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Independent Research Project: How can spatial analysis of GIS identify potential areas to develop hydro-electric renewable energy schemes on the Isle of Arran?

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- **Date:** 07/12/24

Abstract:

A key area for development of the Isle of Arran ('Arran') is the creation of community owned, sustainable renewable energy. This is a significant goal for the local North Ayrshire government (North Ayrshire Council, 2024). One way of achieving this goal would be through the development of hydro-electricity on Arran, an area of great potential. This project aims to identify areas in which this development could occur using spatial analysis. To do this, Multi-Criteria Evaluation will be used by assessing various factors to which consideration needs to be given (proximity to water source, proximity to electricity and slope angle). A suitability map will be developed so that this can be visualised. Data on available land will then be used to overlay the Suitability Map in order to identify tangible and specfic areas for construction.

GitHub Repository

- **GitHub Link:** https://github.com/gracepenny27/IRP

Declaration

> In submitting this assignment, I hereby confirm that I have read the University's statement on Good Academic Practice. The following work is my own. Significant academic debts and borrowings have been properly acknowledged and referenced.

```
from google.colab import drive
drive.mount('/content/drive')
```

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

Table of Contents:

Introduction

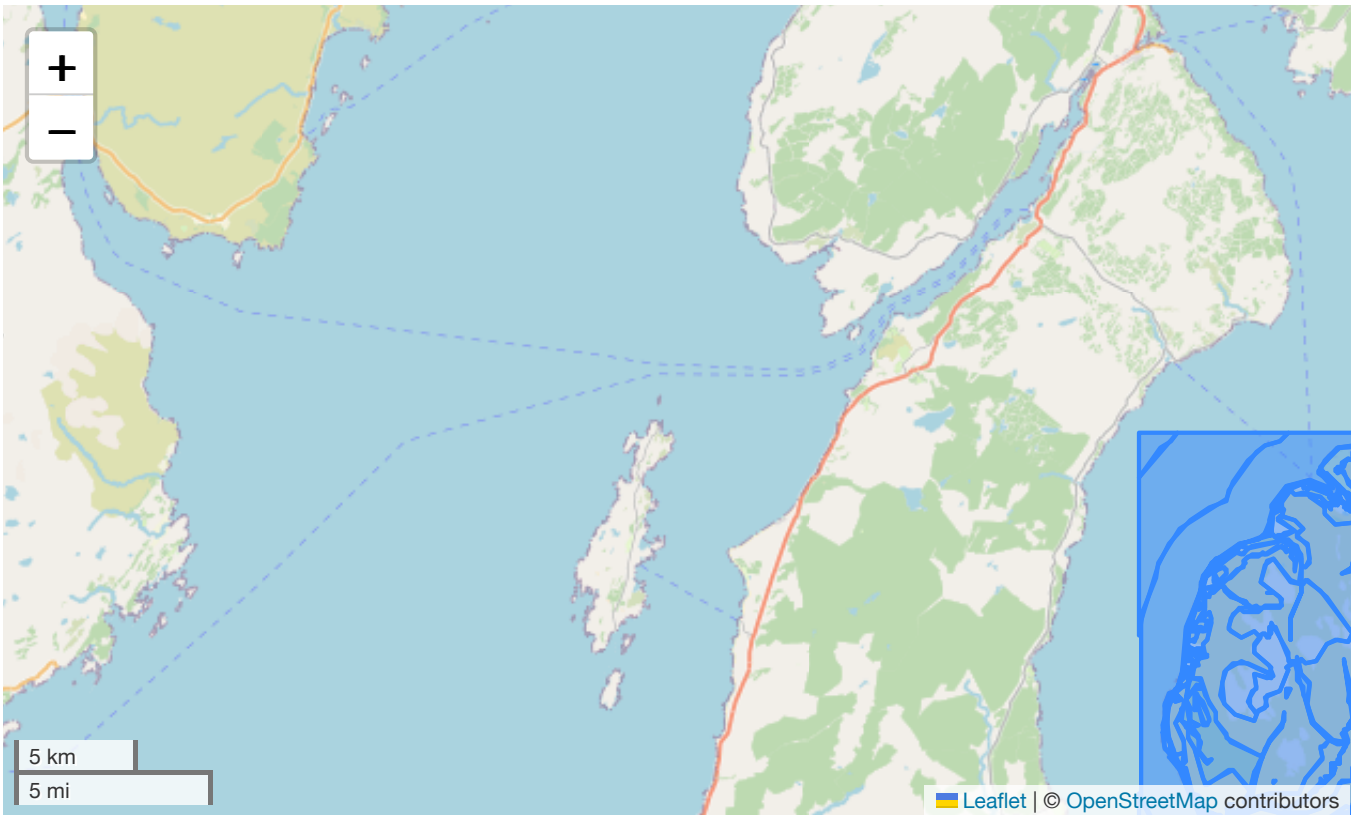
The purpose of this research was to identify an appropriate area for the development of potential hydro-electric renewable energy systems on the Isle of Arran. Arran is an island off the West Coast of Scotland, in the region of North Aryshire. It has a population of approximately 5000 people. A signficant goal for the local government of North Ayrshire is to help develop sustainable community owned renewable energy to help Arran adapt to a more sustainable future (Arran Community Renewables, 2024). Research such as this aims to assist in achieving this goal.

Hydro-electicity is a non-disruptive relatively inexpensive option. It has been identified as the most appropriate form of renewable energy regarding Arran's specific geographic traits. This proposed hydro-electric scheme would likely be a river-run off project due to the remote nature and relatively small size of Arran. The River-run off form of hydro-electricity involves utilising the natural flow of the river followed by harnessing electricity using a turbine and generator (UK government, 2024) The abundance of small rivers on Arran make this the most suitable type of hydroelectric power to use. Previous literature has identified this as the most appropriate way of sustainably harnessing renewable energy on Arran (Arran renewables,2024)

In general, renewable energy development on small islands is an area into which there has been an abudance of research into. In such cases there tend to be numerous stakeholders within the community who must also be considered when planning. A development similar to this proposed project was undertaken in the British Overseas territory of St Helena by their government, with the aim of enabling the island to be self-sufficient in terms of renewable energy. It is acknowledged that Islands tend to be generally more reliant in terms of energy production as a result of to their isolation. Thus, this proposed development aims to solve these similar issues of lack of long-term sustainable sources of renewable energy for Arran.

Figure 1: Isle of Arran Map This figures provides contextual information of the Isle of Arran, showing it to be an island off the West Coast of Scotland. The blue surrouding area is the area of interest (Copernicus,2024).

```
Arran_map= gpd.read_file('/content/ARRANMAPLANDUSE.gpkg')
Arran_map.explore()
```



Methodology

Multi-Criteria Evaluation was the principle method used in this research. Data was obtained from a variety of sources. North Ayrshire Council Open Data Portal provided shapefile data about locations of water sources and potential powerlines. Data on land available for use and construction was also obtained from this data portal for the latter parts of this research. Land use data for the island was obtained from Copernicus (Land Monitoring Service, 2024) and slope data was obtained from Eurodem(EuroGeographics, 2024).

Initially the data was clipped to only include the area of Arran within the 'North Ayrshire' data, this allowed the focus to be on the specific study area of the Island itself.

Method 1: Water Analysis (50m)

Using the rivers file obtained from the North Ayrshire Council Data Portal was downloaded the shapefile into QGIS. This provided a map of all of the rivers, and thus potential water sources on Arran. This vector layer was then converted to a raster using the GDAL Vector to raster tool. From this a rasterised map of rivers was produced. In order to work out distance calculations the proximity tool was used to find areas which are within 50m of a water source. 50m was chosen given the relatively small scale of this project: projects of similar scale also use this distance . Finally, this layer was normalised using the raster calculator. The result of this was presented in a map (Figure 2), which when converted to python used a colour scheme to allow easier visualisation of data.

Method 2: Electricity analysis (200m)

As there was limited data on powerlines (indicating access to electricity) on the Isle of Arran it was assumed that with roads came powerlines. The remote and rural nature of Arran gives further support to this assumption as it is unlikely powerlines would be located elsewhere. Accordingly, the roads data from the North Ayrshire Open Data Portal was used. As with the rivers this was converted from a vector to raster using GDAL (Vector to raster). Then, as before the proximity tool was used to calculate the minumum proxmitity to powerlines, this being 200m. This distance layer was then normalised using the raster calculation. This was then presented in a map (Figure 3), as with the rivers analysis when this map was converted to python a colour scheme was included.

Method 3: Slope Constraint (50° or under)

There is conflicting literature surrounding the benefits and limitations of constructing hydro-electric dams on slopes. Slopes can largely be advantageous, particularly in run-off river projects such as this. Furthermore, when looking at the DEM data for Arran(Eurogeographics, 2024) it was decided that 50 degrees or under would be optimal. Between 30° and 50° is considered a steep slope. Arran's terrain is mountanious in parts (particularly in the North of the island), meaning there are vast amounts of areas with large slope angles. This can be effectively utilised for this proposed project. With this comes the advantages of high head run

off. This means greater energy potential simply due to natural gravity assisting conversion of this into electricity.

This constraint was represented and calculated using the GDAL- slope tool function.

Method 4: Suitability Map

Considering the two key factors (water and electricity) and the slope constraint a suitability map was made in order to visualise the area which would be best to construct this potential hydro- electric system. The raster calculator was used for this function with the weighting of the criterias being equal with water being 50% and proximity to electricity being 50%. As a result of the way hydro-electricity energy is harnessed both factors are as vital as each other, hence the allocation of this weighting. The inclusion of the slope constraint represents any areas of over 50° as unsuitable.

Method 5: Overlay of available land

Using Python the suitability map was overlaid with the areas of available land sourced from the North Ayrshire Open data portal. This data was clipped to include only relevant data of Arran. This was then useful to identify whether these available areas correlated with the suitable areas considering the chosen factors, as discussed above. It must be noted that such data only includes public land available for development on.

Results

Figure 2: Arran Water source proximity map This map shows the first criteria of proximity to water. The yellow indicates the areas that are suitable for development of the Hydro-electric project. This is because they are within 50m of a water source . 50m was chosen because of the nature of this project, namely a small scale run-off river scheme.

```
arran_rivers=rasterio.open('/content/C1.tif')
import matplotlib.pyplot as plt
plt.imshow(arran_rivers.read(1,masked=True))

plt.title ("Arran Water Source Map" )
plt.xlabel ("Longitude")
plt.ylabel ("Latitude")
plt.colorbar(label= "Rivers distance")
plt.show()
```

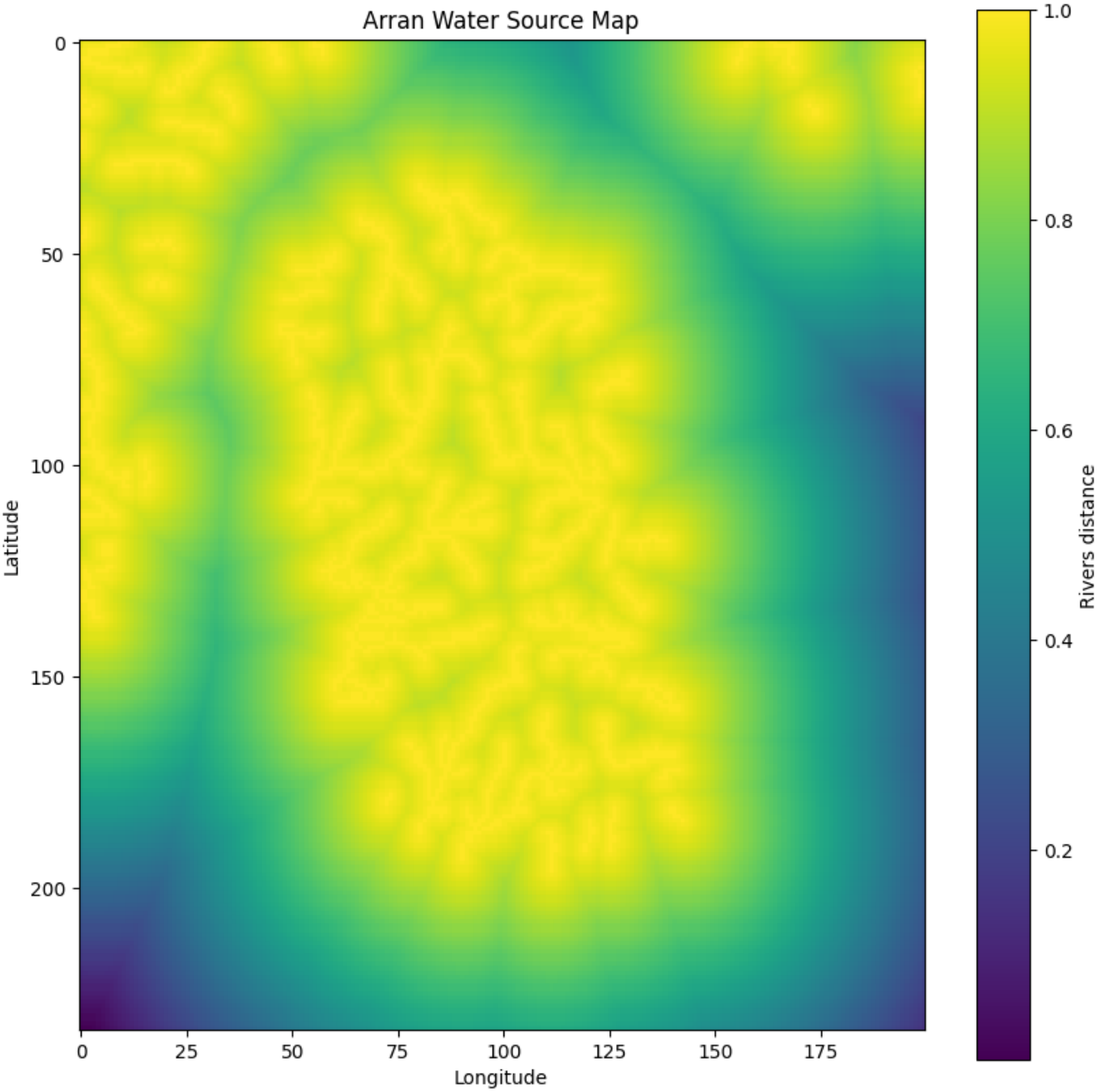

Arran Water Source Map
Latitude
Longitude
Rivers distance
0
50
100
150
200
0
25
50
75
100
125
150
175
1.0
0.8
0.6
0.4
0.2

Figure 3: Proximity to Electricity Map

As with Figure 1 the yellow areas of the map indicate areas which are within 200m of powerlines. Powerlines data was not acccessible, therefore the data on roads was used instead as it is assumed that powerlines are associated with main roads. This is particularly pertinent with Arran as it is a small island therefore the powerlines are most likely to be associated with the main arteriral roads such as the String Road (the main road which runs through the centre of the island).

```
arran_electricity =rasterio.open('/content/powerlines.tif')
import matplotlib.pyplot as plt
plt.imshow(arran_electricity.read(1,masked=True))

plt.title ("Arran Proximity to Powerlines Map" )
plt.xlabel ("Longitude")
plt.ylabel ("Latitude")
plt.colorbar(label= "Powerlines distance")
plt.show()
```

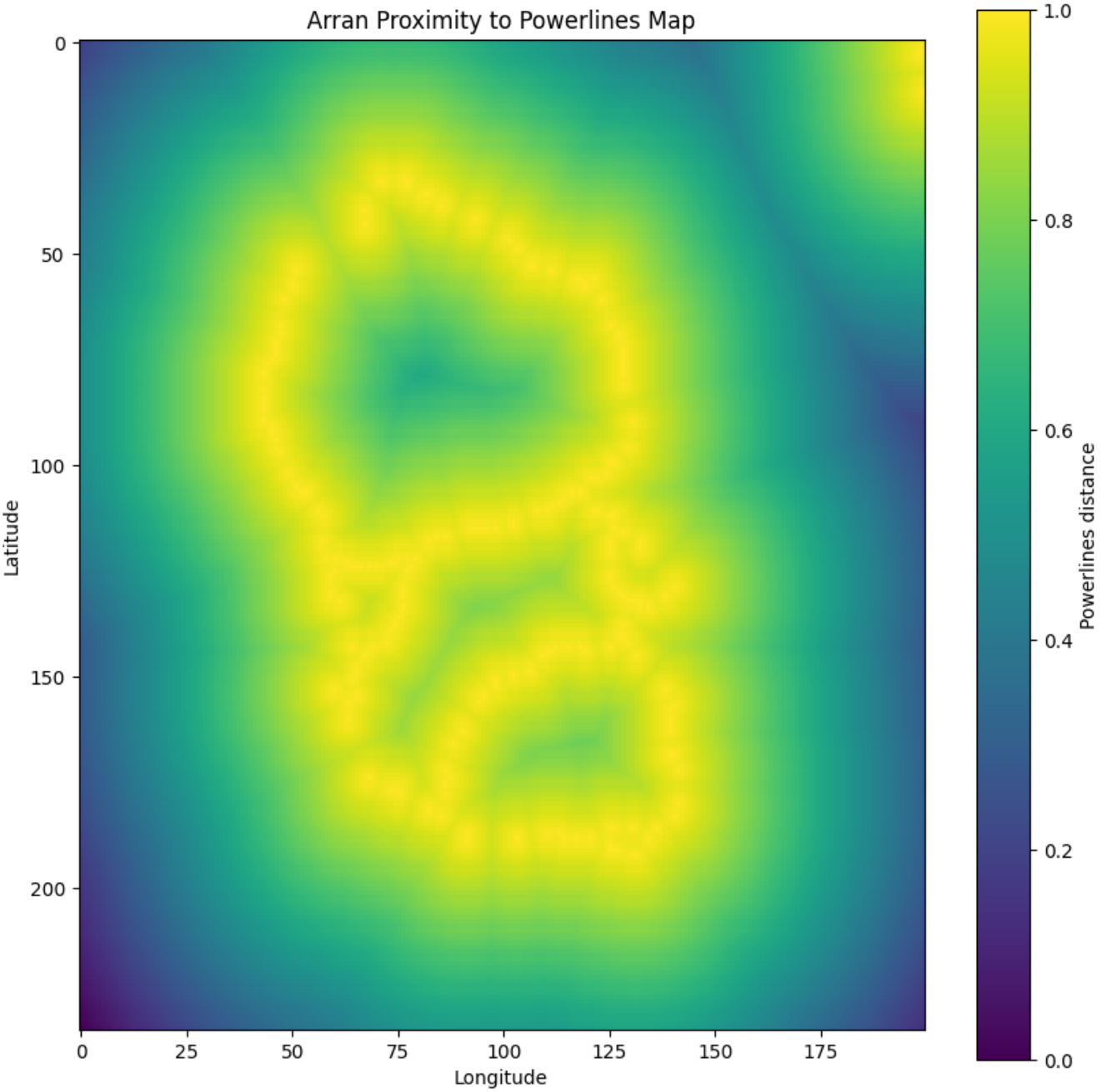

Arran Proximity to Powerlines Map
Latitude
Longitude
Powerlines distance
0
50
100
150
200
0
25
50
75
100
125
150
175
1.0
0.8
0.6
0.4
0.2
0.0

Figure 4: Slope Constraint

Slope was used as a constraint for this multi-criteria evaluation. It was decided any area with a slope angle of 50° or less would be appropriate for development. 50° is still seen as relatively steep. However, this value was decided due to Arran's mountanious areas having areas of high slope angle and elevation such as that in the North East of the island. This combined with the associated benefits of developing hydro-electric systems on relatively high slope angles, make this a suitable choice. The figure shows the areas in black as being above 50°. It can be seen there are small pockets of areas, for instance in the west of the island that will be suitable for development.

```
import rasterio
import matplotlib.pyplot as plt

arran_slope = rasterio.open('/content/C3.tif')
plt.imshow(arran_slope.read(1, masked=True), cmap='gray')

plt.title("Slope Constraint")
plt.xlabel("Longitude")
plt.ylabel("Latitude")
plt.legend("label= 0= slope above 75, 1= slope below")

plt.show()
```

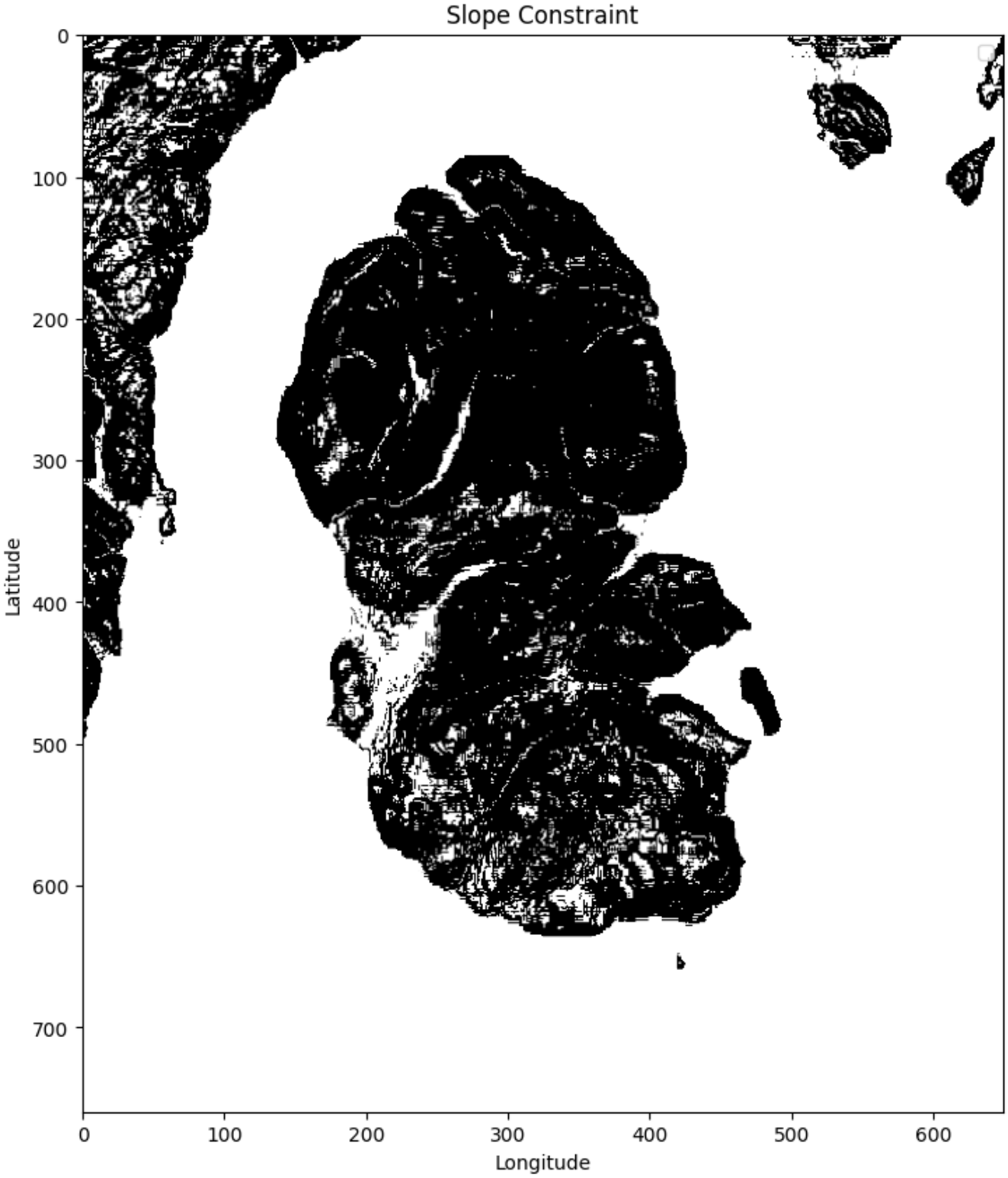

Slope Constraint
Latitude
Longitude
0
100
200
300
400
500
600
700

Figure 5: Suitability Map for water source, proximity to electricity and slope constraint

A suitability map was created using the raster calculator function to take into account both the factors and constraint. This figure illustrates suitable areas are in the colour yellow and areas not suitable in purple. These areas are not suitable because they are not within 50m of a water source, 200m of electricity and slope angle below 50°.

```
arran_suitability = rasterio.open ('/content/SUITABILITYARRANFINAL.tif')
import matplotlib.pyplot as plt
plt.imshow(arran_suitability.read(1,masked=True))

plt.title ("Suitability" )
plt.xlabel ("Longitude")
plt.ylabel ("Latitude")
plt.colorbar(label= "Suitability [0=not suitable, 1= suitable]")
plt.show()
```

Show hidden output

Figure 6: Available land map

Using Python, data on the available land in Arran was loaded. The blue areas indicate known areas for potential development. It must be recognised that these are potential public areas that could be used for development, not including private land. The potential for development on private land and implications for stakeholders may be considered in future research.

```
Arran_openspace = gpd.read_file('/content/Arran Open Space.gpkg')
Arran_openspace.explore()
```

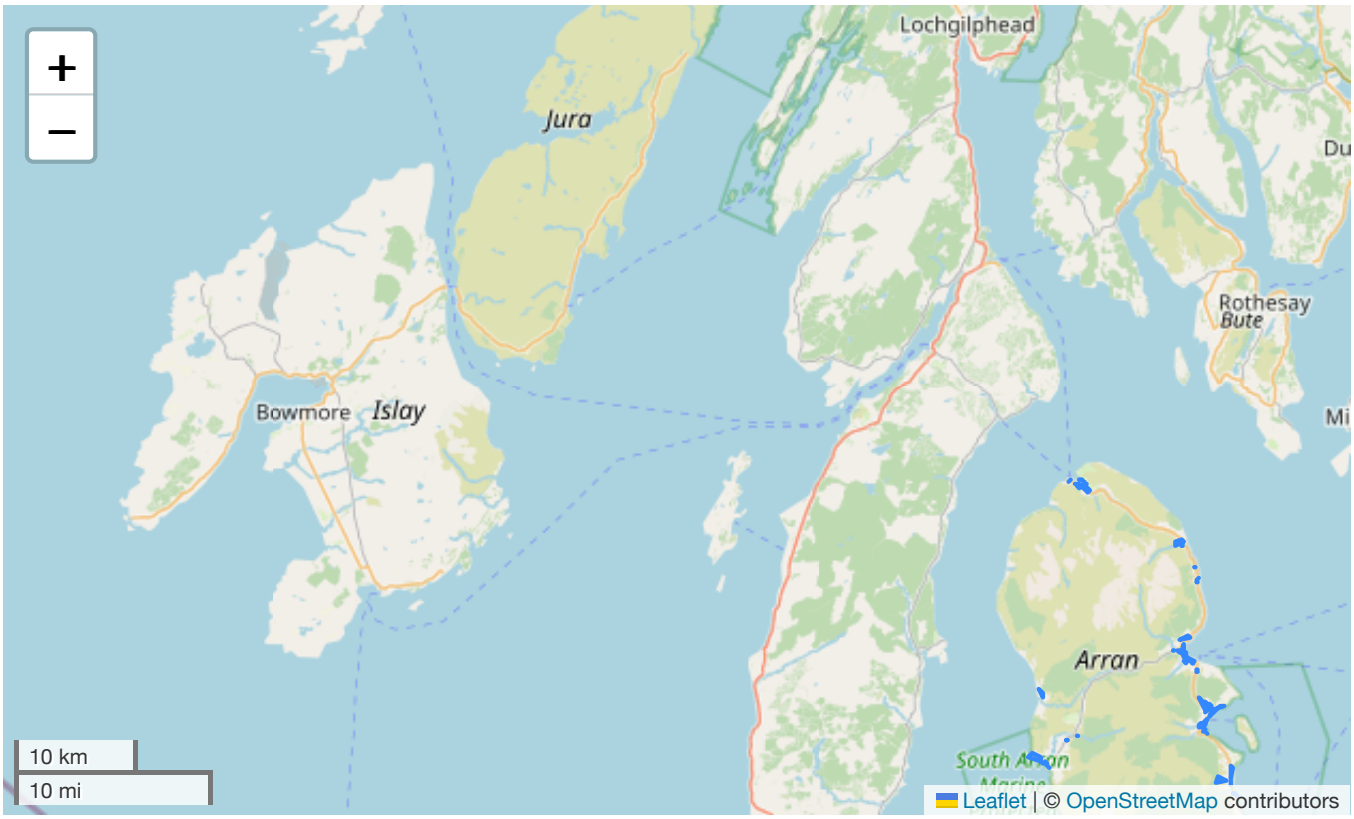


Figure 7: Overlay of available land

This data was overlaid onto a map of the island.

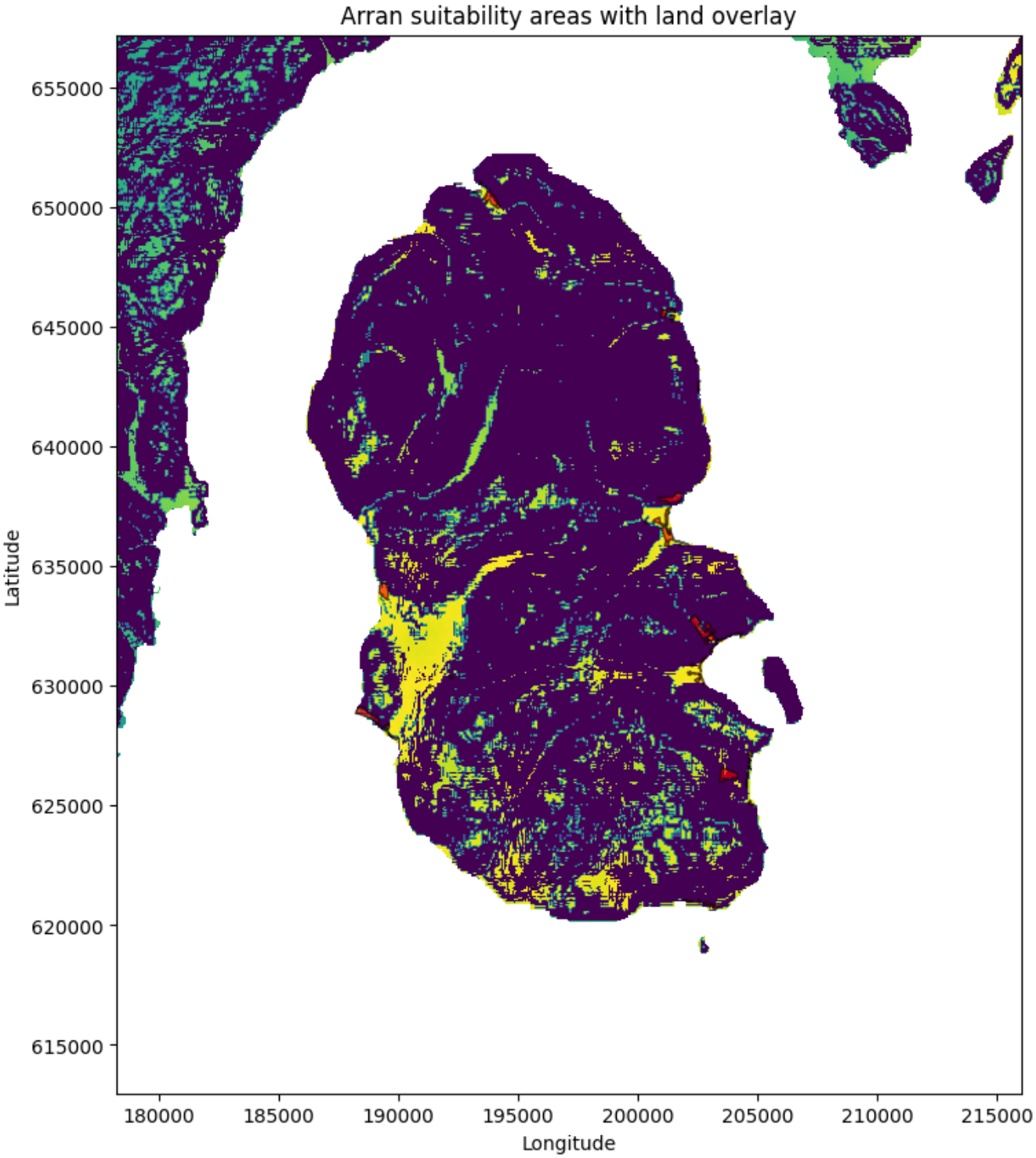
```
Arran_land = gpd.read_file('/content/Arran Open Space.gpkg')
Arran_land = Arran_land.to_crs(epsg=3857)
fig, ax = plt.subplots(figsize=(10, 10))
Arran_land.plot(ax=ax, alpha=0.6, edgecolor='black', cmap='Oranges')
ctx.add_basemap(ax, source=ctx.providers.OpenStreetMap.Mapnik)
plt.title("Available Land")
plt.xlabel("Longitude")
plt.ylabel("Latitude")
plt.show()
```

Show hidden output

Figure 8: Suitability Map including overlay of available land

In order to combine the suitability map and the available land data, the vector data (available landed) was coded to overlay the raster data (the suitability map). The red areas that are in the yellow sections of the map are the areas identified as suitable for development. The most suitable locations are in the west of the island in the Blackwaterfoot, Shiskine Valley and Machrie area.

```
import rasterio
from rasterio.plot import show
import geopandas as gpd
import matplotlib.pyplot as plt

Arran_land = gpd.read_file('/content/Arran Open Space.gpkg')
with rasterio.open('/content/SUITABILITYARRANFINAL.tif') as src:

    arran_suitability = src.read(1, masked=True)
    transform = src.transform

fig, ax = plt.subplots(figsize=(10, 10))

show(arran_suitability, transform=transform, ax=ax, cmap='viridis')
Arran_land.plot(ax=ax, alpha=0.6, edgecolor='black', color='red')

plt.title("Arran suitability areas with land overlay")
plt.xlabel("Longitude")
plt.ylabel("Latitude")
plt.show()
```


Arran suitability areas with land overlay
655000
650000
645000
640000
635000
630000
625000
620000
615000
Latitude
180000
185000
190000
195000
200000
205000
210000
215000
Longitude

Discussion

Addressing research question in context of literature

When completing this research similar projects were looked at in order to provide context. In this research spatial analysis using GIS has helped to successfully identify areas and general regions which would be suitable for the development of hydro-electric systems on Arran. The results suggest that the west of the island would be the most suitable and specifically the Shiskine Valley or Machrie area. This is suitable in terms of access to a water source and electricity, both vital elements of a hydro-electric renewable energy system. The slope angle of these potential areas will also not be above 50°. Furthermore, these areas have prospects of public areas available for development. This project addresses gaps in current research for Arran, providing tangible solutions to the lack of community owned and sustainable renewable energy sources.

Advantages

The data for this project was easy to access on the North Ayrshire Data Portal which allowed me to manipulate and analyse this data in the form of a suitability map. The publications by the North Ayrshire Council additionally helped to provide vital contextual information for this research.

Limitations

In terms of the overlaying of the available land, this dataset may be less extensive than it potentially could be. This is due to a limitation of the availiable data. As previously mentioned, the 'land available' shapefile only included public land areas. Therefore, there may be privately owned land which could be used for development (contingent on the stakeholders involved). This should be taken forward into further research and exploration. Moreover, another limitation in this research is that since the ambition for this to be a community owned renewable energy system the planning of this development must consider all of the stakeholders involved and potential resistance to hydro-electric systems being developed on the island.

Conclusion

To conclude, spatial analysis with GIS can effectively be used to identify potential areas for development of a small-scale hydro-electric renewable energy scheme on Arran. Results showed that there are hotspots of areas where this could occur, specifically in the western areas of the island. These areas would have close proximity to water sources and electricity, as well as appropriate slope angle. Specific areas were further indicated with the inclusion of available land data. This research has the potential to precede further research investigating the opportunities to develop more small- scale hydro-electric schemes on private land on Arran.

Appendix and Installed Libraries

```
pip install contextily
```

Show hidden output

```
pip install mapclassify
```

Show hidden output

```
import numpy as np
import pandas as pd
import matplotlib as plt
%matplotlib inline
import geopandas as gpd
import contextily as ctx
import rasterio as rio
from rasterio import plot
```

```
import rasterio
```

```
import geopandas as gdp
```

```
pip install geopandas mapclassify
```

Show hidden output

```
import rasterio
```

```
pip install rasterio
```

Show hidden output

```
pip install contextily
```

Show hidden output

```
import matplotlib.pyplot as plt
%matplotlib inline
```

```
plt.rcParams['figure.figsize'] = (10, 10)
```

```
!jupyter nbconvert --to pdf IRP_GEP.ipynb
```

Show hidden output

```
!pip install nbconvert==6.5.4
```

Show hidden output

```
pip install geopandas
```

Show hidden output

```
pip install bibtexparser
```

Show hidden output

References

Arran Community Renewables (2024), Available at: https://www.arranrenewables.com/about

Copernicus.eu(2024), Coastal Zones Land Cover/Land Use 2018 (vector), Europe, 6-yearly-GDB, Available at: https://eur01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fcopernicus-fme.eea.europa.eu%2Fclmsdatadownload%2Fresults%2F132081.zip&data=05%7C02%7Cgp99%40st-andrews.ac.uk%7Ce4e42d863d034babae2e08dd18778c7d%7Cf85626cb0da849d3aa5864ef678ef01a%7C0%7C0%7C638693623918087179%7CUnknown%7CTWFpbGZsb3d8eyJFbXB0eU1hcGkiOnRydWUsIlYiOiIwLjAuMDAwMCIsIlAiOiJXaW4zMiIsIkFOIjoiTWFpbCIsIldUIjoyfQ%3D%3D%7C0%7C%7C%7C&sdata=u8NSwh5jYboD82B4CRMbzCAU%2FvGfiA1NqIsonwyetnE%3D&reserved=0

Eurographics, EURODEM, Available at https://www.mapsforeurope.org/datasets/euro-dem

Larentis, D, Collishon, W, Oliveria, F, Tucci, C, (2010), GIS potential for hydropower potential spotting, Energy, Volume 35, Issue 10, https://doi.org/10.1016/j.energy.2010.07.014

Serpoush, B, Khanian, M, Shamshai, A, (2017) Hydropower plant site spotting using geographic information system and a MATLAB based algorithm, Journal of Cleaner Production, Volume 152, pp7-16

North Ayrshire Council, Policy for community benefits for renewable energy development (2024), North Ayrshire Council, https://www.north-ayrshire.gov.uk/documents/policy-community-benefits-renewable-energy-development

St Helena Government (2013), St Helena Energy Statement, Available at https://www.sainthelena.gov.sh/wp-content/uploads/2019/11/161025_St-Helena-Government-Energy-Strategy-FINAL-October-2016.pdf

Saima, F, Talkduer, T, Rimon, Muksituzzaman, Ali, J,(2022) Renewable Power System Calculation and Management for Remote Island, International Confrence for Convergence in Technology https://doi.org/10.1109/I2CT54291.2022.9824000

UK Government (2024), Harnessing Hydroelectric Power Guidance, Available at https://www.gov.uk/guidance/harnessing-hydroelectric-power