Time-series analysis of the Normalised Difference Water Index (NDWI) from Sentinel-2 during the 2021 drought in Uttarakhand's Terai region

Introduction :

Over the years, Uttarakhand's Terai region have been noted to have experienced seasonal drought period. The latest of these drought occurences was in 2021. An analysis to examine the spatial distribution of the effect of the area of interest using sentinel-2 imageries is to be conducted using Google Earth Engine (GEE) Python API.

Firstly, I will Import Google Earth Engine Python and authenticate it

In [1]:
```
#import GEE python API
import ee
#Authenticate
ee.Authenticate()
```

To authorize access needed by Earth Engine, open the following URL in a web browser and follow the instructions

https://code.earthengine.google.com/client-auth?scopes=https%3A//www.googleapis.com/auth/earthengine%20https%3A//www.googleapis.com/auth/devstorag
vmY60BTX7amnevQexdhuS3c&tc=FqmM0LzF4iHP7S1YL-P_dA1TAeqwD1sr6qQNxraF_yw&cc=SmjhD4vlX6pyR3vE

The authorization workflow will generate a code, which you should paste in the box below

```
Enter verification code: 4/1AdQt8qjHUFnNYe05hKEiTF8yf_Ed_mdEjcI7s6PD6iSgkiVtyKopXXTBcO0

Successfully saved authorization token.
```

In [195…
```
#Initialize GEE
ee.Initialize()
```

In [192…
```
#importing important python libraries
import geemap as gm
import matplotlib.pyplot as plt
import time
import json
import os
import requests
from geemap import geojson_to_ee, ee_to_geojson
from ipyleaflet import GeoJSON
import folium
from datetime import datetime as dt
import pandas as pd
import altair as alt
import geojson

# allow images to display
from IPython.display import Image

#magic command
%matplotlib inline
```

Area of Interest (AOI) :

The area of interest is Uttarakhand. To delineate this, a shapefile of the area of interest have been uploaded to GEE assets thereby creating a Feature collection and consequently pulled into this notebook

In [4]:
```
#Defining area of interest(Terai)
#importing GEE Feature Collection
utta = ee.FeatureCollection("users/Adeolu/utta")
```

In [193…
```
geom = utta.geometry()
```

In [214…
```
#creating a GeeMap empty map canvas
aoi = gm.Map(center = [30.340907609005814, 79.02625123013941], zoom = 6)
#add imported shapefile
aoi.addLayer(utta)
#add map control tools
aoi.addLayerControl()

# display area of interest
aoi
```

```
Map(center=[30.340907609005814, 79.02625123013941], controls=(WidgetControl(options=['po
sition', 'transparent_…
```

Data Collection:

After establishing the area of interest, next is to start collecting the sentinel-2 images for the drought period from July, 2011 to the end of the end of the drought.

In [231…
```
#create empty map canvas
Map = gm.Map(center = [29.734597684044125, 79.97382199903063], zoom = 6)
#add layer control tools to map
Map.addLayerControl()
#display map
Map
```

```
Map(center=[29.734597684044125, 79.97382199903063], controls=(WidgetControl(options=['po
sition', 'transparent_…
```

In [ ]:
```
#declare relative file path
file_path = os.path.abspath('./data/uttarakhand.json')

#read file using python with open tool
if not os.path.exists(file_path):
    url = 'https://drive.google.com/uc?export=download&id=1cQOHH_N_cNdTWpAnYb1tNkyt8SDdn
    r = requests.get(url)
    with open(file_path, 'w') as f:
        f.write(r.content.decode("utf-8"))
#load json file
with open(file_path) as f:
    json_data = json.load(f)
```

In [9]:
```
#convert to GeoJSON format
json_layer = GeoJSON(
    data=json_data,
    name='Uttarakhand JSON',
    hover_style={'fillColor': 'red', 'fillOpacity': 0.5},
)
#add GeoJSON as a layer to map
Map.add_layer(json_layer)
```

In [10]:
```
#determine polygon geometry using GEE
coords = json_data['features'][0]['geometry']['coordinates']
```

```
poi = ee.Geometry.Polygon(coords)
```

Modified from https://geemap.org/notebooks/07_geojson/

Declaring important functions that will be used in the course of analysis of imageries.

In [197…

```
#Creates a region reduction function that return the mean of the pixels intersecting the

def create_reduce_region_function(geometry,
                                  reducer=ee.Reducer.mean(),
                                  scale=1000,
                                  crs='EPSG:4326',
                                  bestEffort=True,
                                  maxPixels=1e13,
                                  tileScale=4):
  """

  """

  def reduce_region_function(img):
    """Applies the ee.Image.reduceRegion() method.
    """

    stat = img.reduceRegion(
        reducer=reducer,
        geometry=geometry,
        scale=scale,
        crs=crs,
        bestEffort=bestEffort,
        maxPixels=maxPixels,
        tileScale=tileScale)

    return ee.Feature(geometry, stat).set({'millis': img.date().millis()})
  return reduce_region_function
```

Code Block from https://colab.research.google.com/github/google/earthengine-community/blob/master/tutorials/time-series-visualization-with-altair/index.ipynb#scrollTo=YfTfhCiX8Ew4

In [198…

```
#converts features props to dictionary
def fc_to_dict(fc):
    prop_names = fc.first().propertyNames()
    prop_lists = fc.reduceColumns(
      reducer=ee.Reducer.toList().repeat(prop_names.size()),
      selectors=prop_names).get('list')

    return ee.Dictionary.fromLists(prop_names, prop_lists)
```

Code Block from https://colab.research.google.com/github/google/earthengine-community/blob/master/tutorials/time-series-visualization-with-altair/index.ipynb#scrollTo=YfTfhCiX8Ew4

In [199…

```
#renaming pandas dataframe columns
def add_date_info(df):
    df['Timestamp'] = pd.to_datetime(df['millis'], unit='ms')
    df['Year'] = pd.DatetimeIndex(df['Timestamp']).year
    df['Month'] = pd.DatetimeIndex(df['Timestamp']).month
    df['Day'] = pd.DatetimeIndex(df['Timestamp']).day
    df['DOY'] = pd.DatetimeIndex(df['Timestamp']).dayofyear
    return df
```

Code Block from https://colab.research.google.com/github/google/earthengine-community/blob/master/tutorials/time-series-visualization-with-altair/index.ipynb#scrollTo=YfTfhCiX8Ew4

Creating an GEE ImageCollection of sentinel-2A images of the AOI under the time in consideration.

Sentinel-2A was chosen for this analysis because they have been instrumentally corrected for cloud interference

In [234…
```
#function that adds the system start time to images in an imagecollection
def add_image_bands(image):
    return image.addBands(image.metadata('system:time_start'))

def clipcol(image):
    clipimage = image.clip(utta)
    return clipimage

sentinel_coll = ee.ImageCollection('COPERNICUS/S2_SR')\
    .filterDate('2021-07-01','2022-02-28')\
    .filterBounds(utta)\
    .map(clipcol)\
    .filter(ee.Filter.lt('CLOUDY_PIXEL_PERCENTAGE', 20))

rgb = {'min': 1, 'max': 3000, 'bands': ['B2', 'B3', 'B4']};

Map.addLayer(sentinel_coll.median(), rgb, 'RGB Median');
Map
```

```
Map(bottom=7074.0, center=[29.734597684044125, 79.97382199903063], controls=(WidgetContr
ol(options=['position'…
```

The Normalized Difference Water Index (NDWI)

The NDWI results from the following equation: Index = (NIR - MIR) / (NIR + MIR) using Sentinel-2 Band 8 (NIR) and Band 12 (MIR). The NDWI is a vegetation index sensitive to the water content of vegetation and is complementary to the NDVI.

From https://foodsecurity-tep.net/S2_NDWI#:~:text=The%20NDWI%20results%20from%20the,is%20complementary%20to%20the%20ND

Generating Various NDWI Layers For The AOI

In [239…
```
#Defining image collection
images = (
    ee.ImageCollection("COPERNICUS/S2_SR")
    .filterBounds(utta)
    .filterDate('2021-07-01', '2022-02-28')
    .map(add_image_bands)
    .sort("CLOUD_COVERAGE_ASSESSMENT", False)
)

#function which calculate ndwi, rename and add a 'NDWI' layer
def add_ndwi (image):
    ndwi = image.normalizedDifference(['B3', 'B8']).rename('NDWI')
    return image.addBands(ndwi)

#Mapping ndwi function over the image collection
sentinel_ndwi = images.map(add_ndwi);
```

In [240…
```
#Select NDWI layer from ndwi image collection
ndwi_2021 = sentinel_ndwi.filterDate('2021-07-01', '2022-02-28').select('NDWI')
```

```
# Define specific visualization parameters for the NDWI and visualize it.
ndwi_Params = {min: -0.1, max: 0.5, 'palette': ['red', 'yellow', 'green', 'blue']};

#add selected ndwi to map layer
Map.addLayer(ndwi_2021.median().clip(utta), ndwi_Params, 'NDWI median');
```

In [243…

```
#select ndwi median for period of drought
drought_median = sentinel_ndwi.filterDate('2021-07-01', '2021-08-31')\
        .select('NDWI')\
        .median()

#add drought_median layer to Map
Map.addLayer(drought_median.clip(utta), ndwi_Params, 'Drought Median')

#select ndwi median for post drought
postdrought_median = sentinel_ndwi\
              .filterDate('2021-12-01', '2022-02-28')\
              .select('NDWI')\
              .median()

#add postdrought_median layer to Map
Map.addLayer(postdrought_median.clip(utta), ndwi_Params, 'Post-Drought Median')


#Calculate ndwi difference between drought_median and postdrought_median

ndwi_diff = drought_median.subtract(postdrought_median).clip(utta);

#ndwi difference visualisation parameter
dndviParams = {min: -1, max: 1, 'palette': ['orange', 'LimeGreen','white', 'brown']};

Map.addLayer(ndwi_diff, dndviParams, 'NDWI diff Image');
# print(ndwi_diff, 'NDWI difference Image)');

#Display different map layers
Map
```

```
Map(bottom=7074.0, center=[29.734597684044125, 79.97382199903063], controls=(WidgetContr
ol(options=['position'…
```

Each Map Layer can be viewed by toggling the geemap layer icon

Generating Statistics from NDWI values

In [244…

```
#filter an image collection of the AOI under the period in review
ndwi_coll = sentinel_ndwi.filterDate('2021-07-01', '2022-02-28').select('NDWI')

#reducer function that returns mean of pixels
reduce_ndwi = create_reduce_region_function(
    geometry=geom, reducer=ee.Reducer.mean(), scale=1000, crs='EPSG:4326')

#mapping reducer function to reduce each image
ndwi_stats_fc = ee.FeatureCollection(ndwi_coll.map(reduce_ndwi)).filter(
    ee.Filter.notNull(ndwi_coll.first().bandNames()))
```

modified from https://colab.research.google.com/github/google/earthengine-community/blob/master/tutorials/time-series-visualization-with-altair/index.ipynb#scrollTo=qwtO27KMIemk

In [21]:

```
#Export to GEE asset
task = ee.batch.Export.table.toAsset(
    collection=ndwi_stats_fc,
    description='ndwi_stats_fc export',
```

```
    assetId='users/Adeolu/ndwi_stats_fc')
task.start()
```

In [48]:
```
#View Export Task Status
task.status()
```

Out[48]:
```
{'state': 'COMPLETED',
 'description': 'ndwi_stats_fc export',
 'creation_timestamp_ms': 1658124161414,
 'update_timestamp_ms': 1658124753455,
 'start_timestamp_ms': 1658124172123,
 'task_type': 'EXPORT_FEATURES',
 'destination_uris': ['https://code.earthengine.google.com/?asset=projects/earthengine-legacy/assets/users/Adeolu/ndwi_stats_fc'],
 'attempt': 1,
 'batch_eecu_usage_seconds': 2.2515385150909424,
 'id': '5PQJRYCHBCVC5RJWLBRRLODY',
 'name': 'projects/earthengine-legacy/operations/5PQJRYCHBCVC5RJWLBRRLODY'}
```

In [246…
```
#Import GEE asset into the notebook
dwi_stat_fc = ee.FeatureCollection('users/Adeolu/ndwi_stats_fc')
```

In [247…
```
ndwi_dict = fc_to_dict(ndwi_stat_fc).getInfo()

#comverting to pandas dataframe
ndwi_df = pd.DataFrame(ndwi_dict)
display(ndwi_df)
print(ndwi_df.dtypes)
```

	NDWI	millis	system:index
0	-0.033191	1626586852302	00000000000000000000
1	-0.015065	1626586834588	00000000000000000001
2	-0.004847	1626586826828	00000000000000000002
3	-0.021712	1627450849073	00000000000000000003
4	-0.004835	1627450826880	00000000000000000004
...	...	...	...
1066	-0.315251	1645162839365	0000000000000000042a
1067	-0.395088	1644903055006	0000000000000000042b
1068	-0.338911	1645335062901	0000000000000000042c
1069	-0.252554	1643434817597	0000000000000000042d
1070	-0.259083	1645162817299	0000000000000000042e

1071 rows × 3 columns

```
NDWI            float64
millis            int64
system:index     object
dtype: object
```

In [245…
```
#call add_date_info function to prepare df for plotting
ndwi_df = add_date_info(ndwi_df)
ndwi_df
```

Out[245]:

	NDWI	millis	system:index	Timestamp	Year	Month	Day	DOY
0	-0.033191	1626586852302	00000000000000000000	2021-07-18 05:40:52.302	2021	7	18	199

1	-0.015065	1626586834588	00000000000000000001	2021-07-18 05:40:34.588	2021	7	18	199
2	-0.004847	1626586826828	00000000000000000002	2021-07-18 05:40:26.828	2021	7	18	199
3	-0.021712	1627450849073	00000000000000000003	2021-07-28 05:40:49.073	2021	7	28	209
4	-0.004835	1627450826880	00000000000000000004	2021-07-28 05:40:26.880	2021	7	28	209
...	...	...	...	...	...	...	...	...
1066	-0.315251	1645162839365	0000000000000000042a	2022-02-18 05:40:39.365	2022	2	18	49
1067	-0.395088	1644903055006	0000000000000000042b	2022-02-15 05:30:55.006	2022	2	15	46
1068	-0.338911	1645335062901	0000000000000000042c	2022-02-20 05:31:02.901	2022	2	20	51
1069	-0.252554	1643434817597	0000000000000000042d	2022-01-29 05:40:17.597	2022	1	29	29
1070	-0.259083	1645162817299	0000000000000000042e	2022-02-18 05:40:17.299	2022	2	18	49

1071 rows × 8 columns

In [21]:
```
#descriptive statistics of df
ndwi_df.describe()
```

Out[21]:

	NDWI	millis	Year	Month	Day	DOY
count	1071.000000	1.071000e+03	1071.000000	1071.000000	1071.000000	1071.000000
mean	-0.221037	1.635408e+12	2021.232493	7.612512	15.602241	216.246499
std	0.218706	5.989524e+09	0.422619	3.710832	8.754094	113.008307
min	-0.701398	1.625203e+12	2021.000000	1.000000	1.000000	1.000000
25%	-0.396792	1.630215e+12	2021.000000	7.000000	8.000000	186.000000
50%	-0.162084	1.635227e+12	2021.000000	9.000000	16.000000	246.000000
75%	-0.024341	1.640583e+12	2021.000000	10.000000	23.000000	304.000000
max	0.101489	1.645939e+12	2022.000000	12.000000	31.000000	364.000000

In [22]:
```
#group ndwi values by monthly mean
monthly_df = ndwi_df.groupby('Month').mean()
monthly_df
```

Out[22]:

Month	NDWI	millis	Year	Day	DOY
1	-0.160477	1.642333e+12	2022.0	16.255474	16.255474
2	-0.150638	1.644837e+12	2022.0	14.232143	45.232143
7	-0.120769	1.626453e+12	2021.0	16.452555	197.452555
8	-0.116453	1.629054e+12	2021.0	15.554745	227.554745
9	-0.189430	1.631678e+12	2021.0	14.934307	257.934307
10	-0.350152	1.634333e+12	2021.0	15.655405	288.655405
11	-0.366782	1.637023e+12	2021.0	15.795455	319.795455
12	-0.299119	1.639606e+12	2021.0	15.694656	349.694656

In [23]:
```
#sort monthly mean in ascending order
```

```
monthly_df_sorted = monthly_df.sort_values(by=['Year'], ascending=True)
monthly_df_sorted
```

Out[23]:

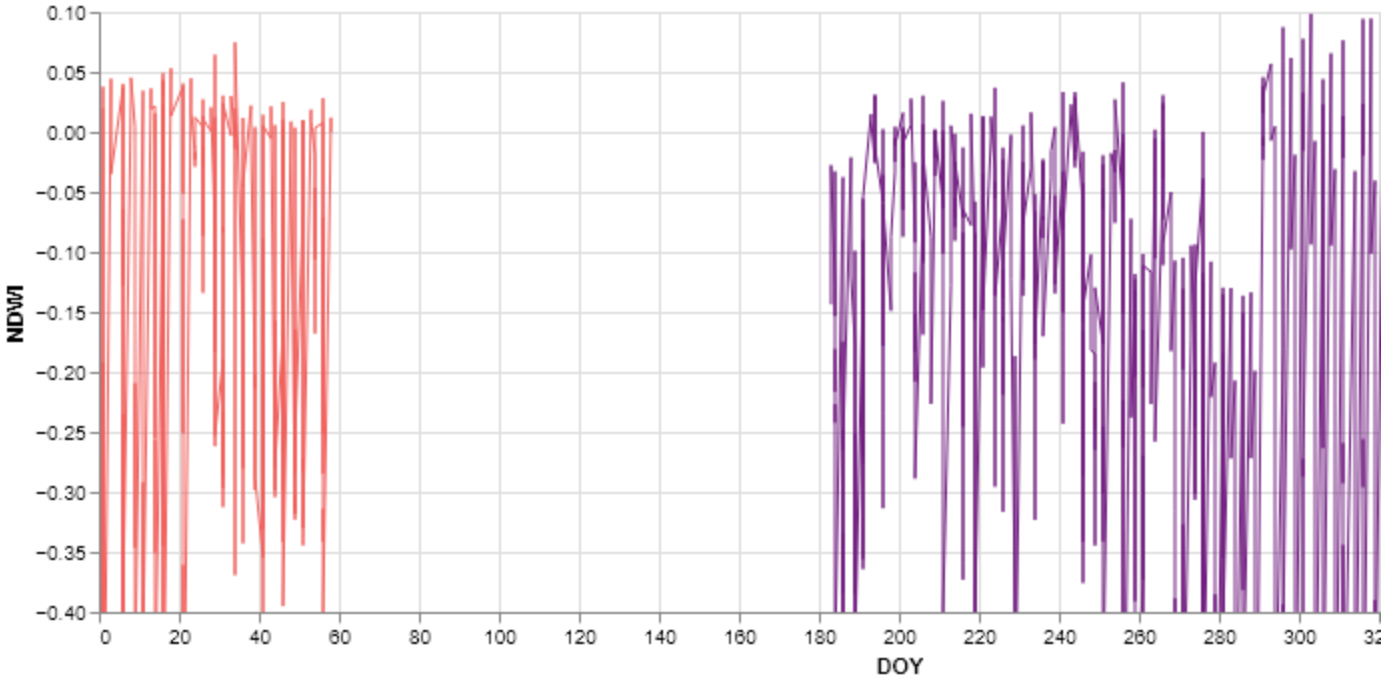
Month	NDWI	millis	Year	Day	DOY
7	-0.120769	1.626453e+12	2021.0	16.452555	197.452555
8	-0.116453	1.629054e+12	2021.0	15.554745	227.554745
9	-0.189430	1.631678e+12	2021.0	14.934307	257.934307
10	-0.350152	1.634333e+12	2021.0	15.655405	288.655405
11	-0.366782	1.637023e+12	2021.0	15.795455	319.795455
12	-0.299119	1.639606e+12	2021.0	15.694656	349.694656
1	-0.160477	1.642333e+12	2022.0	16.255474	16.255474
2	-0.150638	1.644837e+12	2022.0	14.232143	45.232143

Plotting a Day of Year (DOY) chart of NDWI's

In [24]:

```
highlight = alt.selection(
    type='single', on='mouseover', fields=['Year'], nearest=True)

base = alt.Chart(ndwi_df).encode(
    x=alt.X('DOY:Q', scale=alt.Scale(domain=[0, 353], clamp=True)),
    y=alt.Y('NDWI:Q', scale=alt.Scale(domain=[-0.40, 0.1])),
    color=alt.Color('Year:O', scale=alt.Scale(scheme='magma')))

points = base.mark_circle().encode(
    opacity=alt.value(0),
    tooltip=[
        alt.Tooltip('Year:O', title='Year'),
        alt.Tooltip('DOY:Q', title='DOY'),
        alt.Tooltip('NDWI:Q', title='NDWI')
    ]).add_selection(highlight)

lines = base.mark_line().encode(
    size=alt.condition(~highlight, alt.value(1), alt.value(3)))

(points + lines).properties(width=800, height=300).interactive()
```

Out[24]:

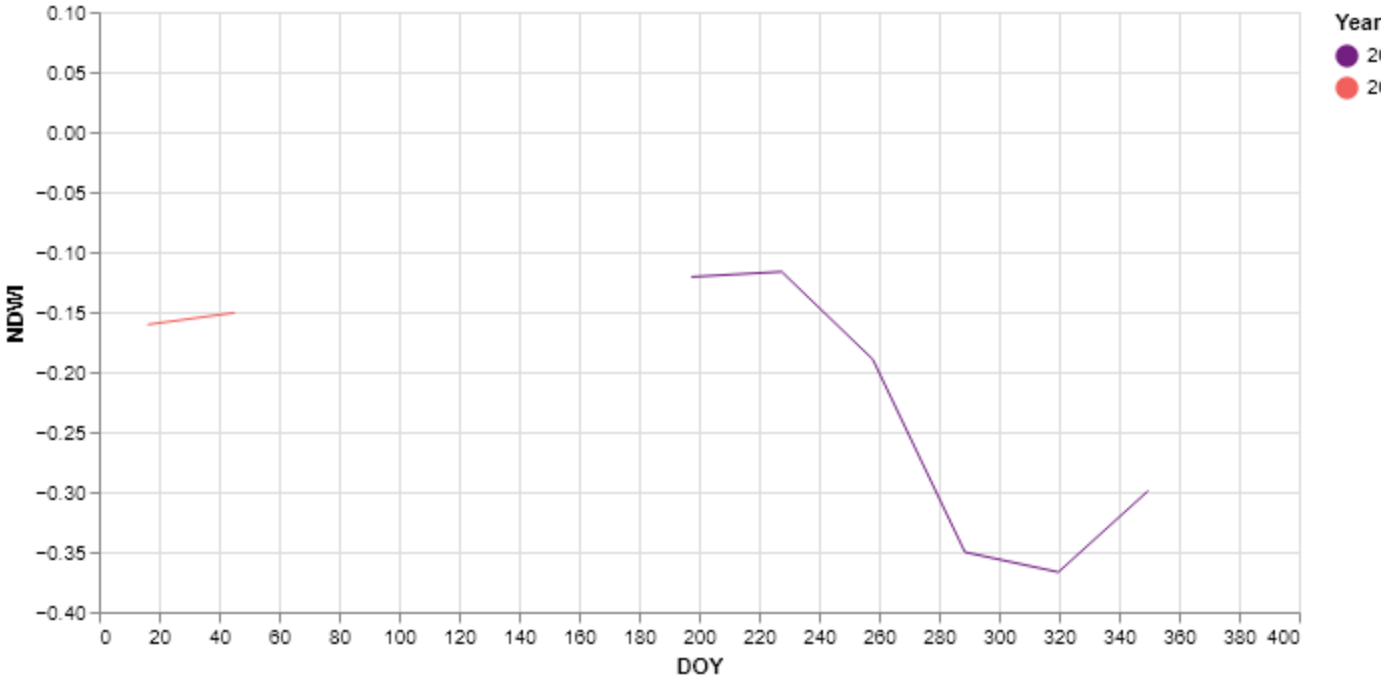


Plotting a Day of Year (DOY) chart of monthly NDWI's mean

In [25]:

```
highlight = alt.selection(
    type='single', on='mouseover', fields=['Year'], nearest=True)

base = alt.Chart(monthly_df_sorted).encode(
    x=alt.X('DOY:Q', scale=alt.Scale(domain=[0, 353], clamp=True)),
    y=alt.Y('NDWI:Q', scale=alt.Scale(domain=[-0.40, 0.1])),
    color=alt.Color('Year:O', scale=alt.Scale(scheme='magma')))

points = base.mark_circle().encode(
    opacity=alt.value(0),
    tooltip=[
        alt.Tooltip('Year:O', title='Year'),
        alt.Tooltip('DOY:Q', title='DOY'),
        alt.Tooltip('NDWI:Q', title='NDWI')
    ]).add_selection(highlight)

lines = base.mark_line().encode(
    size=alt.condition(~highlight, alt.value(1), alt.value(3)))

(points + lines).properties(width=600, height=300).interactive()
```

Out[25]:



More Statistics

In [251…

```
#define a new image collection
startDate = '2021-07-01'
endDate = '2022-02-28'

gif_ndwi = sentinel_ndwi.select('NDWI').filterDate('2021-07-01', '2022-02-28')

def custom_fun(n):
    date = ee.Date(startDate).advance(n,'month')
    m = date.get("month")
    y = date.get("year")
    dic = ee.Dictionary({
        'Date':date.format('yyyy-MM')
    })

    tempNDVI = (gif_ndwi.filter(ee.Filter.calendarRange(y, y, 'year'))
                .filter(ee.Filter.calendarRange(m, m, 'month'))
                .mean()
                .reduceRegion(
                    reducer = ee.Reducer.mean(),
                    geometry = poi,
                    scale = 250))
    return dic.combine(tempNDVI)

modis_YrMo = ee.List.sequence(0, 8-1).map(custom_fun)

dataframe = pd.DataFrame(modis_YrMo.getInfo())
```

In [252…

```
dataframe
```

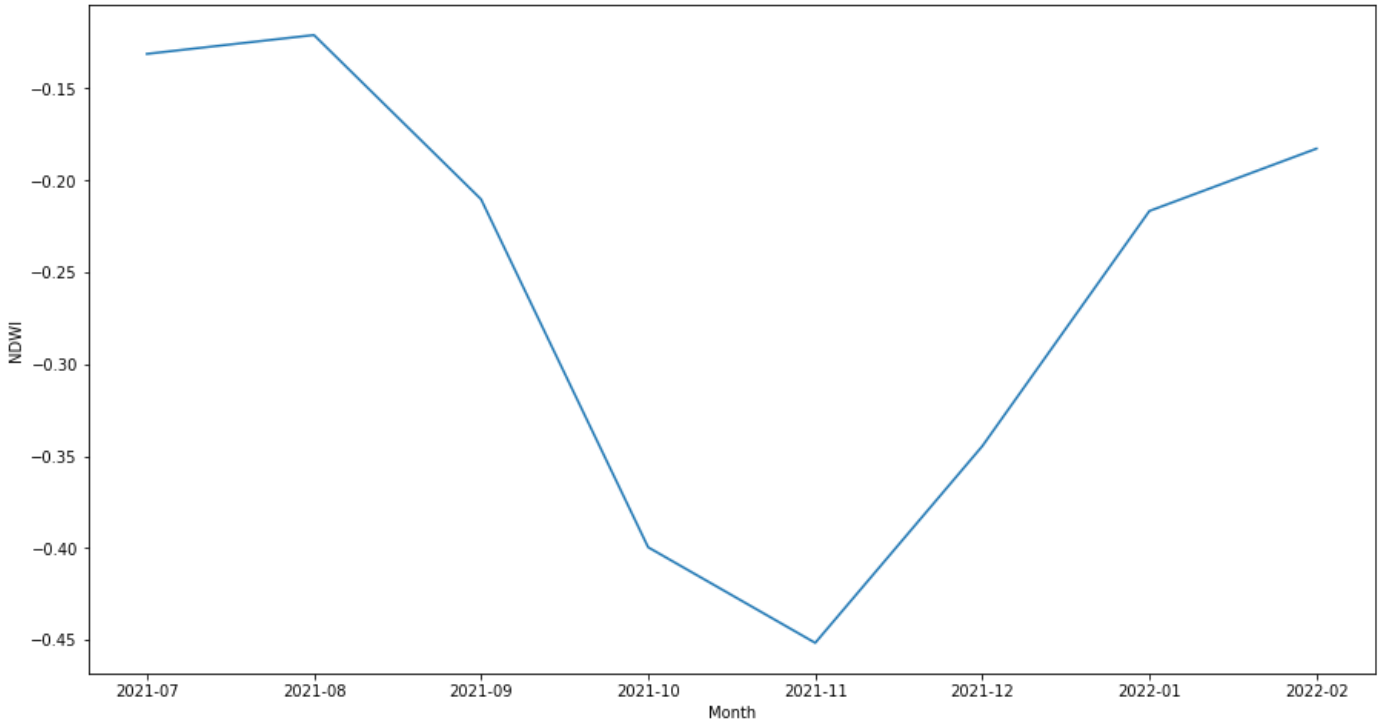
Out[252]:

	Date	NDWI
0	2021-07	-0.131200
1	2021-08	-0.120952
2	2021-09	-0.210259
3	2021-10	-0.399521
4	2021-11	-0.451519

5	2021-12	-0.344506
6	2022-01	-0.216643
7	2022-02	-0.182732

In [261…

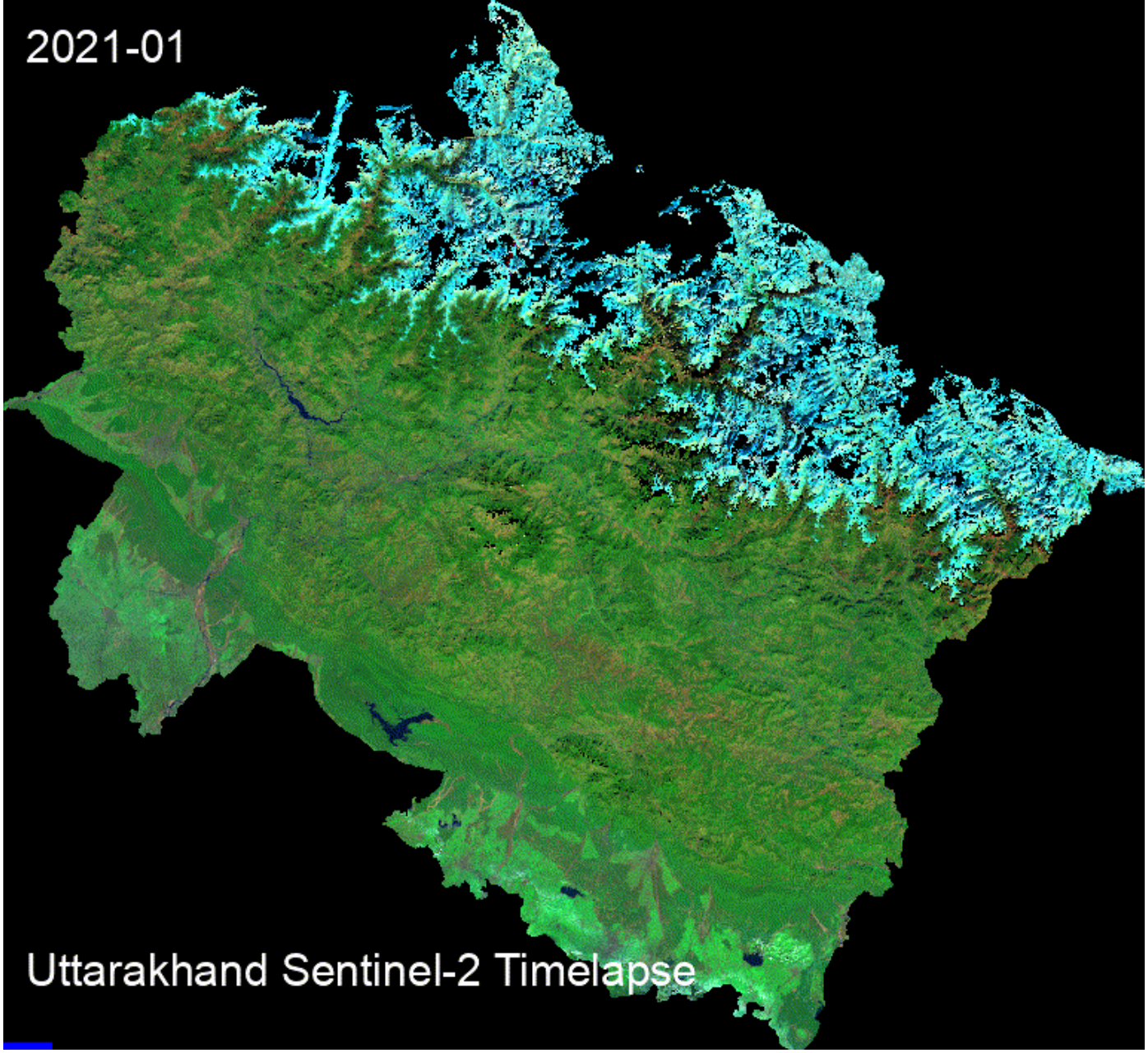
```
fig = plt.figure(figsize=(15, 8))

x = dataframe['Date'] # X-axis points
y = dataframe['NDWI']  # Y-axis points
plt.xlabel('Month')
plt.ylabel('NDWI')

plt.plot(x, y)  # Plot the chart
plt.show()
```



Imageries Movie

In [272…

```
from IPython.display import Image
with open('./data/uttarakhand.gif','rb') as file:
    display(Image(file.read()))
```



Conclusion

The analysis of the sentinel imageries from the Uttarakhand area of the Terai region and the calculation of the temporal variation of the associated NDWI values have given a clear picture on the nature of the effect of drought in the AOI over the period of study. The NDWI imageries obtained showed that some of the area where the drought impact was most severe includes: **Haldawani, Nainital(Jim Corbett), Dehradun, Kausani** areas of the AOI.