	Tetu	7.4002E-06	7.16E-06	7.91E-06	8.48E-06	

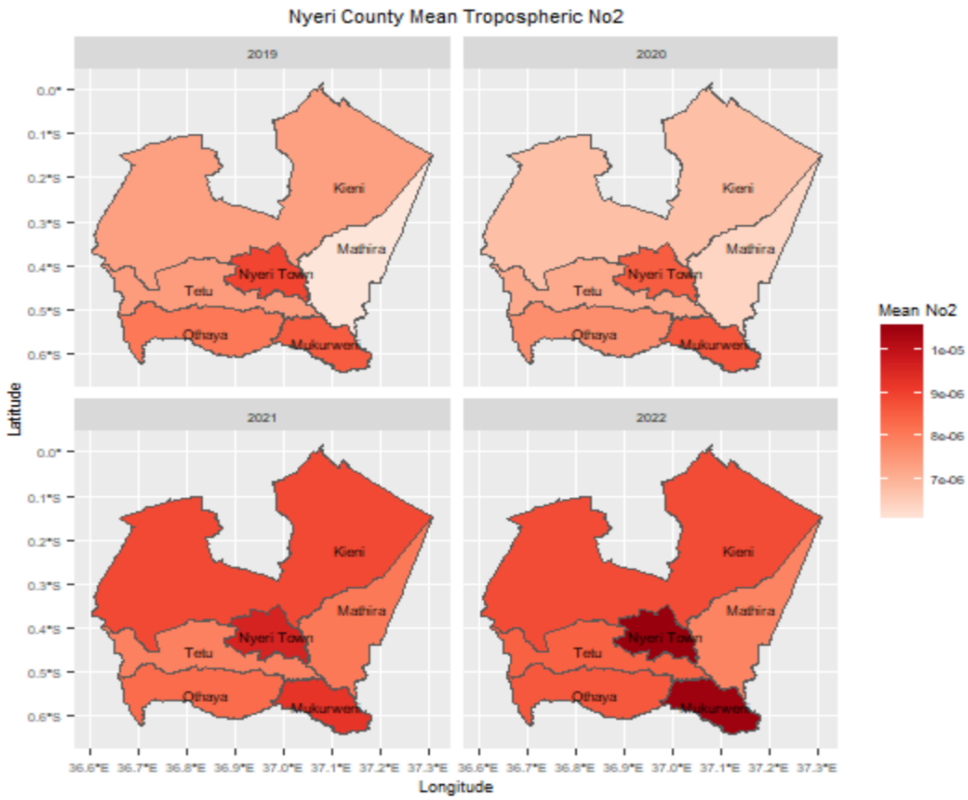
2. **Map for total No2 for the whole county**



3. **A boxplot for the mean No2 over the years**



4. A map showing mean No2 for each sub county



4.5 Conclusion

Through this study, I was able to monitor how Nitrogen Dioxide has been varying from the year 2019 to 2022. This is equivalent to the before lockdown, during lockdown and after lockdown period. From the study, there has been an increase in the No2 concentrations for the year 2021 and 2022 with Nyeri town and Mukurweini having the most concentrations while Mathira sub county has got the least concentrations for all the years.

However, a deeper analysis can be done on this project to determine what has been triggering the increment on the concentrations. Some of the drivers that can be looked at are: population-weighting of the concentrations, agricultural activities, traffic and transportation patterns and also the industrial activities that have been happening .