

Geographical Information Systems: Location-based Healthcare Information Services

Henry COBBOLD

‘School of Applied Computing’ (SoAC)

University of Wales Trinity Saint David

Swansea, City and Council of Swansea

hcobbold.149234@student.uwtsd.ac.uk

Table of Contents

I.	TABLE OF FIGURES	1
II.	TABLE OF TABLES	2
III.	INTRODUCTION.....	2
IV.	LOCATION-BASED HEALTHCARE INFORMATION SERVICES.....	2
A.	LOCATION-BASED SERVICES.....	3
B.	USING GIS AND LBS TOOLS	4
V.	ANALYSING MENINGITIS THREAT ACROSS SWANSEA.....	5
A.	HEALTHCARE SERVICES	5
B.	SECONDARY SCHOOLS	8
C.	PRIMARY FEEDER SCHOOLS	9
1)	<i>Bishopston Comprehensive</i>	9
2)	<i>Pentrehafod School</i>	11
VI.	DEVELOPING A WEB-BASED GIS TOOL.....	14
VII.	CONCLUSION AND REFLECTION	16
VIII.	REFERENCES AND CITED WORK(S).....	18
IX.	APPENDICES.....	20
A.	ACCESSING SITE LINKS	20

I. TABLE OF FIGURES

Figure 1:	The evolution and move towards mobile GIS services [7]	3
Figure 2:	"Convergence of LBS Technologies" - from Pontikakos et. al [8]	4
Figure 3:	Hospitals Across the City and Council of Swansea	6
Figure 4:	City Hospitals and Townsend Score for the City and Council of Swansea	7
Figure 5:	City Secondary Schools and Townsend Index for the City and Council of Swansea	9
Figure 6:	Townsend Score for Bishopston Comprehensive and Associated Feeder Primary Schools.....	10
Figure 7:	Bishopston Comprehensive Uptake of Meningitis Vaccine (Age 1, 2nd Dose) between 2017-2018.....	10
Figure 8:	Townsend Score for Pentrehafod Secondary School and Associated Feeder Primary Schools	12

Figure 9: City Centre Area Overcrowding	12
Figure 10: Pentrehafoed Secondary School Uptake of Meningitis Vaccine (Age 1, 2nd Dose) between 2017-2018	13
Figure 11: "Vaccinated Population" with herd threshold satisfied [27]. Note: vastly simplified example	14
Figure 12: The Secondary School Browser Visualisation.....	15
Figure 13: Feeder Primary's for Bishopston Comprehensive.....	15
Figure 14: A quick-reference view of school details	16
Figure 15: A view of Hospitals and OAC deprivation.....	16
Figure 16: The Large MSOA Regional Boundaries for Gower.....	17

II. TABLE OF TABLES

Table 1: Typical Mobile Device Cell Range Constraints [2]	2
Table 2: "Key Differences between Desktop GIS and Internet GIS". Table simplified from work by Aziz [7].	4

III. INTRODUCTION

There can be little doubt that the rise of location-specific technologies by means of mobile terminals has vastly increased the opportunities for mobile technology and demonstrated new levels of device usage in the physical environment [1]. Mobile signal triangulation provided by precise technologies such as ‘Enhanced Observed Time Difference’ (E-OTD) [1] or ‘Observed Time Difference of Arrival’ (OTDOA) [1] over broader, more generic digital communication channels such as ‘Global System for Mobile Communications’ (GSM) [1]; has supported the development of a framework that provides precise signal reception to ‘base station’ hardware depending on device proximity [2]. This issue of physical proximity is noted by Kos, Grgic and Sisul [2] who have defined the range constraints of common hardware cells – as illustrated in **Table 1** suggesting that the different ranges have opened up opportunities to reduce device content to as limited a location as “*a small segment of a highway*” [2] or “*the side of a city block*” [2].

Table 1: Typical Mobile Device Cell Range Constraints [2]

Cell Type	Cell Radius (m)
Large microcell	3000-30000
Small microcell	1000-3000
Microcell	100-1000
Picocell	10-100
Nanocell	1-10

IV. LOCATION-BASED HEALTHCARE INFORMATION SERVICES

Whilst such technologies have already been outlined in the mobile service context however, it is important to understand how these systems can be used for data analysis purposes in order to provide a greater insight into public related data. As such, this section first discusses the main issues of Location-based Services (LBS hereafter) and how these locale tools can be used to support more accurate Geographical Information

Services (GIS) platforms and visualisations. Section A. outlines the key literature surrounding this topic whilst Section B. looks at how location-specific services can be applied more precisely within the healthcare context.

A. Location-based Services

LBS were anticipated to experience considerable growth between 2006 and 2010, so much so that it was expected to more than triple its market value in Europe alone during this period [3]. Since this speculative forecast, the rise of systems that amalgamate portable devices and communication technologies that can provide location-based information has massively increased [4],[5]. As previously eluded, this service is concisely described by Junglas and Watson [3] as *“any service that takes into account the geographic location of an entity”* – therefore a concept that requires two or more entities in order to display positional relativity [3]. Virrantaus *et. al* [6] come at a definition LBS from a cellular perspective describing LBS as *“services utilising the ability to dynamically determine and transmit the location of persons within a mobile network”* [6]. This evolutionary path towards agile, mobile location-based geographical services is represented in **Figure 1** whereby the move towards lightweight web platforms and services has increased platform (and location) access to visual mapping services [7].

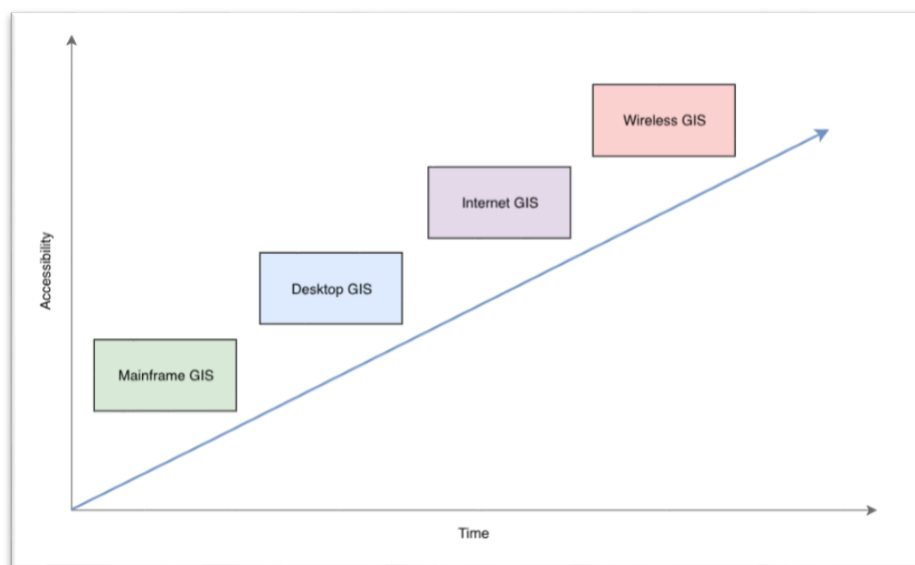


Figure 1: The evolution and move towards mobile GIS services [7]

Given the extensive use of services with which to provide location-specific information, the field is broad and covers a range of technologies and subject areas. This service and field amalgamation can be most clearly seen in **Figure 2** whereby the cornerstones of ‘Internet’, ‘Mobile Services’, ‘GIS’ and ‘Positioning’ converge to *“provide added value to a [given] user service”* [8].

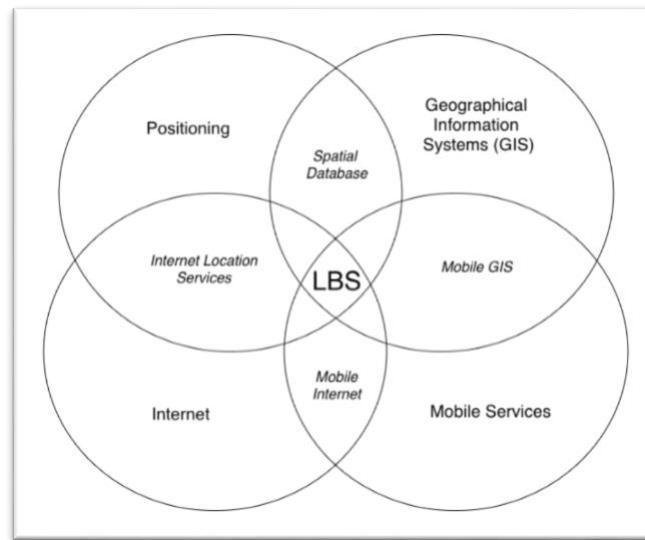


Figure 2: "Convergence of LBS Technologies" from Pontikakos *et. al* [8]

With reference to ‘real-world’ examples of location-based data provision, Virrantaus *et. al* [6] infer that this ubiquitous technology has and will continue to refine the “*here and now*” [6] concept of information access. This ‘anytime’ retrieval facilitates highly tailored results and views on a location and for an audience of any size; a tool made more powerful with a move towards web-based systems. This transition to web-based services sees a range of new platforms and tools used for geographic visualisations – a brief condensed summary of which is presented below in **Table 2** that aims to clearly distinguish between the traditional machine-based platform and accessible, globally available mapping services by means of server-side GIS applications.

Table 2: "Key Differences between Desktop GIS and Internet GIS". Table simplified from work by Aziz [7].

	Visualisation Attributes	Software
Desktop GIS	- Specialist professionals develop and use software - Maps not widely available - Steep learning curve	<i>Proprietary:</i> ArcGIS, GeoMedia, MapInfo, Maptitude
		<i>Open Source:</i> GRASS, MapWindow, Quantum GIS
Internet GIS	- Maps open to public access - Cannot be publicly edited - Reduced spatial analytic capabilities	<i>Proprietary:</i> ArcISM, ArcGIS Server, Manifold IMS
		<i>Open Source Software:</i> CartoWeb, GeoServer, MapServer

B. Using GIS and LBS Tools

Given the importance of GIS and LBS discussed in previous sections it is imperative to understand that there is a clear link between healthcare services and LBS because *“health data is inextricably linked to a specific location”* [9]. The relationship between GIS and LBS was of considerable importance during the early-to-mid noughties with the development of a strong and dependable LBS framework based around existing ‘OpenGIS’ *“modelling and processing”* [6] frameworks. Further standardisation attempts such as ISO 211TC [10] and the refinement of the interoperable XML-based GML (Geographical Mark-up Language) [6] have helped to clearly recognise the *“high importance of LBS”* [6] to the field of Geographical Information Science [11].

Schuurman, Leight and Berube [12] refer to GIS systems as part of the wider family of Decision Support System (DSS) tools that include a range of modelling and *“data streamlining capacities”* [12] to understand information relationships that are built behind *“powerful but simple user interfaces”* [12],[13]. The GIS tool itself is a platform that handles geographical or spatially-based information data sets in such a way that allows a user to perform efficient spatial analysis and execute powerful data queries in order to develop high quality visual outputs [6]. McLafferty [14] recognising these actions understands that GIS plays an important part in *“describing people’s ability to use health services [and] when and where they are needed”* [14]. Whilst GIS tools have been widely linked to *“disease surveillance”* [9] such as studies of public risk and exposure to Lyme’s disease, Pneumonia and Leptospirosis performed by Cromley *et. al* [15], Arno *et. al* [16] and Barcellos and Sabroza [17] respectively; they have also been applied to public healthcare provision studies [18].

V. ANALYSING MENINGITIS THREAT ACROSS SWANSEA

Given the importance of GIS visualisations in understanding how various socio-demographic data influences healthcare provisions, this section will evaluate the state of deprivation across the city of Swansea. With particular reference to the Townsend Index [19],[20], a widely supported barometer of social deprivation, the author will explore how the provision of the Meningitis virus vaccine can be most effectively supplied to the population in and surrounding Swansea. This comprehensive deprivation method considers four key metrics (vehicle ownership, home ownership, domestic overcrowding and unemployment figures) in order to provide a broad view of deprivation [19],[20]. Despite this useful measure, Jordan, Roderick and Martin [20] recognise that areas lacking in individual elements should not be necessarily marked as deprived – such as the statistic of average car ownership which can harbour other demographic traits and is of particular relevance throughout this article.

In order to understand where this social deprivation or affluence is mostly likely to conceal a possible breakout the location and endorsement of educational establishments – locations of varied human interaction – is of value. The author will also discuss the distribution of healthcare services to as to highlight areas of possible vulnerability with physical, fixed healthcare services.

A. Healthcare Services

The City of Swansea has twelve primary hospitals distributed across the city as seen in **Figure 3** - the largest of which are Singleton and Morriston hospitals – both positioned centrally on large arterial roads around and out of the region. Morriston provides specialist care for the elderly, alongside other specialist departments (and further sub-speciality) facilities and “one of the busiest Emergency Departments (A&E) in Wales” [21]. Singleton Hospital too is large and offers specialist treatment and care departments as well as a ‘GP acute unit’ in order to provide GP’s with easier access to core consultancy and treatment services – increasing the speed and completion of patient treatments [22]. Alongside these principle hospitals numerous smaller hospitals, some without 24-hour A&E provisions etc.) are located around the city, typically strategically positioned adjacent to housing estates and other built up estates. One secondary healthcare centre is located in Gorseinon (Garngoch Hospital) and provides a range of ‘walk-in’ services but no 24hr provisions or in-patient care; the latter seeing patients referred to the nearby Cefn Coed Hospital [23].

Given the context of Meningitis explored throughout this report, an understanding must first be gained as to the deprivation of the across Swansea and how the pressures applied by location deprivation or affluence could be affecting the provision of healthcare services throughout the region. **Figure 4**, illustrated below, extends the map of Swansea Health centres by applying an underlying thematic layer of the fore-mentioned Townsend Score of deprivation.



Figure 3: Hospitals Across the City and Council of Swansea [© Crown 2019]

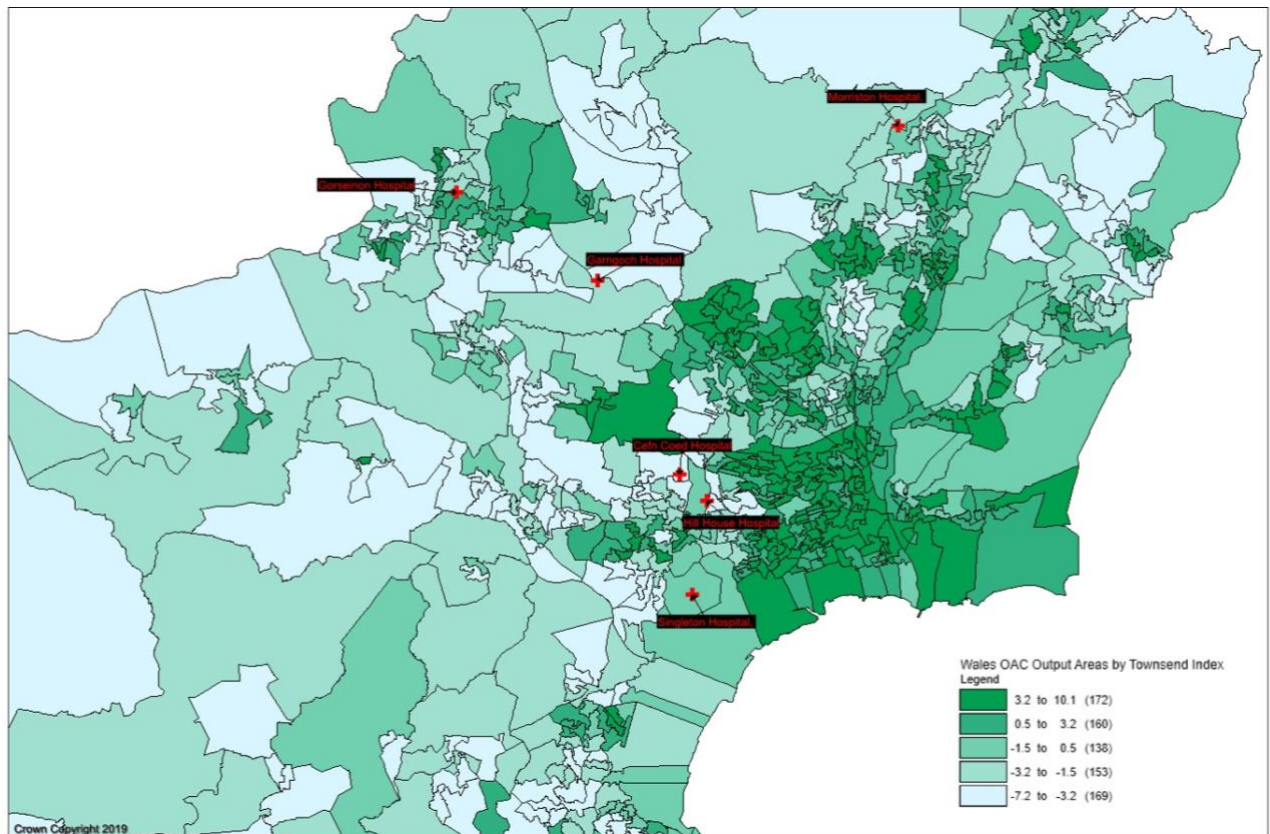


Figure 4: City Hospitals and Townsend Score for the City and Council of Swansea [© Crown 2019]

This map, in which hospitals and key health centres in Port Talbot and Bridgend have been omitted, shows the Townsend Score whereby the *lighter the green theme the more affluent* the OAC (Output Area Classification) postcode area is considered. Therefore, the opposite is true in that the *darker the green theme the greater the deprivation* the area was experiencing during 2011 census gathered public data.

From this visualisation several clear trends, and subsequent statements, can be drawn as to the general pressures that different centres might be experiencing. Firstly, it is clear that the areas of greater deprivation across Swansea postcodes are generally located in and around the City Centre. There are several notable exceptions north of the centre in outlying housing and industrial estates (such as Ammanford and Pontadawe) that are experiencing greater levels of deprivation than surrounding rural areas. The opposite of this conclusion also appears true in that the less densely populated rural areas, especially those West of Swansea in the Mumbles and Gower regions, are generally experiencing far less deprivation. There are certain exceptions to this trend such as the West Cross Estate between Sketty and Mumbles which is displayed as a small patch of darker green in this view.

In terms of the hospital usage, it is anticipated that areas closest to the City Centre will see the heaviest patronage in lieu of the greater levels of health degradation that sit with reduced exposure to healthy living factors such as air quality, fuel access and food and water provisions [24]. Various studies performed after the release of the landmark ‘Black Report’ [25] during the ‘80s on societal living trends have aimed to validate the findings of this research and understand the impact that societal inequality and imbalance has had on public health trends and healthcare provision. The Marmot Review [24] represents one such study that supported this view by suggesting

“people from poorer neighbourhoods die” [26], at least on average, *“7 years sooner”* [26] than those from more comfortable surroundings [24],[26]. Health centres located in suburbs such as Gorseinon are likely to be drawing in patients from the local estate but also from Gower regions. The same conclusions can be drawn for Singleton hospital which is likely to receive a considerable number of patients from the more affluent areas of Mumbles and Gower as well people from the local boroughs of Sketty and Uplands. However, in order to understand how the meningitis vaccine across Swansea can be most effectively distributed a view of city hospitals is not enough. The next logical process is to view the location of city secondary and primary schools in which the disease has historically spread and that represent prolonged exposure to wide groups of young people from different city communities.

B. Secondary Schools

In *Figure 5* (below) the Townsend Score has been applied one again but with the location-based information for *all* the cities secondary schools. Again, several key conclusions can be drawn with the most obvious being that all of the secondary schools illustrated in *Figure 5* are placed in or alongside at least one or more areas of ‘above-average’ or ‘high’ social deprivation. Bishopston Comprehensive, although located deep in the Gower area and amongst widely affluent areas, is served by the less primary schools within the more impoverished West Cross estate. Furthermore, it can be seen that several primary schools are located in the centre of areas that, during 2011, score highly on the Townsend Score (such as Dylan Thomas, Pentrehafod and Bishop Vaughan Secondary). Schools in these areas take in students from areas of (according to the Townsend framework) students from less advantaged local communities.

Whilst these broad statements can be made about the likelihood of an epidemic outbreak in a certain school, or across the city, a greater level of detail is required that allows healthcare professionals to understand the chances of contamination on a school-by-school level. To more easily form these conclusions a view of the feeder primary schools is required.

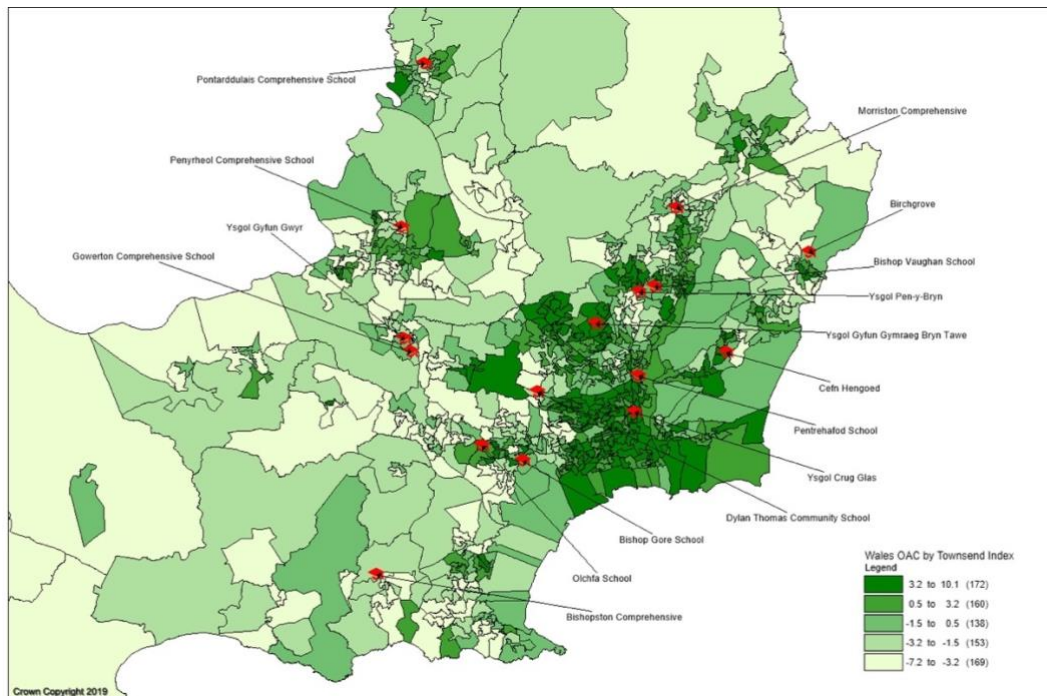


Figure 5: City Secondary Schools and Townsend Index for the City and Council of Swansea [© Crown 2019]

C. *Primary Feeder Schools*

Albeit stated above that healthcare professionals would require a view of each secondary school's feeder schools respectively, this section concentrates on two Secondary's in contrasting City and Council regions. Firstly, the author will consider Bishopston Comprehensive located on the edge of Gower and away from the City Centre before comparing these conclusions to those drawn from Primary schools that feed into the suburban Pentrehafod Secondary school located in a less comfortable area of the city.

1) Bishopston Comprehensive

Bishopston Comprehensive is the most Westerly secondary school in the Swansea postcode range and is served by primary schools scattered across the Gower peninsula; Three Crosses (Crwys Primary), Knelston (Knelston Primary), Pennard (Penndard Primary), Newton (Newton Primary) and West Cross (Mayals Primary). From **Figure 6** (below) it can be seen that this area (on which the Townsend Score has been applied) is not, despite parts of West Cross, suffering from any noticeable deprivation.

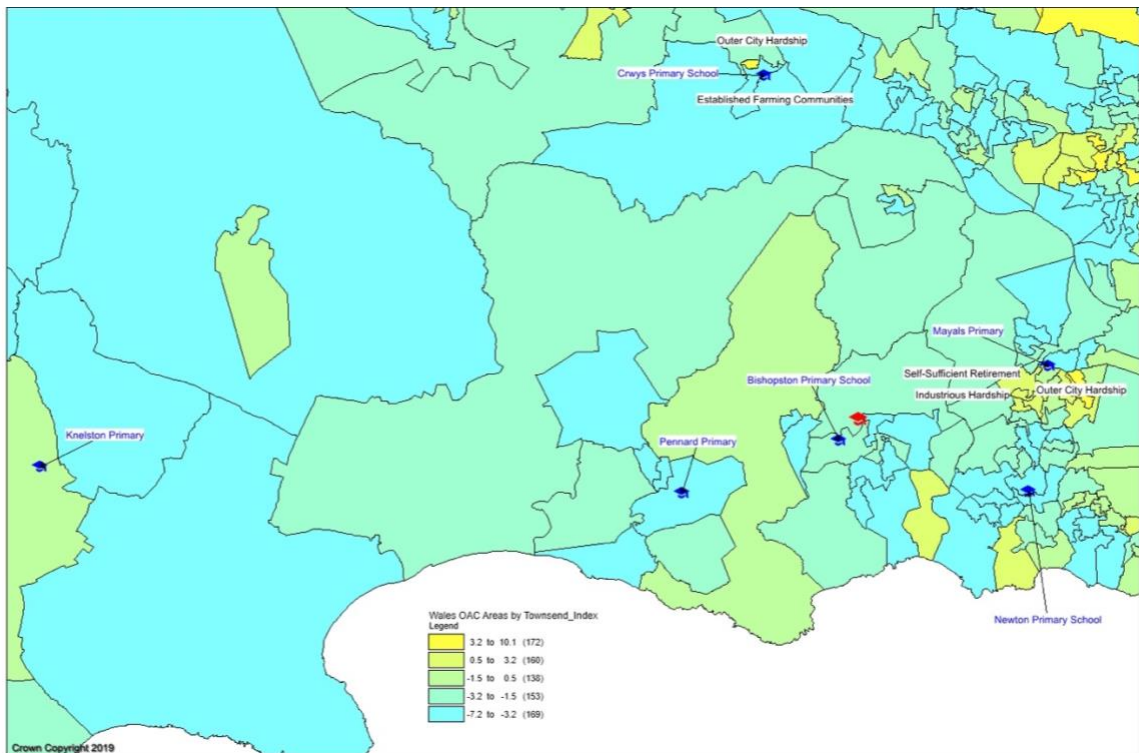


Figure 6: Townsend Score for Bishopston Comprehensive and Associated Feeder Primary Schools [© Crown 2019]

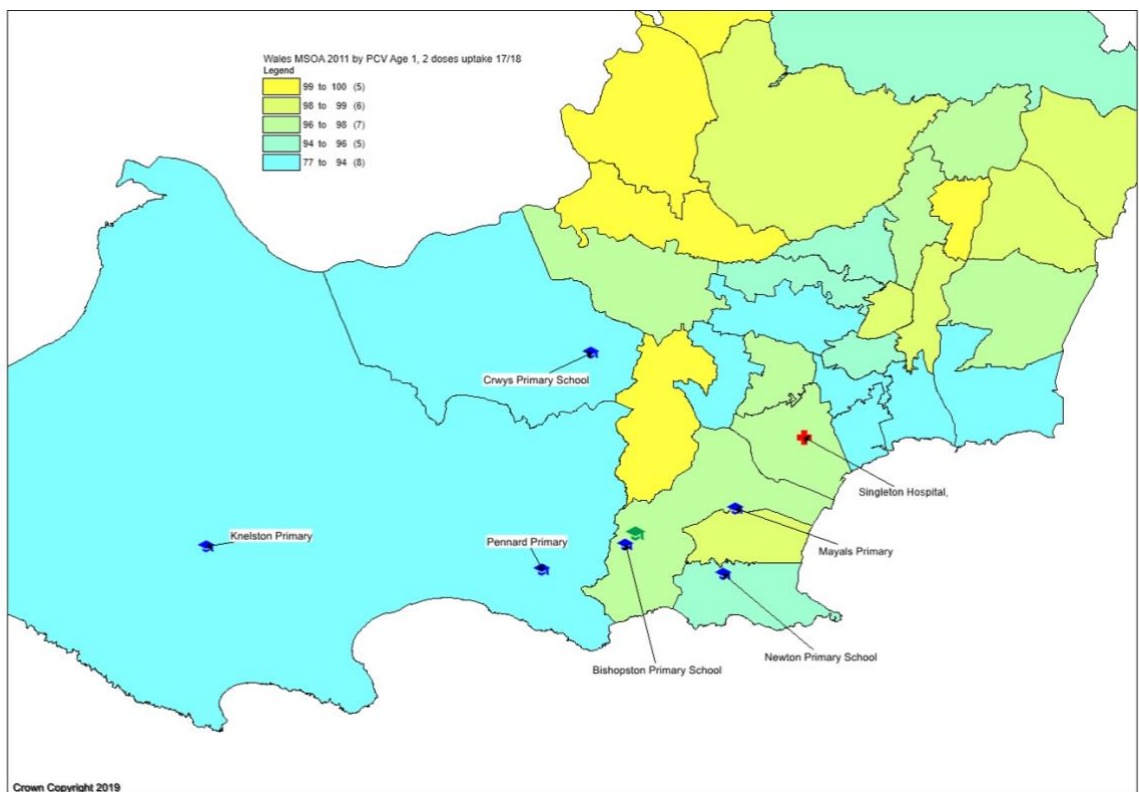


Figure 7: Bishopston Comprehensive Uptake of Meningitis Vaccine (Age 1, 2nd Dose) between 2017-2018 [© Crown 2019]

In these rural areas population density is reduced, and unemployment rates are higher as a result of the retirement community that settle in these country towns and villages. Home ownership too is high in lieu of a wealthier age group and the percentage of household car ownership, due to the distributed nature of public services is considerably greater than that of the city centre (or even suburbia). As such these Gower areas represent a less confined and more spacious environment – factors that are conducive to increased health, and with it a reduced human exposure required to initiate or maintain the spread of an infectious virus across a wide area.

Despite the affluent, distributed nature of the feeder primary schools across the region, certain vaccine strategies can be developed from this map. In terms of Meningitis vaccine distribution and provision the most obvious weak spot, and potential origin of a breakout is Mayals Primary in West Cross. This estate represents the weak link in this system with a primary school that is located in a more densely populated area in which household overcrowding and unemployment are considerably higher than the surrounding areas. However, despite this obvious conclusion the statistics illustrating the uptake of the vaccine during 2017-2018, as seen in **Figure 7**, prove more positive. These show that the areas of denser population, such as West Cross, has seen between 96 and 98% uptake of the vaccine for 1-year-old second doses across 2017-2018; clearly supporting the view that either the public awareness is widespread and/or the marketing and provision of the vaccine for parents is currently very effective.

2) Pentrehafod School

In order to draw more convincing conclusions as to the extent of a meningitis epidemic schools towards the centre of the city must also be evaluated. In direct contrast to Bishopston Comprehensive is Pentrehafod Secondary. Located in the middle of the city amongst some of the highest levels of deprivation this school attracts students from equally deprived urbanised environments, as illustrated below in **Figure 8**.

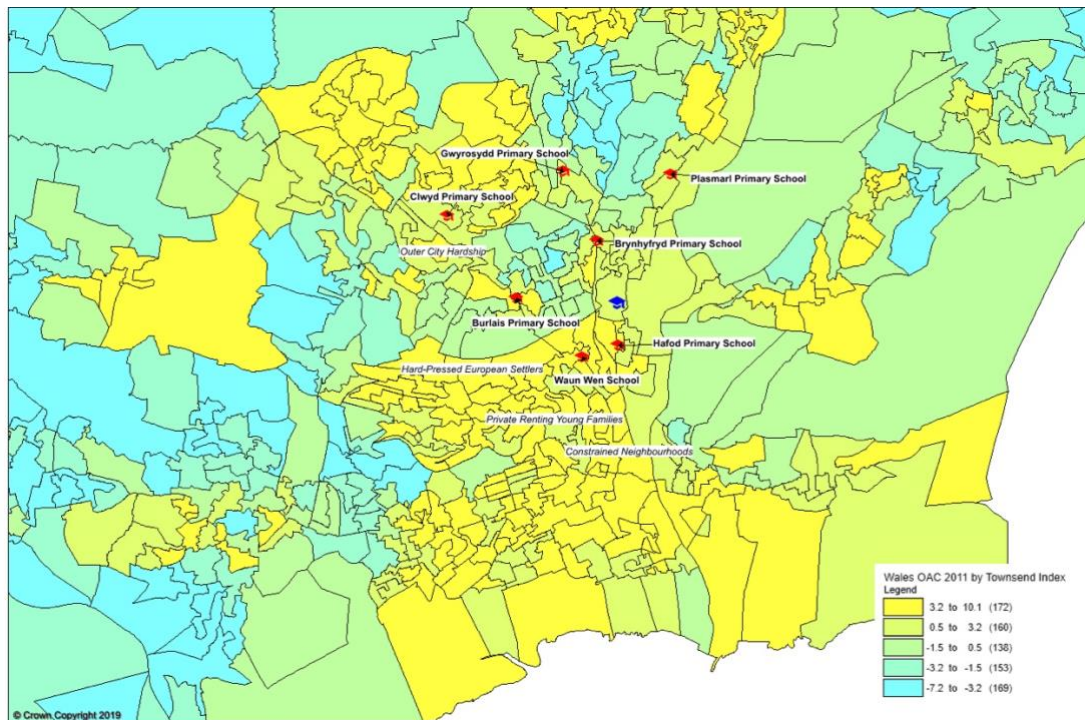


Figure 8: Townsend Score for Pentrehafod Secondary School and Associated Feeder Primary Schools [© Crown 2019]

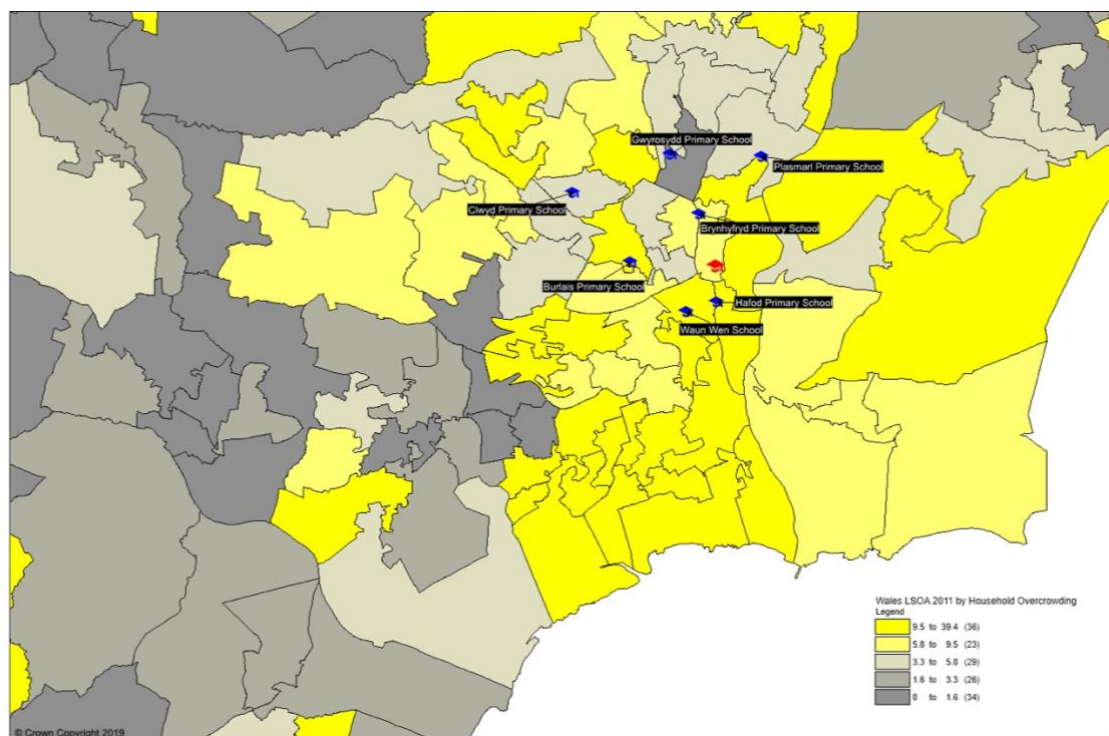


Figure 9: City Centre Area Overcrowding [© Crown 2019]

Shown in blue (in *Figure 8*) the feeder primary schools are located in or directly beside areas of 'high' deprivation levels described by the OAC area datasets as '*Outer City Hardship*'. Furthermore, these tight communities of '*Hard-Pressed European Settlers*' and '*Private Renting Young Families*' epitomise areas of

regular, prolonged and diverse human contact that, if present, can facilitate the transmission of the Meningitis virus. The factor of population overcrowding in the core urban areas can be more clearly seen in *Figure 9* where in numerous locations the issue of household overcrowding average is equal to or greater than 9.5%. The highest figures across Swansea from this data shows that in at least one area one in four households is too densely inhabited.

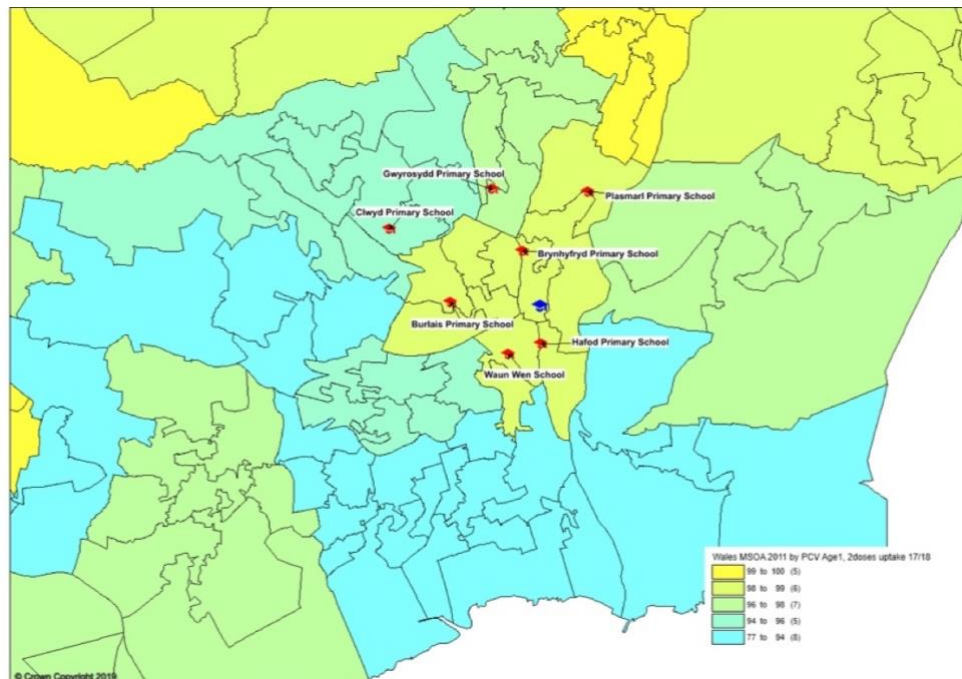


Figure 10: Pentrehafod Secondary School Uptake of Meningitis Vaccine (Age 1, 2nd Dose) between 2017-2018 [© Crown 2019]

Unlike the considerable public awareness demonstrated by the public in the West Cross and Gower region of the city the uptake of the vaccine, despite the far greater likelihood of an outbreak, is relatively low in numerous city centre areas. The possibility of a breakout at this current level of inconsistent immunity is illustrated in *Figure 11*. In areas of extensive dense population a certain level of population immunisation offers herd immunity [27],[28], a level of tolerance that represents an ideal level of group resilience to restrict virus transmission. This degree of vaccination in theory means that a virus (represented by arrows moving between circles) performs limited damage and reduced transmission before it meets an immunised individual. Here the virus is stopped by those immunised (shown in green) before it can be contracted by those who are vulnerable (shown in yellow) or have already contracted the disease [27]. Originally applied to Measles, Fine [28] suggests that this threshold lies between “70 to 95%” [28] of the population; meaning that lying between 77-94% some areas in the city of Swansea are near to this accepted lower-range immunisation figure.

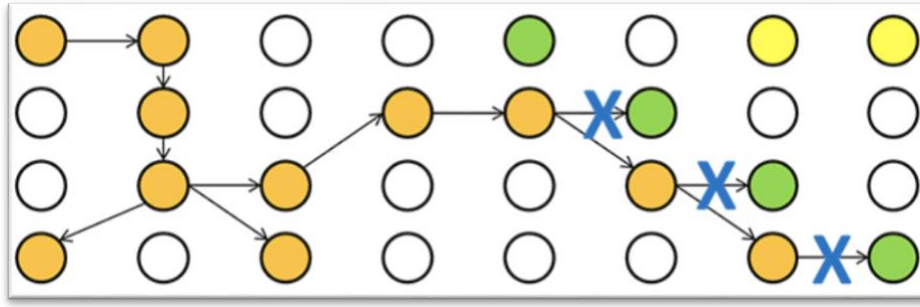


Figure 11: "Vaccinated Population" with herd threshold satisfied [27]. *Note: vastly simplified example*

VI. DEVELOPING A WEB-BASED GIS TOOL

Having developed a range of valuable meningitis visualisation, section VI. briefly documents the purpose and development of a web-based GIS tool for displaying and sharing the current data surrounding possible future outbreaks of the Meningitis [29] outbreaks in Swansea. This tool follows the format of a 'Web GIS-based Public Health Surveillance System' (WGPSS) [9], a platform that has seen considerable evolution on the back of new web standards [9] and an advancement that has enabled the development of "*interactive, customisable, sociable*" [9] and lightweight multi-platform tools for location-based data analysis purposes.

The benefit of producing a sharable platform such as a web tool is that a service can be created for a broad range of users that represent healthcare and local government professionals "*at all levels [of decision making]*" [9] that can access so as to view valuable up-to-date decision-making information [30]. The importance of a wide range of users is noted by Luan and Law [9] who state the importance of an efficient and streamlined user interface – referring to Frank's [31] statement of "*the user interface is the system*" [31] and the importance of ease of use and key trend understanding. This perspective is supported by Brimicombe and Li [32] who note the significance of the even broader human-computer interaction (HCI) field in the development of end-user decision-making visualisation support tools.

Several of the key visualisations referred to in previous sections of this report have been incorporated into an end-user web tool, screen captures of which in the OS X browser are shown in **Figure 12** to **Figure 16** below. A user can view the main regional health centres and explore the secondary schools (and for the two select schools explored throughout this report) the feeder primary schools. *Please see Section IX. A. below.*

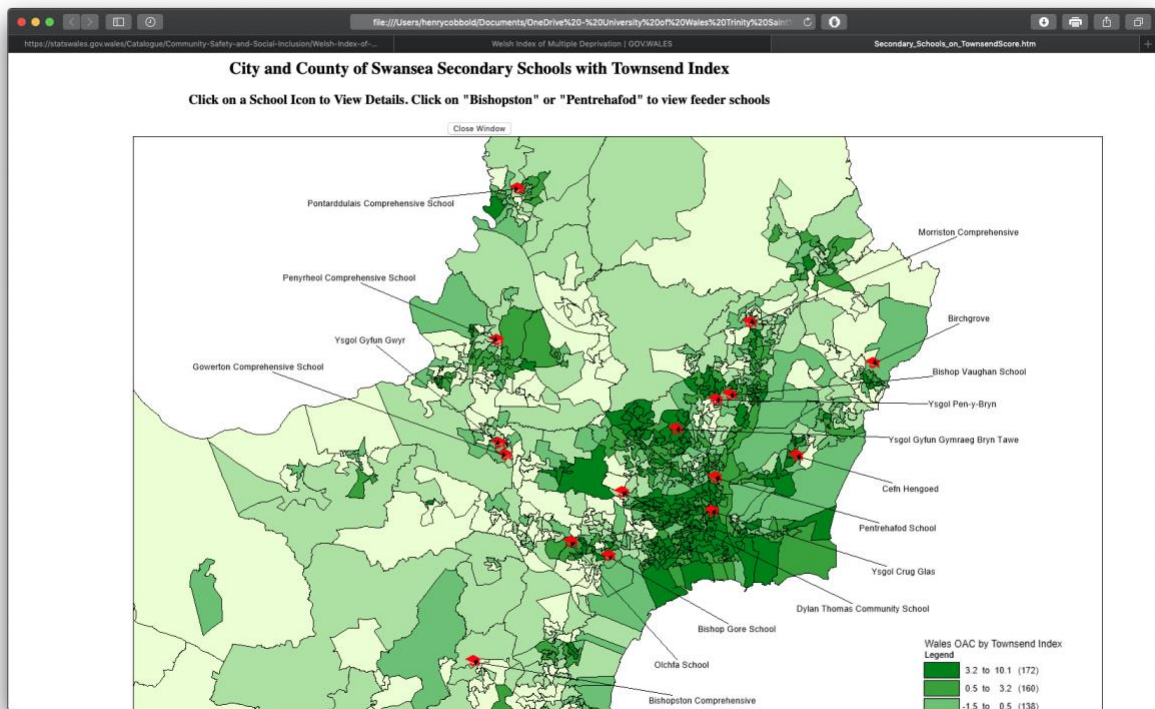


Figure 12: The Secondary School Browser Visualisation

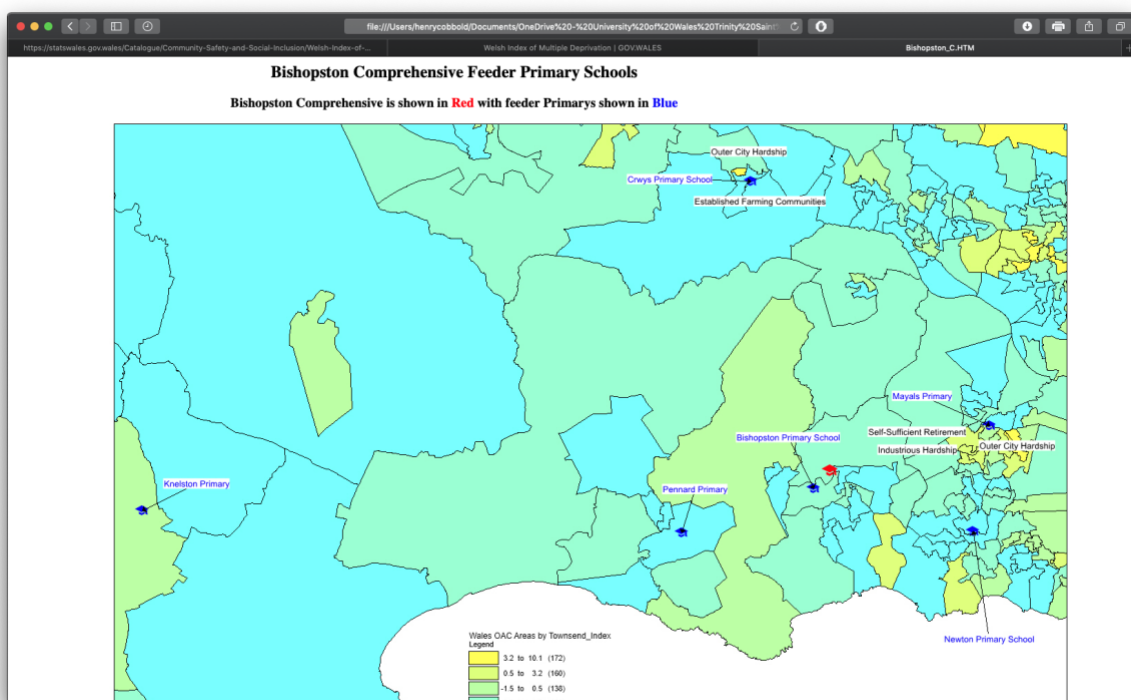


Figure 13: Feeder Primary's for Bishopston Comprehensive

VII. SUMMARY OF FINDINGS AND CONCLUSION

To increase the usefulness of the visualisation tool more in-depth data would need to be acquired on the uptake of the Meningitis vaccine. Being able to obtain postcode level OAC (Output Area Classification) datasets would allow healthcare professionals in Swansea to be able to query and understand where the uptake of the virus is below the current display threshold of 77% (where the data is linked to the Swansea MSOA [Medium Super Output Area] boundary view). The current lack of detail in regards to postcode area is shown in the MSOA thematic views in **Figure 16** below whereby the region of Gower should be broken down further.

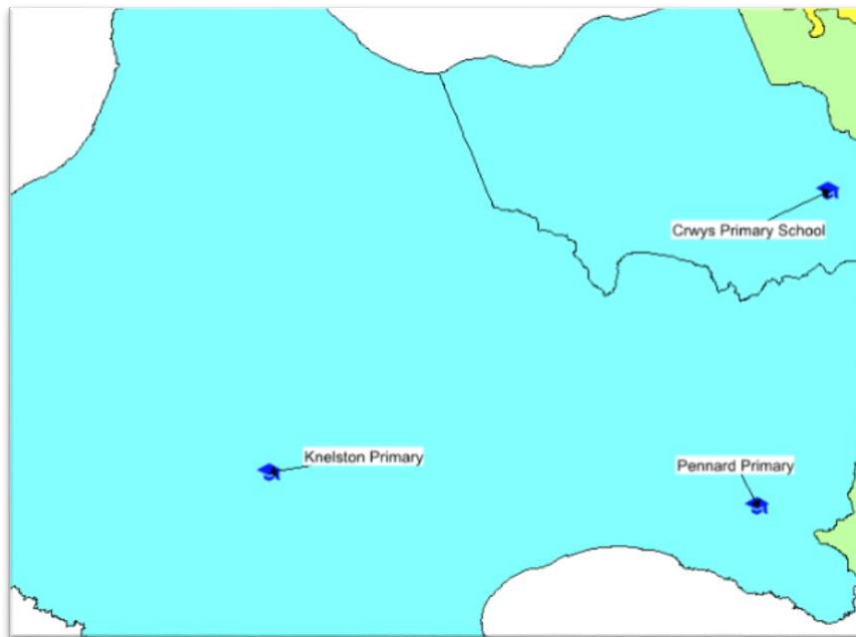


Figure 16: The Large MSOA Regional Boundaries for Gower [© Crown 2019]

Alongside the issue of Output Area scale experienced there are other aspects of socio-demographic data for this visualisation study that can also be debated. Whilst the Townsend Score used throughout is good at “*combining a set of variables into a single, summary measure*” [33] the usefulness of this all-round framework in this scenario can be debated given the relatively limited nature of the metrics on which it bases its deprivation score. Despite a range of alternative models that have been explored at length in the literature ([34]–[37]) the author offers the application of the ‘Welsh Index of Multiple Deprivation’ (WIMD) [38],[39] framework – a scale that applies eight wide areas of data (“*income, employment, health, education, access to services, community safety, physical environment and housing*” [38]) rather than four; providing a far wider range of socio-demographic factors into a single score that can subsequently be applied to “*small areas in Wales*” [38] and that is already applied to areas within Wales. Such a framework could be applied to each of the Secondary school feeder districts as discussed upon which a greater level of understand could be gained.

Despite this recognised limitation the tool allows the author to conclude the article with a range of statements that describe the likelihood of a future epidemic. Firstly, it is clear that the city, at least during the 2011

census year, was experiencing dramatically contrasting levels of deprivation and that the literature and poverty scales applied to the area have raised concerns as to extent to which the environment conditions have (and still are) offering scope for a future disease breakout in the region. Although the secondary and primary school conclusions drawn require expansion from the other 14 secondary schools in the 'SAxx' postcode region, the study of this scale suggests that public awareness is mixed. The application of the Townsend Index supports the long-term argument that vaccine uptake is linked to deprivation as the key report conclusion is that the public perception of the vaccine is more widespread in less impoverished areas of Swansea. As such the primary recommendations for NHS Wales in the city is that central districts demand higher levels of vaccine promotion and distribution in order to increase public immunisation and further decrease the scope for disease contraction and dispersion.

VIII. REFERENCES AND CITED WORK(S)

- [1] S. J. Barnes, "Location-Based Services: The State of the Art," *e-Service J.*, vol. 2, no. 3, p. 59, 2003.
- [2] T. Kos, M. Grgic, and G. Sisul, "Mobile User Positioning in GSM/UMTS Cellular Networks," *48th Int. Symp. ELMAR-2006*, no. June, pp. 185–188, 2006.
- [3] B. I. A. Junglas and R. T. Watson, "Location-Based Services," *Commun. ACM*, vol. 51, no. 3, pp. 65–70, 2008.
- [4] B. Jiang and X. Yao, "Location-based services and GIS in perspective," *Comput. Environ. Urban Syst.*, vol. 30, no. 6, pp. 712–725, 2006.
- [5] H. Yun, D. Han, and C. C. Lee, "Understanding the Use of Location-Based Service Applications : Do Privacy Concerns Matter ?," *J. Electron. Commer. Res.*, vol. 14, no. 3, pp. 215–231, 2013.
- [6] K. Virrantaus *et al.*, "Developing GIS-Supported Location-Based Services," in *Proceedings of the Second International Conference on Web Information Systems Engineering*, 2002, vol. 2, pp. 66–75.
- [7] M. B. Aziz, "Wireless Applications of GIS in Dynamic platforms a case study in Laptops and Mobile Phones," Mangalore University, Department for Geoinformatics, Thesis.
- [8] C. Pontikakos, M. Sambrakos, T. Glezakos, and T. Tsiligiridis, "Location-based services: A framework for an architecture design," *Neural Parallel Sci. Comput.*, vol. 14, no. 2/3, p. 273, 2006.
- [9] H. Luan and J. Law, "Web GIS-Based Public Health Surveillance Systems: A Systematic Review," *ISPRS Int. J. Geo-Information*, vol. 3, no. 2, pp. 481–506, 2014.
- [10] International Organisation for Standardisation (ISO) Group, "ISO/TC 211 - Geographic information/Geomatics," *ISO/TC 211*, 1994. [Online]. Available: <https://www.iso.org/committee/54904.html>. [Accessed: 19-May-2019].
- [11] D. O'Sullivan, "Geographical information science: critical GIS," *Prog. Hum. Geogr.*, vol. 30, no. 6, pp. 783–791, 2006.
- [12] N. Schuurman, M. Leight, and M. Berube, "A Web-based graphical user interface for evidence-based decision making for health care allocations in rural areas," *Int. J. Health Geogr.*, vol. 7, pp. 1–12, 2008.
- [13] Shim J. P., Warkentin M., Courtney J. F., Power D. J., Sharda R., and Carlsson C., "Past, Present, and Future of Decision Support Technology," *Decis. Support Syst.*, vol. 33, no. 2, pp. 111–126, 2002.
- [14] S. L. McLafferty, "GIS and Health Care," *Annu. Rev. Public Health*, vol. 24, no. 1, pp. 25–42, 2003.

- [15] E. K. Cromley, M. L. Cartter, R. D. Mrozinski, and S. H. Ertel, "Residential setting as a risk factor for Lyme disease in a hyperendemic region," *Am. J. Epidemiol.*, vol. 147, no. 5, pp. 472–477, 1998.
- [16] P. S. Arno *et al.*, "Analysis of a population-based *Pneumocystis carinii* pneumonia Index as an outcome measure of access and quality of care for the treatment of HIV disease," *Am. J. Public Health*, vol. 92, no. 3, pp. 395–398, 2002.
- [17] C. Barcellos and P. C. Sabroza, "Socio-environmental determinants of the leptospirosis outbreak of 1996 in western Rio de Janeiro: A geographical approach," *Int. J. Environ. Health Res.*, vol. 10, no. 4, pp. 301–313, 2000.
- [18] C. I. J. Nykiforuk and L. M. Flaman, "Geographic Information Systems (GIS) for Health Promotion and Public Health: A Review," *Health Promot. Pract.*, vol. 12, no. 1, pp. 63–73, 2011.
- [19] P. Townsend, P. Phillimore, and A. Beattie, *Health and Deprivation: Inequality and the North*. London, UK: Routledge, 1988.
- [20] M. S. Gilthorpe, "The importance of normalisation in the construction of deprivation indices," *J. Epidemiol. Community Health*, vol. 49, no. SUPPL. 2, pp. 45–50, 1995.
- [21] Abertawe Bro Morgannwg University Health Board, "Swansea Bay University Health Board - Morriston Hospital," *Hospitals*, 2019. [Online]. Available: <http://www.wales.nhs.uk/sitesplus/863/page/39263>. [Accessed: 24-May-2019].
- [22] Abertawe Bro Morgannwg University Health Board, "Swansea Bay University Health Board - Singleton Hospital," *Hospitals*, 2019. [Online]. Available: <http://www.wales.nhs.uk/sitesplus/863/page/39264>. [Accessed: 21-May-2019].
- [23] NHS Wales Direct, "Ty Garngoch Hospital," *Location Hospital Services*, 2019. [Online]. Available: <https://www.nhsdirect.wales.nhs.uk/localservices/ViewLocalService.aspx?id=3115&s=Hospital>. [Accessed: 21-May-2019].
- [24] M. Marmot *et al.*, "Fair Society, Healthy Lives: The Marmot Review," *Strateg. Rev. Heal. Inequalities Engl. post-2010*, vol. February, no. final, 2010.
- [25] A. M. Gray, "Inequalities in Health. The Black Report: A Summary and Comment," *Int. J. Heal. Serv.*, vol. 12, no. 3, pp. 349–380, 1982.
- [26] P. F. Collins, R. J. Stratton, R. J. Kurukulaaratchy, and M. Elia, "Influence of deprivation on health care use, health care costs, and mortality in COPD," *Int. J. COPD*, vol. 13, pp. 1289–1296, 2018.
- [27] Manish Sadarangani, "Herd Immunity: How does it work?," *Oxford Vaccine Group*, 2016. [Online]. Available: <https://www.ovg.ox.ac.uk/news/herd-immunity-how-does-it-work>. [Accessed: 21-May-2019].
- [28] P. E. Fine, "Herd immunity: history, theory, practice.," *Epidemiol. Rev.*, vol. 15, no. 2, pp. 265–302, 1993.
- [29] A. R. Tunkel *et al.*, "Practice Guidelines for the Management of Bacterial Meningitis," *Clin. Infect. Dis.*, vol. 39, no. 9, pp. 1267–1284, 2004.
- [30] D. Nash, B. Elul, M. Rabkin, M. Tun, S. Saito, and M. Becker, "Strategies for more effective monitoring and evaluation systems in hiv programmatic scale-up in resource-limited settings: Implications for health systems strengthening," *J. Acquir. Immune Defic. Syndr.*, vol. 52, no. SUPPL. 1, pp. S58–S62, 2009.
- [31] A. U. Frank, "The Use of Geographical Information Systems: The User Interface is the System," in *Human Factors in Geographical Information Systems*, London, UK: Belhaven Press, 1993, pp. 3–14.
- [32] A. Brimicombe and C. Li, *Location-Based Services and Geo-Information Engineering*, 1st ed. Wiley-

- Blackwell, 2009.
- [33] P. Norman, “The changing geography of deprivation in Britain: 1971 to 2011 and beyond,” in *Population Change in the United Kingdom*, London, UK: Rowman and Littlefield, 2016, pp. 193–214.
 - [34] A. B. Atkinson, “Multidimensional deprivation: contrasting social welfare and counting approaches,” *J. Econ. Inequal.*, vol. 1, pp. 51–65, 2003.
 - [35] I. Kawachi, B. P. Kennedy, and R. G. Wilkinson, “Crime: Social disorganization and relative deprivation,” *Soc. Sci. Med.*, vol. 48, no. 6, pp. 719–731, 1999.
 - [36] P. Geoff, P. Judy, and H. Mark, ““Refuse of All Classes”? Social Indicators and Social Deprivation,” *Sociol. Res. Online*, vol. 1, no. 1, pp. 1–19, 1996.
 - [37] H. Noll, “Indicators : Theoretical Framework and System,” *Soc. Indic. Res.*, vol. 58, pp. 47–87, 2002.
 - [38] Cyngor Abertawe/Swansea Council, “Swansea - Deprivation,” *Performance and Statistics*, 2018. [Online]. Available: <https://www.swansea.gov.uk/deprivation>. [Accessed: 22-May-2019].
 - [39] Llywodraeth Cymru/Welsh Government, “Welsh Index of Multiple Deprivation,” *Statistics and Research*, 2018. [Online]. Available: <https://gov.wales/welsh-index-multiple-deprivation-indicator-update-2017>. [Accessed: 22-May-2019].

IX. APPENDICES

A. Accessing Site links

- For the Hospital Web Information Tool please open file: “*Swansea_Hospitals_on_Townsend_Score.htm*”
- For the Primary and Secondary Schools Web Information Tool please open file: “*Secondary_Schools_on_TownsendScore.htm*”
- **Note:** Not all the thematic and location-based views developed by the author have been added to the report. Please see accompanying resource file for the complete set of MapInfo visualisations.
- The solution workspace can be found at: “*FINAL_A2_WORKSPACE.WOR*”