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Assignment 4

1. Study Location and Time Frame

I'm examining the recent escalation of the conflict between Israel and Palestine that has been taking place in the Gaza Strip on the eastern coast of the Mediterranean Sea. October, 2023 – when Hamas invaders killed at least a thousand Israeli civilians and took hundreds as hostage, – is considered as the impetus for the conflict's most recent escalation. I focus on examining the extent of the destruction and change in the urban landscape of Gaza after the Israeli military declared a war against Palestine and Hamas as response to the killings. The military response has been an extensive armed attack – including aerial bombardment and attacks on land – to the Gaza Strip, where tens of thousands of Palestinians have been killed and millions have been forced to flee their homes (UN, 2024).

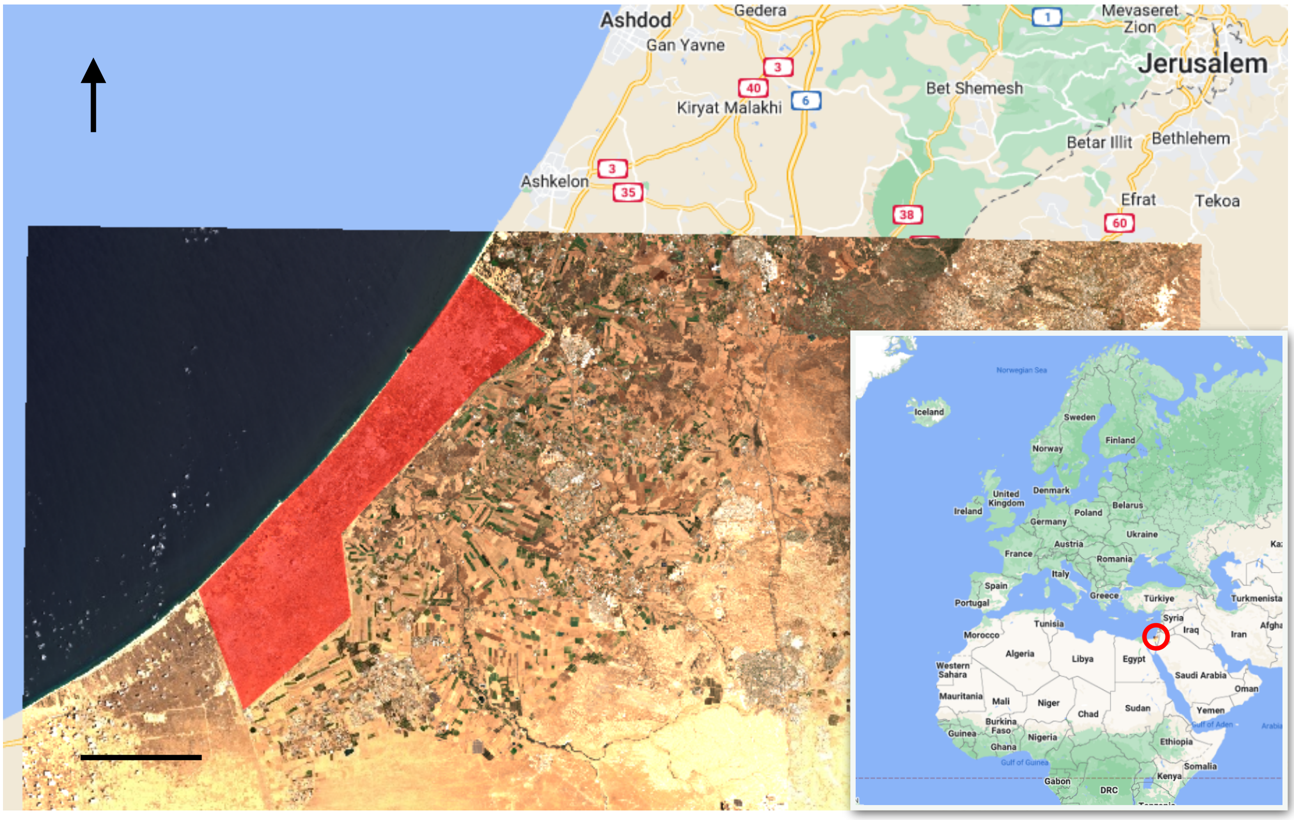

Figure 1. Location of the Gaza Strip (highlighted in red) in reference to Jerusalem, Israel. On the bottom right is the study area on an intercontinental scale. Scale bar on the bottom left is 10km, top left is the north arrow.

My time frame of examining the conflict is from April, 2023 to April, 2024. By including the few months before the war was announced, I'm able to get a reference period for the urban environment in Gaza before the destruction and by applying a one year time frame seasonal changes impacting the environment can be accounted for.

I am interested in acquiring and analysing data about the conflict objectively. As always in war, both sides tell their own story about the proceedings of the fighting. The stories include propaganda and skewing or hiding relevant information to create a narrative that justifies the actions of the story-teller. Therefore, to get a clear understanding of what's going on, it is important to not only rely on sources involved in the conflict, but to seek information that is non-affiliated. I want to examine what satellite data has to offer in forensic investigations that, first-and-foremost, require transparency and objectivity in the investigation process. In addition to being objective, satellite data offers a way to investigate conflicts safely from afar.

To filter the satellite data I used to the time period, I used the method *.filterDate("2023-04-01", "2024-05-1")* with the dates shown there.

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2. Used Data

I used Sentinel-2 L2A multi-spectral imaging that offers orthorectified surface reflectance data to examine the chosen environmental change. The Sentinel-2 constellation has a high temporal resolution with a global revisit time of 5 days, and a high spatial resolution at 10 meters with the bands that were used in my analysis (VNIR). High temporal and spatial resolutions allow for detailed investigations, creating more useful data.

In addition, the Sentinel-2 data's metadata includes information about cloud coverage, and so it is handy to filter out images with high cloud coverage that would be useless for analysing surface phenomena. I filtered the imagery data with a condition that only allows for images with less than 1% of cloud coverage in the image. For the specified time period, this resulted in 45 images to be analysed. However, the number of images is misleading due to some cropped "duplicates". An example of such a duplicate pair IDs from the collection:

COPERNICUS/S2_SR_HARMONIZED/20230624T081609_20230624T082252_T36RXV
COPERNICUS/S2_SR_HARMONIZED/20230624T081609_20230624T082252_T36SXA

The image products are duplicates except for the six last characters. In the GEE's Sentinel-2 documentation, these characters are told to refer to the "unique granule identifier indicating its [the image's] UTM grid reference". This has something to do with the Military Grid Reference System (MGRS) that is used by NATO militaries. I didn't go deeper into this as it seems to be a topic for another research paper, but what I did do was to remove all the images that had the "T36SXA" identifier from my analysis. All of them were only partially covering my region of interest and produced only partial and misleading information. After filtering these images, the analysis included 27 images in total.

By acquiring and analysing two to three images of the Gaza Strip per month from a 12-month period, I expected to get a long term view of the latest escalation of the war. Large changes in the region's infrastructure (destroyed neighbourhoods, buildings, roads, etc.) would be visible even just in true colour imagery. Smoke plumes can also be observed because highly flammable explosives are being used in the war.

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3. Spectral Indices

In addition to true colour imagery, I used the Normalised Difference Vegetation Index (NDVI) and an Index-based Built-up Index (IBI) to analyse how the landscape has changed. NDVI is a simple, widely used index to "quantify vegetation greenness and is useful in understanding vegetation density and assessing changes in plant health" (USGS, 2024). NDVI's function, represented in equation 1, uses the Sentinel-2 bands B8 (near-infrared) and B4 (red). NIR's wavelength on the electromagnetic spectrum is at 840nm and the visible red is at 670nm. Vegetation absorbs most of the red wavelengths for photosynthesis, but reflects the near-infrared prominently. Exploiting this unique difference in vegetation makes NDVI a popular index for analysing vegetation.

$$NDVI = \frac{NIR - R}{NIR + R}$$

Equation 1. NDVI equation

I chose NDVI as an index to measure because war often leaves the ground bare: vegetation – just like people – don't like it when you use explosives near or at them. In addition, since the Gaza Strip is mainly densely built urban area, I thought that an index measuring specifically the urban built-up area would be useful. For this purpose I found the IBI. Originally developed by Xu (2008), it uses three different indices, soil adjusted vegetation index (SAVI), modified normalised difference water index (MNDWI), and normalised difference built-up index (NDBI) to calculate the index.

The assumption behind the calculation is that an urban environment can be split roughly into three components; green vegetation, impervious surface material, and exposed soil (Ridd, 1995), which the three indices represent. The function to calculate the IBI with the three aforementioned indices rewritten without the need to calculate all the indices separately is represented in equation 2.

$$IBI = \frac{2MIR/(MIR+NIR) - [NIR/(NIR+RED + Green/(Green+MIR)]}{2MIR/(MIR+NIR) + [NIR/(NIR+RED + Green/(Green+MIR)]}$$

Equation 2. Index-based Built-up Index formula (Xu, 2008).

In my analysis, I created binary values out of IBI by following Xu's classification where a threshold value of 0.013 has been manually determined. This value seemed to yield accurate classification in my analysis, as well. IBI values over that threshold were assigned a value of one and considered as urban area whereas values under the threshold were assigned as zero, non-urban area.

4. Results

As the result of my analysis, two image pairs, a gif-animation, and two time series charts were produced in Google Earth Engine. The true colour gif-animation is submitted as its own file in MyCourses, other results are shown underneath.

First is an image pair showing the NDVI in the Gaza Strip outlined with a black line. Figure 2 on the left is from April 5th, 2023 and figure 3 on the right is from April 4th, 2024. With these figures almost exactly one year apart, I wanted to give a reference of the state of vegetation while negating seasonal change. NDVI values range from -1 to 1 where 1 is healthy vegetation, 0 is bare ground, and -1 is water. In my pictures, the left side of the image is the Mediterranean Sea, but for some reason it doesn't show a deeper black colour. I am not sure as to why.

Figure 2. NDVI April 5th, 2023.

Figure 3. NDVI April 4th, 2024.

From the images one can observe how the 2024 image (figure 3) is slightly more washed out; light greens and white are more prominent in the Gaza Strip when compared to the situation a year earlier.

The second image pair is the IBI layered on top of the Gaza Strip that is outlined with white. As in the NDVI, figure 4 on the left is from April 2023, figure 5 on the right is from April 2024. Where the NDVI image pair qualitatively shows only slight differences between the two measurement times, the IBI tells a completely different story. Where the non-urban blue clearly dominates the Gaza Strip in the figure from 2023, the figure from 2024 shows that the urban red has taken over.

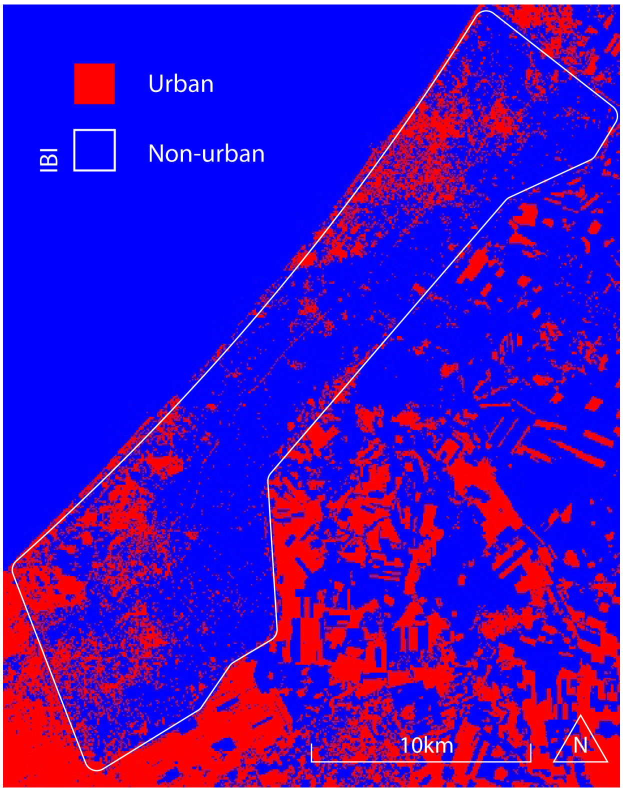

Figure 4. IBI April 5th, 2023.

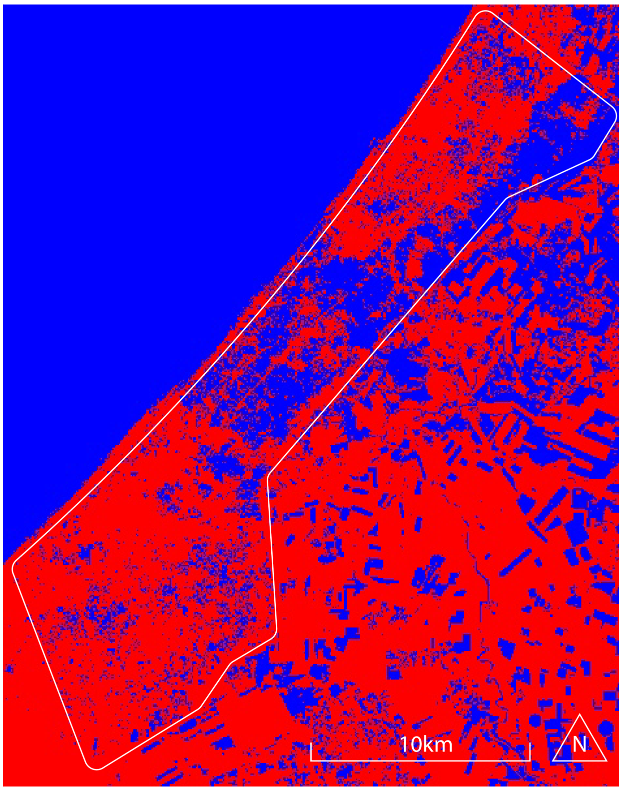

Figure 5. IBI April 4th, 2024.

In this case the building of new infrastructure and buildings is not the reason for the "urban expansion" we see in figure 5. A more probable explanation for the difference is due to the SAVI and MNDWI indices that make up the IBI. SAVI is a modification of NDVI, and so it correlates positively with the analysis we made with NDVI already: 2024 seems to have less vegetation than 2023 in the region of interest. MNDWI differentiates between water and urban area. Reports about Gaza have highlighted the fact that there is not enough water for the millions of Palestinians to drink (e.g. UNICEF, 2023). When people don't have enough to drink, it is safe to assume that no moisture or water can be observed in the environment by satellite imagery: every droplet of water goes into sustaining human life.

In addition to imagery, I charted the changes in mean NDVI and IBI for the one year period under examination. One NDVI average value per satellite image was calculated for the whole Gaza Strip in figure 6. In figure 7, IBI pixel counts for the same area were counted and charted next to each other. The pixel area for calculating both indices was determined to be 30m by 30m.

Based on the charts, NDVI and IBI correlate negatively with each other. For example, January to April in 2024 has high NDVI values, but low counts of urban area measured by IBI. This does make sense, and was also mentioned by Xu (2008) in their article. Interestingly, NDVI values and IBI counts are significantly different for the months of April one year apart. This is clearly shown by the IBI image pair, as well. It seems that there is a trend for "urbanisation" – healthy vegetation decreasing and more bare ground and urban materials (e.g. concrete) are exposed. This would have to be confirmed by a study with a longer time period, but does give an inkling of the effects of the war. One additional note about the charts: the heaviest rainfall in the study area is from December to March (ISTD, 2024), which most probably explains the peaks in NDVI values and non-urban counts during that time.

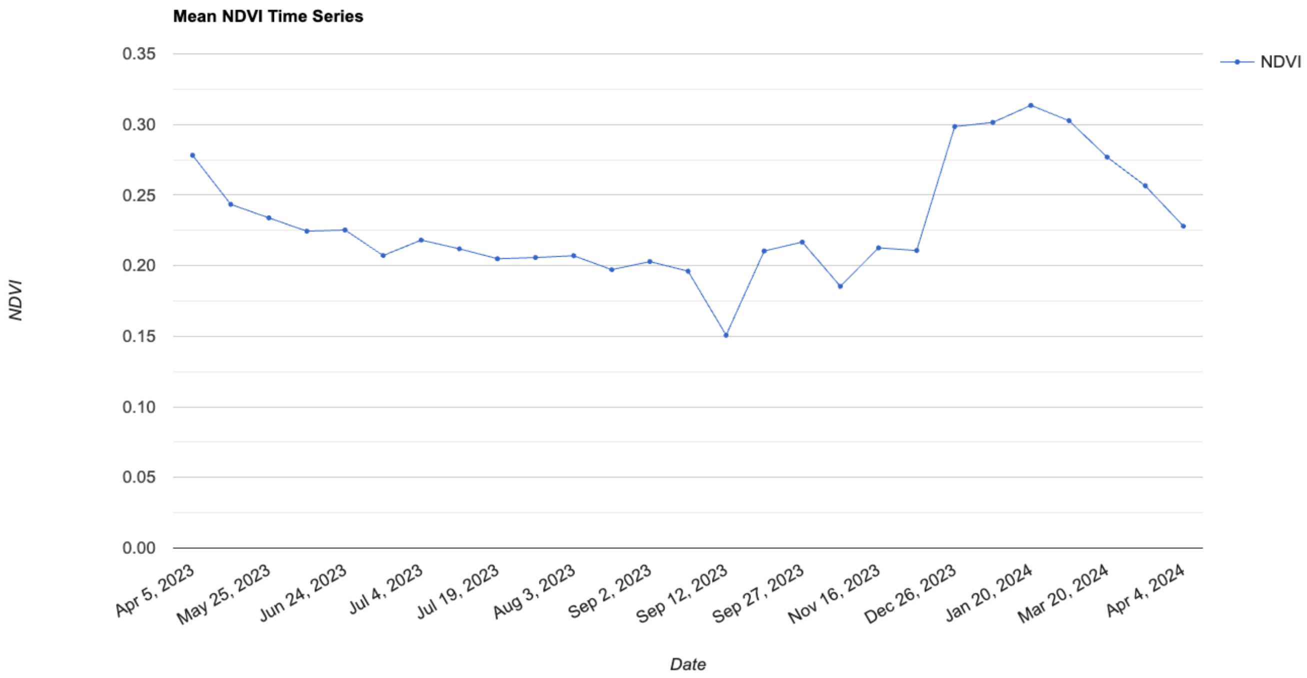

Figure 6. Time series of mean NDVI values in the Gaza Strip for the study time frame.

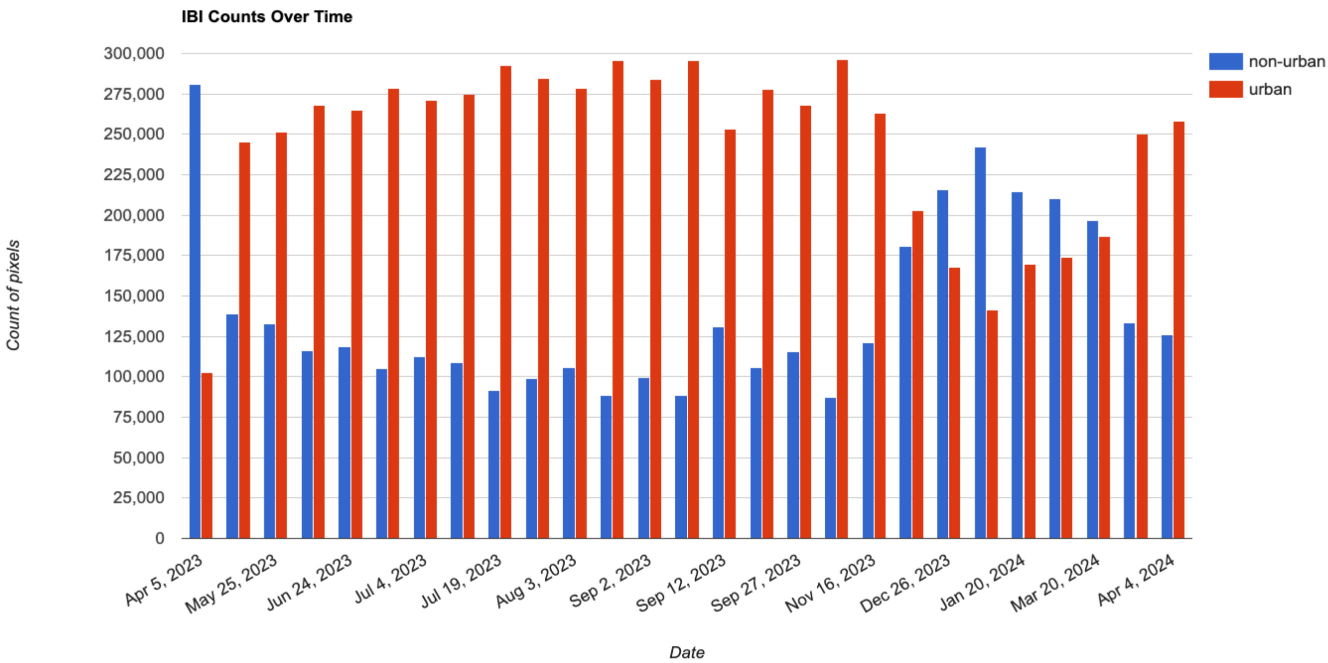

Figure 7. Time series of IBI pixel counts in the Gaza Strip for the study time frame.

The gif-animation shows the discussed phenomena in true colour. Days that a large smoke plume above the northern parts of the Gaza Strip can be observed are 2nd of September, 16th of November, and 26th of December in 2023. These smokes indicate that the Israeli bombing has been continuous and mostly focused on the northern part.

5. Observed Changes

Detailed changes in the urban environment are difficult to observe on this scale. A building still looks like a building, even if its facade has been blown off, when the pixel size is 10m by 10m or 30m by 30m. The clearest, abrupt signs of the war are the smoke plumes that can be seen in the gif-animation. The gradual change in NDVI and IBI also give an indication of something unusual happening – especially when comparing the months of April – but are not easily connected to a war going on.

6. Uncertainties in the Study

The biggest shortcoming of this study is the limited comparison of the results. At least another year e.g. 2022-2023 with the same time frame would be a good reference point for comparing the results onto and thus getting a better idea about the war's significance. In addition, a higher temporal and spatial resolution for the imagery would obviously increase the quality of the analysis.

Other spectral indices could have also been included to the study. For example surface temperature could have been an index to look into: urban areas have a higher temperature than vegetated areas.

7. GEE Code

```
// AUTOMATICALLY GENERATED: imported vars from saved link.
var CONVERT_TO_IMPORT = (
[{"type":"imageCollection","name":"sent2","record":{"id":"COPERNICUS/S2_SR_HARMONIZED"}},
{"type":"geometry","name":"gaza","record":{"geometries":[{"type":"Polygon","coordinates":
[[[34.222186299269225,31.324595819970114],[34.26750490278485,31.223066782339156],
[34.373248310987975,31.303477395514587],[34.36432191938641,31.372094955386814],
[34.50165102094891,31.497470991393268],[34.565509053175475,31.5402010695869],
[34.4899780473161,31.591100422432845],
[34.36981508344891,31.4529641268055]]],"evenOdd":true}],"displayProperties":[],"properties":
{},"color":"#ff1d1d","mode":"Geometry","shown":false,"locked":false}}])

// AUTOMATICALLY GENERATED: location from saved link.
Map.setCenter(264.8, 34.8, 4)

// Define the image collection we are working with
var collection = ee.ImageCollection(sent2.filterDate("2023-04-01", "2024-05-1").filterBounds(gaza)

// Filter the collection by only approving cloudless pics
.filter(ee.Filter.lt("CLOUDY_PIXEL_PERCENTAGE", 1)));

// Need to exclude some of the images that are cropped duplicates of the images I need.
// Something to do with the last six characters (unique granule identifier indicating its UTM grid reference)
var excludeIDs = [
  "20230510T081601_20230510T082247_T36SXA",
  "20230515T081609_20230515T082251_T36SXA",
  "20230530T081611_20230530T082252_T36SXA",
  "20230624T081609_20230624T082252_T36SXA",
  "20230704T081609_20230704T082253_T36SXA",
  "20230714T081609_20230714T082954_T36SXA",
  "20230719T081611_20230719T082252_T36SXA",
  "20230803T081609_20230803T082458_T36SXA",
  "20230823T081609_20230823T082524_T36SXA",
  "20230907T081611_20230907T082047_T36SXA",
  "20230912T081609_20230912T082758_T36SXA",
  "20231022T081959_20231022T082119_T36SXA",
  "20231101T082009_20231101T082250_T36SXA",
  "20231126T082251_20231126T082253_T36SXA",
```

```
  "20231226T082341_20231226T082343_T36SXA",
  "20240305T081821_20240305T082250_T36SXA",
  "20240330T081609_20240330T083029_T36SXA",
  "20240404T081601_20240404T082245_T36SXA"
];
var filteredCollection = collection.filter(ee.Filter.inList('system:index', excludeIDs).not());


// Bands 4,3 and 2 needed for RGB
var trueColour = {
    bands: ["B4", "B3", "B2"],
    min: 0,
    max: 3000
    };

print(collection.getInfo(), filteredCollection.getInfo());

// Add a true colour image for reference
Map.addLayer(collection.first(), trueColour, "True colour");

///////////////////////////////////////////////////////////////////////////////////////////////////
// NDVI -----------------------------------------------------------------------------------------
// Calculate NDVI
function calculateNDVI(image) {
  var NDVI = image.expression("(NIR - R) / (NIR + R)",
    {
      NIR: image.select("B8"),
      R: image.select("B4")  // Red
    }).rename("NDVI");
  return image.addBands(NDVI);
}

var NDVIParams = {
  min: -1,
  max: 1,
  palette: ["black", "white", "green"]
};

var NDVICollection = filteredCollection.map(calculateNDVI);

// Create a list so that I can select a specific image from the collection
var NDVIlist = NDVICollection.toList(NDVICollection.size());
var JuneNDVIImg = ee.Image(NDVIlist.get(0));  // First image of the collection, April 5th, 2023
var JanNDVIImg = ee.Image(NDVIlist.get(26));  // Last, April 4th, 2024

Map.addLayer(JuneNDVIImg.select("NDVI"), NDVIParams, "June, 2023 NDVI");
Map.addLayer(JanNDVIImg.select("NDVI"), NDVIParams, "January, 2024 NDVI");

// Chart the mean NDVI for the area
var ndviTimeSeries = ui.Chart.image.series({
  imageCollection: NDVICollection.select("NDVI"),
  region: gaza,
  reducer: ee.Reducer.mean(),
  scale: 30
})
.setOptions({
  title: "Mean NDVI Time Series",
  hAxis: {title: "Date", format: "M/d/yy", gridlines: {count: 15}, type: "category"},
  vAxis: {title: "NDVI"},
  lineWidth: 1,
  pointSize: 3
});

print(ndviTimeSeries);

///////////////////////////////////////////////////////////////////////////////////////////////////
```

```
// IBI ------------------------------------------------------------------------------------------------
// Calculate an Indices-built Built-up Index (IBI) for all the images in the collection
// according to Xu (2008)
function calculateIBI(image) {
  var IBI = image.expression(
    "(2 * SWIR1 / (SWIR1 + NIR) - (NIR / (NIR + R) + G / (G + SWIR1))) / (2 * SWIR1 / (SWIR1 + NIR) +
(NIR / (NIR + R) + G / (G + SWIR1)))",
    {
      SWIR1: image.select("B11"), // Shortwave infrared
      NIR: image.select("B8"),  // Near-infrared
      R: image.select("B4"),  // Red
      G: image.select("B3"),  // Green
    }).rename("IBI");
    return image.addBands(IBI);
}

var IBICollection = filteredCollection.map(calculateIBI);

// Count the values from the IBI for charting. Greater than 0.013 values of IBI are urban area, others are not.
// Threshold value 0.013 according to Xu (2008)
function classifyIBI(image) {
  var IBI = image.select("IBI");
  var classified = IBI.gt(0.013).rename("classified_IBI");
  return image.addBands(classified);
}

// Map the classification function over the image collection
var classifiedCollection = IBICollection.map(classifyIBI);

var IBIParams = {
  min: 0,
  max: 1,
  palette: ["blue", "red"]
};

var IBIlist = classifiedCollection.toList(classifiedCollection.size());
var JuneIBIImg = ee.Image(IBIlist.get(0));
var JanIBIImg = ee.Image(IBIlist.get(26));

Map.addLayer(JuneIBIImg.select("classified_IBI"), IBIParams, "June, 2023 IBI");
Map.addLayer(JanIBIImg.select("classified_IBI"), IBIParams, "January, 2024 IBI");

function countValues(image) {
  var count0 = image.select("IBI").sample({region: gaza, scale: 30}).filter(ee.Filter.lt("IBI", 0.013)).size();
  var count1 = image.select("IBI").sample({region: gaza, scale: 30}).filter(ee.Filter.gt("IBI", 0.013)).size();

  return ee.Feature(gaza, {
    "non-urban": count0,
    "urban": count1,
    "date": ee.Date(image.get("system:time_start"))
  });
}

// Apply the countValues function
var countCollection = IBICollection.map(countValues);

//////////////////////////////////////////////////////////////////////////////////////////////////////
// Charting & Images ------------------------------------------------------------------------------
// Chart out the pixels of urban and non-urban area according to the IBI
var chartIBI = ui.Chart.feature.byFeature(countCollection, "date", ["non-urban",
"urban"]).setChartType("ColumnChart")
  .setOptions({
    title: "IBI Counts Over Time",
    hAxis: {title: "Date", format: "M/d/yy", gridlines: {count: 15}, type: "category"},
    vAxis: {title: "Count of pixels"},
    bar: {groupWidth: "100px"}
```

```
    }
  );

print(chartIBI);

// Make gif file of the true colour images. Lot's of info there
// Code taken (with minor modifications) from the introductory lecture by Dr. Iuliia Burdun
var videoArgs = {
  dimensions: 600,
  region: gaza,
  framesPerSecond: 1
};

var text = require('users/gena/packages:text');
var annotations = [
  { position: 'left',
    offset: '1%',
    margin: '1%',
    property: 'label',
    scale: 140,
    font: 'monospace'
  }
];

function addText(image){
  var timeStamp = ee.Number(image.date().format('YYYY-MM-dd'));
  var timeStamp = ee.String('Date: ').cat(ee.String(timeStamp));
  var image = image.visualize({
    min: 0,
    max: 3000,
    bands: ["B4", "B3", "B2"],
    gamma: [1.1, 1.1, 1.1]
  }).set({'label':timeStamp});
  var annotated = text.annotateImage(image, {}, gaza, annotations);
  return annotated;
}

var dataset = filteredCollection.map(addText);

print(ui.Thumbnail({
      image: dataset,
      params: videoArgs,
      style: {fontWeight:500, border: '1px solid black'}
}));

// IBI and NDVI layers as images to the console, first June 14th, 2023 then Jan 10th, 2024
// Did it this way because exporting proved difficult
// NDVI
print(ui.Thumbnail({
      image: JuneNDVIImg,
      params: {
        min: -1,
        max: 1,
        palette: ["black", "white", "green"],
        region: gaza,
        bands: "NDVI",
        dimensions: 600
      }
}));

print(ui.Thumbnail({
      image: JanNDVIImg,
      params: {
        min: -1,
        max: 1,
        palette: ["black", "white", "green"],
```

```
    region: gaza,
    bands: "NDVI",
    dimensions: 600
  }
}));

// IBI
print(ui.Thumbnail({
  image: JuneIBIImg,
  params: {
    min: 0,
    max: 1,
    palette: ["blue", "red"],
    region: gaza,
    bands: "classified_IBI",
    dimensions: 600
  }
}));

print(ui.Thumbnail({
  image: JanIBIImg,
  params: {
    min: 0,
    max: 1,
    palette: ["blue", "red"],
    region: gaza,
    bands: "classified_IBI",
    dimensions: 600
  }
}));
```

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8. Time Estimate

It took me around 25h to finish this assignment.

References:

Israel Science and Technology Directory (ISTD) (2024). Climate and Seasons in Israel. Retrieved 21 May 2024, from https://www.science.co.il/weather/Israel-climate.php

Ridd, M.K., (1995), Exploring a V-I-S (vegetation-impervious surface-soil) model for urban ecosystem analysis through remote sensing: comparative anatomy for cities. International Journal of Remote Sensing, 16, pp. 2165–2185.

UN (2024). Israel-Gaza Crisis. Retrieved 16 May 2024, from https://www.un.org/en/situation-in-occupied-palestine-and-israel

UNICEF (2023). ‘Barely a drop to drink’: children in the Gaza Strip do not access 90 per cent of their normal water use. Retrieved 21 May 2024, from https://www.unicef.org/press-releases/barely-drop-drink-children-gaza-strip-do-not-access-90-cent-their-normal-water-use

USGS (2024). Landsat Normalized Difference Vegetation Index. Retrieved 20 May 2024, from https://usgs.gov/landsat-missions/landsat-normalized-difference-vegetation-index#:~:text=NDVI%20is%20used%20to%20quantify,)

Xu, H. (2008). *A new index for delineating built-up land features in satellite imagery*, International Journal of Remote Sensing, 29:14, 4269-4276, DOI: 10.1080/01431160802039957