Installing all the Libraries and Packages needed

[ ]:
```
!pip install geopandas
!pip install rioxarray
!pip install folium
!pip install opencv-contrib-python
```

Importing all the Libraries installed above

[14]:
```
import numpy as np
import geopandas as gpd
import rioxarray
import matplotlib.pyplot as plt
from shapely.geometry import Point, Polygon
import folium
from sklearn.metrics import cohen_kappa_score
from google.colab import drive
import cv2
```

Mounting my Google Drive where Data was uploaded to

[3]:
```
drive.mount('/content/drive/')
```

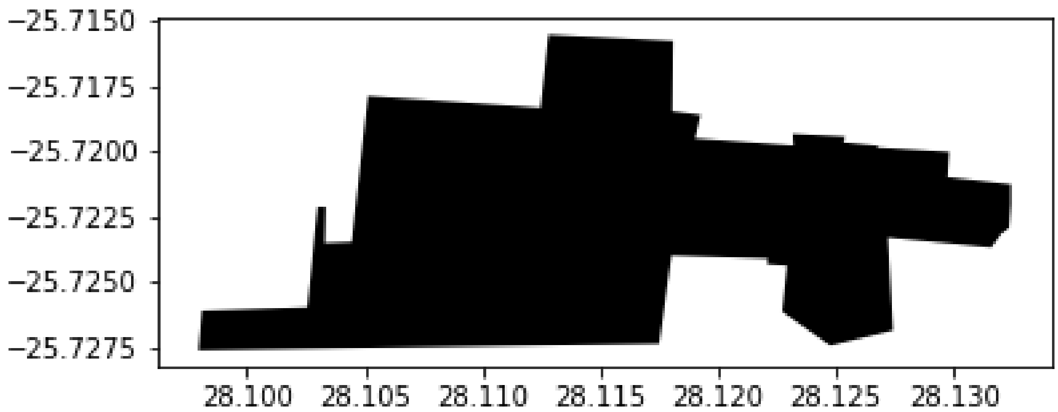
```
Mounted at /content/drive/
```

Read the *Melusi* area file to get the Boundaries

[4]:
```
melusi_area = gpd.read_file('/content/drive/MyDrive/HonsProj-Data/
 ↪GTI_Data_Delivery20210902/SHP/Melusi_Area.shp')
```

[5]:
```
melusi_area.plot(color="black")
```

[5]:
```
<matplotlib.axes._subplots.AxesSubplot at 0x7f33e9c1fb10>
```



[6]:
```
melusi_area.total_bounds
```

[6]: array([28.09795264, -25.72762111, 28.13242493, -25.71553163])

[12]:
```
xmin, ymin, xmax, ymax = melusi_area.total_bounds
```

Create first interactive map of the *Melusi* Area

[8]:
```
map1 = folium.Map(location=[-25.72,28.11], tiles='OpenStreetMap', zoom_start=15)
```

Add the *Melusi* Area to the first map

[9]:
```
for _, r in melusi_area.iterrows():
    sim_geo = gpd.GeoSeries(r['geometry']).simplify(tolerance=0.001)
    geo_j = sim_geo.to_json()
    geo_j = folium.GeoJson(data=geo_j,
                           style_function=lambda x: {'fillColor': 'blue'})
    geo_j.add_to(map1)
```

Display the first map by asking for the object representation

[ ]:
```
map1
```

Save the first interactive map

[11]:
```
map1.save('melusi_area.html')
```

Create second interactive map of the *Melusi* Area

[19]:
```
map2 = folium.Map(location=[-25.72,28.11], tiles='Carto DB Positron',␣
 ↪zoom_start=15)
```

Add the *Melusi* Area to the second map

```
[20]: for _, r in melusi_area.iterrows():
          sim_geo = gpd.GeoSeries(r['geometry']).simplify(tolerance=0.001)
          geo_j = sim_geo.to_json()
          geo_j = folium.GeoJson(data=geo_j,
                                 style_function=lambda x: {'fillColor': 'blue'})
          geo_j.add_to(map2)
```

Display the second map by asking for the object representation

```
[ ]: map2
```

Save the second interactive map

```
[22]: map2.save('melusi_area2.html')
```

Read the other data files

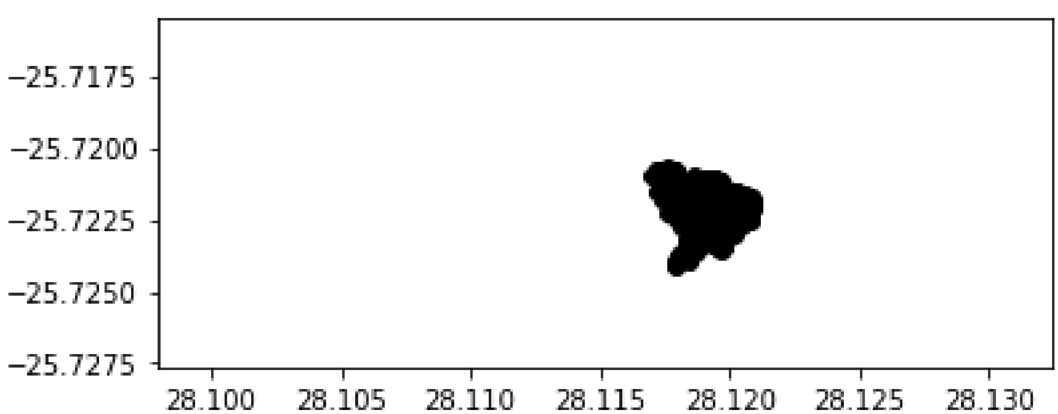
```
[23]: melusi_area_2010 = gpd.read_file('/content/drive/MyDrive/HonsProj-Data/
       ↪GTI_Data_Delivery20210902/SHP/Melusi_Building_Based_Land_Use_Points_2010.shp')
      melusi_area_2020 = gpd.read_file('/content/drive/MyDrive/HonsProj-Data/
       ↪GTI_Data_Delivery20210902/SHP/Melusi_Building_Based_Land_Use_Points_2020.shp')
      roads = gpd.read_file('/content/drive/MyDrive/HonsProj-Data/roads_lines_shp/
       ↪hotosm_zaf_roads_lines.shp')
      population = rioxarray.open_rasterio("/content/drive/MyDrive/HonsProj-Data/
       ↪population_zaf_2019-07-01_geotiff/population_zaf_2019-07-01.tif")
```

Limit the Roads and Population data to just the *Melusi* Area

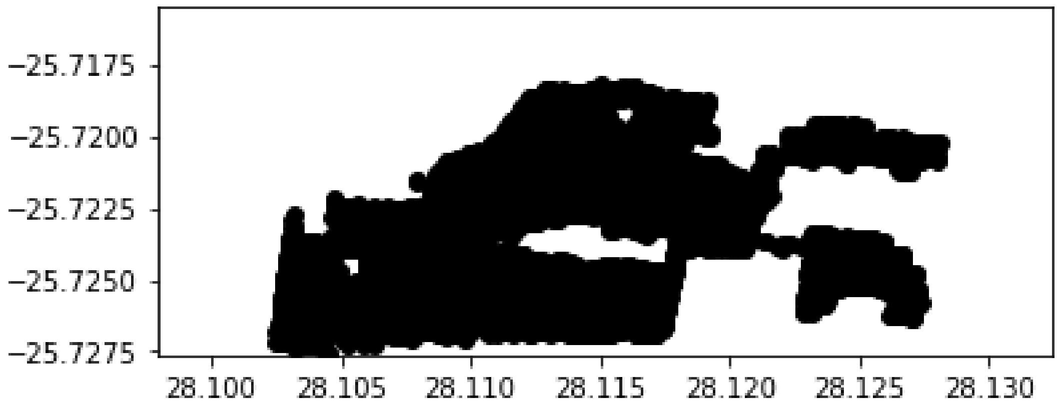
```
[24]: roads = roads.cx[xmin:xmax, ymin:ymax]
      population = population.rio.clip_box(minx=xmin, miny=ymin, maxx=xmax, maxy=ymax)
```

Plot the new data files

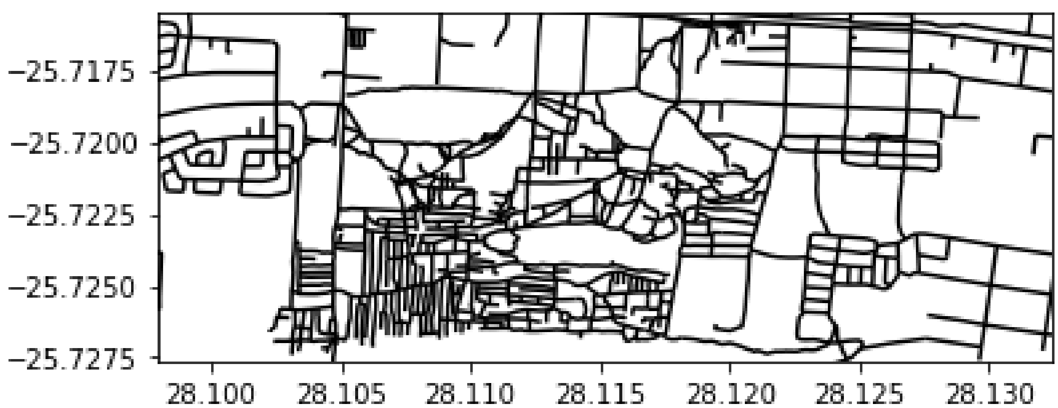
```
[27]: ax = melusi_area_2010.plot(color="black")
      ax.set(xlim=(xmin, xmax), ylim=(ymin, ymax))
      ax.autoscale_view(scalex=False, scaley=False)
      ax.autoscale(enable=False)
```



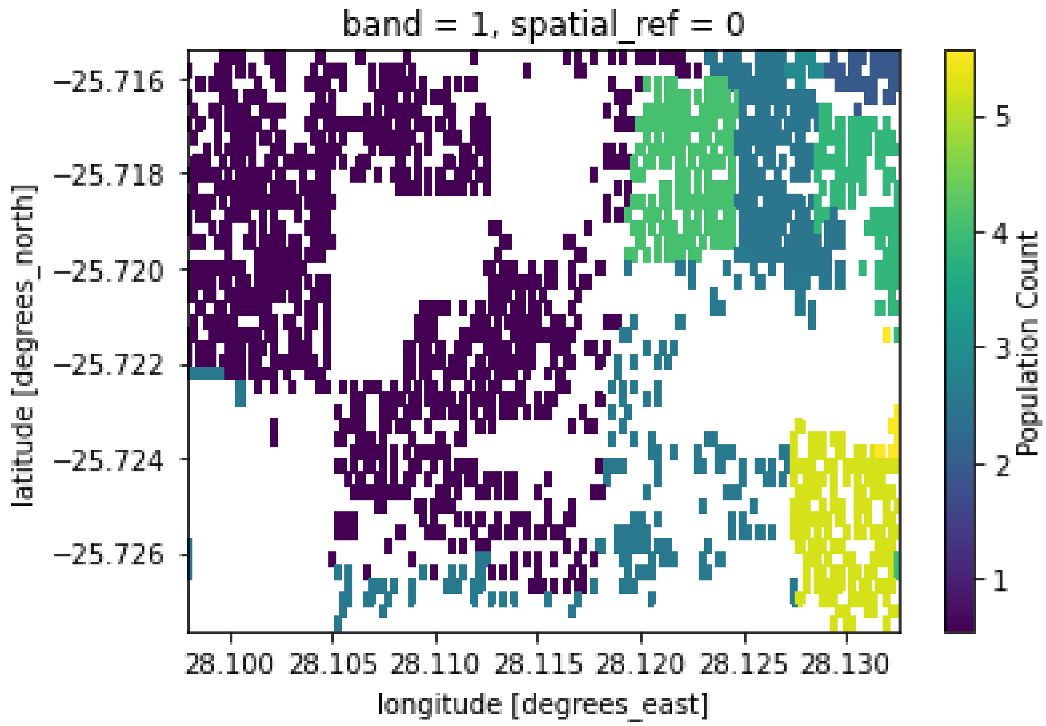
```
[28]: ax = melusi_area_2020.plot(color="black")
      ax.set(xlim=(xmin, xmax), ylim=(ymin, ymax))
      ax.autoscale_view(scalex=False, scaley=False)
      ax.autoscale(enable=False)
```




```
[29]: ax = roads.plot(color="black")
      ax.set(xlim=(xmin, xmax), ylim=(ymin, ymax))
      ax.autoscale_view(scalex=False, scaley=False)
      ax.autoscale(enable=False)
```




```
[32]: ax = population.plot()
```



Get the Coordinate Reference System for all the data

[33]:
```
melusi_area.crs
```

[33]:
```
<Geographic 2D CRS: EPSG:4326>
Name: WGS 84
Axis Info [ellipsoidal]:
- Lat[north]: Geodetic latitude (degree)
- Lon[east]: Geodetic longitude (degree)
Area of Use:
- name: World.
- bounds: (-180.0, -90.0, 180.0, 90.0)
Datum: World Geodetic System 1984 ensemble
- Ellipsoid: WGS 84
- Prime Meridian: Greenwich
```

[34]:
```
melusi_area_2010.crs
```

[34]:
```
<Geographic 2D CRS: EPSG:4326>
Name: WGS 84
Axis Info [ellipsoidal]:
- Lat[north]: Geodetic latitude (degree)
- Lon[east]: Geodetic longitude (degree)
Area of Use:
```

```
- name: World.
- bounds: (-180.0, -90.0, 180.0, 90.0)
Datum: World Geodetic System 1984 ensemble
- Ellipsoid: WGS 84
- Prime Meridian: Greenwich
```

[36]:
```python
melusi_area_2020.crs
```

[36]:
```
<Geographic 2D CRS: EPSG:4326>
Name: WGS 84
Axis Info [ellipsoidal]:
- Lat[north]: Geodetic latitude (degree)
- Lon[east]: Geodetic longitude (degree)
Area of Use:
- name: World.
- bounds: (-180.0, -90.0, 180.0, 90.0)
Datum: World Geodetic System 1984 ensemble
- Ellipsoid: WGS 84
- Prime Meridian: Greenwich
```

[ ]:
```python

```

[18]:
```python
type(population.values)
```

[18]:
```
numpy.ndarray
```

[ ]:
```python
melusi_area.crs
```

[ ]:
```
<Geographic 2D CRS: EPSG:4326>
Name: WGS 84
Axis Info [ellipsoidal]:
- Lat[north]: Geodetic latitude (degree)
- Lon[east]: Geodetic longitude (degree)
Area of Use:
- name: World.
- bounds: (-180.0, -90.0, 180.0, 90.0)
Datum: World Geodetic System 1984 ensemble
- Ellipsoid: WGS 84
- Prime Meridian: Greenwich
```

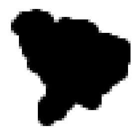
[38]:
```python
print(f'CRS: {population.rio.crs}')
print(f'Bounds: {population.rio.bounds()}')
print(f'Width: {population.rio.width}')
print(f'Height: {population.rio.height}')
```

```
CRS: EPSG:4326
Bounds: (28.09791666667597, -25.727638888891768, 28.132638888898217,
-25.71541666666954)
```

```
Width: 125
Height: 44
```

Save the Plotted Images without the Axes

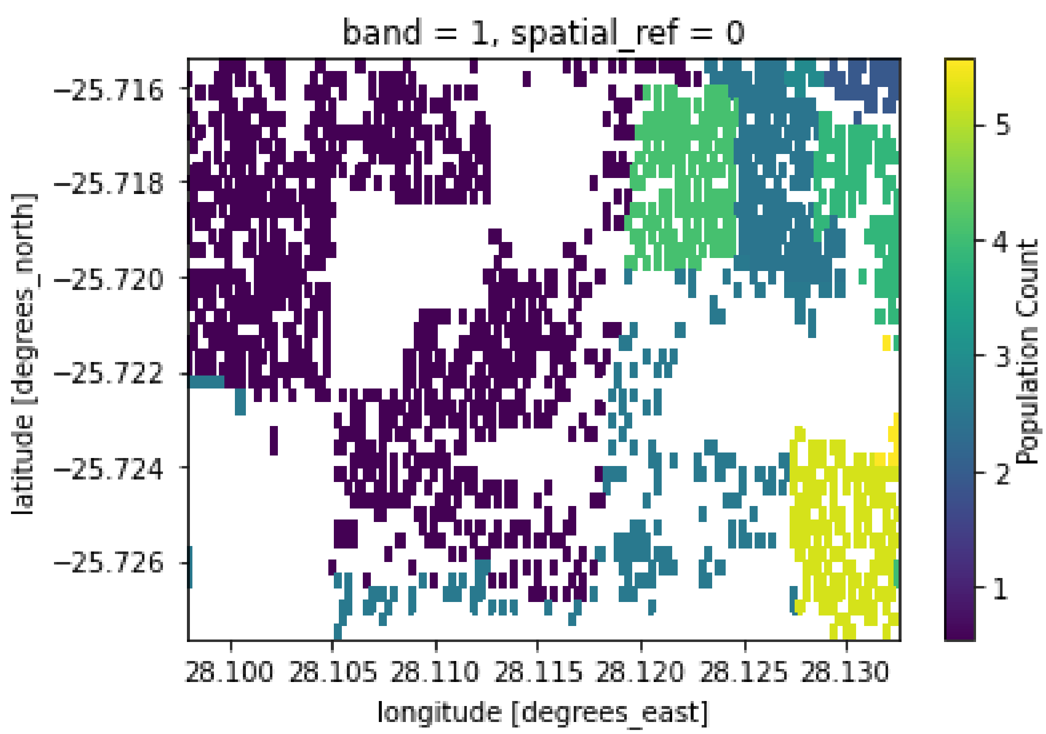
[51]:
```
ax = melusi_area_2010.plot(color="black")
ax.set_axis_off()
ax.set(xlim=(xmin, xmax), ylim=(ymin, ymax))
ax.autoscale_view(scalex=False, scaley=False)
ax.autoscale(enable=False)
plt.savefig("melusi-area2010-noaxis.png",dpi=1200)
```



[52]:
```
ax = melusi_area_2020.plot(color="black")
ax.set_axis_off()
ax.set(xlim=(xmin, xmax), ylim=(ymin, ymax))
ax.autoscale_view(scalex=False, scaley=False)
ax.autoscale(enable=False)
plt.savefig("melusi-area2020-noaxis.png",dpi=1200)
```

[53]:
```
ax = roads.plot(color="black")
ax.set_axis_off()
ax.set(xlim=(xmin, xmax), ylim=(ymin, ymax))
ax.autoscale_view(scalex=False, scaley=False)
ax.autoscale(enable=False)
plt.savefig("roads-noaxis.png",dpi=1200)
```

[43]:
```
ax = population.plot()
plt.savefig("population-noaxis.png",dpi=1200)
```



Grayscale Images that were saved and resave

[54]:
```
image = cv2.imread('melusi-area2010-noaxis.png')
melusi2010_gray = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)
cv2.imwrite('melusi-area2010_gray.png', melusi2010_gray)
```

[54]: True

[55]:
```
image = cv2.imread('melusi-area2020-noaxis.png')
melusi2020_gray = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)
cv2.imwrite('melusi-area2020_gray.png', melusi2020_gray)
```

[55]: True

[56]:
```
image = cv2.imread('roads-noaxis.png')
roads2019gray = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)
cv2.imwrite('roads2019_gray.png', roads2019gray)
```

[56]: True

Resize and scale new grayscale images

[57]:
```
scale_percent = 33.333333333 # percent of original size
```

[58]:
```
roads_gray = cv2.imread('roads2019_gray.png')
roads_gray = cv2.cvtColor(roads_gray, cv2.COLOR_BGR2GRAY)
width = int(roads_gray.shape[1] * scale_percent / 100)
height = int(roads_gray.shape[0] * scale_percent / 100)
dim = (width, height)
roads_gray_resized = cv2.resize(roads_gray, dim, interpolation = cv2.INTER_AREA)
cv2.imwrite('roads_gray_resized.png', roads_gray_resized)
```

[58]: True

[59]:
```
melusi2010_gray = cv2.imread('melusi-area2010_gray.png')
melusi2010_gray = cv2.cvtColor(melusi2010_gray, cv2.COLOR_BGR2GRAY)
width = int(melusi2010_gray.shape[1] * scale_percent / 100)
height = int(melusi2010_gray.shape[0] * scale_percent / 100)
dim = (width, height)
melusi2010_gray_resized = cv2.resize(melusi2010_gray, dim, interpolation = cv2.
 ↪INTER_AREA)
cv2.imwrite('melusi2010_gray_resized.png', melusi2010_gray_resized)
```

[59]: True

[60]:
```
melusi2020_gray = cv2.imread('melusi-area2010_gray.png')
melusi2020_gray = cv2.cvtColor(melusi2020_gray, cv2.COLOR_BGR2GRAY)
width = int(melusi2020_gray.shape[1] * scale_percent / 100)
height = int(melusi2020_gray.shape[0] * scale_percent / 100)
```

```
dim = (width, height)
melusi2020_gray_resized = cv2.resize(melusi2020_gray, dim, interpolation = cv2.
 ↪INTER_AREA)
cv2.imwrite('melusi2020_gray_resized.png', melusi2020_gray_resized)
```

[60]: True

Replace colors in roads with just black and white

```
[61]: def thresholdReplaceRoads(x):
        if x > 230:
          return 255
        elif x < 230 and x > 0:
          return 0
        else:
          return 0
```

```
[62]: vectorizeRoadsFunction = np.vectorize(thresholdReplaceRoads)
      roads_gray_resized = vectorizeRoadsFunction(roads_gray_resized)
```

```
[64]: np.unique(roads_gray_resized)
```

[64]: array([0, 255])

Replace colours in Grayscale Population Image with just 5 colours

```
[66]: def thresholdReplacePopulation(x):
        if x < 220 and x > 195: # Yellows in original picture
          return 215
        elif x > 25 and x < 35: # Purples in original picture
          return 30
        elif x > 80 and x < 115: # Blues in original picture
          return 99
        elif x > 130 and x < 150: # Greens in original picture
          return 146
        else: # To replace background colors
          return 255
```

```
[68]: population_gray_resized = cv2.imread('/content/drive/MyDrive/HonsArtifact/
       ↪Pictures/2019population.png')
      population_gray_resized = cv2.cvtColor(population_gray_resized, cv2.
       ↪COLOR_BGR2GRAY)
      vectorizePopulationFunction = np.vectorize(thresholdReplacePopulation)
      population_gray_resized = vectorizePopulationFunction(population_gray_resized)
      cv2.imwrite('population_new.png',population_gray_resized)
```

[68]: True

Methods to be utilised for Cellular Automata Modelling

[70]:
```
# Replacing the grayscale colours with Population Density
def replaceWithPopulationDensity(x):
  if x == 30: # Purples in original picture
    return 0.5483527804562259
  elif x == 99: # Blues in original picture
    return 2.5802248275941975
  elif x == 146: # Greens in original picture
    return 4.0719211311237515
  elif x == 215: # Yellows in original picture
    return 5.236094447939968
  else: #To replace background colors
    return 0.1
```

[71]:
```
vectorizePopulationFunction = np.vectorize(replaceWithPopulationDensity)
```

[72]:
```
# If Road is present in pixel replace with 1
def replaceRoadsForCalc(x):
  if x == 255:
    return 0
  else:
    return 1
```

[73]:
```
vectorizeRoadsFunction = np.vectorize(replaceRoadsForCalc)
```

[75]:
```
# Replace Black and White pixels with 1s and 0s for Calculations
def replaceBWForCalculations(x):
  if x == 255:
    return 0
  else:
    return 1
```

[76]:
```
vectorizeBWFunction = np.vectorize(replaceBWForCalculations)
```

Read and Grayscale Final Images for CA Modelling

[77]:
```
melusi2010 = cv2.imread('/content/drive/MyDrive/HonsArtifact/Pictures/
 ↪melusi2010gray01s_new.png')
melusi2020 = cv2.imread('/content/drive/MyDrive/HonsArtifact/Pictures/
 ↪melusi2020gray01s_new.png')
population = cv2.imread('/content/drive/MyDrive/HonsArtifact/Pictures/
 ↪population2019gray01s_new.png')
roads = cv2.imread('/content/drive/MyDrive/HonsArtifact/Pictures/
 ↪roads_gray_01s_new.png')
```

[78]:
```
melusi2010 = cv2.cvtColor(melusi2010, cv2.COLOR_BGR2GRAY)
melusi2020 = cv2.cvtColor(melusi2020, cv2.COLOR_BGR2GRAY)
population = cv2.cvtColor(population, cv2.COLOR_BGR2GRAY)
roads = cv2.cvtColor(roads, cv2.COLOR_BGR2GRAY)
```

Vectorize and replace Roads and Population data for Calculations

[79]:
```
roads = vectorizeRoadsFunction(roads)
population = vectorizePopulationFunction(population)
```

Create copies of original data (so original remains unchanged)

[80]:
```
melusi2010_copy = melusi2010.copy()
melusi2020_copy = melusi2020.copy()
population_copy = population.copy()
roads_copy = roads.copy()
```

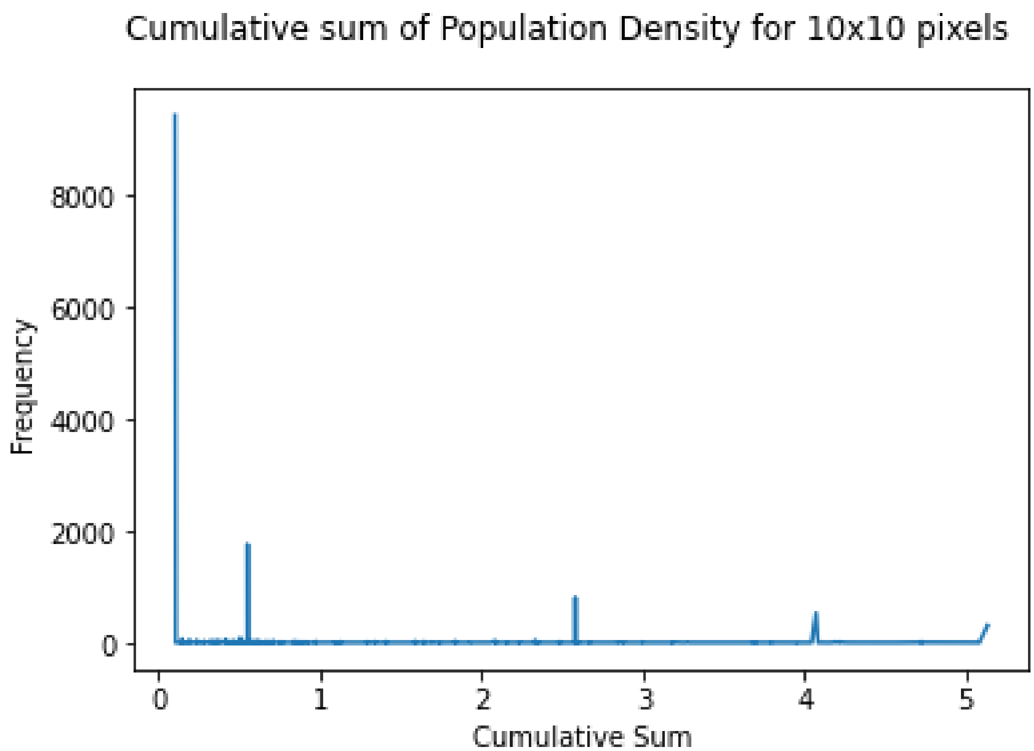
Calculate Cumulative Sum Averages for Population and Roads

[81]:
```
# Every 10 by 10 pixel block is calculated
row = 0
column = 0
step = 10
doubleStep = 20
maxHeight = 830
maxWidth = 2160

firstRow = 0
secondRow = 10
secondLastRow = 810
lastRow = 820


firstColumn = 0
secondColumn = 10
secondLastColumn = 2140
lastColumn = 2150

cumsumPopulationList = []
cumsumRoadList = []

for row in range(0,len(melusi2010_copy),10):
    for column in range(0,len(melusi2010_copy[row]),10):

      if(row < maxHeight and column < maxWidth):
        populationBlock = population_copy[row:row+step,column:column+step]
        roadsBlock = roads_copy[row:row+step,column:column+step]
        roadsCumulativeCalc = np.cumsum(roadsBlock)[-1]/100
        populationCumulativeCalc = np.cumsum(populationBlock)[-1]/100
        cumsumPopulationList.append(populationCumulativeCalc)
        cumsumRoadList.append(roadsCumulativeCalc)
```

Create Graph for Population Cumulative Sum Averages

[82]:
```
npArrayPopulation = np.array(cumsumPopulationList)
binsPopulation = np.unique(npArrayPopulation)
graphPopulation = np.histogram(npArrayPopulation, bins=binsPopulation)
xPopulation = list(graphPopulation[1][:-1])
yPopulation = list(graphPopulation[0])
```

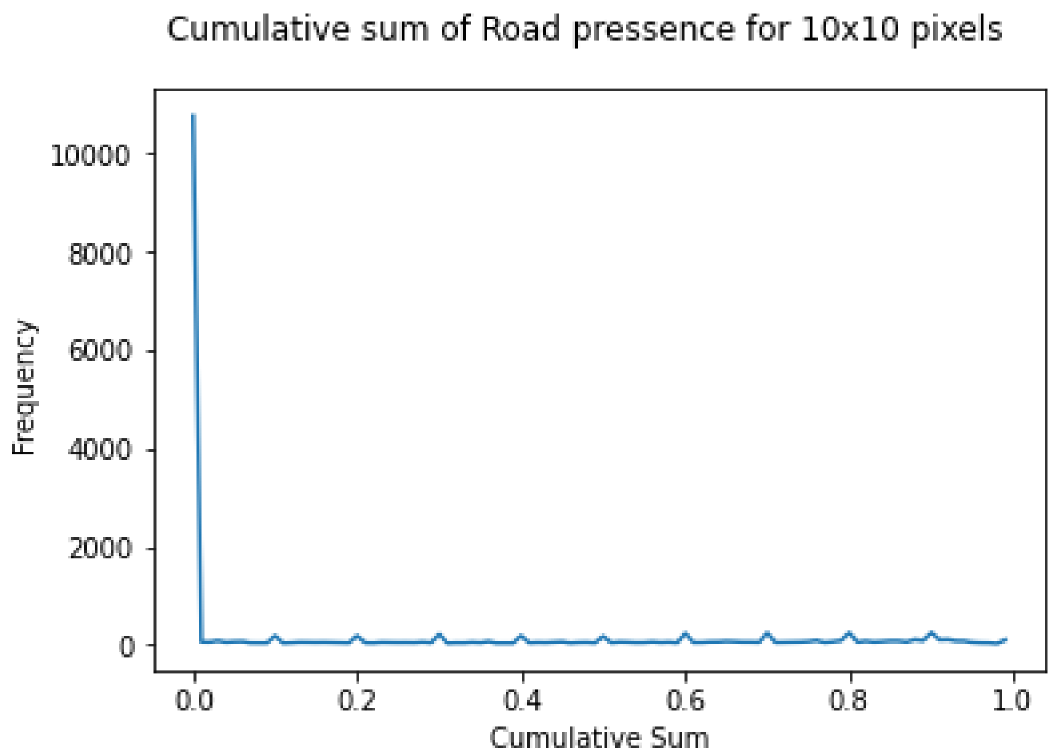
[84]:
```
populationFigure = plt.figure()
plt.plot(xPopulation,yPopulation)
populationFigure.suptitle("Cumulative sum of Population Density for 10x10␣
    ↪pixels")
plt.xlabel('Cumulative Sum')
plt.ylabel('Frequency')
populationFigure.savefig('populationFigure.jpg')
```



Create Graph for Cumulative Sums Averages for Roads

[85]:
```
npArrayRoads = np.array(cumsumRoadList)
binsRoads = np.unique(npArrayRoads)
graphRoads = np.histogram(npArrayRoads, bins=binsRoads)
xRoads = list(graphRoads[1][:-1])
yRoads = list(graphRoads[0])
```

[86]:
```
roadsFigure = plt.figure()
plt.plot(xRoads,yRoads)
roadsFigure.suptitle("Cumulative sum of Road pressence for 10x10 pixels")
plt.xlabel('Cumulative Sum')
plt.ylabel('Frequency')
roadsFigure.savefig('roadsFigure.jpg')
```



Cellular Automata Model

[87]:
```
# Create Variables for the model

row = 0
column = 0
step = 10
doubleStep = 20
maxHeight = 830
maxWidth = 2160

firstRow = 0
secondRow = 10
secondLastRow = 810
lastRow = 820
```

```
firstColumn = 0
secondColumn = 10
secondLastColumn = 2140
lastColumn = 2150

# Start Model with 0 for each rule tested
roadsConditional = 0
populationConditional = 0
topBottomConditional = 0
diagonalConditional = 0

# Create a Temporary Copy of the Initial State
tempMelusi = melusi2010.copy()

# Create Flat array for Accuracy Testing
accuracyBenchmark = melusi2020_copy.flatten()
accuracyList = []

# Run Model for 50 Generations
for generations in range(1,51):
  # Go through entire 10 by 10 pixels in the Array
  for row in range(0,len(melusi2010_copy),step):
    for column in range(0,len(melusi2010_copy[row]),step):
      #Blocks for cellular automata
      TopMiddle = None
      BottomMiddle = None
      MiddleRight = None
      MiddleLeft = None
      TopLeft = None
      TopRight = None
      BottomLeft = None
      BottomRight = None

      # Cumulative Sums for Blocks created above
      sumTopMiddle = 0
      sumBottomMiddle = 0
      sumMiddleRight = 0
      sumMiddleLeft = 0
      sumTopLeft = 0
      sumTopRight = 0
      sumBottomLeft = 0
      sumBottomRight = 0
      # Averages for Cumulative Sums Blocks created above
      averageOfSumsTopsBottoms = 0
      averageOfSumsDiagonals = 0
```

```python
    if(row < maxHeight and column < maxWidth):
      populationBlock = population_copy[row:row+step,column:column+step]
      roadsBlock = roads_copy[row:row+step,column:column+step]
      roadsCumulativeCalc = np.cumsum(roadsBlock)[-1]/100
      populationCumulativeCalc = np.cumsum(populationBlock)[-1]/100

      # Check if Top Middle Block exists
      if (row >= secondRow and row <= lastRow and column >= firstColumn and column <= lastColumn):
        TopMiddle = melusi2010_copy[row-step:row, column:column+step]
        TopMiddle = vectorizeBWFunction(TopMiddle)
        sumTopMiddle = np.cumsum(TopMiddle)[-1]/100

      # Check if Bottom Middle Block exists
      if (row >= firstRow and row <= secondLastRow and column >= firstColumn and column <= lastColumn):
        BottomMiddle = melusi2010_copy[row:row+step, column:column+step]
        BottomMiddle = vectorizeBWFunction(BottomMiddle)
        sumBottomMiddle = np.cumsum(BottomMiddle)[-1]/100

      # Check if Middle Right Block exists
      if (row >= firstRow and row <= lastRow and column >= firstColumn and column <= secondLastColumn):
        MiddleRight = melusi2010_copy[row:row+step, column+step:column+doubleStep]
        MiddleRight = vectorizeBWFunction(MiddleRight)
        sumMiddleRight = np.cumsum(MiddleRight)[-1]/100

      # Check if Middle Left Block exists
      if (row >= firstRow and row <= lastRow and column >= secondColumn and column <= lastColumn):
        MiddleLeft = melusi2010_copy[row:row+step, column-step:column]
        MiddleLeft = vectorizeBWFunction(MiddleLeft)
        sumMiddleLeft = np.cumsum(MiddleLeft)[-1]/100

      # Check if Top Left Block exists
      if (row >= secondRow and row <= lastRow and column >= secondColumn and column <= lastColumn):
        TopLeft = melusi2010_copy[row-step:row, column-step:column]
        TopLeft = vectorizeBWFunction(TopLeft)
        sumTopLeft = np.cumsum(TopLeft)[-1]/100

      # Check if Top Right Block exists
      if (row >= secondRow and row <= lastRow and column >= firstColumn and column <= secondLastColumn):
        TopRight = melusi2010_copy[row-step:row, column+step:column+doubleStep]
```

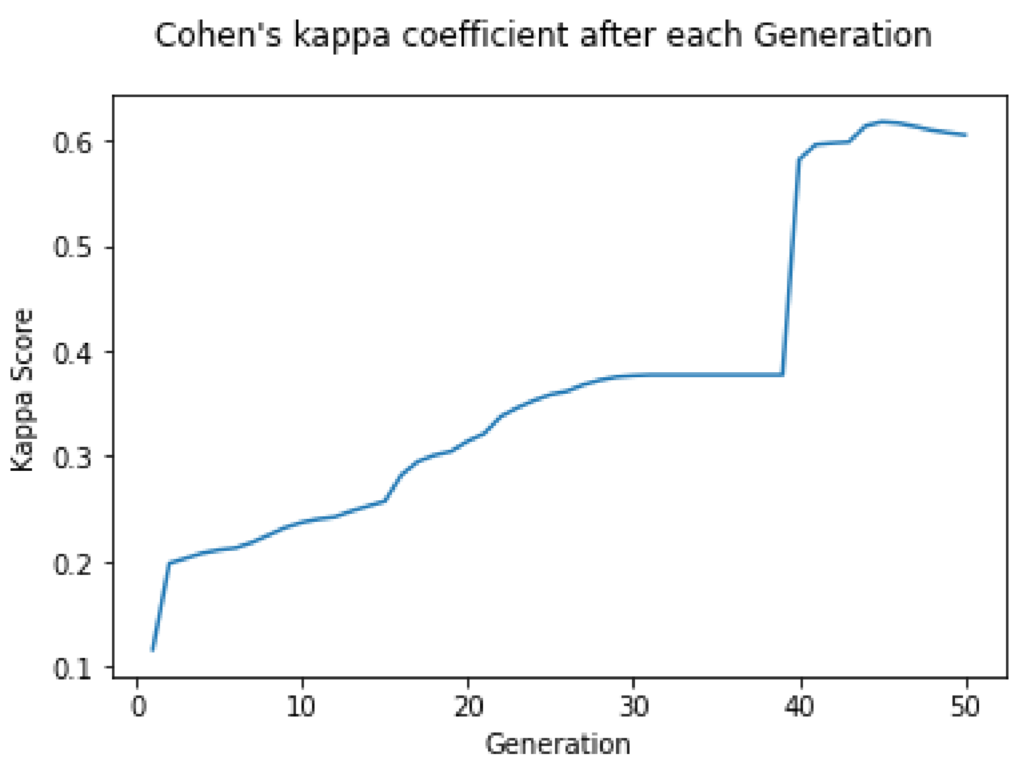
```
        TopRight = vectorizeBWFunction(TopRight)
        sumTopRight = np.cumsum(TopRight)[-1]/100

      # Check if Bottom Left Block exists
      if (row >= firstRow and row < secondLastRow and column >= secondColumn␣
↪and column <= lastColumn):
        BottomLeft = melusi2010_copy[row+step:row+doubleStep, column-step:
↪column]
        BottomLeft = vectorizeBWFunction(BottomLeft)
        sumBottomLeft = np.cumsum(BottomLeft)[-1]/100

      # Check if Bottom Right Block exists
      if (row >= firstRow and row <= secondLastRow and column >= firstColumn␣
↪and column <= secondLastColumn):
        BottomRight = melusi2010_copy[row+step:row+doubleStep, column+step:
↪column+doubleStep]
        BottomRight = vectorizeBWFunction(BottomRight)
        sumBottomRight = np.cumsum(BottomRight)[-1]/100

      # Add Top and Bottom Blocks to a list
      countTopsBottoms = [TopMiddle, BottomMiddle, MiddleRight, MiddleLeft]
      # Add Diagonal Blocks to a list
      countDiags = [TopLeft, TopRight, BottomLeft, BottomRight]

      # Count how many Neighbour Blocks there are for Current Block
      noneCountsTops = len([x for x in countTopsBottoms if x is not None])
      noneCountsDiag = len([x for x in countDiags if x is not None])

      # Get Averages of Top and Bottom Blocks Cumulative Sums
      averageOfSumsTopsBottoms = (sumTopMiddle + sumBottomMiddle +␣
↪sumMiddleRight + sumMiddleLeft) / noneCountsTops
      # Get Averages of Diagonals Blocks Cumulative Sums
      averageOfSumsDiagonals = (sumTopLeft + sumTopRight + sumBottomLeft +␣
↪sumBottomRight) / noneCountsDiag

      # First Generation
      if (generations == 1):
          roadsConditional = 0.01
          populationConditional = 0.08
          diagonalsCondidtional = 0.1
          topBottomConditional = 0.1
          # First Generation Rules are Checked
          if ((roadsCumulativeCalc >= roadsConditional or␣
↪populationCumulativeCalc >= populationConditional) and (averageOfSumsDiagonals␣
↪> diagonalsCondidtional or averageOfSumsTopsBottoms > topBottomConditional)):
            # Fill Current Block as Alive
```

```
            for m in range(row,row+step):
              for n in range(column,column+step):
                tempMelusi[m,n] = 0
      # Second Generation
      elif (generations == 2):
          roadsConditional = 0.01
          populationConditional = 0.08
          diagonalsCondidtional = 0.1
          topBottomConditional = 0.1
          # Second Generation Rules are Checked
          if ((roadsCumulativeCalc >= roadsConditional and␣
↪populationCumulativeCalc >= populationConditional) and (averageOfSumsDiagonals␣
↪> diagonalsCondidtional or averageOfSumsTopsBottoms > topBottomConditional)):
            # Fill Current Block as Alive
            for m in range(row,row+step):
              for n in range(column,column+step):
                tempMelusi[m,n] = 0
      # Generations less than 40
      elif (generations < 40):
          roadsConditional = 0.1
          populationConditional = 0.1
          diagonalsCondidtional = 0.1
          topBottomConditional = 0.1
          # Generations less than 40 Rules are Checked
          if ((roadsCumulativeCalc >= roadsConditional and␣
↪populationCumulativeCalc >= populationConditional) and (averageOfSumsDiagonals␣
↪> diagonalsCondidtional or averageOfSumsTopsBottoms > topBottomConditional)):
            # Fill Current Block as Alive
            for m in range(row,row+step):
              for n in range(column,column+step):
                tempMelusi[m,n] = 0
      # Generations more than 40 and less than 51
      else:
          roadsConditional = 0.09
          populationConditional = 0.05
          diagonalsCondidtional = 0.15
          topBottomConditional = 0.1
          # Generations(40 < x < 50) Rules are Checked
          if ((roadsCumulativeCalc >= roadsConditional and␣
↪populationCumulativeCalc >= populationConditional) and (averageOfSumsDiagonals␣
↪> diagonalsCondidtional or averageOfSumsTopsBottoms > topBottomConditional)):
            # Fill Current Block as Alive
            for m in range(row,row+step):
              for n in range(column,column+step):
                tempMelusi[m,n] = 0
# Copy temporary array to final array
melusi2010_copy = tempMelusi
```

```
    # Calculate Accuracy
    accuracyTemp = melusi2010_copy.copy().flatten()
    score = cohen_kappa_score(accuracyBenchmark,accuracyTemp)
    accuracyList.append(score)
    # Write Current Simulated Generation to an image
    filename = f"pics/generation-{str(generations)}-melusi.png"
    cv2.imwrite(filename,melusi2010_copy)
```

Create Graph for Accuracy results

[88]:
```
generationsList = list(map(lambda x: x, range(1,51)))
scoresFigure = plt.figure()
plt.plot(generationsList,accuracyList)
scoresFigure.suptitle("Cohen's kappa coefficient after each Generation")
plt.xlabel('Generation')
plt.ylabel('Kappa Score')
scoresFigure.savefig('scoresFigure.jpg')
```



Get Maximum Accuracy achieved

[89]:
```
max(accuracyList)
```

[89]: 0.6177552964145456

Get Accuracy for each generation

[91]:
```
for i in range(1,51):
  print(f'Generation: {i}\t{accuracyList[i-1]}')
```

```
Generation: 1   0.11625181498059378
Generation: 2   0.19824922121107136
Generation: 3   0.2030628354462608
Generation: 4   0.20793481429046645
Generation: 5   0.21093437785824343
Generation: 6   0.21283046681369622
Generation: 7   0.21812986043325577
Generation: 8   0.22511088417746883
Generation: 9   0.23225494066337948
Generation: 10  0.23712807908806854
Generation: 11  0.24030784142599682
Generation: 12  0.24236259441785502
Generation: 13  0.24795555301338124
Generation: 14  0.25260419032659376
Generation: 15  0.2572418136274782
Generation: 16  0.2822792436920437
Generation: 17  0.29504157655474317
Generation: 18  0.30102906854032363
Generation: 19  0.304648848523116
Generation: 20  0.3143884842889031
Generation: 21  0.3215714223769961
Generation: 22  0.33780443805206917
Generation: 23  0.3461394892632711
Generation: 24  0.35302831352863406
Generation: 25  0.3586621586000974
Generation: 26  0.3618238888941685
Generation: 27  0.36795669505675166
Generation: 28  0.3723251828092663
Generation: 29  0.37529002091648256
Generation: 30  0.3765094905705702
Generation: 31  0.37720597829276714
Generation: 32  0.37720597829276714
Generation: 33  0.37720597829276714
Generation: 34  0.37720597829276714
Generation: 35  0.37720597829276714
Generation: 36  0.37720597829276714
Generation: 37  0.37720597829276714
Generation: 38  0.37720597829276714
Generation: 39  0.37720597829276714
Generation: 40  0.5819724568141758
Generation: 41  0.5961732519113635
Generation: 42  0.5976537496457666
Generation: 43  0.5986502595275387
```

```
Generation: 44  0.6137553851011719
Generation: 45  0.6177552964145456
Generation: 46  0.6164457180001524
Generation: 47  0.6132858520005323
Generation: 48  0.6098248847431835
Generation: 49  0.6074016200347852
Generation: 50  0.6053238869335381
```