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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Abstract:

A key area of development for the Isle of Arran is creation of community owned, sustainable renewable energy. This is an important goal of the local North Ayrshire government (North Ayrshire Council, 2024). Hydro-electricity on Arran is an area which has large amounts of potential, with this aim in mind. This project intends to indentify areas in which this development could occur using spatial analysis. Multi-Criteria Evaluation will be used to do this by assessing various factors that need to be considered when identifying these areas. A suitability map will be developed to visualise this. Data on available land will then be used to overlay the Suitability Map in order to identify tangible and specfic areas for construction.

Keywords:

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')
```

```
Drive already mounted at /content/drive; to attempt to forcibly remount, call drive.mount("/content/drive", force_remount=True).
```

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

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

```
import rasterio
```

```
import geopandas as gdp
```

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Introduction

The purpose of this research was to identify an appropriate area for the development of potential hydroelectric renewable energy systems on the Isle of Arran. The Isle of Arran is a small island off the West Coast of Scotland, in the region of North Aryshire. It has a population of approximately 5000 people. A signfiicant 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 moderately cheap option. It has been identified as the most appropriate method to do this considering Arran's specific geographic traits. This proposed hydro-electric scheme would likely be a river-run off project due to 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 in which there has been an abudance of research into. In these cases there are usually numerous stakeholders within the community who must also be considered in this planning. Similar development to this proposed project was done in the Overseas British territory of St Helena by their government. This was with the similar aim of allowing the island to be self-sufficient in terms of renewable energy. It is acknowledged that Islands tend to be generally more reliant as a result of to their isolation. Substantive efforts must therefore be made to combat this. Thus, this proposed development aims to solve these similar issues for the Isle of Arran.

Figure 1: Isle of Arran Map This figures provides contextual information of the Isle of Arran, showing it to be a small 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()
```


```
pip install geopandas mapclassify
```

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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: Rivers Analysis (50m)

Using the rivers file obtained from the North Ayrshire Council Data Portal I downloaded the shapefile into QGIS. This provided a map of all of the rivers, and thus potential water sources on Arran. Then I converted this vector layer 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 considering the scale of this project being relatively small, projects of similar scale also use this distance . Finally, this layer was normalised using the raster calculator.

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. Given the remote and rural nature of Arran this assumption is more further supported, as it is unlikely powerlines would be located elsewhere. Therefore, 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 calculatoin.

Method 3: Slope Constraint (under 50degrees)

There is conflicting literature surrounding benefits and limitations of constructing hydro-electric dams on slope angles. 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 under 50 degrees would be optimal. 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. 50 degrees is considered a steep slope. 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 and the 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 degrees as unsuitable.

Method 5: Overlay of available land

Using Python the suitability map was overlain with the areas of available land sourced from the North Ayrshire Open data portal. This data was clipped to only include 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

```
import rasterio
```

```
pip install rasterio
```

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```
pip install geopandas
```

Show hidden output

```
pip install contextily
```

Show hidden output

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 aiming to be 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 ("Width")
plt.ylabel ("Height")
plt.colorbar(label= "Rivers distance")
plt.show()
```

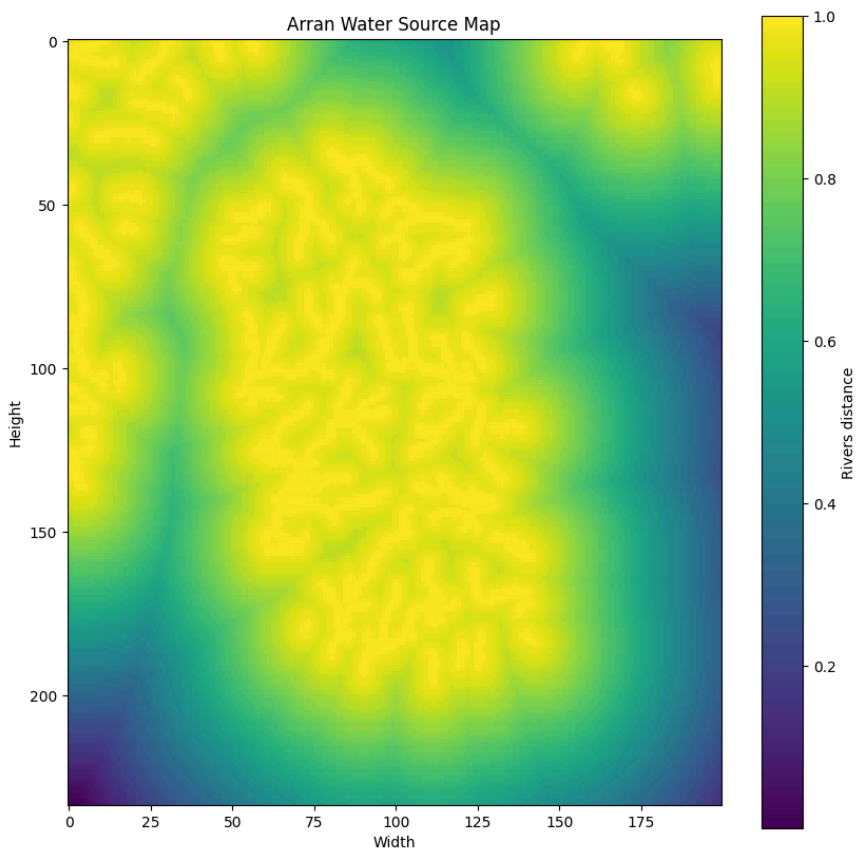

Figure 3: Proximity to Electricity Map

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 raods. 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 ("Width")
plt.ylabel ("Height")
plt.colorbar(label= "Powerlines distance")
plt.show()
```

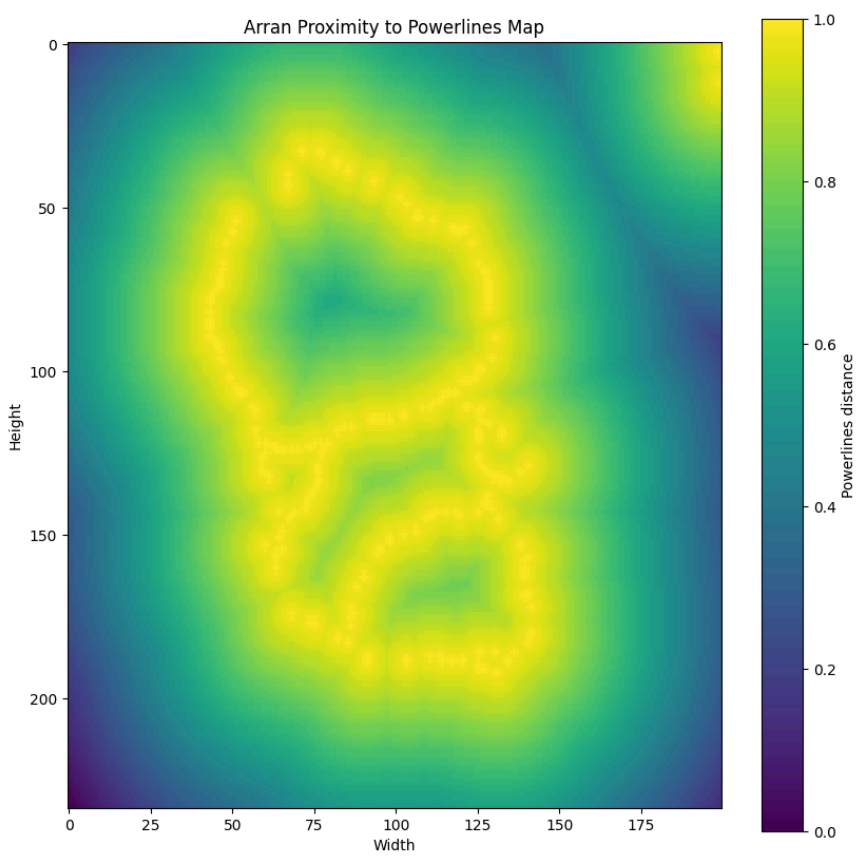

Figure 4: Elevation/Slope Constraint

Slope was used as a constraint for this multi-criteria evaluation. It was decided any area with a slope angle of less than 50 degrees would not be appropriate for development. This 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 assocaited benefits of developing hydro-electric systems on relatively high slope angles, make this a suitable choice. The figure shows the areas in black as not being below 50 degrees. 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.bar("label= 0= slope above 75, 1= slope below")

plt.show()
```

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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 not suitable areas are 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 degrees.

```
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()
```

Show hidden output

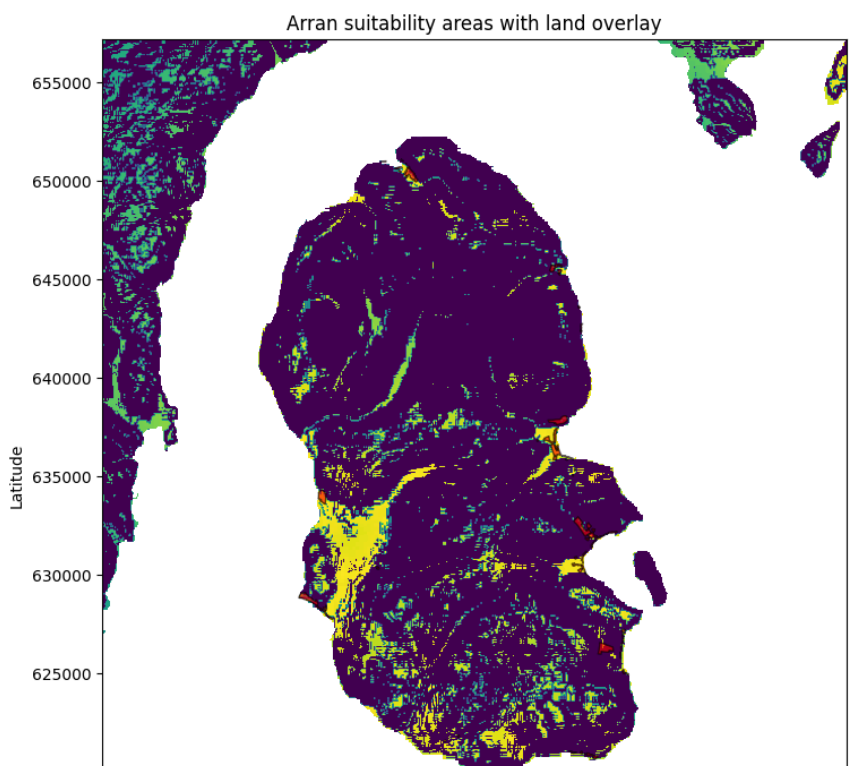
Figure 7: Overlay of available land This data was overlain onto a map of the island.

```
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("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 identified areas suitable for development. The most suitable locations are in the West of the island in the Shiskine Valley 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()
```



Discussion

Addressing research question in context of literature

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 in the Shiskine Valley or Machrie area. This is suitable in terms of access to a water source and electricity, both evidently vital elements of a Hydro-electric renewable energy system. The slope angle of these potential areas will also not be below 50 degrees. Furthermore, these areas have prospects of public areas available for development.

Advantages

The data for this project was easy to access on the North Ayrshire Data Portal allowing me to manipualte and analyse this data in the form of a suitability map.

Limitations

In terms of the overlaying of the available land, this may be less extensive than it could be. This is a limiation of the data available. As previously mentionned 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 as this is aims 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