

Evaluating the Use of GIS Software as a Modelling Tool for Environmental Analysis

GIS and Data Analysis
Environmental Conservation
M6X01081
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1.0 Introduction

Geographic Information Systems (GIS) are a useful tool in analysing geographical, social and environmental trends and changes over spatio-temporal dimensions (Heywood, et al., 2011; Mason, 2019). Primary and secondary data with a geographic reference can be taken from excel spreadsheet format and applied into GIS allowing the data to be visually represented across geographic regions, allowing for analysis that can potentially explain more than if kept in database format (Heywood, et al., 2011; Mason, 2019). This report will create thematic visual maps using socio-economic and environmental footprint data to describe and assess the uses of GIS in these fields.

2.0 Overview of GIS

Geographical Information Systems (GIS) since their inception have become a widely used and valuable tool that can be used across wide applications, ranging from social sciences and economics to agriculture and ecology (Swetnam, et al., 2017; Higgs, et al., 2015). It can help draw conclusions about why particular trends are happening within society – for example health and illness – while also helping analyse impacts that humans may have upon the environment. A key feature of GIS is mapping, GIS uses two differing map types that can be read by computers (Ordnance Survey, 2018);

1. Raster maps – The area in question is shown in pixelated format, the data for that area is stored in each pixel giving high data volume for that map. Problems include when scaling down an image, features may become unrecognizable or lost.
2. Vector – A series of points, lines or polygons that together can create maps using points with the co-ordinates of a given area. It allows for accurate representations of boundaries and features and allows for attribute data to be added to a point, line or polygon.

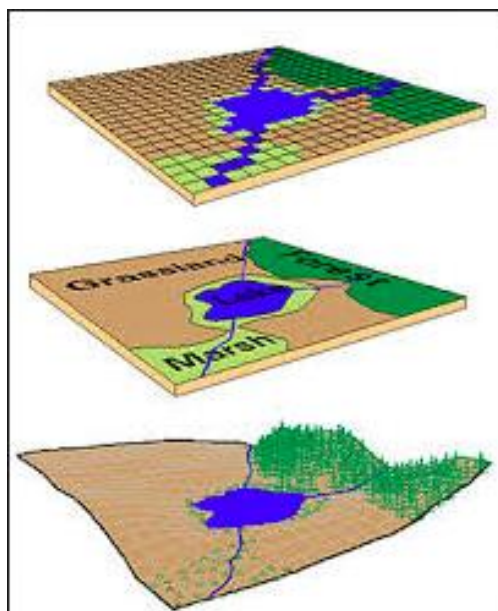


Figure 1 Raster and Vector Map Images. Top layer is Raster seen as pixelated image. Second layer is Vector, seen as a combination of lines and polygons. Bottom layer is the real world image that the other layers are representing. (Geospatial Innovation Facility, Berkeley, N/A)

GIS allows for the use of multiple data sets in a geo-spatial visual framework so that patterns, trends and conditions can be identified to assist in policy creation and decision making (Heywood, et al., 2011). GIS can work in multiple dimensions - two dimensional through the use of x, y, co-ordinates, 3 dimensional which uses z, as depth or height – this is the spatial data of GIS that indicates locations and gives maps (Heywood, et al., 2011; University of Southampton, 2018). Temporal data can also be applied to GIS, this is where the aspect of time is introduced into the data, this is highly valuable as it allows trends and patterns over a period of time to be identified (Heywood, et al., 2011). Thematic data in the form of qualitative or quantitative data, can help describe the characteristics of a given location according to a particular theme, for example census data of age ranges in a particular location (Heywood, et al., 2011). These data types are combined in GIS to allow for models to be created, meaning trends and patterns in a certain area can be viewed in spatial, temporal and thematic frameworks (University of Southampton, 2018).

2.1 Previous Studies

The use of data to create maps makes it an invaluable tool for environmental analysis of all types. Environmental analysis is the process of identifying factors that may have an impact on the surrounding environment . The use of GIS to assist environmental analysis is commonplace, Yalaw, et al. (2016), used GIS to evaluate land suitability for crop production in the Abbay Upper Blue Nile basin in Ethiopia. Criteria were identified for suitable crop growth and processed into raster layers which was then effectively used to identify the best suited areas in that region.

Its application is also readily used in environmental impact assessments; Tayyebi, et al. (2015) used GIS to create spatio-temporal mapping to look at the effects that past and future land uses in the Ohio river basin will have on the freshwater resource. This study used historical thematic data and applied it into a spatio-temporal model as an assessment tool to predict future impacts and effects of land use in the region.

Though GIS is largely used around an environmental-spatial context, its use in analysing data can be applied to an anthropogenic setting. GIS can help identify causes of health problems though correlation with certain environmental conditions and geographical position (Shaw & McGuire, 2017). This application is seen through a study by Moreno-Jimenez, et al., (2016) that identify area's in Madrid and Barcelona that are most effected by Nitrous Oxide pollution. Data collected of worst polluted areas is correlated with thematic data of the populations in those areas to identify the most at risk groups of people. This analysis can helped introduce measures that will reduce the health implications for the at risk members of society, such as lowering of speed limits or congestion charges.

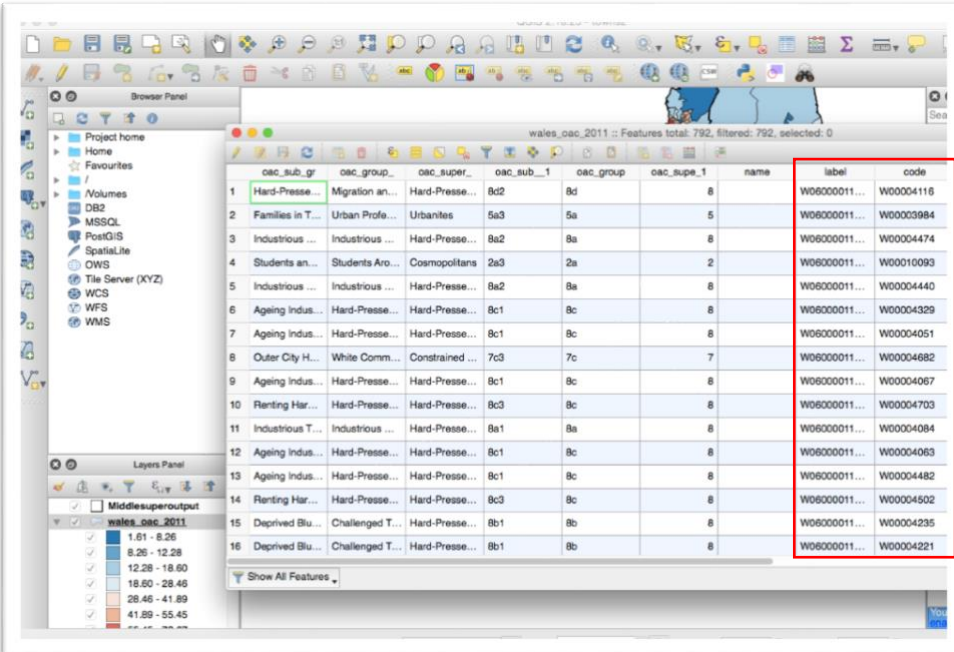
This report will consider the uses of GIS in a social and environmental context, with focus on thematic mapping in areas of Swansea, South Wales. Available national data will be processed and applied into GIS, followed by an analysis of the findings and a review into the uses of GIS. This report uses QGIS 2.18 Las Palmas, geographical information system.

3.0 Townsend Depravity Index

This section applies the Townsend deprivation index to the City and County of Swansea area. The Townsend deprivation index is an equation which uses four data statistics to show the material deprivation of individuals or households over an area (Townsend, et al., 1986). The four variables are: 1. Percentage of economically active residence 2. Percentage of households without a car 3. Percentage of households with more than one person per room 4. Percentage of non-owner occupied houses (Townsend, et al., 1986). Secondary Geo-demographic UK census data is collected from UK Data Service, website via the InFuse 2011 Population Statistics section. The data collected and method for calculation is shown in Appendix 1.

3.1 Application into Thematic Visual Map

To allow for the data to be made into a visual representation a number of Vector maps must be downloaded and added into the GIS workspace. The maps can be obtained from the UK Data Service (2011) website, for this project 4 boundary maps of the region of Swansea were downloaded: 1. Swansea Output Area Classification 2. Lower Super Output 3. Middle Super Output 4. Census Merge Wards. The Townsend spreadsheet contains Geocode/Geolabel which correlates with the code/label in the Swansea OAC vector map as can be seen in Figure 2 and 3.

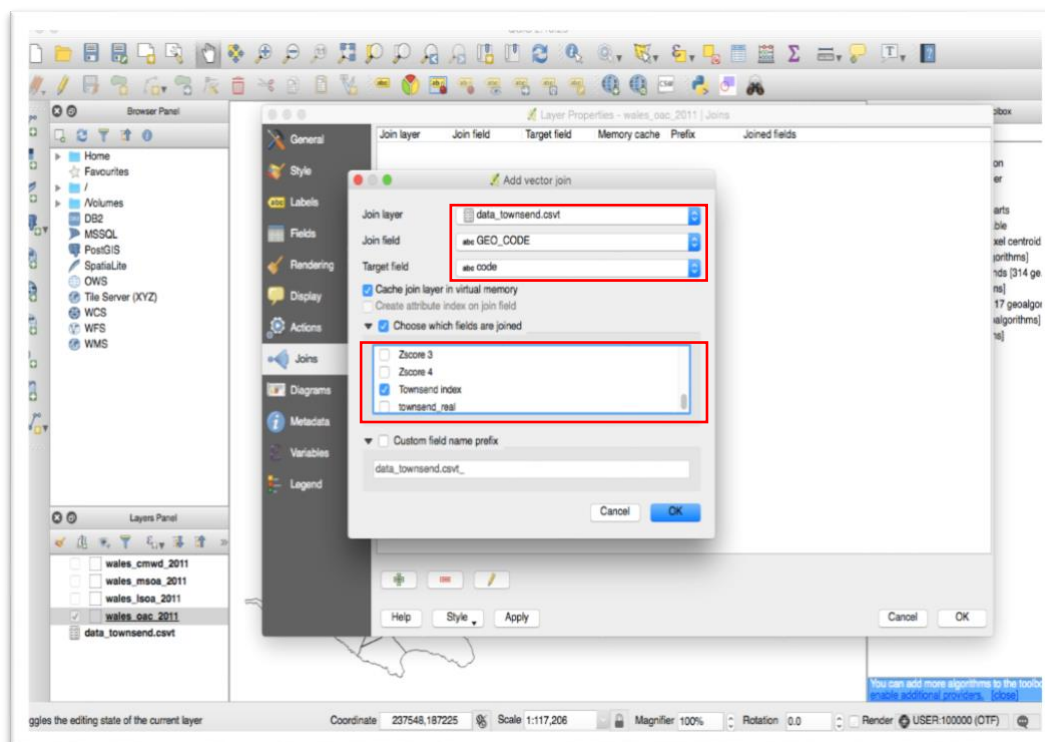


oac_sub_gr	oac_group	oac_super	oac_sub_1	oac_group	oac_supe_1	name	label	code
1	Hard-Press...	Migration an...	Hard-Press...	8d2	8d	8	W06000011...	W00004116
2	Families in T...	Urban Profe...	Urbanites	5a3	5a	5	W06000011...	W00003984
3	Industrious ...	Industrious ...	Hard-Press...	8a2	8a	8	W06000011...	W00004474
4	Students an...	Students Aro...	Cosmopolitans	2a3	2a	2	W06000011...	W00010093
5	Industrious ...	Industrious ...	Hard-Press...	8a2	8a	8	W06000011...	W00004440
6	Ageing Indus...	Hard-Press...	Hard-Press...	8c1	8c	8	W06000011...	W00004329
7	Ageing Indus...	Hard-Press...	Hard-Press...	8c1	8c	8	W06000011...	W00004051
8	Outer City H...	White Comm...	Constrained ...	7c3	7c	7	W06000011...	W00004682
9	Ageing Indus...	Hard-Press...	Hard-Press...	8c1	8c	8	W06000011...	W00004067
10	Renting Har...	Hard-Press...	Hard-Press...	8c3	8c	8	W06000011...	W00004703
11	Industrious T...	Industrious ...	Hard-Press...	8a1	8a	8	W06000011...	W00004084
12	Ageing Indus...	Hard-Press...	Hard-Press...	8c1	8c	8	W06000011...	W00004063
13	Ageing Indus...	Hard-Press...	Hard-Press...	8c1	8c	8	W06000011...	W00004482
14	Renting Har...	Hard-Press...	Hard-Press...	8c3	8c	8	W06000011...	W00004502
15	Deprived Blu...	Challenged T...	Hard-Press...	8b1	8b	8	W06000011...	W00004235
16	Deprived Blu...	Challenged T...	Hard-Press...	8b1	8b	8	W06000011...	W00004221

Figure 2 Geocode and Geolabel on the Swansea OAC Vector Map

	A	B	C	D	E	F	G	H	I	J	K	L
	CDU_ID	GEO_CODE	GEO_LABEL	GEO_TYPE	GEO_TYP2	F248 16-74	F256 16-74	F260 16-74	F267 Full Tin	F557 Full Tin	F559 Full Tin	F989 T
1	286653	W00003947	W00003947	Output Area: OASA		2	33	59	5	6	5	
2	286654	W00003948	W00003948	Output Area: OASA		4	29	72	4	4	14	
3	286655	W00003949	W00003949	Output Area: OASA		2	21	45	3	4	10	
4	286656	W00003950	W00003950	Output Area: OASA		7	33	57	4	7	9	
5	286657	W00003951	W00003951	Output Area: OASA		3	29	59	3	5	5	
6	286658	W00003952	W00003952	Output Area: OASA		2	27	38	9	6	7	
7	286659	W00003953	W00003953	Output Area: OASA		4	26	54	4	9	8	
8	286660	W00003954	W00003954	Output Area: OASA		3	30	72	3	0	8	
9	286661	W00003955	W00003955	Output Area: OASA		2	23	58	4	7	8	
10	286662	W00003956	W00003956	Output Area: OASA		6	34	72	1	11	19	
11	286663	W00003957	W00003957	Output Area: OASA		5	13	57	1	4	6	
12	286664	W00003958	W00003958	Output Area: OASA		8	32	84	10	15	15	
13	286665	W00003960	W00003960	Output Area: OASA		25	30	50	6	1	6	
14	286666	W00003961	W00003961	Output Area: OASA		5	36	114	8	0	7	
15	286667	W00003962	W00003962	Output Area: OASA		4	32	74	4	4	9	
16	286668	W00003963	W00003963	Output Area: OASA		9	47	100	9	6	15	
17	286669	W00003964	W00003964	Output Area: OASA		7	46	72	4	5	6	
18	286670	W00003965	W00003965	Output Area: OASA		20	28	52	2	1	4	
19	286671	W00003966	W00003966	Output Area: OASA		6	30	85	0	4	15	
20	286672	W00003967	W00003967	Output Area: OASA		8	21	56	6	0	3	
21	286673	W00003968	W00003968	Output Area: OASA		13	28	75	3	2	6	
22	286674	W00003969	W00003969	Output Area: OASA		12	31	65	3	0	10	
23	286675	W00003970	W00003970	Output Area: OASA		12	38	83	11	0	5	
24	286676	W00003971	W00003971	Output Area: OASA		9	38	69	3	4	8	
25	286677	W00003972	W00003972	Output Area: OASA		22	34	61	6	1	5	
26	286678	W00003973	W00003973	Output Area: OASA		3	41	89	8	5	6	
27	286679	W00003974	W00003974	Output Area: OASA		8	28	92	5	3	6	
28	286680	W00003975	W00003975	Output Area: OASA		20	51	60	3	3	4	
29	286681	W00003976	W00003976	Output Area: OASA		10	23	52	3	0	2	
30	286682	W00003977	W00003977	Output Area: OASA		18	35	36	2	2	5	
31	286683	W00003978	W00003978	Output Area: OASA		7	26	56	4	7	6	
32	286684	W00003979	W00003979	Output Area: OASA		5	14	34	1	2	8	

Figure 3 Geocode and Geo Label on Townsend Data Spreadsheet.

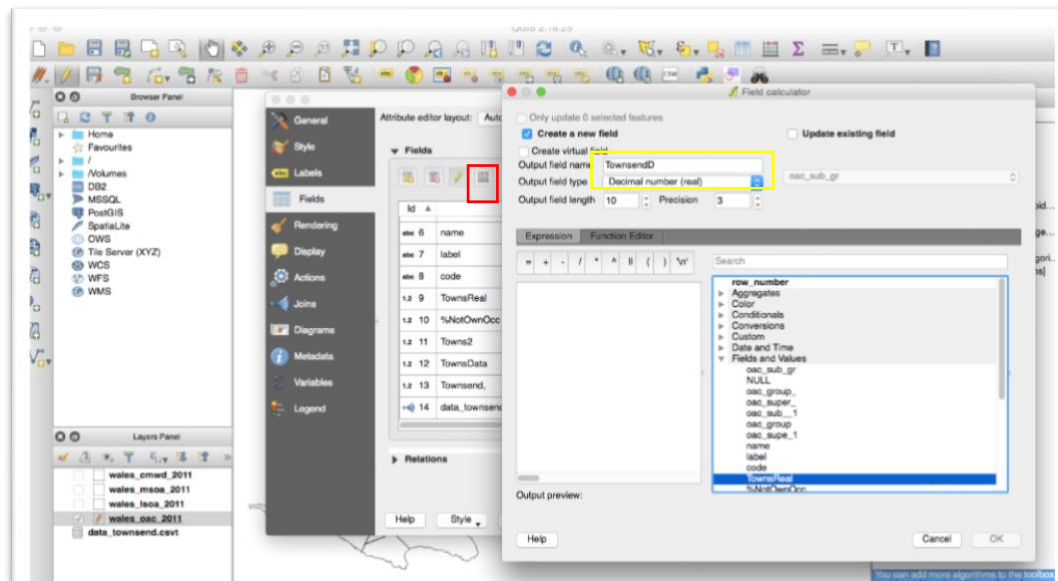


Properties>Joins>Join Layer: Townsend>Join Field: Geocode>Target Field: Code>Choose Field: Townsend

Figure 4 Joining OAC Layer with Townsend. Method for joining the two layers. Geocode matches the code field, Townsend is the chosen field to be added to the layer.

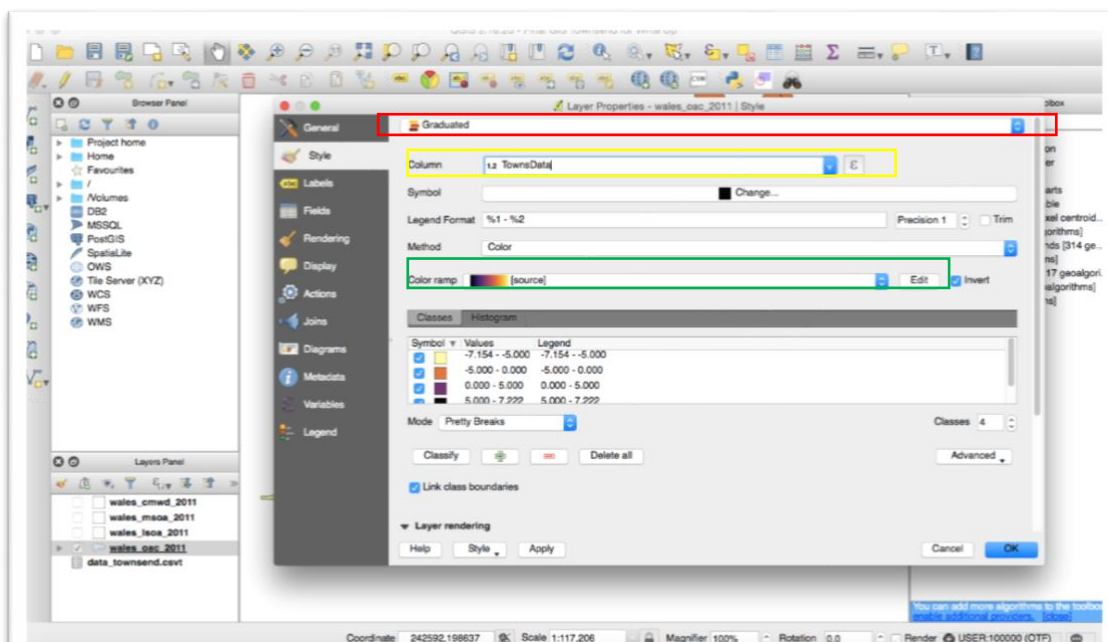
Figure 4 shows the method for attaching the layers and chosen field. Townsend data is now attached to the Swansea output layer, however it needs adjusting as it is present in String

format Real (decimal number) format allows for the data to be seen as visual thematic representation, as seen in Figure 5.



Properties>Field>Toggle Format (red) >Output Field Name: Townsend and Output Field Type: Decimal Number (Yellow)>Fields and Values: Townsend

Figure 5 Changing the Format of the Townsend Data



Properties>Style>Graduated (red)> Column: Townsend Data Real (Yellow)> Colour Ramp: Choose Colour Scheme (Green)>Classify (Blue)

Figure 6 Applying Townsend Data Into Visual Representation

Figure 6 shows how to visualise the data, once applied the Townsend Data will be visually represented into the Output Areas according to colour code. Townsend Index scores areas with higher depravity with a higher score, areas with lower depravity with a lower score (Townsend, et al., 1986). This can be seen in Figure 11 where the darker colours represent the areas of lower depravity, while the lighter colours show areas of greater affluence.

Legend

Swansea Census Merge Wards
Townsend Index

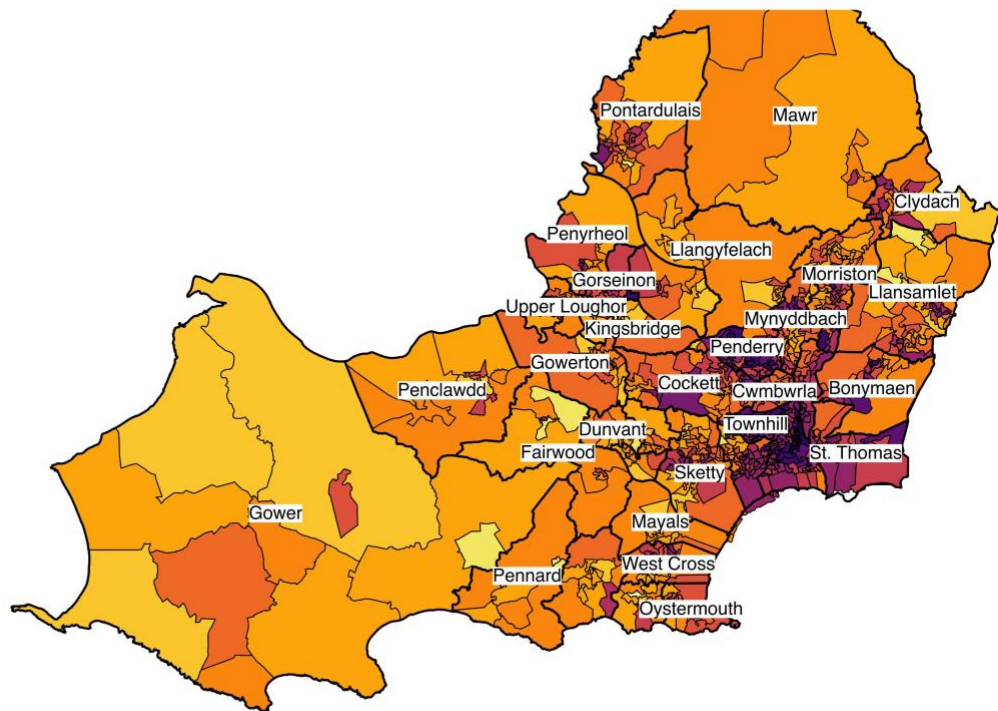
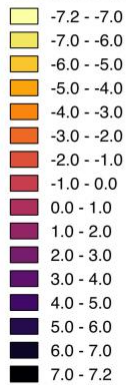


Figure 7 Swansea Region with Townsend Data Applied to Census Output Areas (QGIS Development Team, 2016)

3.2 Analysis

Figures 8 and 9 shows that the highest areas of deprivation in Swansea be found in the centre of Swansea. The areas of Penderry, Townhill and Castle have a higher depravity score, reaching 1.2 or higher on the Index. St Thomas, Uplands, Landore, Clydach, Bonymaen and Gorseinon also show high levels of depravity with a number of areas scoring 0 or above. The less deprived areas are found towards the Gower ward including Fairwood, Mayals and Dunvant all scoring -3 or less, and in the surrounding suburbs of Swanea including Llansamlet and Clydach.

Legend

Townsend

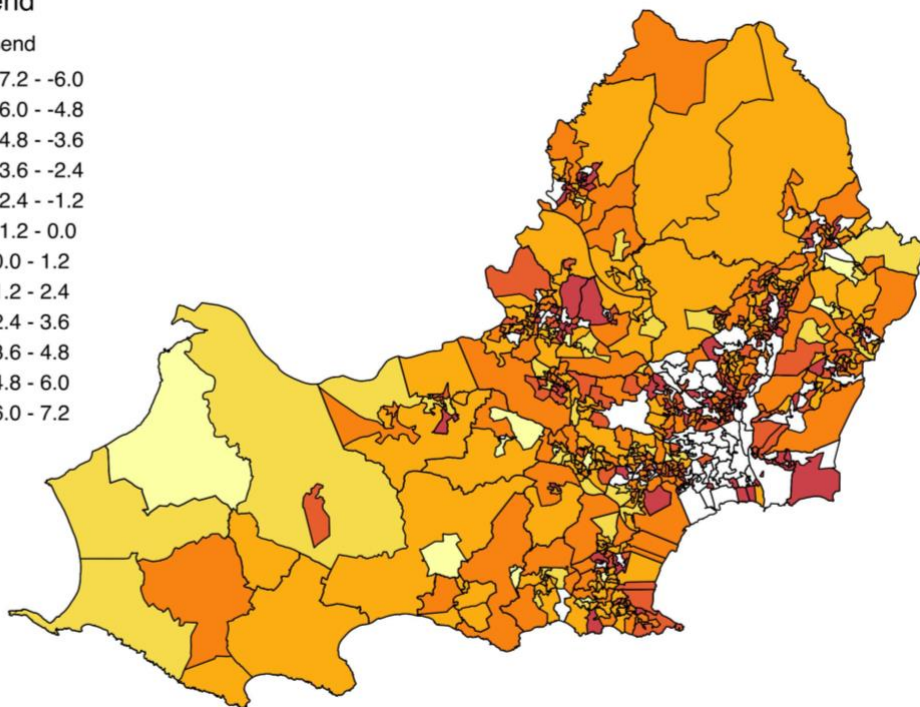
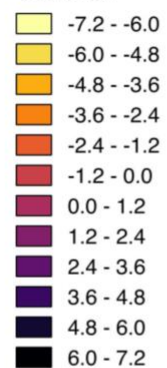


Figure 8 Swansea Townsend Depravity Index Score 0 or lower

Legend

Townsend

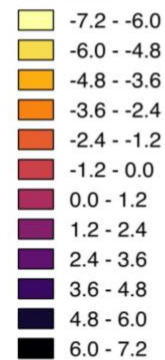


Figure 9 Swansea Depravity Score 0 or Higher

The Index created suggests the areas of Oystermouth, Langland and Caswell are in the mid-range for depravity, however the Welsh Indices of Multiple deprivation puts these areas as as some of the most affluent in Wales (Stas Wales, 2014). The Townsend Index does not include persons above the age of 65 in its calculation, age data from UK Data Service shows that in Mumbles/Newton/Caswell up to 30% of the population are above the age of 65 excluding them from the Townsend Index (UK Data Service, 2011). The lack of inclusion of people in this age bracket may contribute to the unexpectedly lower Townsend scores in these areas, potentially skewing the results and suggesting it to be an unreliable index for deprivation.

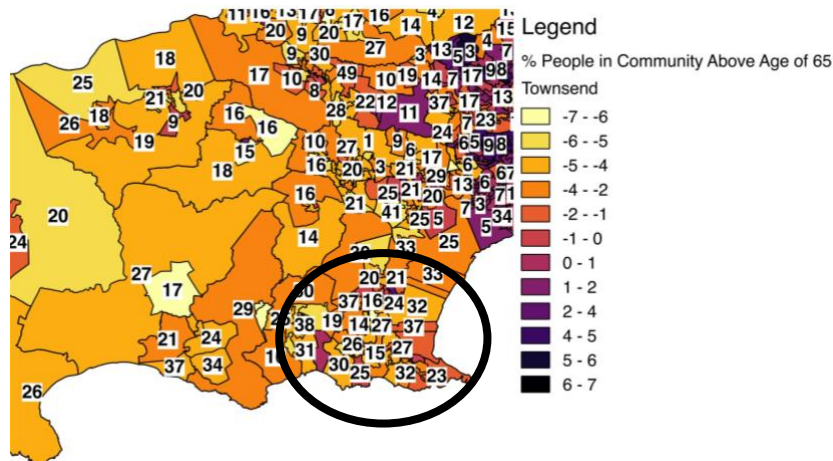


Figure 10 Percentage of Population over the Age of 65

Further criticisms can be made over the use of Car Ownership as a variable for the Index. Christie & Fone (2003), suggest that the car ownership variable is a invalid indicator for depravity. The problem is that if living in a densely urbanised areas access to public transport is easier than that of rural areas and proximity to shops and work is closer, meaning that car ownership is not a necessity, though they may still have higher material wealth. In rural areas car ownership is more of a requirement, meaning that although someone does not have as much material wealth they are more likely to own a car (Christie & Fone, 2003). Figure 8, use histograms to show the 4 paramaters of the Townsend Index, as can be seen the rates of people with no car in rural locations such as Gower, are significantly lower than that of people close to Swansea center supporting Christie & Fone's (2003) critique.

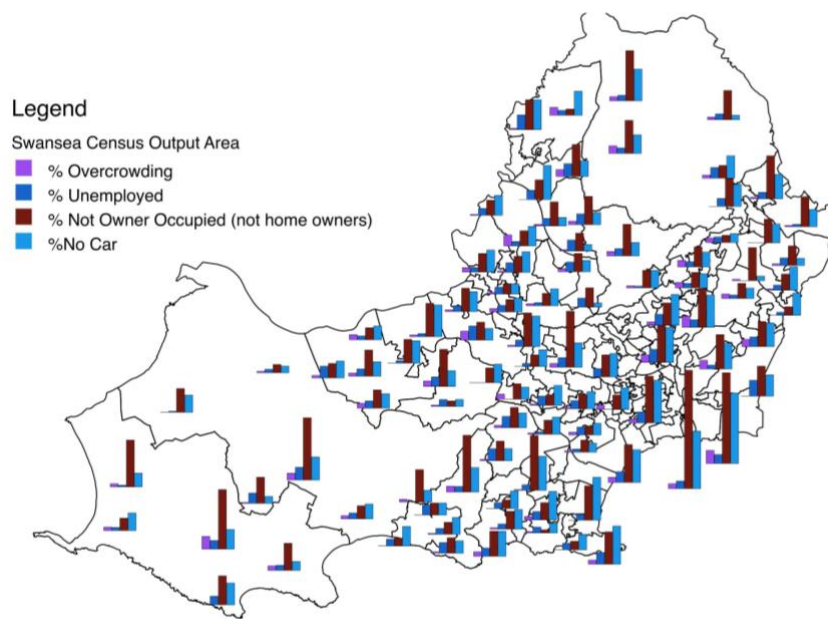


Figure 11 Histograms of the Four Townsend Parameters

The use of Histograms within GIS allows for the user to see what parameters contribute the most to the rates of deprivation. Throughout Swansea, % Not Owner Occupied is consistently highest, this is particularly evident in the areas of Castle, St Thomas and Townhill where the Index shows the highest levels of depravity. In the Oystermouth area levels of Not owner occupied are low, with percentage of people with no car often being higher than owner occupancy. Data from the Office for National Statistics shows that retired people have car ownership as low as 35% for households with one retired person (Office for National Statistics, 2019). As Oystermouth has high levels of older persons (65+), this can be considered to support the evidence that the Townsend score for parts of Oystermouth, Newton and Langland may be skewed by certain aspects of the data collected.

The benefits of GIS in analysing deprivation is clear, it allows for visual representation of depravity using colour codes, allowing for identification of not only affluent and deprived areas but areas that are within the middle boundaries. GIS allows for different index scores to be selected as seen in Figures 8 and 9, to accurately identify the areas where these scores apply. GIS would be useful for governmental strategy in identify areas where affordable housing strategies should be implemented to increase owner occupancy and reduce overcrowding. Figure 10 identifies how other data sets can be added as a layer, explaining the reasons why unexpected results may have occurred or refuting evidence that points to a certain level of depravity. The histogram tool used in Figure 11 helps identify the key factors behind the index scores for each Output area, application of this tool can be used by Regional or National authorities to help target policy towards whatever reason is causing heightened levels of depravity in that area.

4.0 Reap Petite Environmental Data

4.1 Environmental Footprinting

Carbon footprinting is a tool used by environmentalists that quantifies the amount of Carbon produced by an individual – in terms of tonnes/CO₂/equivalent - directly or indirectly, according to their economic decisions and lifestyle choices (Time for Change, 2008). This helps assess the contributions of Carbon Dioxide to the atmosphere that different areas of society provide, while also allowing conclusions to be drawn as to the reasons behind the differing contributions. Ecological footprinting uses the same method, however applies it to the amount of ecological assets that these actions use up (Global Footprint Network, 2019). Ecological footprint is measured in terms of global hectares (gHa), this is the amount of biologically productive land or ocean that is used up through our economic decisions, a deficit occurs once the amount of ecological asset's used outweighs their regenerating potential (Global Footprint Network, 2019).

4.2 REAP Petite

Reap Petite stands for Research of Energy Analysis Program and is a footprint tool created by the Stockholm Environmental Institute that uses data collected from questionnaires to assess the footprint of the individual. The questions relate to 5 different areas, they include:

- Housing
- Travel
- Food
- Shopping
- Activities

Once filled out the data from the questionnaires is added to Excel, the post-codes given on the questionnaire can be adjoined to GIS and the Townsend map created. The questionnaires were filled out by people living in two different post codes; SA1 and SA3 in Swansea.

4.3 Visualising Footprint Data

The Reap Petite data geographic references are the Post codes from which the questionnaires were filled out. To apply the data as a layer into the GIS Townsend Project, the post codes must be applied to a georeferencing point, this requires the acquisition of a data set that contains postcodes within the Swansea region that have a geo-code attached to it. The data set downloaded - NSPD 2018 - in figure 10, contains the corresponding geocodes of each postcode of the lower, middle and output area, along with the easting and northing co-ordinates.

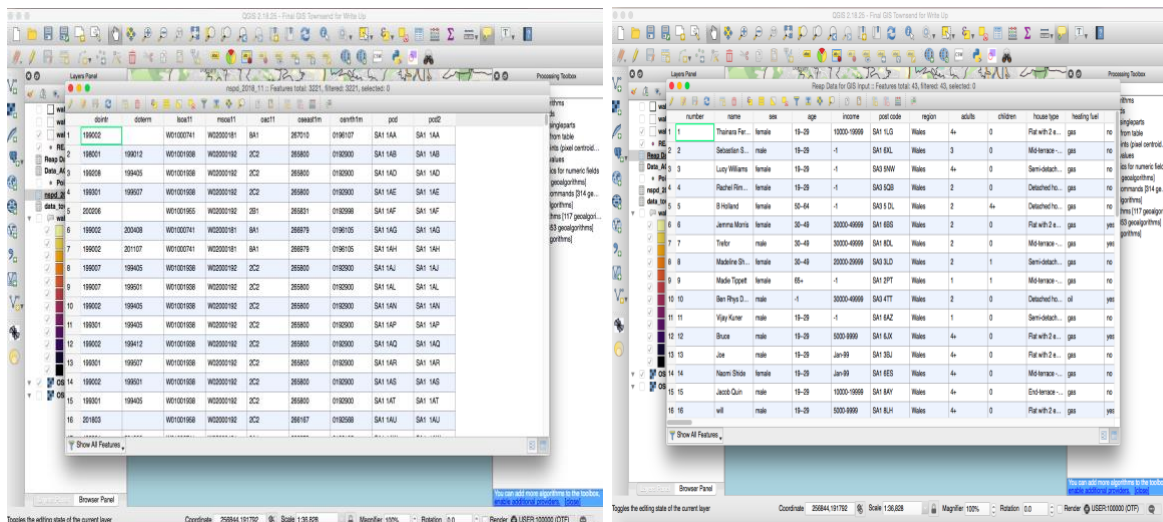
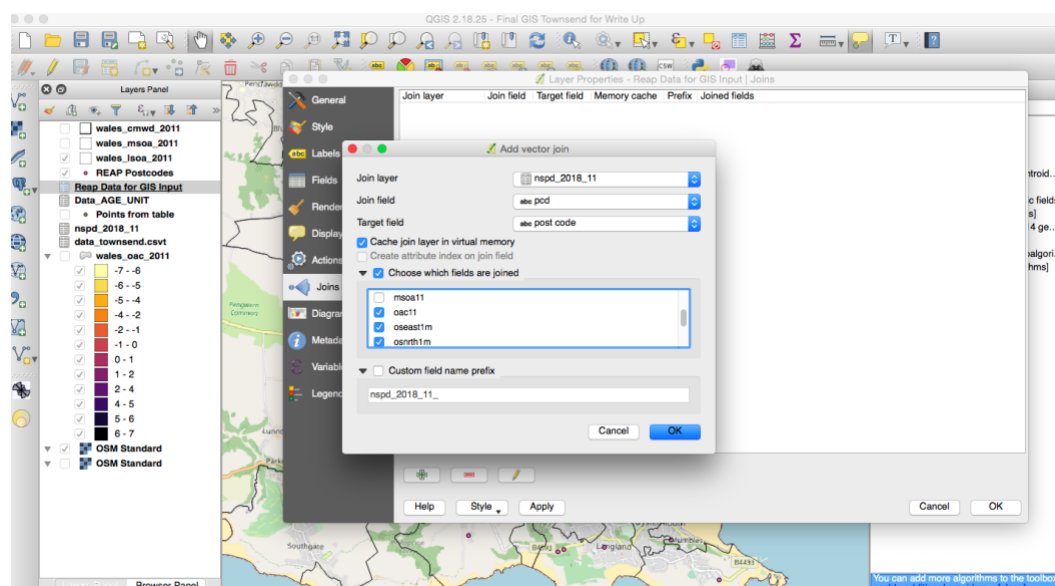


Figure 12 NSPD Swansea Postcodes with Corresponding Geo-codes and Reap Petite Data set

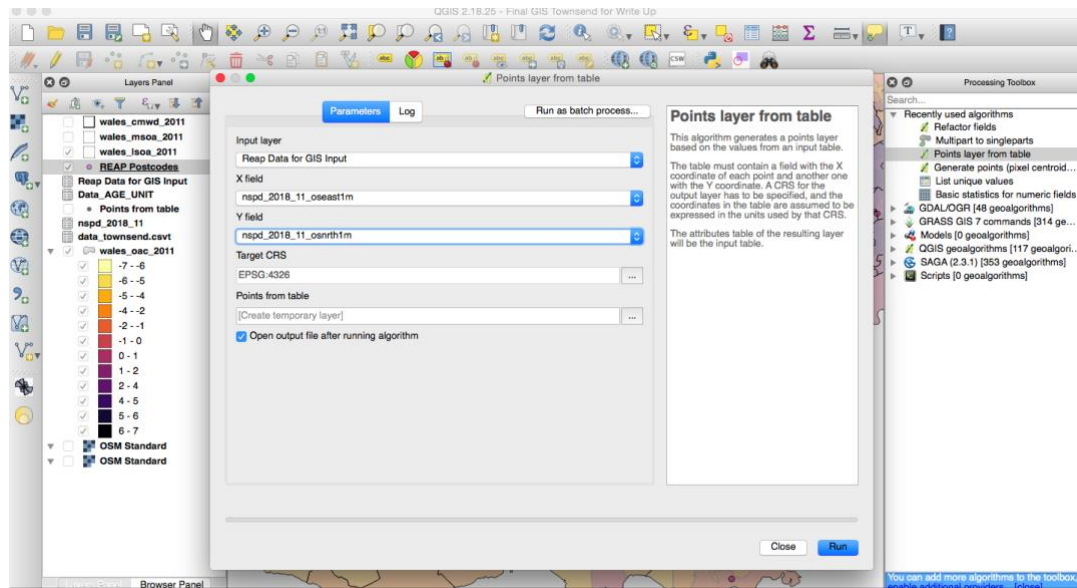
The NSPD Postcode data is then joined to the postcodes in the Reap petite data along with the easting and northing co-ordinates and the geo-codes as seen in Figure 12.



Properties>Join>Join Layer: NSPD>Join Field: Pcd>Target field: Post code>Choose fields: OAC 11, Easting, Northing>Okay.

Figure 13 Joining Postcodes

Once joined it is now possible to create points from the postcodes present in the Reap petite data set by using the Easting and Northing co-ordinates that have been joined.



Reap Data>Toolbox: Points layer from Table> Input: Reap Data> X field: Easting> Y field: Northing> Run

Figure 14 Creating Points from Table

After the application of this process it is possible to see the locations of each postcode from which the footprint data was collected. Using the graduated style and field selection these points can be visually represented in colour scheme according to the size of their footprint.

4.4 Analysis

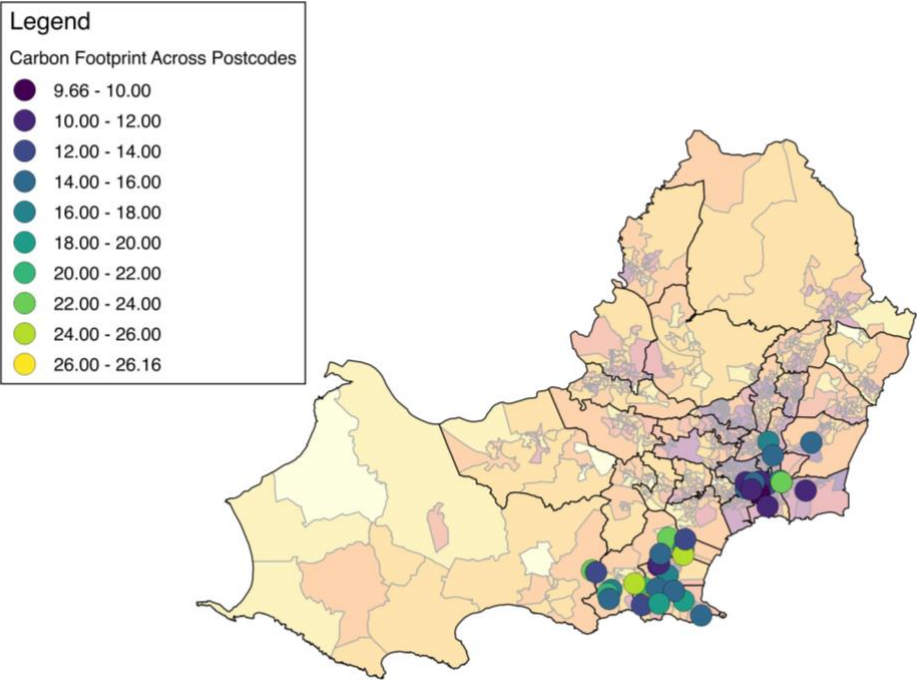


Figure 15Carbon Footprint (t/CO2e) and Locations

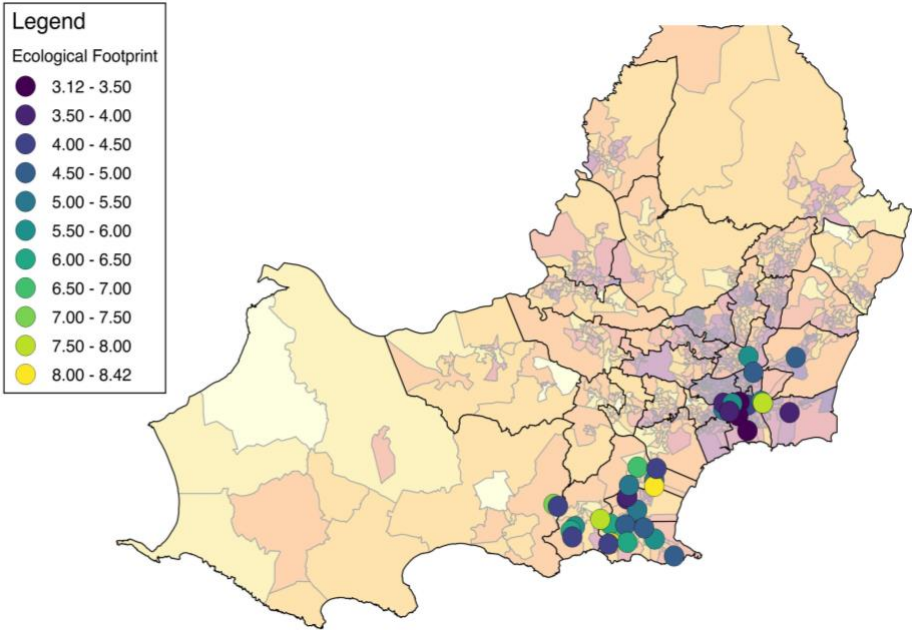


Figure 16 Ecological Footprint (gHa) and Locations

The two maps show the locations of the postcodes collected in the survey. SA1 is located in Swansea centre while the SA3 postcodes are found towards Mumbles and Gower. The points are colour coded according to the size of their footprint. The darker purples indicate lower footprint size, while lighter yellows indicate higher footprint levels. As can be seen in Figure 13 and 14 the footprints in SA1 are consistently lower compared to SA3. The Reap Petite footprint point layer is added on top of the Townsend thematic map. When considered along with the Townsend Index data it is evident that the more deprived areas tend to have lower footprints something that is supported by a number of studies (Druckman & Jackson, 2010; Tukker, et al., 2010).

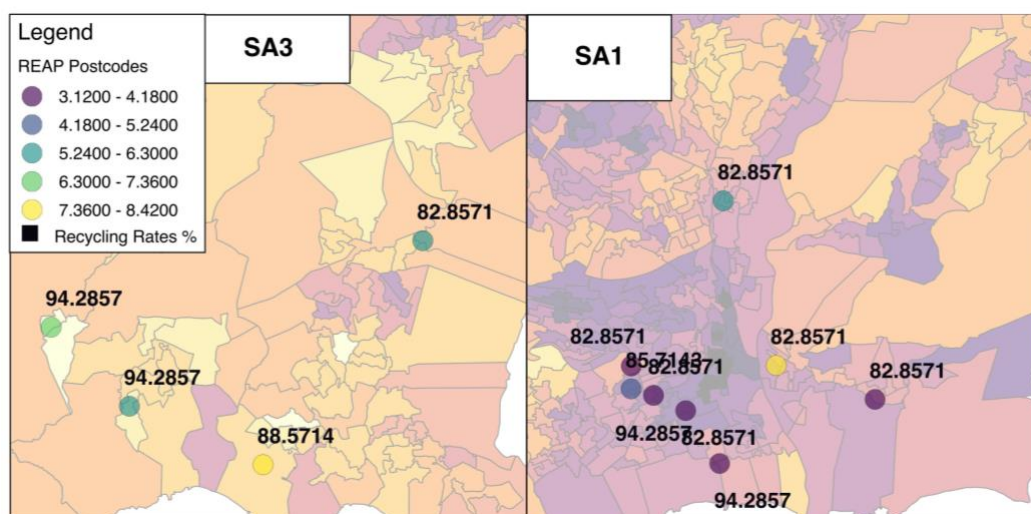


Figure 17 Recycling Rates above 80% in SA1 and SA3

Using the Reap Petite Data in GIS it is possible to look at the recycling rates of individuals across both postcodes. GIS allows the user to filter the data, so that only the highest rates of recycling are shown. Figure 17 shows only 4 people in SA3 recycle above 80% of their total waste, as opposed to 8 people in SA1. Combining this with the Townsend base map below suggests that areas of higher affluence perform worse at recycling by a considerable margin. In the context of environmental management the use of data such as this can be very useful in improving recycling rates over larger areas of the country, focusing policy and management into specific areas that need a more direct approach (Mason, 2019). In this case environmental waste management policy, such as financial penalties for improper recycling or focused education schemes to increase knowledge over the importance of recycling can be implemented.

Though GIS is useful tool, in some areas the use of other software or methods may be more suited to the type of data that is available. Qualitative data has shown to be not easily applied into GIS. The data set for Reap Petite contained phrases such as 'some of the time', 'around that number' and 'probably double' in answer to some of the questions. Use of these phrases within the GIS to describe, for example car use, results in the maps becoming indecipherable even though the information is potentially useful to the user.

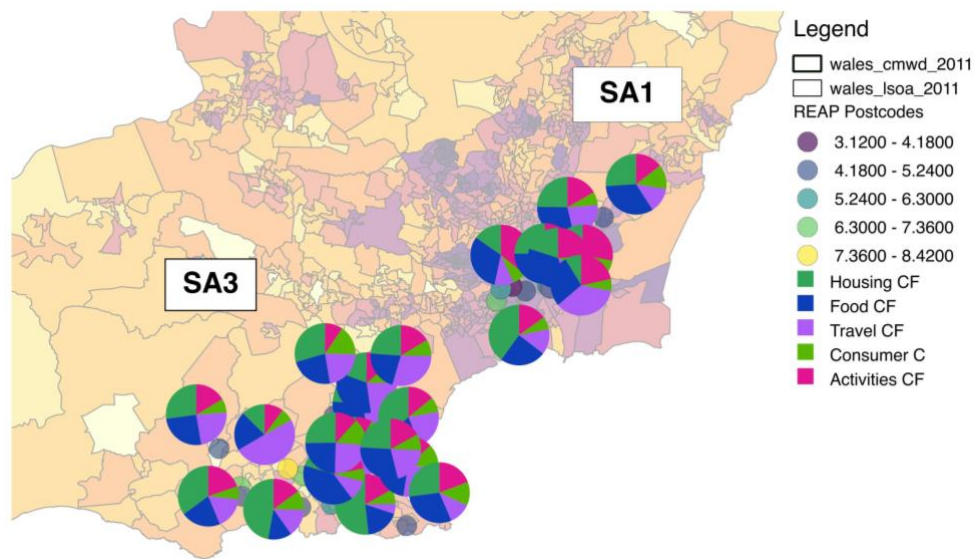


Figure 18 Pie Chart Indicating Areas Contributing to Footprint Size

Figure 18 shows the data is in accordance with the geographic position from which it was taken however it doesn't provide the actual statistic. The lack of accuracy here suggests software such as Excel would be more suited to in depth statistical analysis of the footprints. Figure 18 also shows how large amounts of data being represented onto a region can become indecipherable, with many of the charts being hidden without being able to see the reference point to which they belong.

5.0 Conclusion

This report shows GIS's use in identifying levels depravity and Environmental footprint measurements around Swansea, through not only colour schemes, but through the use of tools such as Histogram mapping, that identifies the contribution of different parameters towards the depravity index. Identifying the areas, but also identifying the reasons why these areas are of higher deprivation or footprints is greatly useful to management planning and policy creation as particular individuals and communities can be focused on, potentially improving the success rate of that policy and lowering the cost of implementation through resource efficiency. The use of data in spatio-visual framework thematic mapping is a highly useful tool that can be applied across a range of sciences allowing for particular conclusions to be drawn that otherwise may not have been possible.

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Data	Formula
'% Overcrowding'	=((Occupancy Rating -2 or less + occupancy rating)/Households) * 100
Bedrooms	
Occupancy Rating -2 or less	
Households	
'% Unemployed'	=(16-74 Unemployed /(Part time + full time + Full time student + Full Time Self Employed with employees + full time self employed no employees)) * 100
Age 16-74 Unemployed	
16-74 Part Time	
16-74 Full Time	
Full Time Student	
Full Time Self Employed with Employees	
Full Time Self Employed No Employees	= (Households no car or van ownership/ Total Households) * 100
'% Car Ownership'	
Total Households	
No car or van	= (Owned houses outright + owns with mortgage or loan) / Total Households
'% Owner Occupied'	
Total Households	
Owned Houses Outright	
Owned With Mortgage or Loan	

Appendix

Appendix A. Townsend Data Types and Formula

Appendix B. Index Formula Continued

Stage 1.	
Var1	Log(%overcrowding +1)
Var2	Log(%unemployed +1)
Var 3	%not Owner Occupancy
Var 4	%NoCar
Stage 2.	
Zscore 1	(Var1 – Mean(Var1))/S.D.(Var1)
Zscore 2	(Var2 – Mean(Var2))/S.D.(Var2)
Zscore 3	(Var3 – Mean(Var3))/S.D.(Var3)
Zscore 4	(Var4 – Mean(Var4))/S.D.(Var4)
Stage 3.	
Index	= Sum(Zscore1 :Zscore4)