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Investigating the influence of settlement pattern and morphology on the sterilisation of shallow coal resources

Minerals and Waste Programme

Commissioned Report CR/10/043N

BRITISH GEOLOGICAL SURVEY

MINERALS AND WASTE PROGRAMME

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Investigating the influence of settlement pattern and morphology on the sterilisation of shallow coal resources

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Front cover

Image of the Rhondda valley produced using Geovisionary software and NextMap elevation data.

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Foreword

In January 2010 the Department for Communities and Local Government (DCLG) commissioned the British Geological Survey (BGS) to undertake an assessment of the impact on shallow coal resources of using separation zones around urban areas. It was requested that a similar methodology to that undertaken previously in Jones (2006a) should be followed but that the study area should be larger than the 100 km^2 previously assessed. An area of approximately 2400 km^2 of the primary and secondary shallow coal resource within the East Midlands and south Yorkshire and the Humber Regions, therefore, was selected for this follow-on study. The research presented here, which was funded by the Department for Communities and Local Government (DCLG) – BGS Joint Minerals Information Programme, show the results of this follow-on study.

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This report assesses the impact of introducing separation zones around urban areas on shallow coal resources. It also provides an assessment of settlement pattern using spatial statistics and an evaluation of settlement morphology (i.e. physical form or shape) based on a pre-existing density profile methodology. Two study areas have been selected for comparison: the Midlands Coalfield (comprising shallow coal resource within the Yorkshire, Nottinghamshire and North Derbyshire Coalfields) and the South Wales Coalfield.

The analysis conducted in this report shows that the settlement pattern within the South Wales Coalfield study area is generally more clustered, and settlements tend to be elongate (or linear) in morphology. This is a result of the topography (steep sided valleys) in this area. In contrast, settlements in the Midlands Coalfield study area are more nucleated, or equidimensional, in morphology and more evenly dispersed over the study area. The research shows that settlement morphology can influence the size of the area of a separation zone. Settlements which are elongate are likely to have larger separation zones (in area) than equivalent sized settlements which are more equidimensional in morphology. The research also shows that the relative effect of a 500 m separation zone around urban areas in the South Wales Coalfield increases the influence of the urban area by 659.6 % (i.e. from 169.74 km^2 to 1119.61 km^2). This is significantly higher than in the Midlands Coalfield study area, where the influence of the urban area when a 500 m separation zone is applied increases by 402.8 % (i.e. from 496.49 km^2 to 1999.75 km^2).

Of the two study areas, the greatest overall impact on the sterilisation of shallow coal resources from urban development is seen within the Midlands Coalfield study area. This is not a consequence of the contrasting settlement patterns; rather it results from the greater proportion of urban areas within the Midlands Coalfield. Urban development encompasses 496.49 km^2 (17.2 %) of the Midlands Coalfield whereas in South Wales, urban development encompasses 169.74 km^2 (6.7 %) of the study area. Of the total urban development within each study area, a greater amount lies within the surface extent of shallow coal resource in the Midlands Coalfield (423.17 km^2 or 85.2 %) than in the South Wales Coalfield study area (86.14 km^2 or 50.7 %). The effect, therefore, of placing a separation zone of 500 m around urban areas within the Midlands Coalfield is that a greater amount (1727.85 km^2 or 72.2 %) of the total surface extent of the shallow coal resource is sterilised than in the South Wales Coalfield study area (563.28 km^2 or 52.8 %).

The study concludes that a number of factors influence the area of a separation zone and thus the amount of shallow coal resource sterilised from urban development:

1. The distribution (settlement pattern) of settlements within the coalfield.
2. The shape of an individual settlement (settlement morphology).
3. The extent of the urban area lying within the coalfield.

However, given two study areas with equally distributed and sized urban areas, the morphology (shape) of the urban settlements may have greatest influence on the size of the separation zone. This could explain why settlements within the South Wales Coalfield have a greater relative impact on separation zone area than settlements in the Midlands Coalfield.

1 Introduction

A key aspect of sustainable development is the safeguarding of non-renewable resources, such as minerals, for future generations. Minerals planning policy (e.g. Minerals Policy Statement 1, Minerals Planning Policy Wales and Scottish Planning Policy) emphasise, amongst other things, the requirement to safeguard mineral resources to prevent unnecessarily sterilisation of those resources which society may require in the future. Scottish Planning Policy (SPP) and Minerals Technical Advice Note (MTAN) 2: Coal, issued by the Welsh Assembly Government, recommends that separation zones are used to protect properties from the effects of opencast coal workings. The Welsh MTAN (2009) specifically states that "*coal working will generally not be acceptable within 500 metres (m) of settlements*". In SPP (2010) "*Surface coal extraction is unlikely to be environmentally acceptable if proposed site boundaries are within 500 m of the edge of a community*". To date, there is no equivalent policy in England.

In January 2010 the Department for Communities and Local Government (DCLG) commissioned BGS to expand upon previous research conducted by Jones (2006a) by undertaking an assessment of the impact on shallow coal resources of using separation zones around urban areas for a larger study area in England. It was requested that a similar methodology to that undertaken previously (Jones, 2006a) should be followed but that the study area should be larger than the 100 km^2 previously assessed. An area of approximately 2400 km^2 of the primary and secondary shallow coal resource within the East Midlands and south Yorkshire and the Humber Regions was, therefore, selected. This area comprises shallow coal resource within the Yorkshire, Nottinghamshire and North Derbyshire Coalfields and for the purposes of this report is hereby classed as the '*Midlands Coalfield*'. The settlement patterns, morphologies and impact of separation zones within the Midlands Coalfield is compared to the settlement patterns, morphologies and impact of separation zones within the primary and secondary (shallow) coal resources of the South Wales Coalfield study area. For a definition of what constitutes primary and secondary (shallow) coal resource, refer to Appendix 1.

1.1 COALFIELD STUDY AREAS

The settlement patterns within the Midlands Coalfield are considered to be different to those within the South Wales Coalfield. The differences in the morphology and distribution of the respective settlements within the two coalfield areas are thought to have different impacts on the surface extent of the shallow coal resource sterilised by settlement separation zones.

1.1.1 South Wales Coalfield

The South Wales Coalfield (Figure 1) was developed in the 19th century as one of the premier mining regions of Britain. The primary and secondary shallow coal resources within the coalfield have a combined surface area extent of approximately 1093.63 km^2 (Table 1 and Figure 2). Tertiary coal resource, as defined in Appendix 1, can also be found within the coalfield, but this has not been included in this study. The area covers much of the old counties of Glamorgan, Monmouth and Carmarthenshire and partially extends into South Pembrokeshire. At its broadest north-south extent, the coalfield is approximately 30 km wide and is characterised by several deep valleys running north-south and east-west.

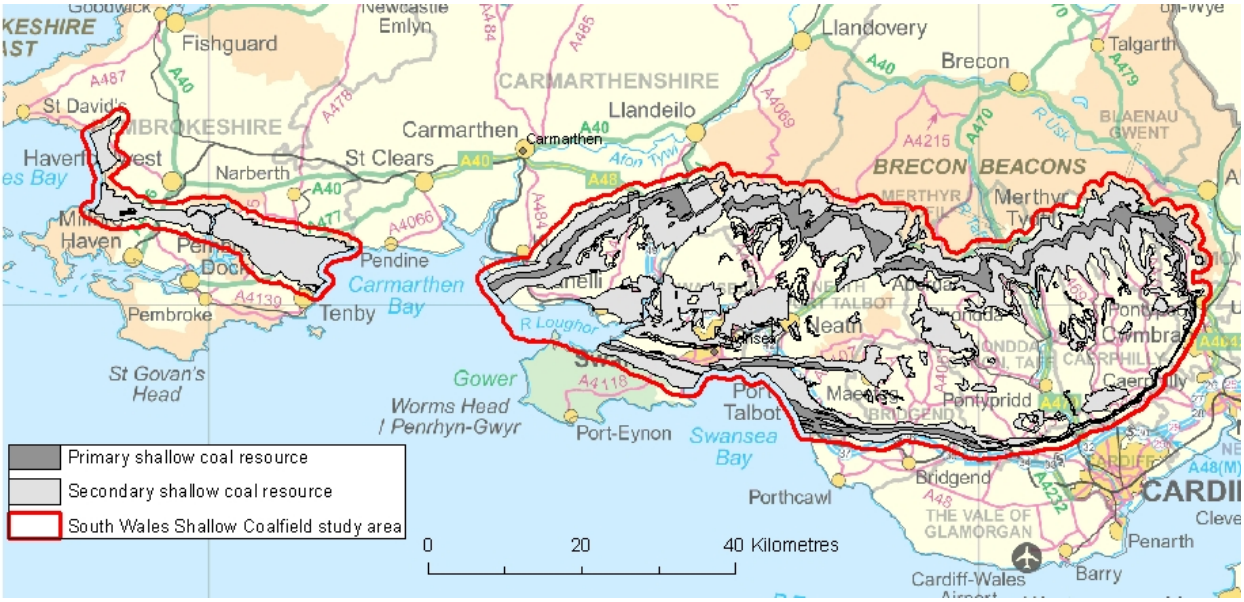


Figure 1 Location of South Wales Coalfield showing primary and secondary (shallow) coal resources

Mining began at the edges of the coalfield where the coal seams are nearer to the surface and thus easier to extract. However, by 1880 and onwards, deeper coal was being extracted from nearer the centre of the coalfield. Urban settlements in the region, such as Rhondda, developed as a result of the coal mining. The settlements were built into tightly packed rows of terraced housing strung out along the narrow valleys and are therefore largely linear in morphology (Figure 3).

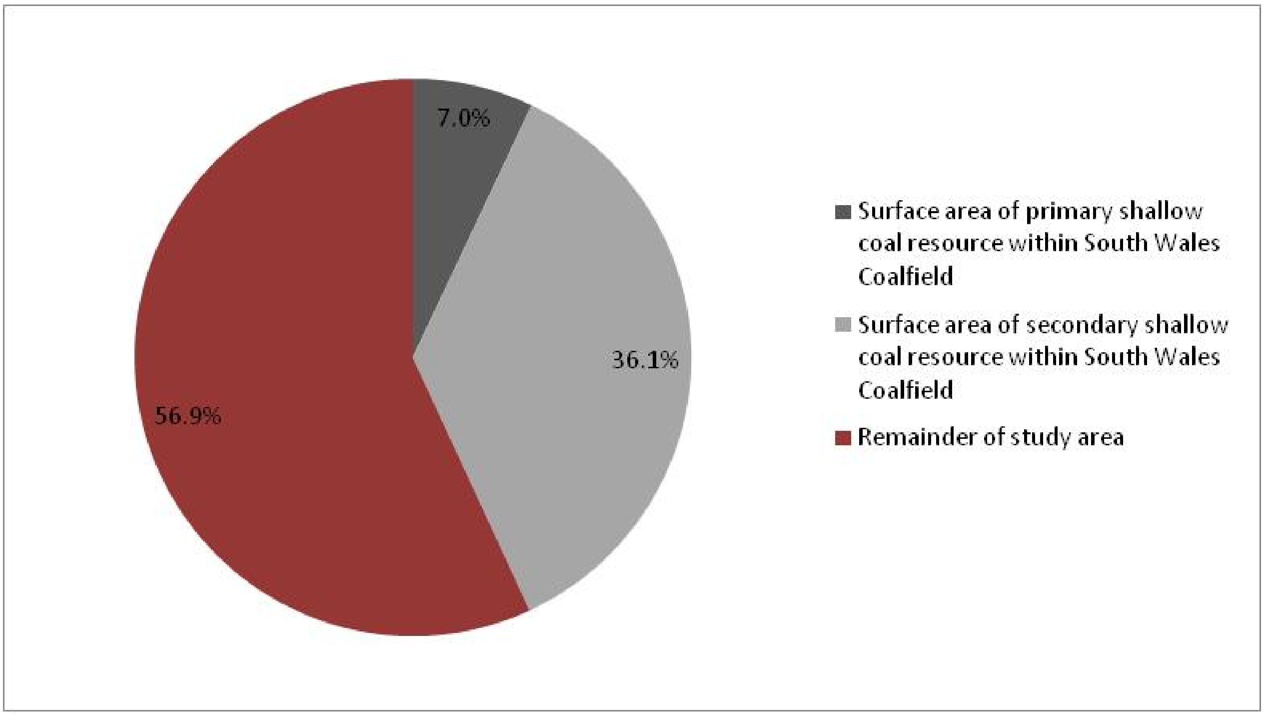


Figure 2 Graphical representation of the surface area of shallow coal resources within the South Wales Coalfield

Table 1 The surface area of the shallow coal resources within the South Wales Coalfield

	Area km^2	% of study area
Primary shallow coal resource	177.98	7.0%
Secondary shallow coal resource	915.65	36.1%
Total shallow coal resource in study area	1093.63	43.1%
Size of study area (red line boundary)	2536.91	100%

Figure 3 Aerial image showing settlement along the Rhondda Valley

(Image produced using Geovisionary Software using NEXTMAP Britain elevation data from Intergaph Technologies)

1.1.2 The Midlands Coalfield

The characterisation of the Midlands Coalfield (Figure 4), comprising the Yorkshire, Nottinghamshire and North Derbyshire Coalfields, is closely related to the physical manifestation of the underlying Carboniferous Coal Measures geology where the changing sequence of rocks and their relative resistances to weathering has given rise to the undulating landform of low hills and ridges separating a sequence of shallow valleys as shown in Figure 5 (Natural England, 2008).

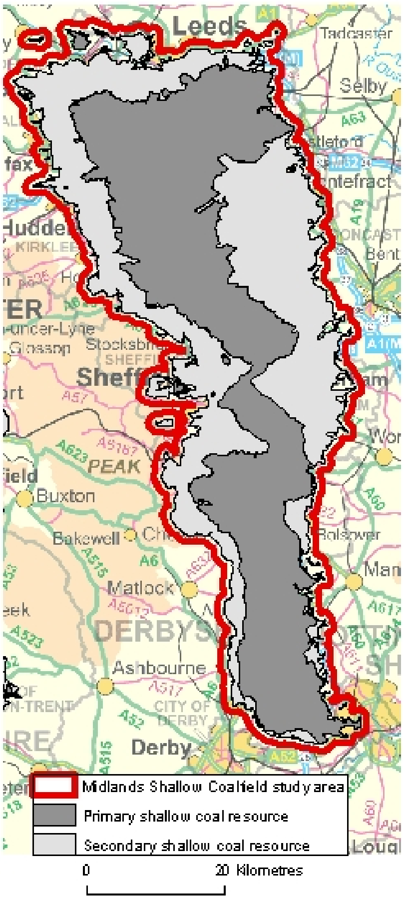


Figure 4 Location of Midlands Coalfield showing primary and secondary (shallow) coal resources

The primary and secondary (shallow) coal resources within the Midlands Coalfield have a combined surface area extent of approximately 2392.79 km^2 (Table 2 and Figure 6). Settlements within the coalfield have seen constant change and development since the industrial revolution which bears testimony to the progressive exploitation of the area.

Figure 5 Aerial image showing the equidimensional morphology of Hucknall

(Image produced using Geovisionary Software using NEXTMAP Britain elevation data from Intergaph Technologies)

Table 2 The surface area of the shallow coal resources within the Midlands Coalfield

	Area km^2	% of study area
Primary shallow coal resource	1296.51	44.8%
Secondary shallow coal resource	1096.28	37.9%
Total shallow coal resource in study area	2392.79	82.8%
Size of study area (red line)	2891.53	100%

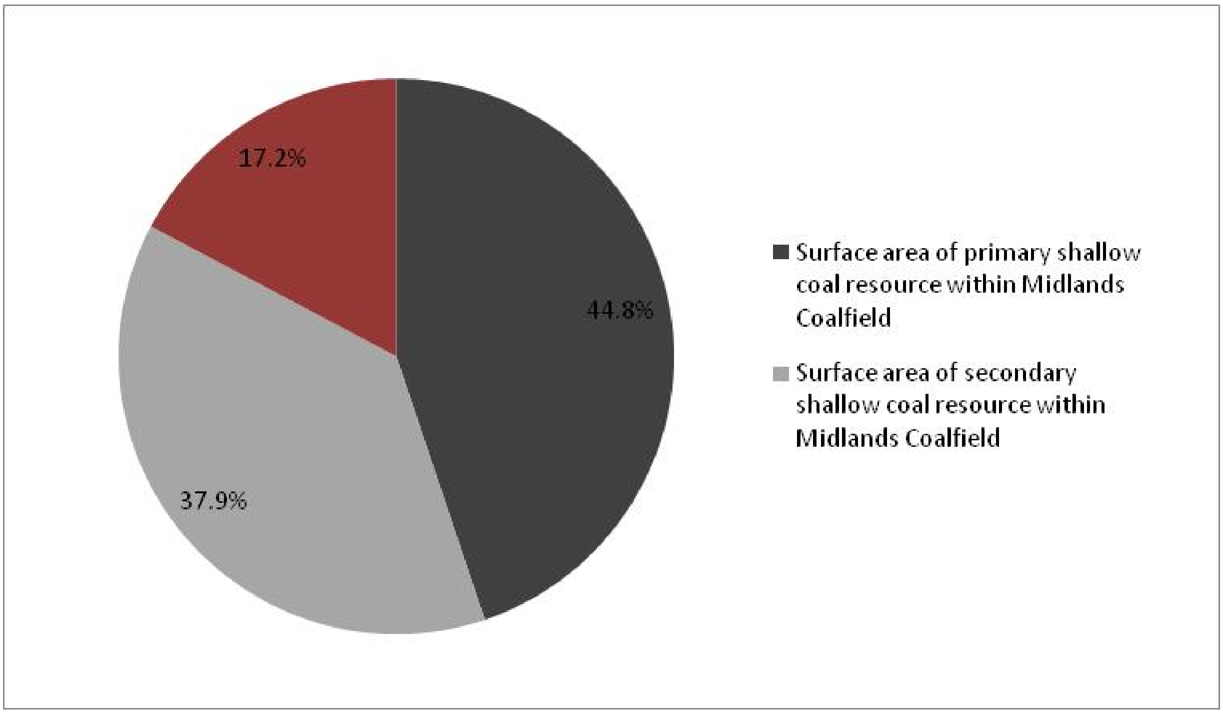


Figure 6 Graphical representation of the surface area of shallow coal resources within the Midlands Coalfield

1.2 DEFINITION OF 'SEPARATION' AND 'BUFFER' ZONES

For the purposes of this study a separation zone is defined as "*areas measured outwards from defined settlement boundaries within which certain coal operations will not be permitted*".

The term buffer zone is sometimes also used in policy and can be defined as "*an area of protection around permitted and proposed mineral workings*".

These definitions are taken from the Coal MTAN 2 consultation draft (2006), although it should be noted that only the latter definition was included in the final MTAN 2: Coal (2009).

This study considers the affect of separation zones on the surface extent of coal resources. It does not investigate buffer zones, but the term 'buffer' is used to describe the geoprocessing tool used within a Geographical Information System (GIS).

1.3 INFLUENCE OF SETTLEMENT MORPHOLOGY ON AREA OF SEPARATION ZONE - THEORY

The morphology of a settlement can affect the size of the area incorporated into a separation zone. For example, in Figure 7 a linear settlement such as that shown by the hypothetical 'Location A' causes the total area included in a given separation zone to increase by a substantially higher amount than a similar sized settlement which is more equidimensional (or nucleated) in morphology such as the hypothetical 'Location B'.

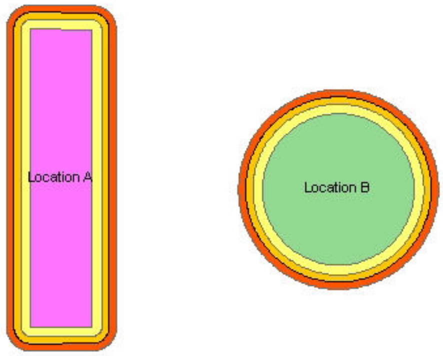


Figure 7 The morphology of 'hypothetical' settlements

Table 3 shows the relative increases in area incorporated into a separation zone for the two hypothetical settlements. If a 500 m buffer zone is applied to both settlements, 'Location A' increases by 105 % of its original area, whilst 'Location B' only increases by 74 % of its original area. The effect of morphology and settlement distribution may, therefore, impact upon the amount of resource being sterilised if a separation zone is applied.

Table 3 Comparing the effect of morphology on the area included in separation zones

		Location A		Location B	
		Area (km^2)	% increase	Area (km^2)	% increase
Urban Area		7.83	n/a	7.73	n/a
separation zone	**200 m**	10.93	39.6%	9.83	27.2%
	350 m	13.41	71.3%	11.56	49.5%
	500 m	16.04	104.9%	13.44	73.9%

As a result of the local geomorphology, settlements within the South Wales Coalfield study area are thought to have morphologies similar to 'Location A', whilst in the Midlands Coalfield, they are thought to be closer to that represented by 'Location B'. This is demonstrated by looking at the shape of the five case study areas for each coalfield area shown in Appendix 2.

1.4 AIM AND OBJECTIVES OF RESEARCH

The aim of this research was to investigate the influence that settlement pattern and morphology have on determining the area of separation zones and then determine the impact their application might have on the sterilisation of the shallow coal resources within the South Wales and the Midlands Shallow Coalfields. The objectives of this research were to:

1. Compare and contrast the settlement patterns of the two study areas.
2. Compare and contrast the morphology (i.e. physical shape/form) of the settlements within the two study areas.
3. Assess the impact that urban areas have on the sterilisation of the shallow coal resources within the two study areas.
4. Assess the impact that separation zones have on the sterilisation of the shallow coal resources within the two study areas.

5. Determine to what extent any difference in settlement pattern and morphology between the two study areas affects the area of separation zone and the amount of shallow coal resource sterilised if a separation zone is applied.

1.5 APPROACH

The research reported here largely follows the methodology undertaken by Jones (2006a) whereby BGS assessed the impact on the shallow coal resource of applying 200, 250 and 500 metres width separation zones around urban areas[1].

In addition to assessing the impact that separation zones may have on the area of available shallow coal resource, the influence of settlement pattern and morphology on the size of these separation zones also required investigation. The settlement pattern within the Midlands Coalfield is compared to that of the South Wales Coalfield using the 'Nearest Neighbour' statistical technique. An evaluation of settlement morphology (i.e. their physical form) is also undertaken based on previous work into density profiles (Bibby and Shepherd, 2001).

[1] For the purposes of this study, an urban area is defined as a settlement of ten or more properties. See Appendix 3.

2 Analysis of settlement pattern

Nearest Neighbour Analysis (NNA) is a spatial statistical technique commonly applied to studies investigating distribution patterns. NNA is useful in determining whether the distribution of 'dots' (e.g. samples, towns) exhibits a particular pattern. It is commonly applied within geography to determine settlement patterns. The technique attempts to measure the distribution of dots (in this case urban settlements) according to whether they are clustered, random or regular. To verify the results further, ESRI ArcGIS '*average nearest neighbour distance'* tool was also applied to the study areas. These statistical techniques and formulae are explained in detail in Appendix 4 along with the limitations of this approach.

To determine the settlement patterns for the two coalfields being studied, the OS Strategi® settlement points were used. Although OS Strategi® was created in 2001, it is still a useful dataset in determining the patterns of how settlements have developed.

2.1 SETTLEMENT PATTERN - SOUTH WALES COALFIELD

The results of the NNA for the South Wales Coalfield, are shown in Table 4. The nearest neighbour statistic, where (Rn) is 1.08, shows that the settlement pattern appears to be fairly random (see Appendix 4 for explanation). However, the results are likely to be skewed by the shape of the coalfield, which essentially generates two separate areas (Figure 8).

Table 4 Nearest neighbour value for the South Wales Coalfield - Areas 1 and 2 combined

Area under study (km^2) ***A***	Mean observed nearest neighbour distance (km) $\bar{d}$	Total number of points (settlement centres) ***n***	Nearest neighbour statistic ***Rn***
2536.91	1.38	387	1.08

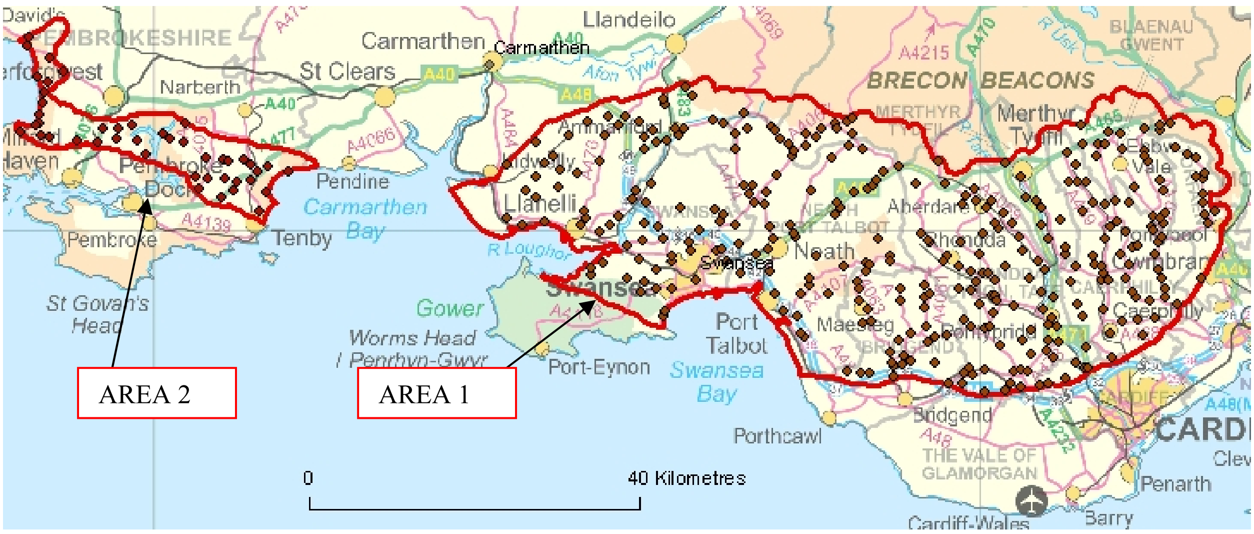


Figure 8 The 'dot distribution' of settlements in the South Wales Coalfield area(s)

Conducting the ESRI ArcGIS '*average nearest neighbour distance*' statistic on this dataset would be meaningless since the tool would calculate a bounding box area encompassing all points, and including the stretch across Carmarthen Bay. As this is likely to skew the results, a more meaningful analysis has been conducted which considers the two areas shown in Figure 8 in isolation. The results of this separate analysis are shown in Table 5 for 'Area 1' and Table 6 for 'Area 2'.

Table 5 Nearest neighbour value for the South Wales Coalfield - Area 1

Area under study (km^2) ***A***	Mean observed nearest neighbour distance (km) $\bar{d}$	Total number of points (settlement centres) ***n***	Nearest neighbour statistic ***Rn***
2308.90	1.37	343	1.06

Table 6 Nearest neighbour value for the South Wales Coalfield - Area 2

Area under study (km^2) ***A***	Mean observed nearest neighbour distance (km) $\bar{d}$	Total number of points (settlement centres) ***n***	Nearest neighbour statistic ***Rn***
218.01	1.47	44	1.32

A nearest neighbour statistic (Rn) of 1.06, leaning more towards clustering than the combined value, is generated when the results of the settlements within just Area 1 are analysed. This result is further verified using the ESRI ArcGIS '*average nearest neighbour distance*' tool (Figure 9). The results suggest that the settlement pattern is somewhat clustered, and that this pattern is only 5-10 % likely to be the result of random chance.

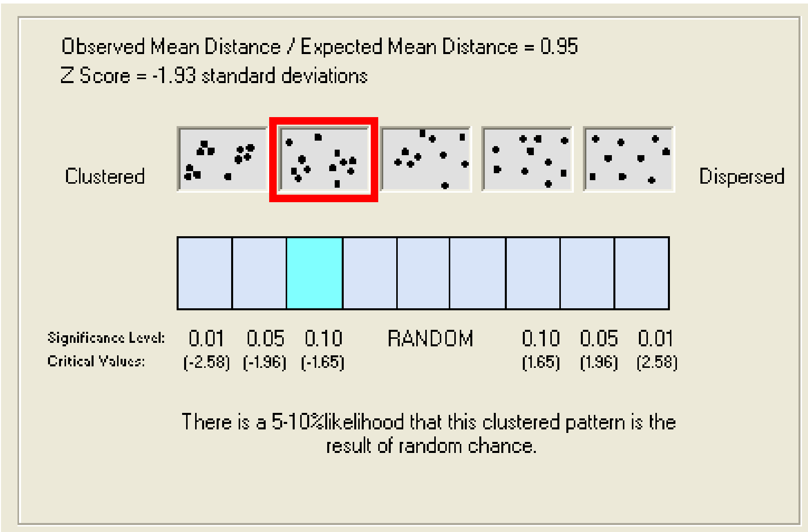


Figure 9 'Average nearest neighbour distance' for the South Wales Coalfield (Area 1)

When Area 2 is analysed in isolation, a nearest neighbour statistic (Rn) of 1.32 is generated (Table 6), which leans towards a more regular (or dispersed) settlement pattern type. This result is further verified using the ESRI ArcGIS 'average nearest neighbour distance' tool (Figure 10). The results suggest that the settlement pattern is dispersed, and that there is a less than 1 % likelihood that this pattern is a result of random chance. This area is less characterised by elongated valleys than Area 1 and, therefore, is likely to have been less influential on the location of settlements in this area.

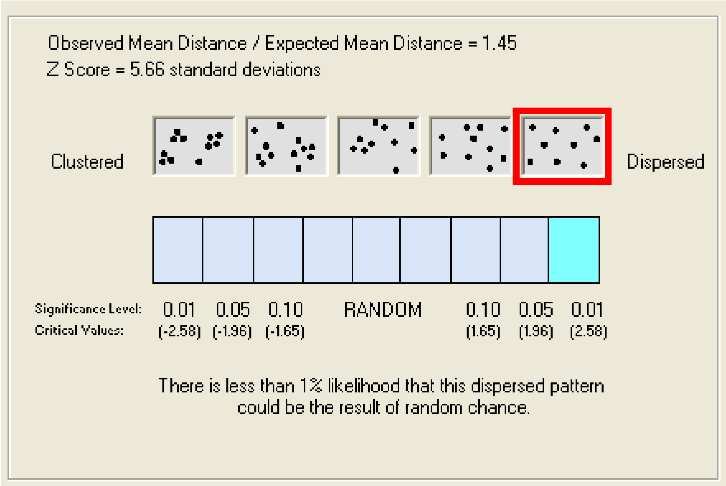


Figure 10 '*Average nearest neighbour distance*' for the South Wales Coalfield (Area 2)

2.2 SETTLEMENT PATTERN - MIDLANDS COALFIELD

The results of the NNA for the Midlands Coalfield (Figure 11) are recorded in Table 7. The nearest neighbour statistic (Rn) is 1.24, showing that the settlement pattern is largely random with a tendency towards regularity.

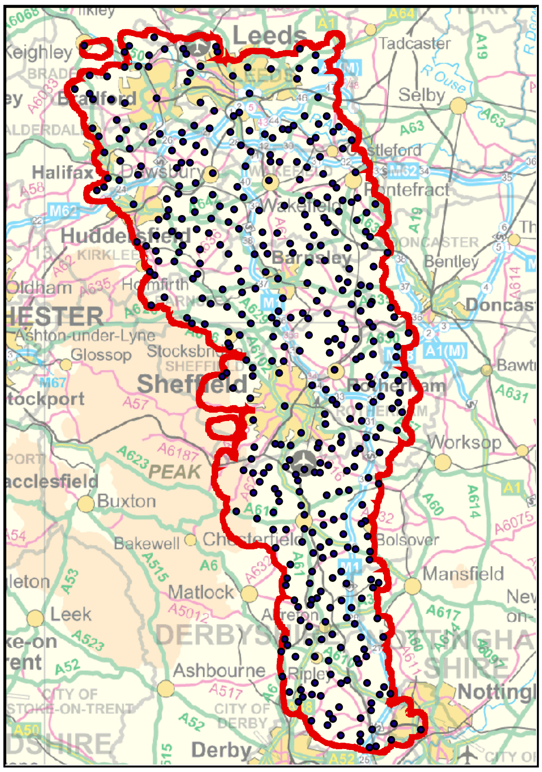


Figure 11 The Midlands Coalfield area showing the 'dot distribution' of settlements

This result is further verified using the ESRI ArcGIS '*average nearest neighbour distance*' tool (Figure 12). The results suggest that the settlements are somewhat dispersed across the study area, and that this may be due to random chance.

Table 7 Nearest neighbour value for the Midlands Coalfield

Area under study (km^2) A	Mean observed nearest neighbour distance (km) $\bar{d}$	Total number of points (settlement centres) n	Nearest neighbour statistic Rn
2891.54	1.63	420	1.24

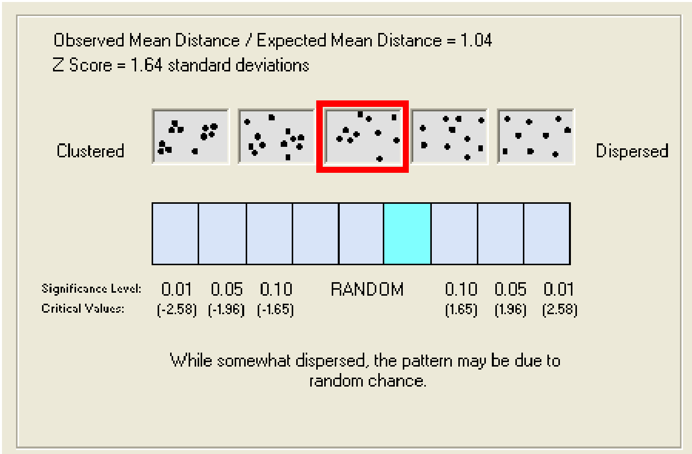


Figure 12 '*Average nearest neighbour distance*' for the Midlands Coalfield

2.3 COMPARING 'LIKE FOR LIKE' AREA

When comparing two or more settlement distribution patterns using NNA it is important to compare like-for-like. Comparisons are only valid if the areas chosen for analysis are the same size. To verify the results observed above for each of the coalfields, a smaller area within the Midlands Coalfield has been generated for analysis which reflects the size of Area 1 of the South Wales Coalfield. This is shown in Figure 13.

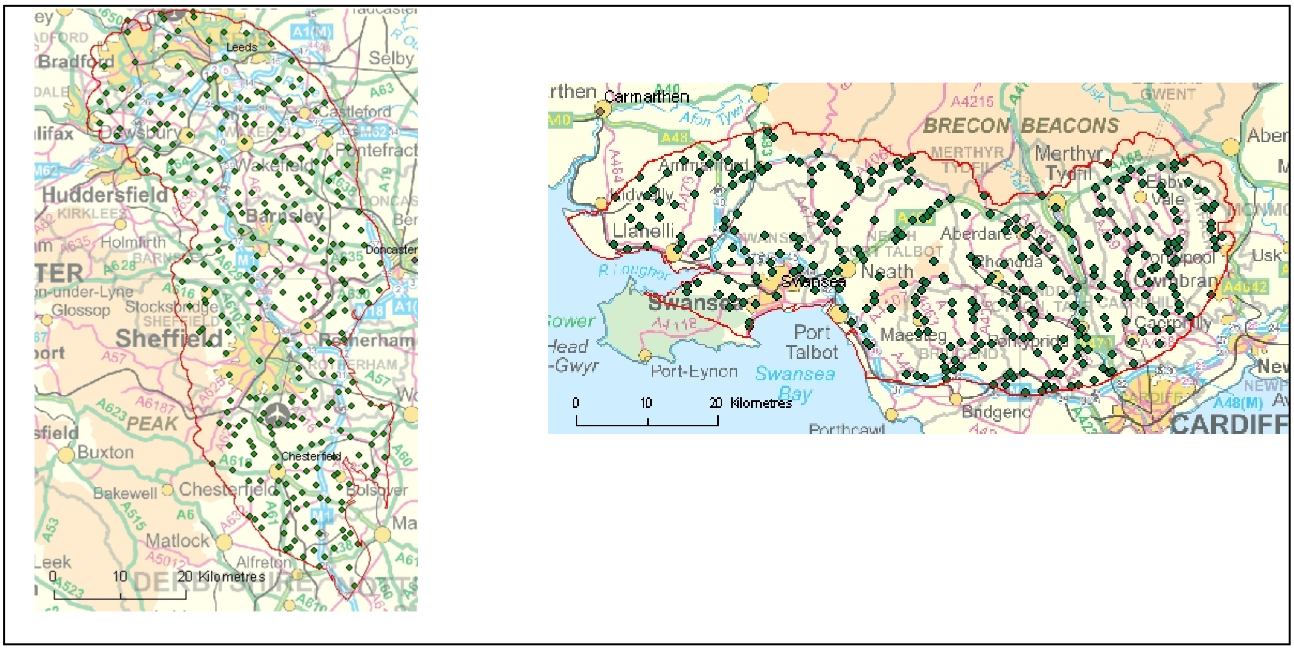


Figure 13 Area 1 of the South Wales Coalfield transposed onto the Midlands Coalfield

Table 8 Nearest Neighbour Analysis results for the like-for-like study areas

Location	Area under study (km^2) *A*	Mean observed nearest neighbour distance (km) $\bar{d}$	Total number of points (settlement centres) *n*	Nearest neighbour statistic *Rn*
Midlands	2308.90	1.67	323	1.25
South Wales	2308.90	1.37	343	1.06

The results of the NNA for the area within the Midlands Coalfield area (Table 8), used as a comparative to Area 1 in the South Wales Coalfield, show that the settlement pattern, where Rn is equal to 1.25, is regular (i.e. more evenly dispersed across the study area). This result is further verified using the ESRI ArcGIS '*average nearest neighbour distance*' tool (Figure 14). This contrast with Area 1 in the South Wales Coalfield which suggest that the settlement pattern there is somewhat clustered (Figure 9).

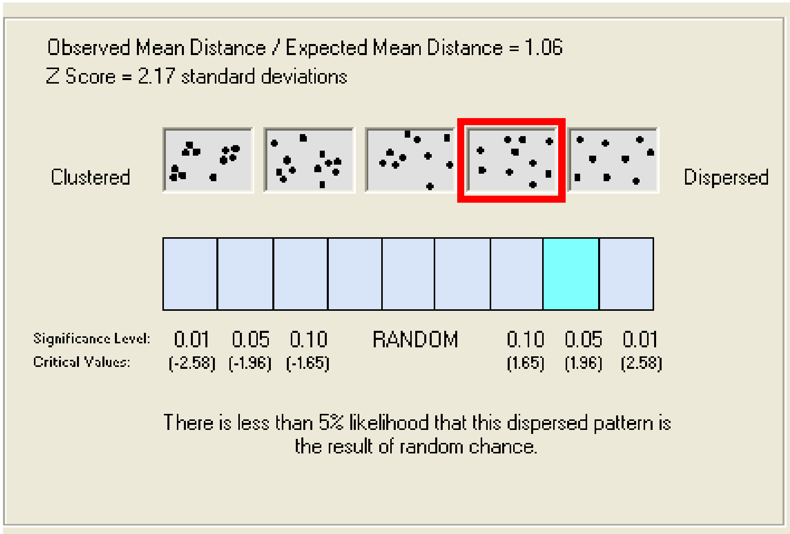


Figure 14 '*Average nearest neighbour distance*' for the Midlands Coalfield within the like-for-like study area

2.4 SUMMARY

The findings of the NNA shows that the settlement pattern within the two coalfield areas differ from each other. The settlement pattern within the Midlands Coalfield is considered to be more evenly dispersed across the study area than within the South Wales Coalfield where settlements are more clustered. These findings support the theory that the settlement pattern observed in the South Wales Coalfield is likely to have been influenced by some controlling factor (e.g. topography), whereas the pattern observed in the Midlands Coalfield study area is more likely to be a result of other, more random, influences on location.

3 Analysis of settlement morphology

In 2001 the then Department of Transport, Local Government and the Regions (DTLR) commissioned a wide-ranging review of the definitions of urban and rural areas in use for policy purposes and statistical reporting. The review covered both England and Wales and involved consultation with over twenty-five Government Departments and sections within them (Bibby and Shepherd, 2001). The methodology used also examined residential densities and compared density profiles of settlements as a means of typifying settlements and enabling, via a set of rules, a classification of settlement types. The methodology is based on the premise that the rate at which density changes away from the 'focus' cell is a function of local settlement structure.

Bibby and Shepherd's methodology has been applied to the two coalfield study areas in this report in order to classify settlement types within the coalfields and compare and contrast their settlement density profiles, and the morphology of these profiles. To replicate this methodology the OS MasterMap ® Address Points layer was used. The GIS methodology and resultant density profiles are included in Appendix 5.

3.1 SETTLEMENT MORPHOLOGY - SOUTH WALES COALFIELD

The density profiles for Area 1 in the South Wales Coalfield show that the area as a whole is not as densely urbanised as in the Midlands Coalfield (see Appendix 5, Figure 52). However, the area is characterised by pockets of 'density' along many valleys, where the majority of settlements exist. This creates settlements with a linear morphology. The linear shape of the settlements is further exemplified by the results of the settlement type analysis devised by Bibby and Shepherd (2001) shown in Figure 15. The settlement morphology in the South Wales Coalfield reflects the settlement morphology of hypothetical 'Location A' in Figure 7. This is especially apparent when it is compared alongside the result for the Midlands Coalfield in Figure 16.

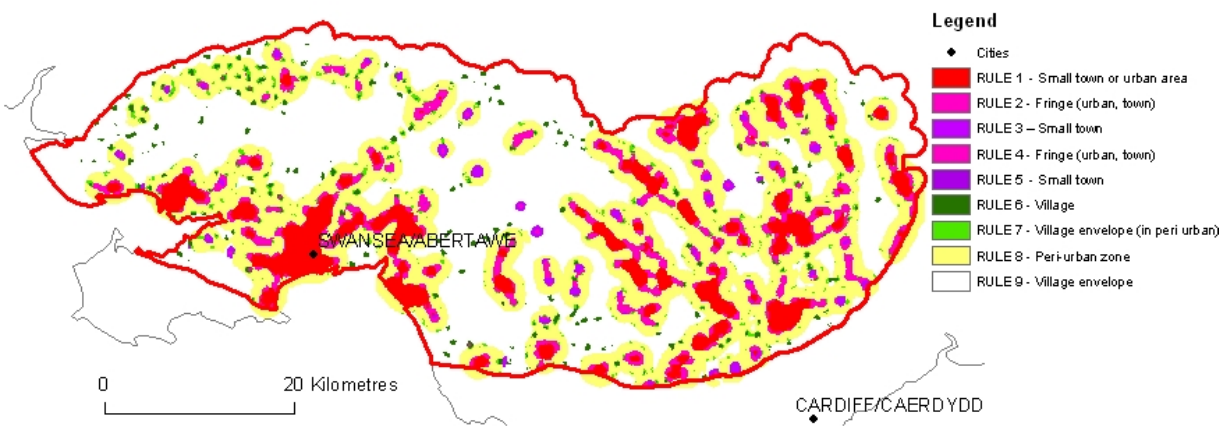


Figure 15 Settlement type in the South Wales Coalfield based on Bibby and Shepherd (2001)

3.2 SETTLEMENT MORPHOLOGY - MIDLANDS COALFIELD

The density profiles reveal that not only is the Midlands Coalfield more densely urbanised than the South Wales Coalfield, but that individual settlements are also largely equidimensional in morphology (see Appendix 5 Figure 53). The equidimensional shape of the settlements is further exemplified by the results of the settlement type analysis devised by Bibby and Shepherd (2001) shown in Figure 16.

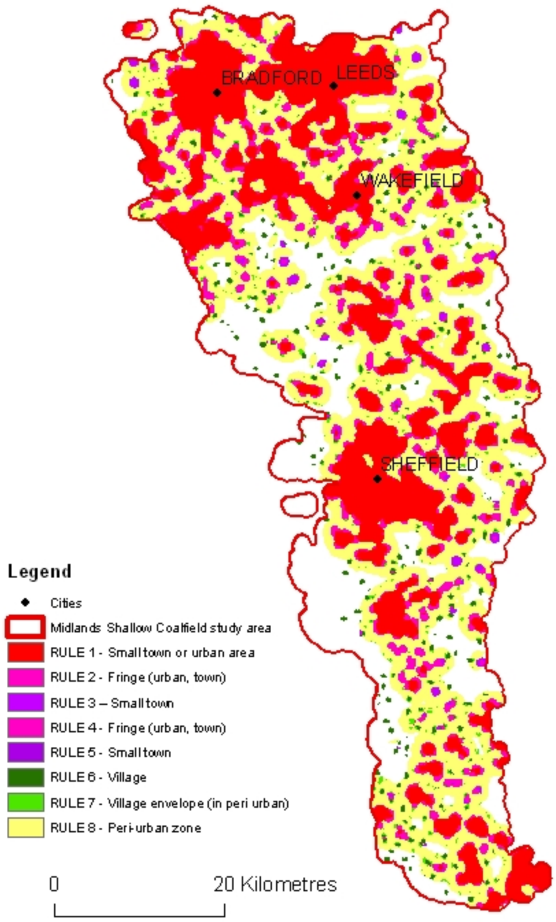


Figure 16 Settlement type in the Midlands Coalfield based on Bibby and Shepherd (2001)

The settlement morphology in the Midlands Coalfield study area reflects the settlement morphology of hypothetical 'Location B' in Figure 7. This is especially apparent when it is compared alongside the result for the South Wales Coalfield study area in Figure 15.

3.3 DENSITY VALUES USING ADDRESS POINTS

The density profiles shown in Figure 15 and Figure 16 confirm differences in settlement morphology across the two coalfield study areas. In order to compare and contrast the differences in settlement density across the two study areas, the average number of dwellings per square kilometre is required. In order to achieve this, OS Mastermap® Address Points have been used as a proxy indicator for the number of dwellings (see Appendix 6 for address point codes). Figure 17 clearly shows that when the coalfield areas are examined in their entirety, the Midlands Coalfield is more dense on average (i.e. there are more address points per square kilometre) than the South Wales Coalfield. This is also true when Areas 1 and 2 within the South Wales Coalfield are examined independently.

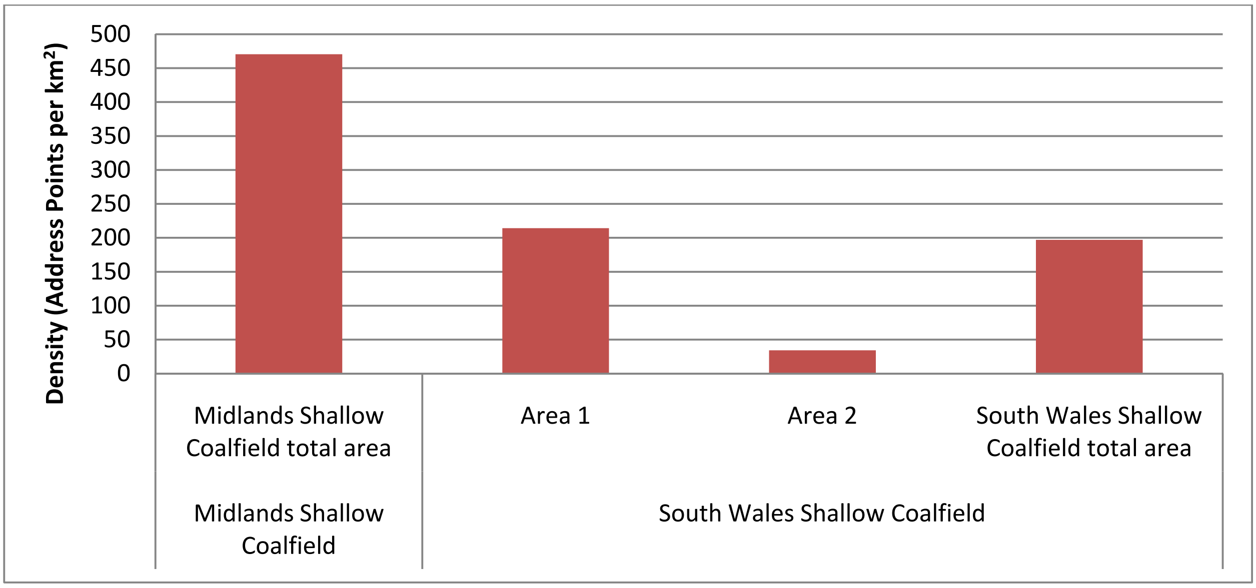


Figure 17 Average number of OS MasterMap® Address Points per km^2 for the two coalfield study areas (red line boundaries)

The results of this analysis do not take into consideration the density of individual settlement areas. In reality, the actual settlement areas within the South Wales Coalfield study area could have a higher number of address points per square kilometre (proxy for number of dwellings) than within the Midlands Coalfield study area. A greater area of ‘open’ space between settlements in this part of South Wales may have caused the average density across the entire coalfield study area to lower, skewing the result. In order to test this, five areas have been identified within each coalfield study area. The average number of address points per square kilometre within each settlement area were then calculated. The results are shown in Figure 18.

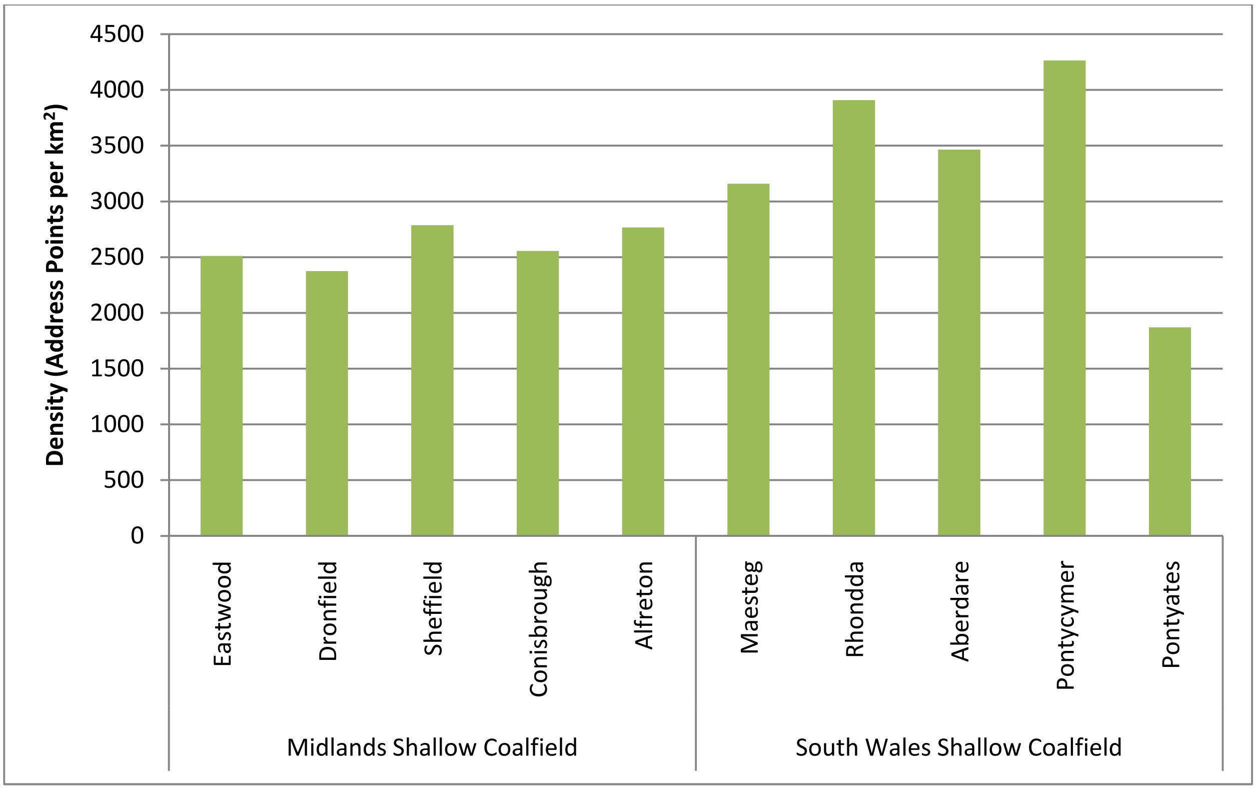


Figure 18 Average number of OS MasterMap® Address Points per km^2 for the ten case studies within the two coalfield study areas

Four out of the five settlements within the South Wales Coalfield have a higher average number of address points per square kilometre (i.e. are more dense) than the five settlements selected within the Midlands Coalfield study area. This result is largely as expected given that settlements in the South Wales Coalfield study area were built into tightly packed rows of terraced housing. The five extracted urban areas, with their respective separation zones, are shown in Appendix 2.

3.4 SUMMARY

The findings highlight that the Midlands Coalfield study area has an overall higher coverage of urban areas than in the South Wales Coalfield study area. It also shows that settlements within the South Wales Coalfield are generally elongated and linear in morphology, following the topography of the valley floors in this area. In contrast in the Midlands Coalfield, where the landscape is more gently undulating, settlements appear equidimensional in morphology.

The analysis shows that, in its entirety, the Midlands Coalfield has on average a higher number address points per square kilometre (proxy for number of dwellings) than the South Wales Coalfield. However, four out of the five settlements analysed within the South Wales Coalfield have a higher average number of address points per square kilometre than the selected settlements within Midlands Coalfield. Individual settlement areas themselves, therefore, appear to be denser in the South Wales Coalfield than in the Midlands Coalfield. This result is largely as expected given that settlements in the South Wales Coalfield were built into tightly packed rows of terraced housing.

4 The impact of settlement morphology on the extent of separation zones

The presence of an urban area (or settlement) within a coalfield effectively renders the shallow coal resource underneath the urban area unobtainable or '*sterilised*'. In order to quantify the extent of the urban development (and hence then be able to calculate the surface extent of shallow coal that is sterilised by urban development) within each of the coalfield study areas it is first necessary to identify the existing area of urban development. To do this, the methodology defined by Lott *et al.* (2006) and repeated by Jones (2006a) was followed and is outlined in more detail in Appendix 3. Separation zones of 200 m 350 m and 500 m were then constructed around the urban clusters to determine whether settlement pattern and morphology influences the areal extent of the separation zones, and hence apparent area of sterilisation from urban development.

4.1 SOUTH WALES COALFIELD

Figure 19 illustrates the typical linear urban morphology (as described previously in Chapter 3.1) of the urban areas and their associated separation zones within the South Wales Coalfield.

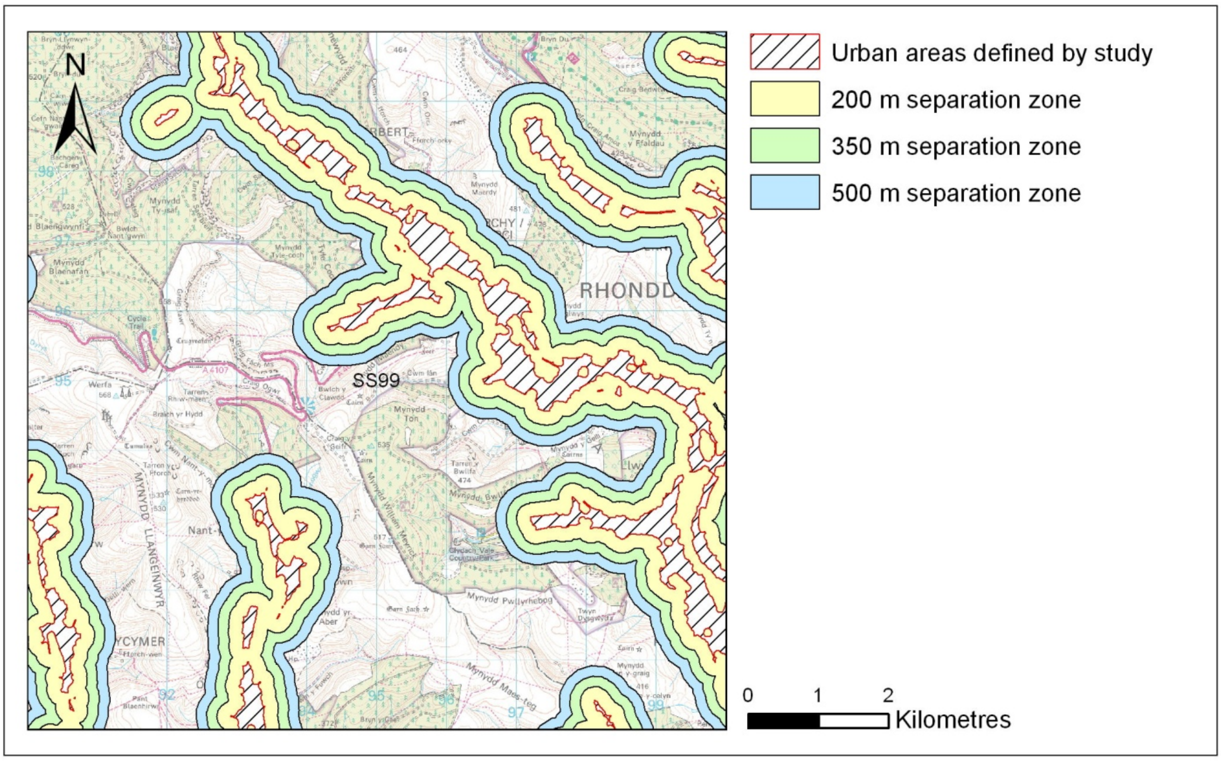


Figure 19 Separation zones around the urban clusters within the SS99 tile of the South Wales Coalfield.

Urban development accounts for 169.74 km^2 (6.7 %) of the total area of the South Wales Coalfield. Table 9 indicates how much the influence of urban development increases in areal extent within the South Wales Coalfield when separation zones are applied.

It can be seen that using a 500 m separation zone around urban development within the South Wales Coalfield has the impact of increasing the influence of the urban area from 169.74 km^2 (6.7 % of the study area) to 1119.61 km^2 (44.1 % of the study area). This means that if a 500 m separation zone was applied, an additional 949.87 km^2 (37.4 % of the study area) would be sterilised to that covered by the actual settlements themselves (169.74 km^2, or 6.7 % of the study area).

Table 9 Areal extent of urban areas and separation zones within South Wales Coalfield

		Incremental increase in area		Area of separation zone (less initial urban area)		Total Area (separation zone and urban area)		Study area remaining (separation zone and urban area removed)	
		(km^2)	% of study area	(km^2)	% of study area	(km^2)	% of study area	(km^2)	% of study area
Initial urban area - 0m separation zone		169.74	6.7%	N/A	N/A	169.74	6.7%	2367.17	93.3%
Separation zone	200m	454.69	17.9%	454.69	17.9%	624.43	24.6%	1912.48	75.4%
	350m	260.75	10.3%	715.44	28.2%	885.18	34.9%	1651.73	65.1%
	500m	234.43	9.2%	949.87	37.4%	1119.61	44.1%	1417.3	55.9%

** Total size of South Wales Coalfield Study area is 2536.91km²*

Table 9 shows the areal impact that urban development and the addition of each separation zone has on the total coalfield study area. Figure 20 illustrates this as a percentage of the total study area whilst the individual increases in area can be visualised in Figure 21.

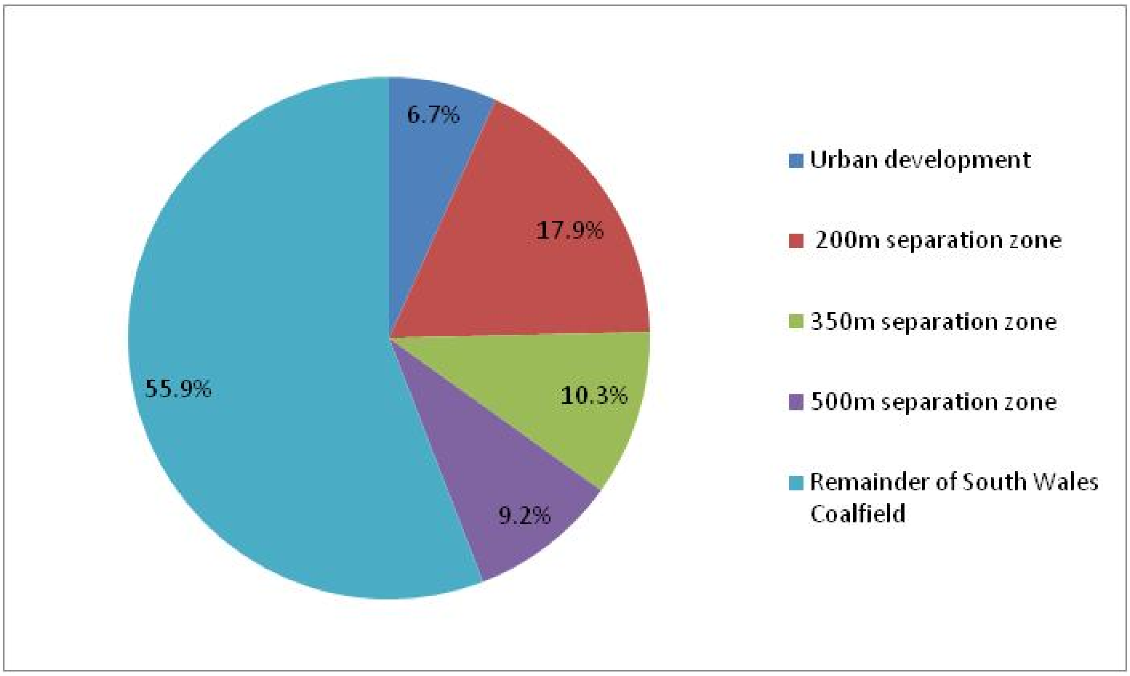
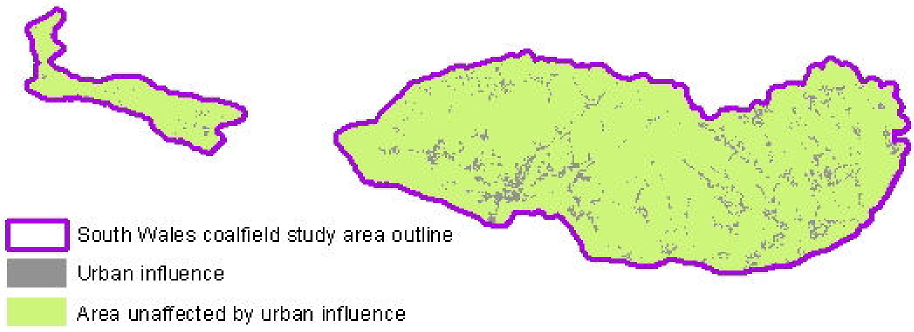
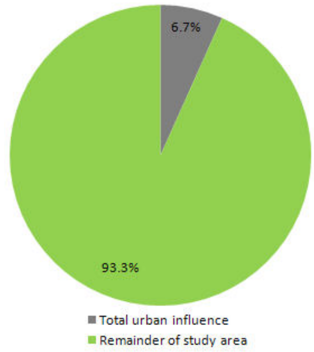


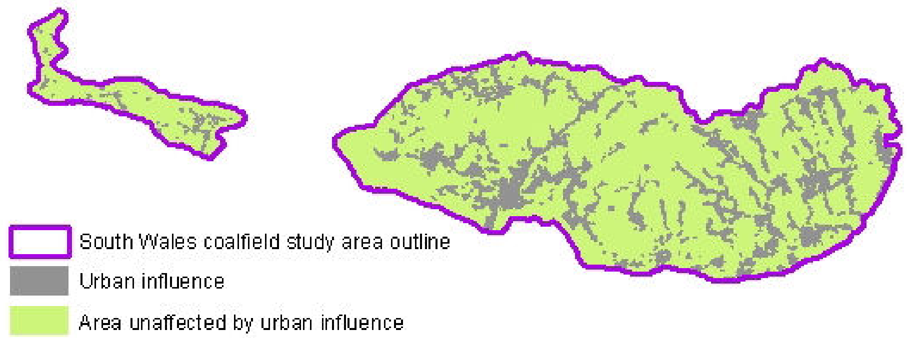
Figure 20 Area of urban development and each separation zone as a percentage of the total South Wales Coalfield

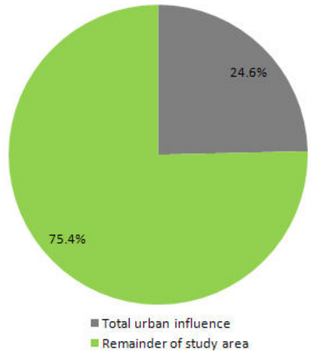
Urban area (no separation zone applied)



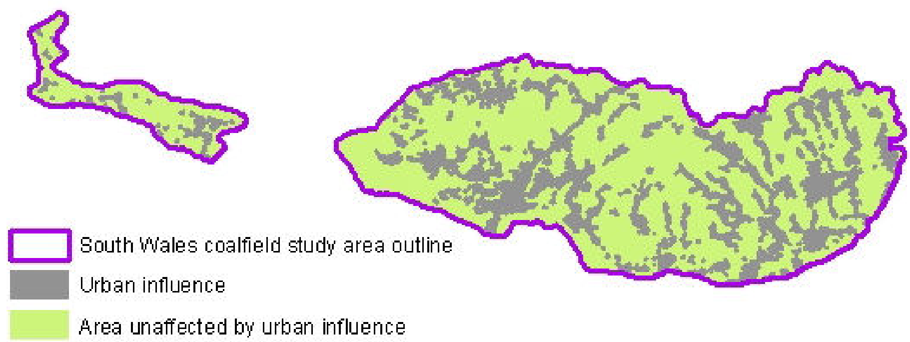


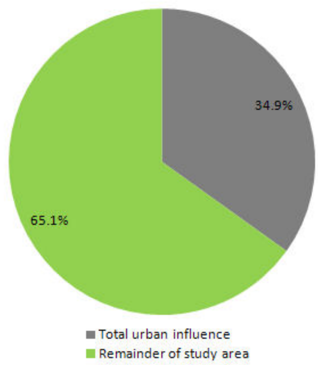
200m Separation zone applied



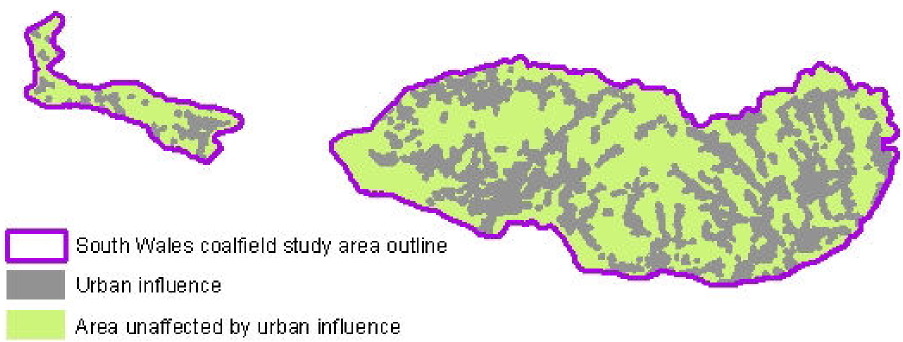


350m Separation zone applied





500m Separation zone applied



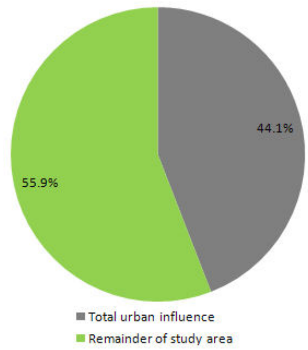


Figure 21 Visualisation of the increased influence of urban development within the South Wales Coalfield for each separation zone

4.2 MIDLANDS COALFIELD

Figure 22 shows a 10 km Ordnance Survey map tile within the Midlands Coalfield showing the typical nucleated urban morphology (as described previously in Chapter 3) and the respective separation zones.

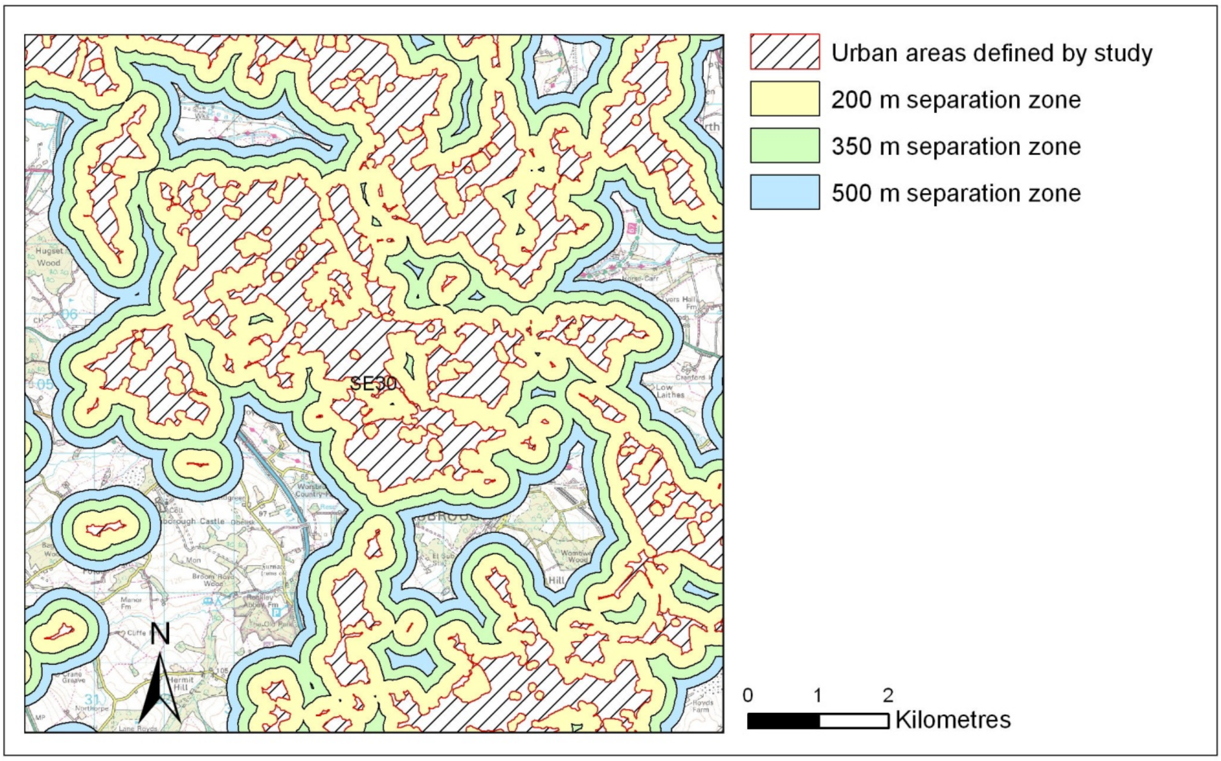


Figure 22 Separation zones around the urban clusters within the SE30 tile of the Midlands Coalfield area

Urban development accounts for 496.49 km^2 (17.2 %) of the total area of the Midlands Coalfield. Table 10 indicates how much the effect of urban development increases in areal extent within the Midlands Coalfield study area when separation zones are applied.

Table 10 Areal extent of urban areas and separation zones within the Midlands Coalfield

		Incremental increase in area		Area of separation zone (less initial urban area)		Total Area (separation zone and urban area)		Study area remaining (separation zone and urban area removed)	
		(km^2)	% of study area	(km^2)	% of study area	(km^2)	% of study area	(km^2)	% of study area
Initial urban area - 0m separation zone		496.49	17.2%	N/A	N/A	496.49	17.2%	2395.04	82.8%
Separation zone	200m	804.66	27.8%	804.66	27.8%	1301.15	45.0%	1590.39	55.0%
	350m	390.49	13.5%	1195.15	41.3%	1691.64	58.5%	1199.89	41.5%
	500m	308.11	10.7%	1503.26	52.0%	1999.75	69.2%	891.78	30.8%

** Total size of Midlands Coalfield Study area is 2891.53km²*

It can be seen that using a 500 m separation zone around urban development within the Midlands Coalfield has the impact of increasing the influence of the urban area from 496.49 km^2 (17.2 % of the study area) to 1999.75 km^2 (69.2 % of the study area). This means that if a 500 m separation zone was applied, an additional 1503.26 km^2 (52.0 % of the study area) would be sterilised to that covered by the actual settlements themselves (496.49 km^2, or 17.2 % of the study area).

The areal impact that urban development and the addition of each separation zone has on the total coalfield study area is shown in Table 10. Figure 23 illustrates this as a percentage of the total study area whilst the individual increases in area are represented graphically in Figure 24.

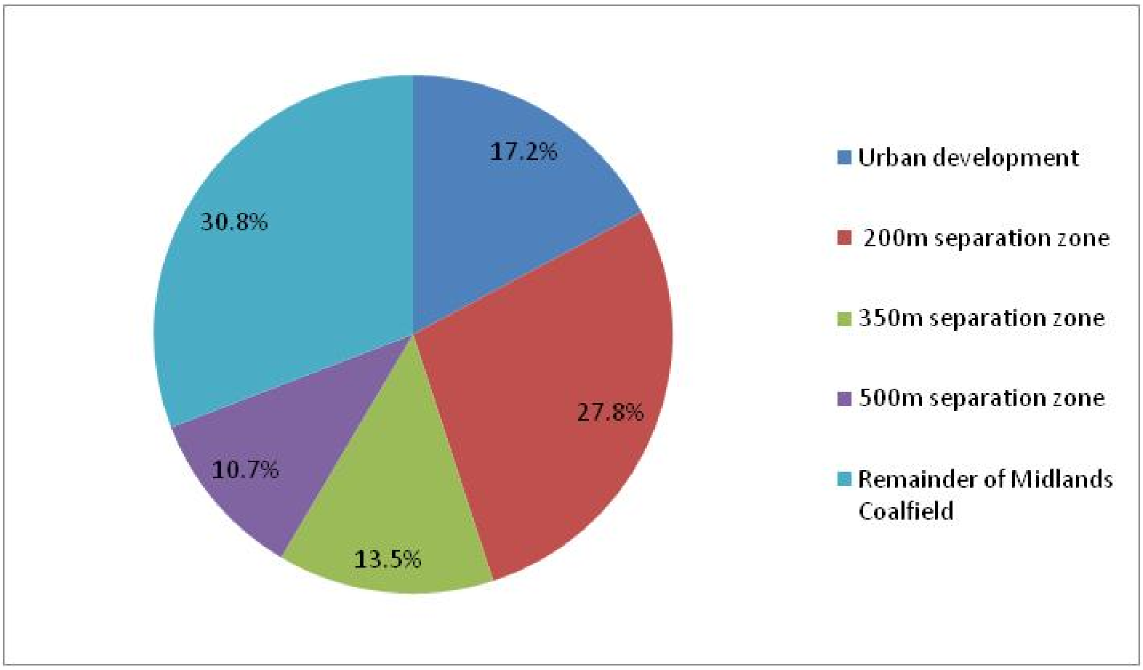


Figure 23 Area of urban development and each separation zone as a percentage of the total Midlands Coalfield

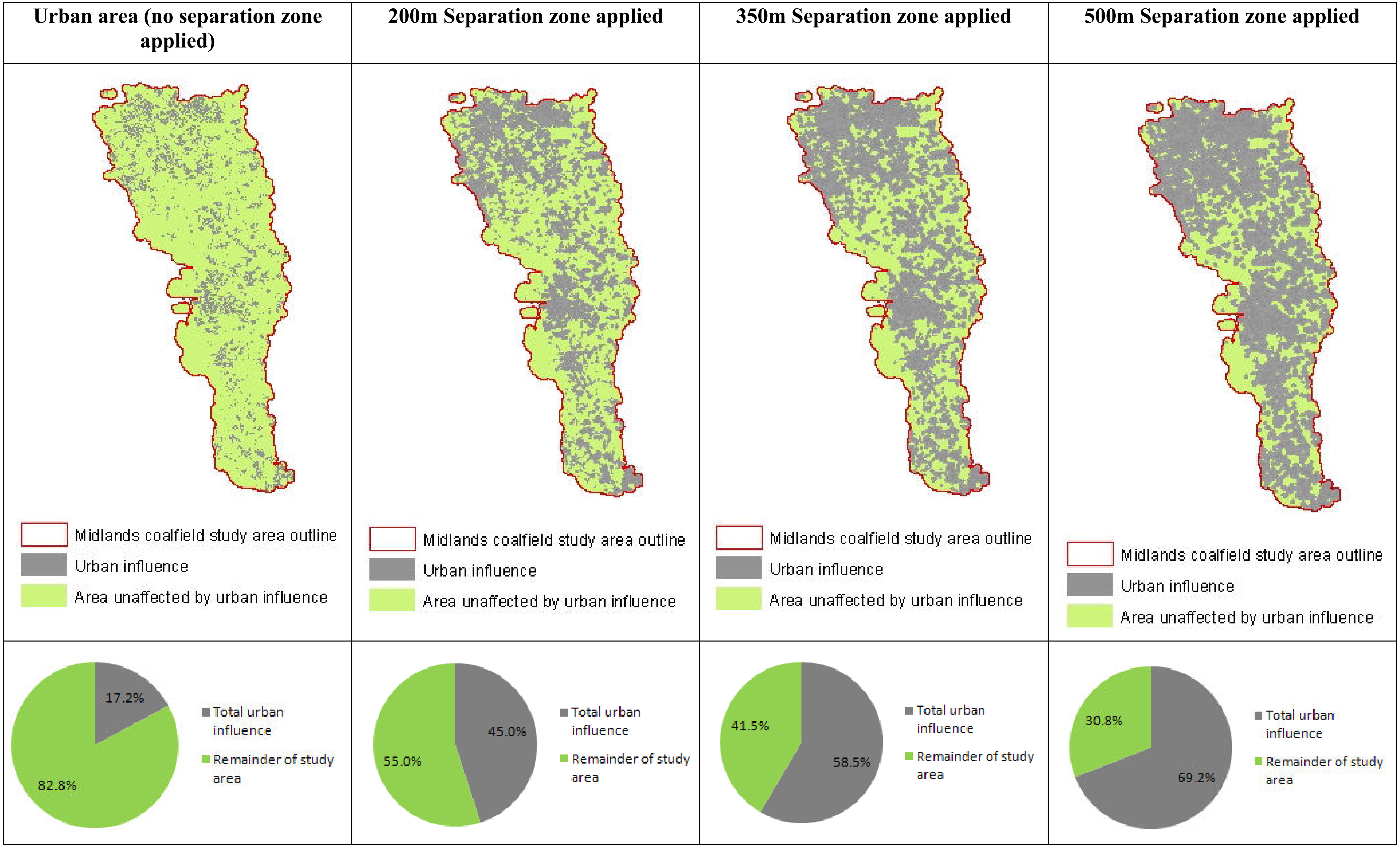


Figure 24 Visualisation of the increased influence of urban development within the Midlands Coalfield for each separation zone

4.3 RELATIVE IMPACT OF SEPARATION ZONES ON THE SIZE OF THE URBAN AREA

In order to compare the impact of settlement morphology on the area of separation zones within the two study areas, the size of the separation zones needs to be calculated relative to area of urban development before a separation zone is applied (i.e. the initial urban area). Table 11 shows the area of urban development when each separation zone is applied for the two study areas expressed as a percentage of the initial urban area.

Table 11 Areal extent of urban areas and separation zones within the two coalfield study areas relative to their initial urban area

			Incremental increase in area		Area of separation zone (less initial urban area)		Total Area (separation zone and initial urban area)	
			(km^2)	% of initial urban area	(km^2)	% of initial urban area	(km^2)	% of initial urban area
South Wales Coalfield	Initial urban area - 0m separation zone		169.74	100.0%	N/A	N/A	169.74	100.0%
South Wales Coalfield	Separation zone	200m	454.69	267.9%	454.69	267.9%	624.43	367.9%
South Wales Coalfield	Separation zone	350m	260.75	153.6%	715.44	421.5%	885.18	521.5%
South Wales Coalfield	Separation zone	500m	234.43	138.1%	949.87	559.6%	1119.61	659.6%
Midlands Coalfield	Initial urban area - 0m separation zone		496.49	100.0%	N/A	N/A	496.49	100.0%
Midlands Coalfield	Separation zone	200m	804.66	162.1%	804.66	162.1%	1301.15	262.1%
Midlands Coalfield	Separation zone	350m	390.49	78.7%	1195.15	240.7%	1691.64	340.7%
Midlands Coalfield	Separation zone	500m	308.11	62.1%	1503.26	302.8%	1999.75	402.8%

Figure 25 expresses the relative effect (i.e. relative to the size of the initial urban area) of the different separation zones on the total size of urban development graphically. It can be seen that applying 200 m, 350 m and 500 m separation zones to urban areas has a greater relative impact on the area of influence that settlements have within the South Wales Coalfield than in the Midlands Coalfield. Settlements with more linear morphologies (e.g. South Wales Coalfield) have a greater relative effect on the area incorporated into a separation zone than settlements which have more equidimensional (or nucleated) morphologies (e.g. the Midlands Coalfield).

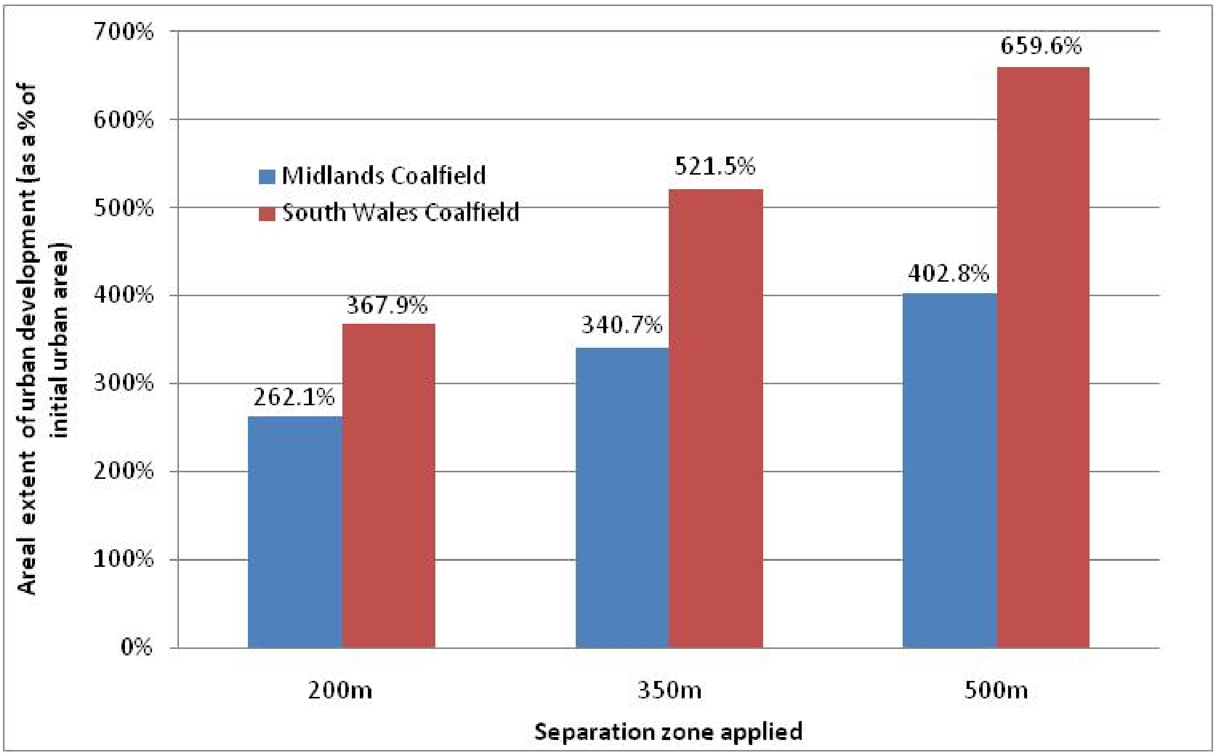
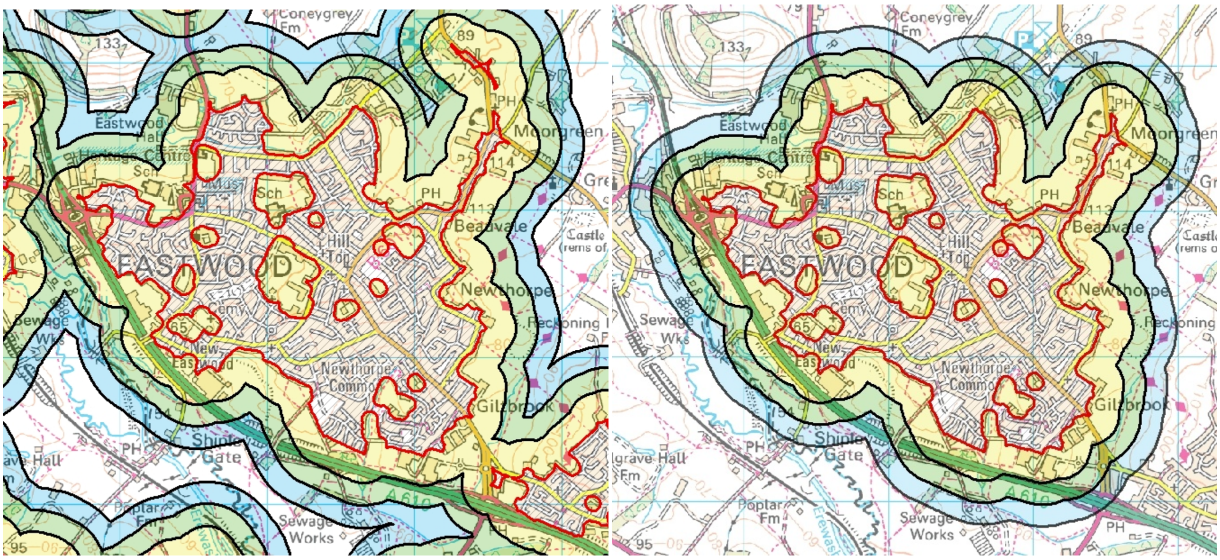


Figure 25 Relative area of influence of settlements (as a % of initial settlement area) when a series of separation zones are applied

4.4 CASE STUDIES

The increase in area through the application of separation zones can be further highlighted by using specific examples from within the Midlands and South Wales Coalfield study areas. Five settlements have been identified within each coalfield. Each of the settlements chosen typifies the settlement morphology found within its coalfield. Separation zones of 200 m, 350 m and 500 m have then been created for these case study settlements in isolation of other settlements as illustrated in the example of Eastwood, located in the Midlands Coalfield, in Figure 26. The five extracted settlement areas, with their respective separation zones, are shown in Appendix 2 along with a table of results charting how the separation zones increase the areal influence of settlements.

The diagonal area with red outline represents the settlement areas defined by this study; the yellow zone represents a 200 m separation zone around the settlement areas, the green zone represents a 350 m separation zone around the settlement areas and the blue zone represents a 500 m separation zone around the settlement areas.



Left slide: Eastwood settlement area with separation zones taken from the Midlands Coalfield settlement areas final dataset.

Right slide: Eastwood settlement cluster extracted from the dataset and new separation zones created to eliminate the effect of neighbouring clusters.

Figure 26 Separation zones for Eastwood in the Midlands Coalfield

The average values calculated show the 200 m, 350 m and 500 m separation zones increase the influence of the five settlement areas studied in the South Wales Coalfield to an average of 466.7 %, 708.5 % and 946.8 % of the original case study settlement area respectively. Conversely, the application of separation zones for the five case study areas within the Midlands Coalfield increase their area by an average of 239.3 %, 306.5 % and 374.8 % respectively as shown below in Table 12.

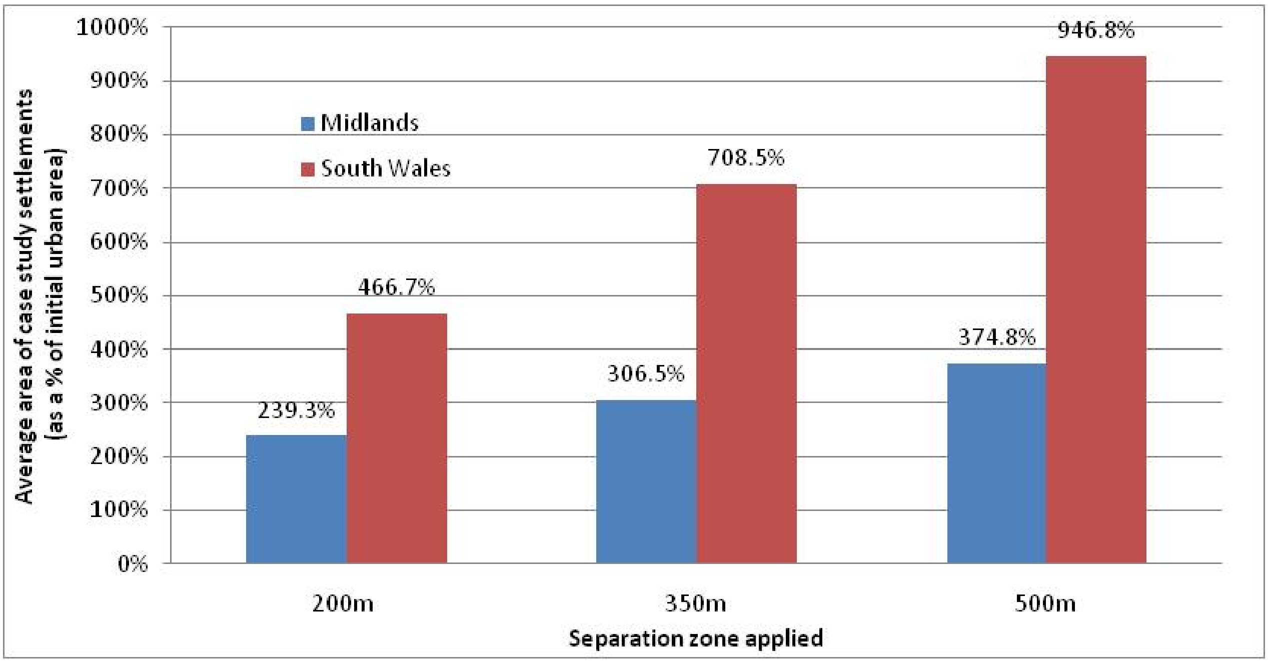


Figure 27 The average area of settlements, as a % of initial settlement area, when separation zones are applied to each of case study examples within each study area

The effect of the separation zones on the urban area within the Midlands Coalfield is proportionally less than in the South Wales Coalfield when a selection of settlement areas are analysed in isolation (Figure 27). This result is most likely attributed to the difference in settlement morphologies within the two areas as a result of the regional geomorphology.

Table 12 Areal influence of settlements when a series of separation zones are applied to each of the five case study examples within each coalfield study area

			Total influence of separation zone (including urban area)					
			200m separation zone		350m separation zone		500m separation zone	
	Location	Initial Area km^2	Area km^2	% of initial area	Area km^2	% of initial area	Area km^2	% of initial area
South Wales Coalfield	Maesteg	3.24	11.57	357.1%	16.48	508.6%	21.04	649.4%
	Rhondda	5.33	16.76	314.4%	23.61	443.0%	30.29	568.3%
	Aberdare	7.00	25.36	362.3%	35.36	505.1%	43.59	622.7%
	Pontycymer	0.53	3.45	650.9%	5.55	1047.2%	7.70	1452.8%
	Pontyates	0.39	2.53	648.7%	4.05	1038.5%	5.62	1441.0%
	Average	**N/A**	**N/A**	**466.7%**	**N/A**	**708.5%**	**N/A**	**946.8%**
Midlands Coalfield	Eastwood	3.06	6.24	203.9%	8.1	264.7%	9.96	325.5%
	Dronfield	3.71	8.00	322.6%	10.21	411.7%	12.41	500.4%
	Sheffield	54.78	106.77	194.9%	122.29	223.2%	133.64	244.0%
	Conisbrough	2.48	5.77	232.7%	7.39	298.0%	9.09	366.5%
	Alfreton	1.23	2.98	242.3%	4.12	335.0%	5.38	437.4%
	Average	**N/A**	**N/A**	**239.3%**	**N/A**	**306.5%**	**N/A**	**374.8%**

4.5 SUMMARY

The findings show that the relative effect of the separation zones is greater within the South Wales Coalfield than in the Midlands Coalfield. This is likely to be as a result of their respective differences in settlement morphology. When a separation zone is placed around settlements which are linear in morphology (e.g. settlements within South Wales Coalfield), the area of the separation zone is proportionally larger than that of a settlement zone placed around more equidimensional shaped settlements (e.g. settlements within Midlands Coalfield).

5 The impact of settlement areas and separation zones on the shallow coal resource

In order to assess the impact that settlements and their respective separation zones have on the sterilisation of shallow coal resources in each study area it is first necessary to subtract the surface extent of the settlement areas from the surface extent of the respective shallow coal resource within each coalfield study area. This value will indicate the extent to which settlements potentially 'sterilises' the shallow coal resource.

Separation zones of 200 m, 350 m and 500 m were calculated for the settlement areas within each of the coalfield areas. Regions outside of these separation zones (i.e. shallow coal resource area minus the total settlement area and its separation zone within the shallow coal resource) for the purposes of this study are considered as 'unsterilised'.

5.1 SOUTH WALES COALFIELD

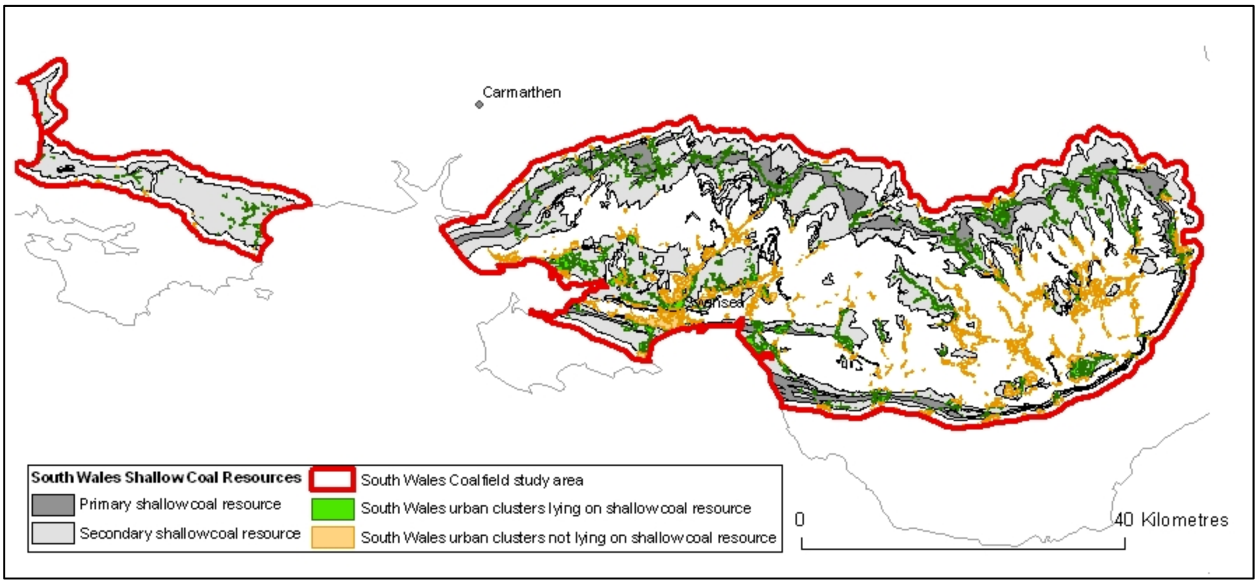


Figure 28 The geographical extent of shallow coal resource and settlements within the South Wales Coalfield study area

The geographical extent of the shallow coal resources and settlements within the South Wales Coalfield is illustrated in Figure 28. Of the total urban settlement area (169.74 km^2) within the South Wales Coalfield, 86.14 km^2 (50.7 %) lies on the shallow coal resource (Table 13 and Figure 29). This is equivalent to 8.1 % of the total surface extent of the shallow coal resource (Table 14).

Table 13 Areal extent of settlements on shallow coal resources within the South Wales Coalfield

	km^2	As a % of total settlement area
Urban area lying within extent of primary or secondary shallow coal resource - i.e. sterilised	86.14	50.7%
Urban area lying outside extent of primary or secondary shallow coal resource - i.e. not sterilised	83.61	49.3%
Total settlement area within coalfield study area	169.74	100%

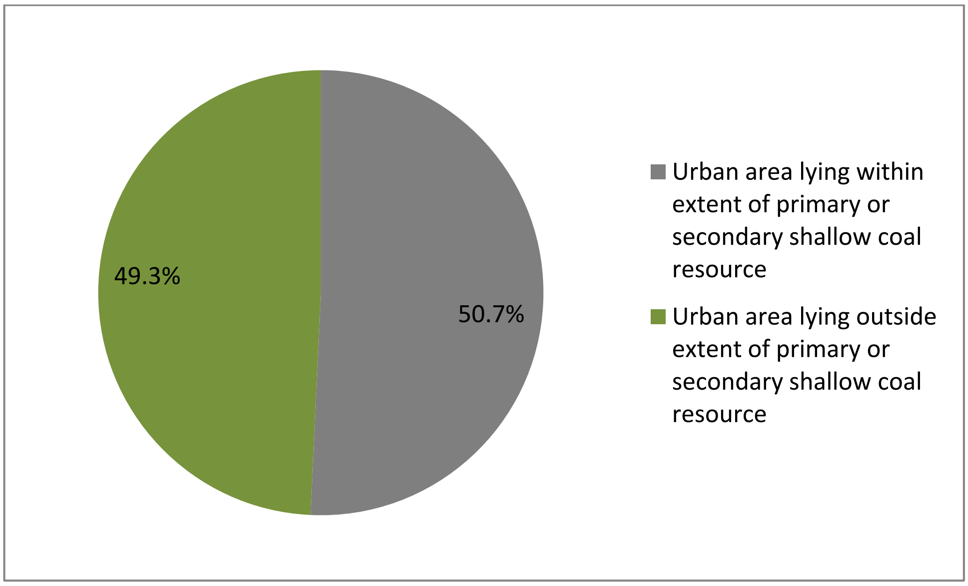


Figure 29 Area of settlements lying within surface extent of shallow coal resource within the South Wales Coalfield

The surface extent of the '*unsterilised*' shallow coal resource within the South Wales Coalfield reduces by a total of 323.25 km^2 (30.3 %), 452.64 km^2 (42.5 %) and 563.28 km^2 (52.8 %) if separation zones of 200 m, 350 m and 500 m are applied (Table 14). These increases in area can are represented graphically in Figure 30.

Table 14 The total impact of urban areas and separation zones on the shallow coal resource within the South Wales Coalfield

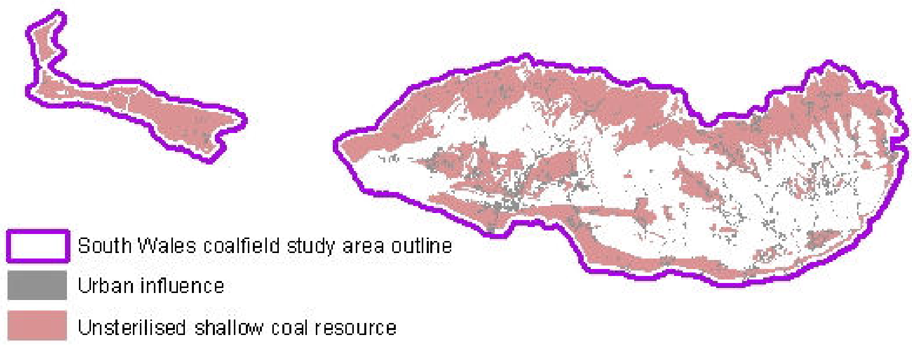
		South Wales Coalfield study area											
		Total area of shallow resource sterilised by settlements						Total area of shallow resource remaining (not sterilised by settlements)					
		Primary resource		Secondary resource		Total shallow resource		Primary resource		Secondary resource		Total shallow resource	
		km²	%	km²	%	km²	%	km²	%	km²	%	km²	%
Urban area lying on shallow coal resources using a separation zone of:	0m	13.46	7.9%	72.68	8.1%	**86.14**	**8.1%**	157.03	92.1%	822.96	91.9%	**979.99**	**91.9%**
	200m	59.34	34.8%	263.91	29.5%	**323.25**	**30.3%**	111.15	65.2%	631.73	70.5%	**742.88**	**69.7%**
	350m	83.06	48.7%	369.58	41.3%	**452.64**	**42.5%**	87.43	51.3%	526.06	58.7%	**613.49**	**57.5%**
	500m	102.89	60.3%	460.39	51.4%	**563.28**	**52.8%**	67.6	39.7%	435.25	48.6%	**502.85**	**47.2%**

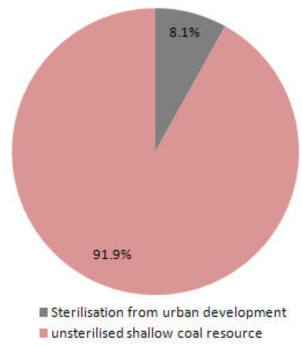
**Total area of shallow coal resource is: 1093.63 km^2 or 43.1% of the study area*

Table 15 Increase in the sterilisation of the shallow coal resource from settlements and separation zones within the South Wales Coalfield

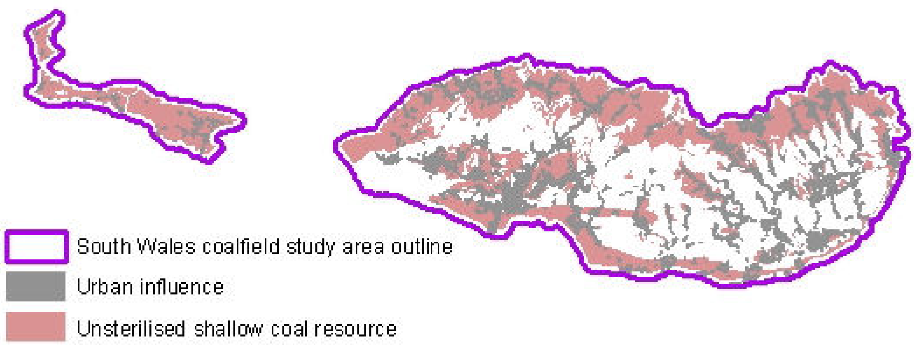
	Increase in sterilisation of primary shallow coal resource as a result of urban areas		Increase in sterilisation of secondary shallow coal resource as a result of urban areas		Increase in sterilisation of all shallow coal resource as a result of urban areas	
	km²	% of resource	km²	% of resource	km²	% of resource
Urban area within shallow coal resource	13.46	7.9%	72.68	8.1%	**86.14**	**8.1%**
200 m separation zone (as an increment)	45.88	26.9%	191.23	21.4%	**237.11**	**22.2%**
350 m separation zone (as an increment)	23.72	13.9%	105.67	11.8%	**129.39**	**12.1%**
500 m separation zone (as an increment)	19.83	11.6%	90.81	10.1%	**110.64**	**10.4%**
Cumulative total	102.89	60.3%	460.39	51.4%	**563.28**	**52.8%**

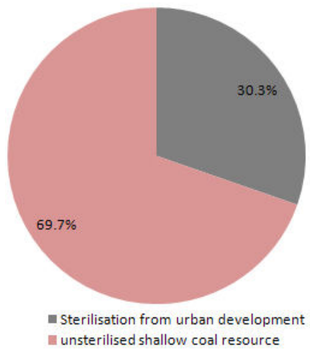
Urban area (no separation zone applied)



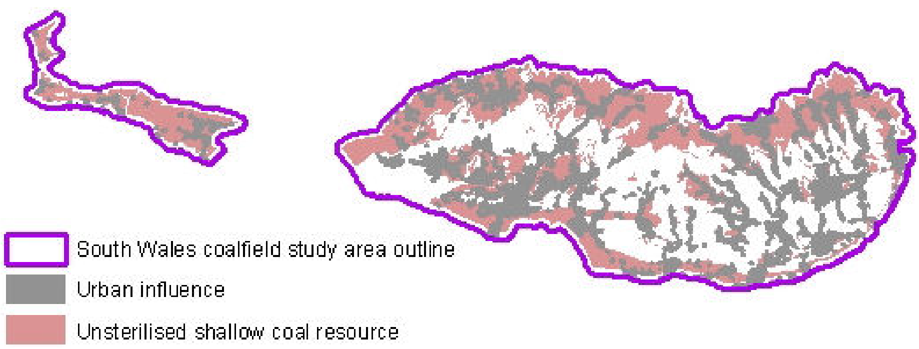


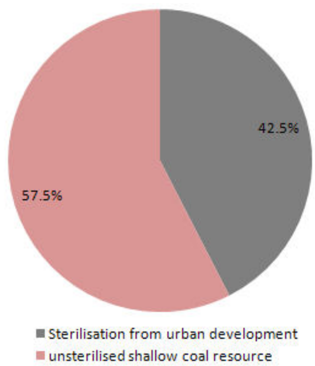
200m Separation zone applied



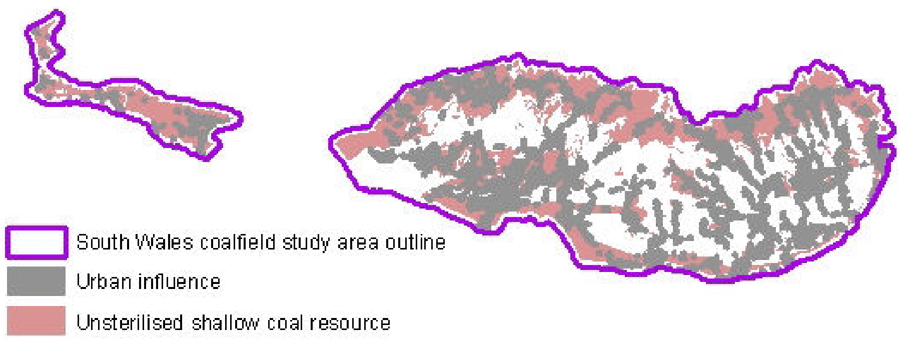


350m Separation zone applied





500m Separation zone applied



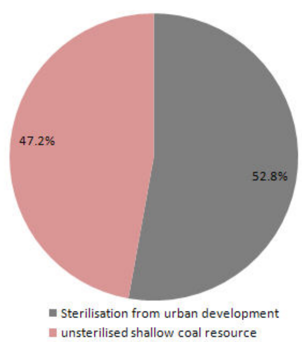


Figure 30 Visualisation of the increased influence of urban development within the South Wales Coalfield for each separation zone

Figure 31 shows the combined effect of the settlement areas and their respective separation zones on the total surface extent of the shallow coal resource within the South Wales Coalfield.

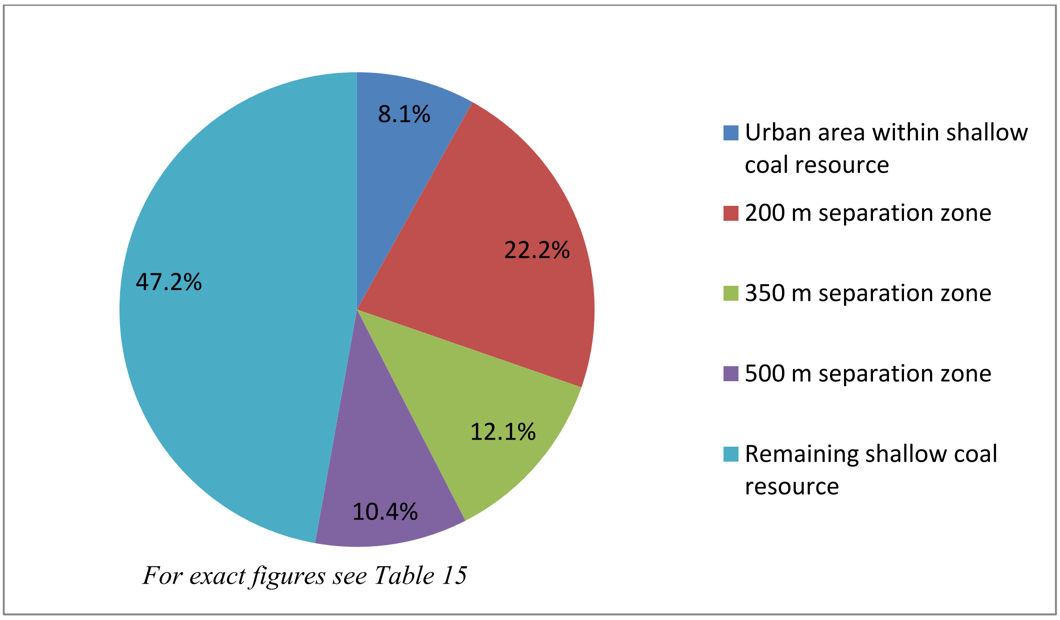


Figure 31 Total impact of settlement areas and separation zones on the shallow coal resource within the South Wales Coalfield

5.2 MIDLANDS COALFIELD

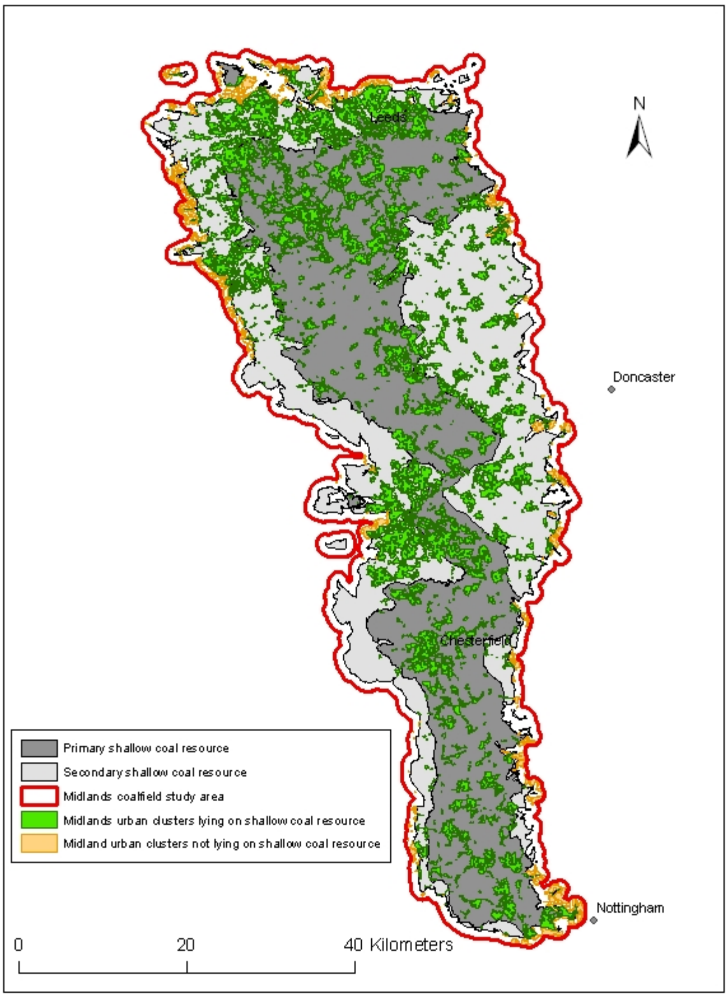


Figure 32 The geographical extent of shallow coal resource and settlements within the Midlands Coalfield

The geographical extent of the shallow coal resource and settlements within the Midlands Coalfield is illustrated in Figure 32. Of the total settlement area (496.49 km^2) within the Midlands Coalfield, 423.17 km^2 (85.2 %) lies on the shallow coal resource (Table 16 and Figure 33). This is equivalent to 17.7 % of the total shallow coal resource (Table 17).

Table 16 Areal extent of settlements on shallow coal resources within the Midlands Coalfield

	km^2	As a % of total settlement area
Settlement area lying within extent of primary or secondary shallow coal resource - i.e. sterilised	423.17	85.2%
Settlement area lying outside extent of primary or secondary shallow coal resource - i.e. not sterilised	73.32	14.8%
Total settlement area within coalfield study area	496.49	100%

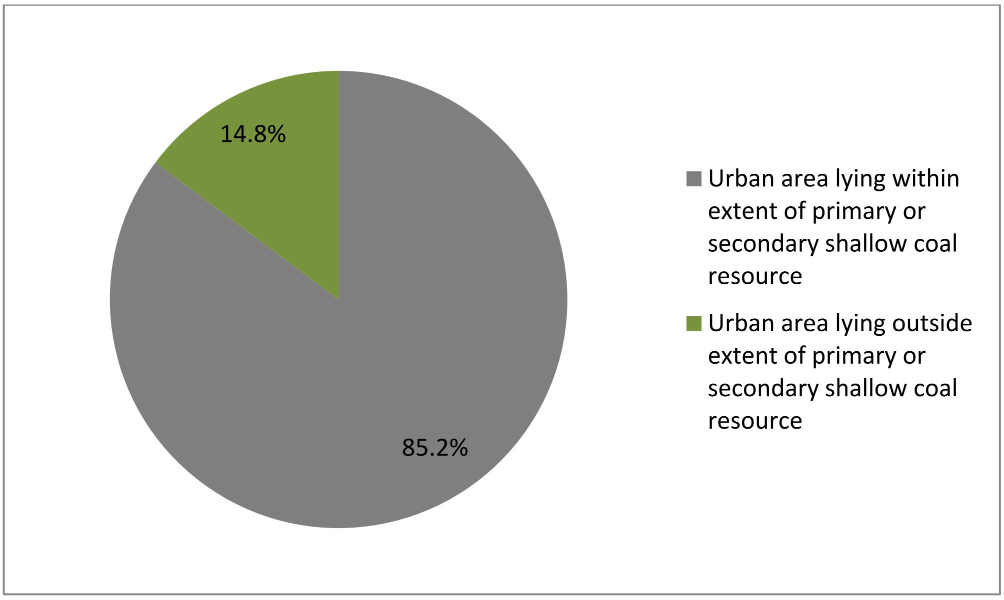


Figure 33 Area of settlements lying within surface extent of shallow coal resource within the Midlands Coalfield

The surface extent of the ‘unsterilised’ shallow coal resource area within the Midlands Coalfield reduces by a total of 1117.17 km^2 (46.7 %), 1459.63 km^2 (61.0 %) and 1727.85 km^2 (72.2 %) if separation zones of 200 m, 350 m and 500 m are applied (Table 17). These increases in area are represented graphically in Figure 34.

Table 17 The total impact of urban areas and separation zones on the shallow coal resource within the Midlands Coalfield

		Midlands Coalfield study area											
		Total area of shallow resource sterilised by settlements						Total area of shallow resource remaining (not sterilised by settlements)					
		Primary resource		Secondary resource		Total shallow resource		Primary resource		Secondary resource		Total shallow resource	
		km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Urban area lying on shallow coal resources using a separation zone of:	0m	228.13	17.6%	195.04	17.8%	**423.17**	**17.7%**	1068.38	82.4%	901.24	82.2%	**1969.62**	**82.3%**
	200m	623.09	48.1%	494.08	45.1%	**1117.17**	**46.7%**	673.42	51.9%	602.2	54.9%	**1275.62**	**53.3%**
	350m	820.32	63.3%	639.31	58.3%	**1459.63**	**61.0%**	476.19	36.7%	456.97	41.7%	**933.16**	**39.0%**
	500m	972.46	75.0%	755.39	68.9%	**1727.85**	**72.2%**	324.05	25.0%	340.89	31.1%	**664.94**	**27.8%**

**Total area of shallow coal resource is: 2392.79 km^2 or 82.8 % of the study area*

Table 18 Increase in the sterilisation of the shallow coal resource from settlements and separation zones within the Midlands Coalfield

	Increase in sterilisation of primary shallow coal resource as a result of urban areas		Increase in sterilisation of secondary shallow coal resource as a result of urban areas		Increase in sterilisation of all shallow coal resource as a result of urban areas	
	km^2	% of resource	km^2	% of resource	km^2	% of resource
Settlement area within shallow coal resource	228.13	17.6%	195.04	17.8%	**423.17**	**17.7%**
200 m separation zone (as an increment)	394.96	30.5%	299.04	27.3%	**694.00**	**29.0%**
350 m separation zone (as an increment)	197.23	15.2%	145.23	13.2%	**342.46**	**14.3%**
500 m separation zone (as an increment)	152.14	11.7%	116.08	10.6%	**268.22**	**11.2%**
Cumulative total	972.46	75.0%	755.39	68.9%	**1727.85**	**72.2%**

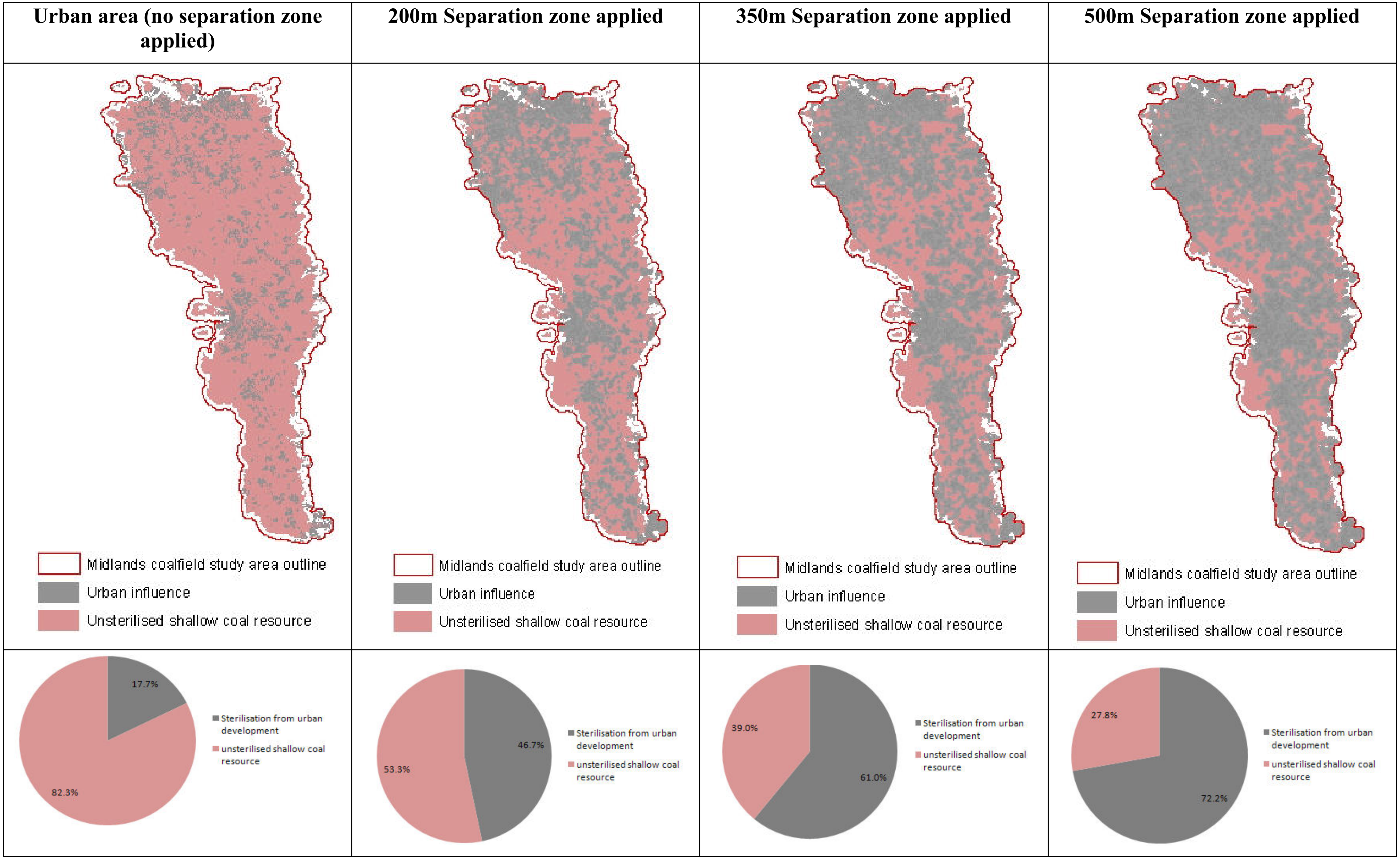


Figure 34 Visualisation of the increased influence of urban development within the Midlands Coalfield for each separation zone

Figure 35 shows the combined effect of the settlement areas and their respective separation zones on the total surface extent of the shallow coal resource within the Midlands Coalfield.

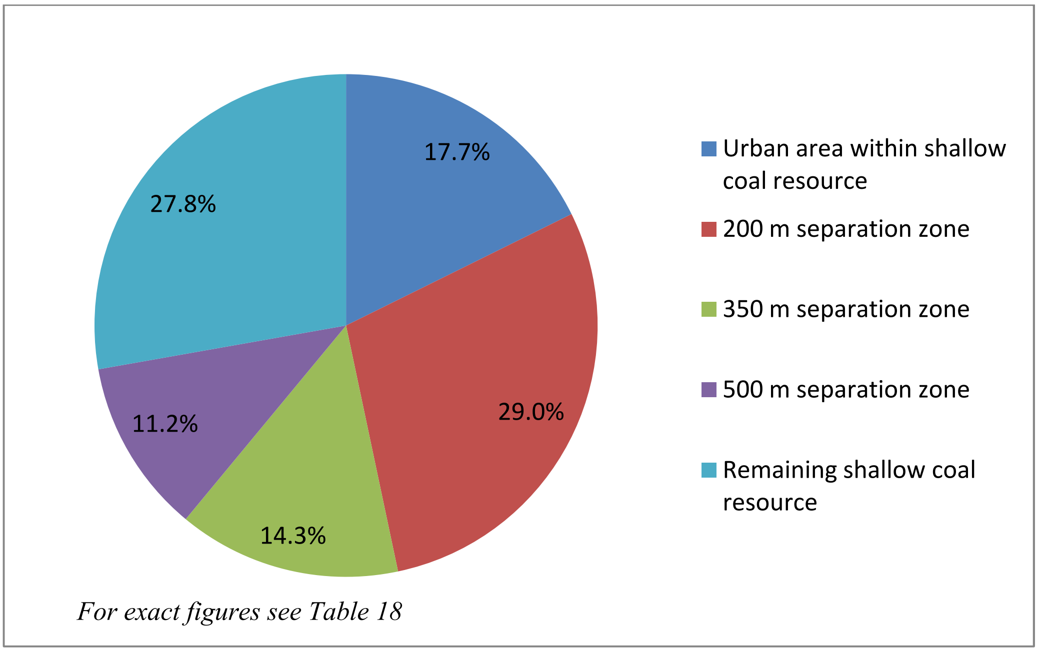


Figure 35 Impact of settlement areas and equivalent separation zones on the shallow coal resource within the Midlands Coalfield

5.3 SUMMARY

Settlement area is greater overall in the Midlands Coalfield (496.49 km^2 or 17.2 % of study area) than in the South Wales Coalfield (169.74 km^2 or 6.7 % of the study area). The impact of a 500 m separation zone around settlement areas within the Midlands Coalfield sterilises more of the surface extent of the total shallow coal resource (1727.85 km^2 or 72.2 %) than in the South Wales Coalfield (563.28 km^2 or 52.8 % of the total area of shallow coal resource). The reasons for this are twofold:

i. The extent of settlement areas within the Midlands Coalfield is greater than in the South Wales Coalfield;
ii. The proportion of settlement area lying outside of where primary and secondary (shallow) coal exists within the South Wales Coalfield is greater.

Of the total settlement area (169.74 km^2) within the South Wales Coalfield, 86.13 km^2 (50.7 %) lies on the shallow coal resource. This is significantly less than the Midlands Coalfield, where 423.17 km^2 (85.2 %) of the total settlement area (496.49 km^2) lies on the shallow coal resource.

6 Conclusions

The pattern and morphology of settlements within the South Wales Coalfield study area differs from those within the Midlands Coalfield Study area.

The South Wales Coalfield is characterised by settlements which are linear in morphology and follow the deep valleys which run north-south and east-west. These steep sided valleys have limited the expansion of settlements to the valley floor causing development to cluster in these areas. In contrast, the Midlands Coalfield is more urbanised. Topography is characterised by the undulating landform of low hills and ridges separating a sequence of shallow valleys. Settlements in this area tend to be more equidimensional (or nucleated) in morphology and adhere to a more evenly distributed pattern.

Overall settlement area is more extensive in the Midlands Coalfield and, therefore, has a greater overall impact on the total shallow coal resource area sterilised by development (and separation zones) than in the South Wales Coalfield.

The Midlands Coalfield has an overall greater coverage of settlement (496.49 km^2 or 17.2 % of study area) than in the South Wales Coalfield study area (169.74 km^2 or 6.7 % of the study area). Individual settlement areas, however, appear to be denser in the South Wales Coalfield than in the Midlands Coalfield. This is likely to be a result of the style of housing (i.e. rows of terraced housing) found within the South Wales Coalfield.

Settlement areas in the Midlands Coalfield reduce the original surface extent of the primary and secondary (shallow) coal resources (2392.79 km^2) by 17.7 % to 1969.62 km^2; settlement areas in the South Wales Coalfield reduce the surface extent of shallow coal resources (1093.63 km^2) by 8.1 % to 979.99 km^2. In addition, the total settlement area lying within the surface extent of shallow coal resource is greater in the Midlands Coalfield. Of the total settlement area (169.74 km^2) within the South Wales Coalfield, 86.14 km^2 (50.7 %) lies on the shallow coal resource compared with 423.17 km^2 (85.2 %) of the total settlement area (496.49 km^2) within the Midlands Coalfield.

Applying a 500 m separation zone around settlement areas sterilises a higher percentage of the surface extent of the total shallow coal resource (1727.85 km^2 or 72.2 %) within the Midlands Coalfield than in the South Wales Coalfield (563.28 km^2 or 52.8 %).

Given equal distributions of urban development within the two coalfields, the difference in settlement morphology would mean that a 500 m separation zone would sterilise more shallow coal in South Wales than in the Midlands.

When settlements and their separation zones are considered comparatively, separation zones applied to settlement areas within the South Wales Coalfield have a greater proportional influence on the area of shallow coal resource sterilised than those applied to the Midlands Coalfield. Applying a 500 m separation zones increases the influence of the urban areas within the South Wales Coalfield to 1119.61 km^2 (a 659.6 % increase in overall area). In contrast, the influence of urban areas within the Midlands Coalfield study area if a 500 m separation zone is applied increases to 1999.75 km^2 (a 402.8 % increase in overall area). This is likely to be as a result of their respective differences in settlement morphology. Settlements with linear morphologies, as in the South Wales Coalfield, have a greater relative impact on the area of the separation zone area than settlements exhibiting equidimensional (nucleated) morphologies, as present within the Midlands Coalfield.

In summary, this study has identified that the following factors can influence the extent of sterilisation by urban development of shallow coal resources:

1. **The distribution (settlement pattern) of settlements within the coalfield.** Sterilisation was greatest within the Midlands Coalfield where settlements were more evenly dispersed across the coalfield.
2. **The shape of an individual settlement (settlement morphology).** Equidimensional shaped urban areas are likely to sterilise less coal resource if a separation zone is applied than an equally sized urban area which is elongated in shape.
3. **The extent of the urban area lying within the coalfield**. The greater the amount of urban development lying within the coalfield, the more sterilisation as a result of urban development there is likely to be.

However, given two study areas with equally distributed and sized urban areas, the morphology (shape) of the urban settlements may have greatest influence on the size of the separation zone.

Glossary

Buffer	-	A geoprocessing tool used within a Geographical Information System (GIS).
Buffer zone	-	An area of protection around permitted and proposed mineral workings.
Clustered (nucleated) settlement pattern	-	A pattern of settlement in which buildings are laid out closely together. Buildings are often found clustered around something such as a church or a village green.
Coalfield	-	An area of certain uniform characteristics where coal is mined.
Dispersed settlements	-	Dispersed settlements are found in areas where a lot of land is required for farming. Houses are far apart from one another and hamlets and villages are small.
Equidimensional	-	An adjective used to describe objects that have nearly the same size or spread in multiple directions
Geographical Information System (GIS)	-	A system that captures, stores, analyses, manages, and presents data that are linked to a specific location.
Geomorphology	-	The scientific study of landforms and the processes that shape them.
Linear settlement pattern	-	A pattern of settlement in which homes and other buildings follow the lines taken by a linear feature (e.g. valley, road, river).
Nearest Neighbour Analysis	-	This analysis attempts to measure point distributions according to whether they are clustered, random or regular.
Nucleated settlements	-	Towns where buildings are close together, often clustered around a central point.
Separation zone	-	An area measured outwards from a defined settlement boundary.
Settlement morphology	-	The form (or shape) of human settlements.
Settlement pattern	-	The distribution of human activities across the landscape and the spatial relationship between these activities and their surrounding environment.
Shallow coal resource	-	Primary and secondary coal resource areas. These areas provide the main target for opencast coal extraction because they are found nearer to the surface.

Appendix 1 Definitions of coal resource areas

In 2006, the British Geological Survey were commissioned by the Coal Authority to provide coal appraisal maps to show the remaining potential for coal exploitation by opencast and deep mine methods in Great Britain (Jones, 2006b). The study built a series of GIS layers which identified potential resource areas. Three main orders of coal resources (primary, secondary and tertiary) were identified in the study. In addition a fourth category was identified; these are areas where coal is present in the subsurface, buried by less than 50 m. The definitions of the resource areas identified are included below. For the purposes of the current study, only primary and secondary (shallow) coal resources have been examined.

Primary resource area
The primary resource area constitutes the main target for opencast coal extraction and comprises a relatively closely spaced succession of variable but generally thick coals. These coals typically occur within a certain discrete stratigraphic interval, which comprises the succession from the middle to upper part of the South Wales and Pennine Lower Coal Measures formations to the lower part of the South Wales and Pennine Upper Coal Measures formations. In other areas e.g. North Staffordshire, the whole of the Pennine Upper Coal Measures Formation contains numerous thick coals and can also be ranked as primary.

Secondary resource area
The secondary resource represents one or more zones that contain opencast coal resources, but in which the coals are generally thinner and less concentrated in vertical and areal distribution. Coals from this resource zone have been exploited and continue to be worked, albeit on a smaller scale than the primary area coals.

Tertiary resource area
In certain coalfields (e.g. South Wales, Bristol-Somerset) coals are locally present in the Late Carboniferous Warwickshire Group succession. Here they typically occur interbedded with thick sandstones of the Pennant Sandstone Formation and Halesowen Formation. These coals form a resource and some of these coals have been previously deep mined. However, they do not generally form an attractive target for opencast mining due to factors such as high overburden ratios and hardness of the overburden. In the Midlands the Warwickshire Group typically comprises red-bed successions that locally contain individual coals. In other areas of England and Wales thin coals exist in the Namurian. All these types of coal occurrences are grouped together as tertiary resources.

Fourth resource area - Buried coal resources overlain by up to 50m overburden
In some areas, particularly down-dip of the main area of mapped resources, coals are present in the subsurface covered by younger strata. A fourth zone was identified, which represents the area where coals are present and overlain by less than 50 m of overburden. In this case the overburden is defined as bedrock; the thickness of superficial deposits was not considered here. In theory such areas may have opencast potential, depending on the thickness and type of overburden and the thickness of the coals below. These underlying coals were not further ranked in terms of whether they represent primary, secondary or tertiary resources.

Appendix 2 Case studies comparing the effects of separation zones

Figure 36 to Figure 40 are examples of the effects of separation zones on equidimensional urban settlements within the Midlands Coalfield when the settlement is analysed in isolation of other settlements. Figure 41 to Figure 45 show the effects on the linear urban settlements in the South Wales Coalfield when the settlement is analysed in isolation of other settlements.

Case studies within the Midlands Coalfield

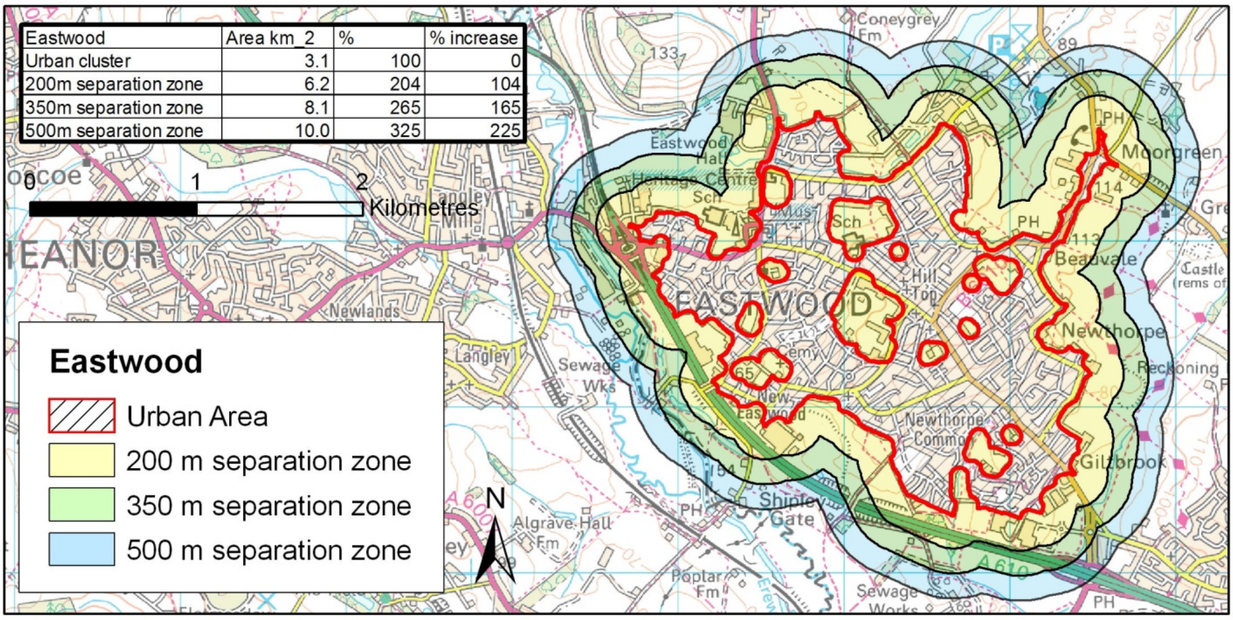


Figure 36 Urban area of Eastwood with separation zones at 200, 350, 500 metres

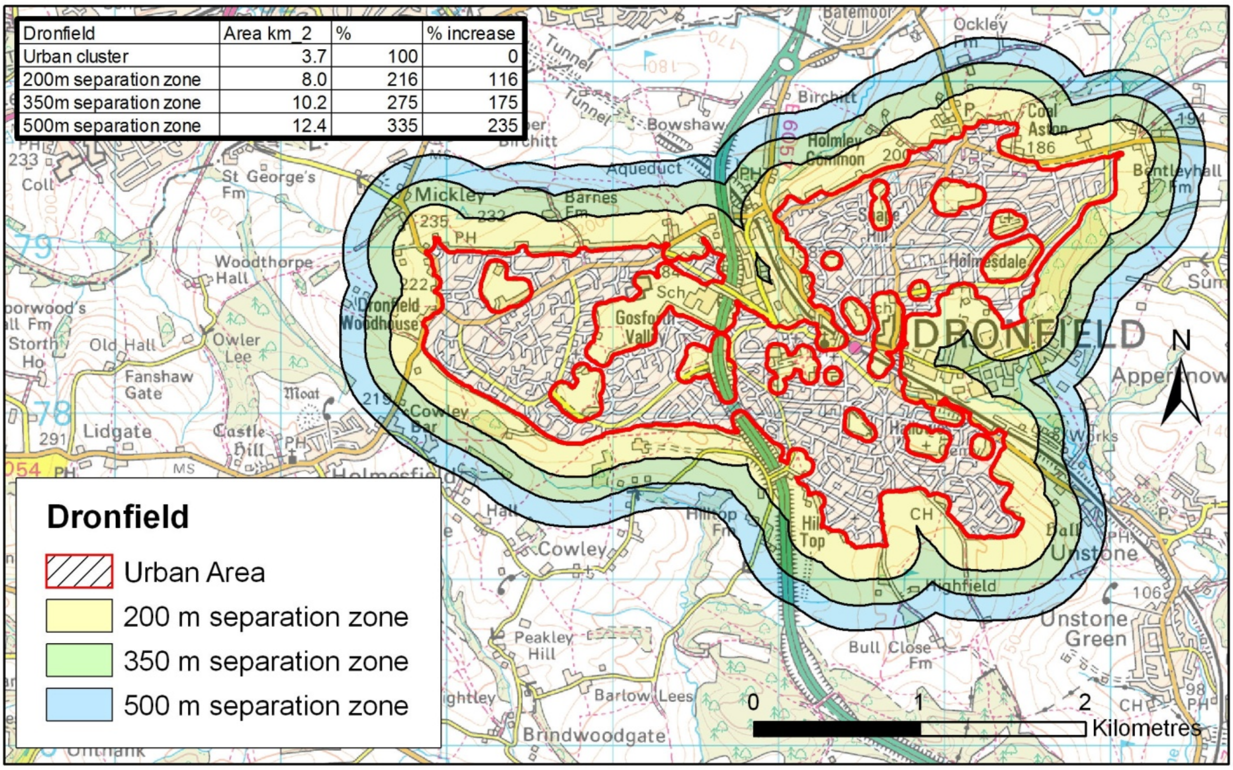


Figure 37 Urban area of Dronfield with separation zones at 200, 350, 500 metres

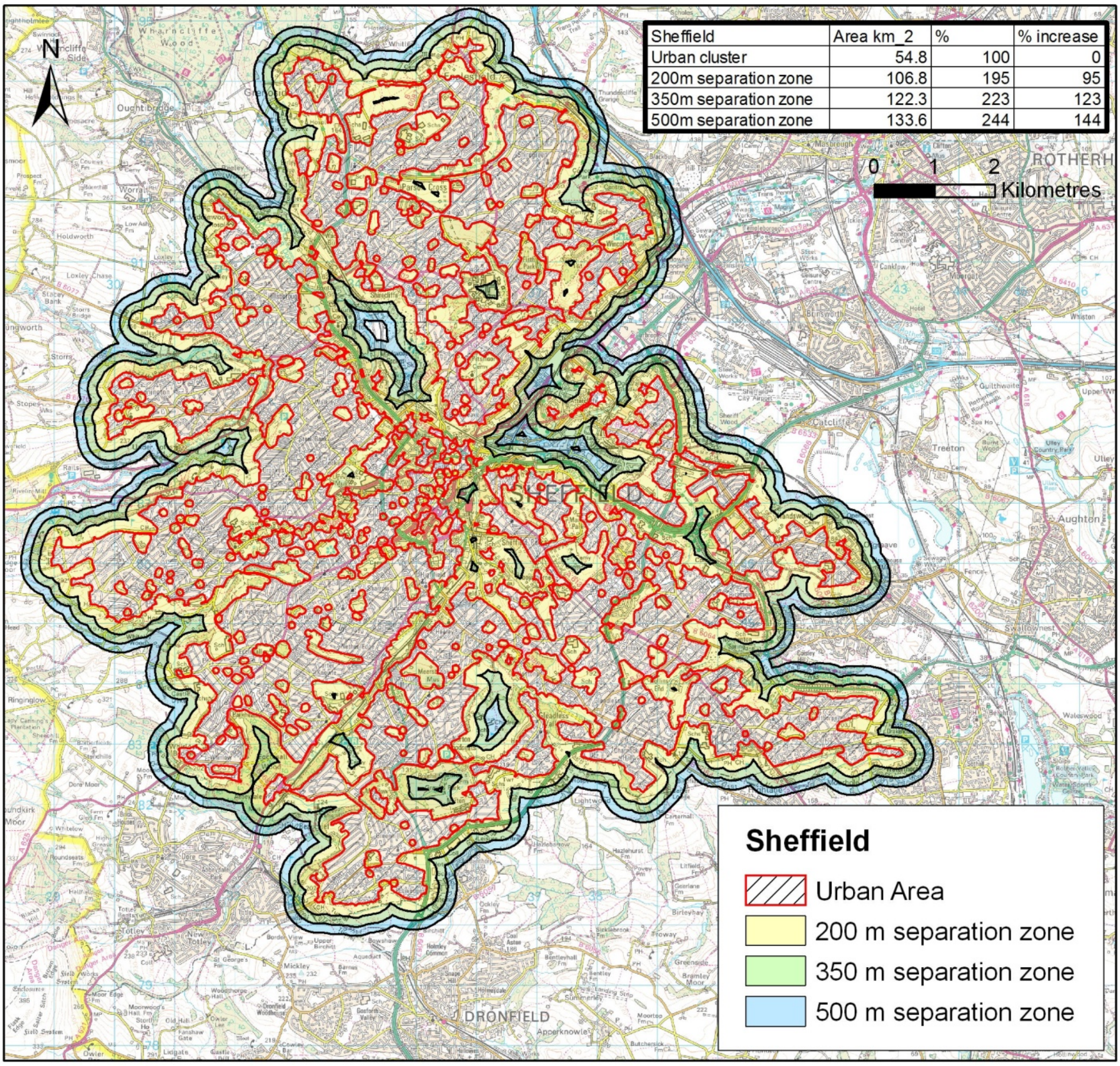


Figure 38 Urban area of Sheffield with separation zones at 200, 350, 500 metres

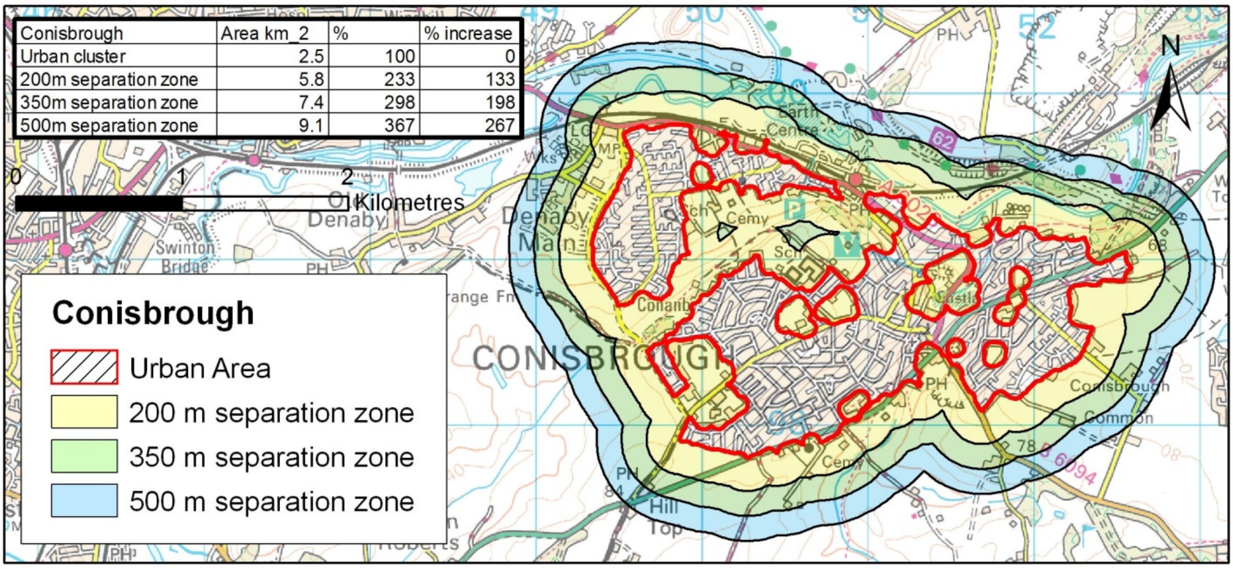


Figure 39 Urban area Conisbrough with separation zones at 200, 350, 500 metres

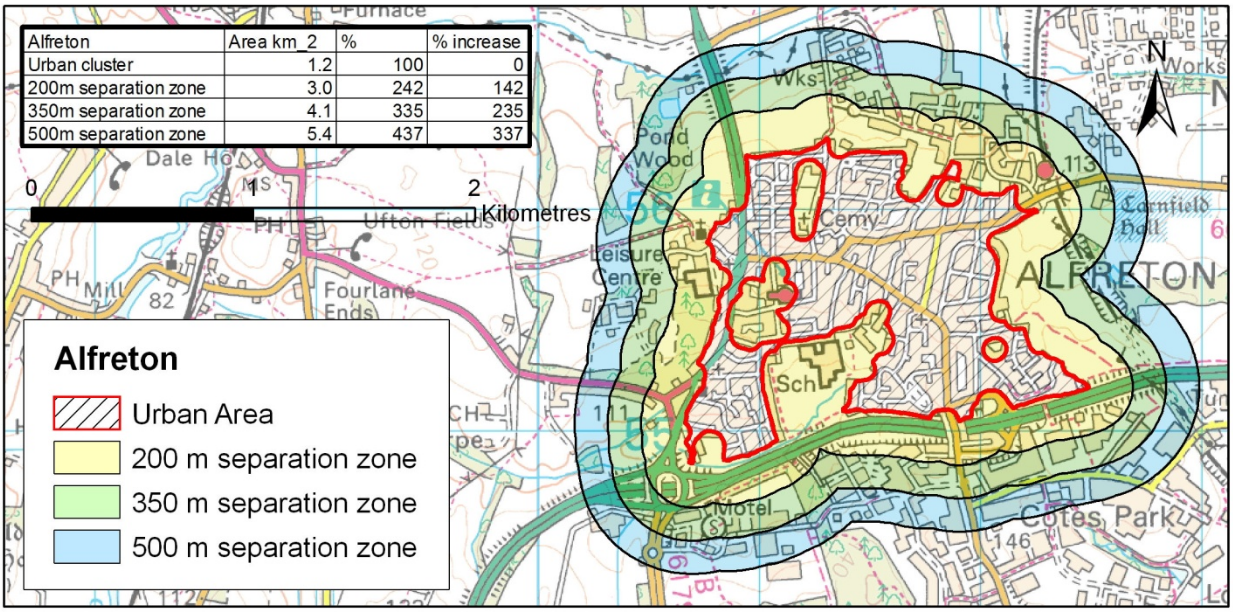


Figure 40 Urban area of Alfreton with separation zones at 200, 350, 500 metres

Case studies within the South Wales Coalfield

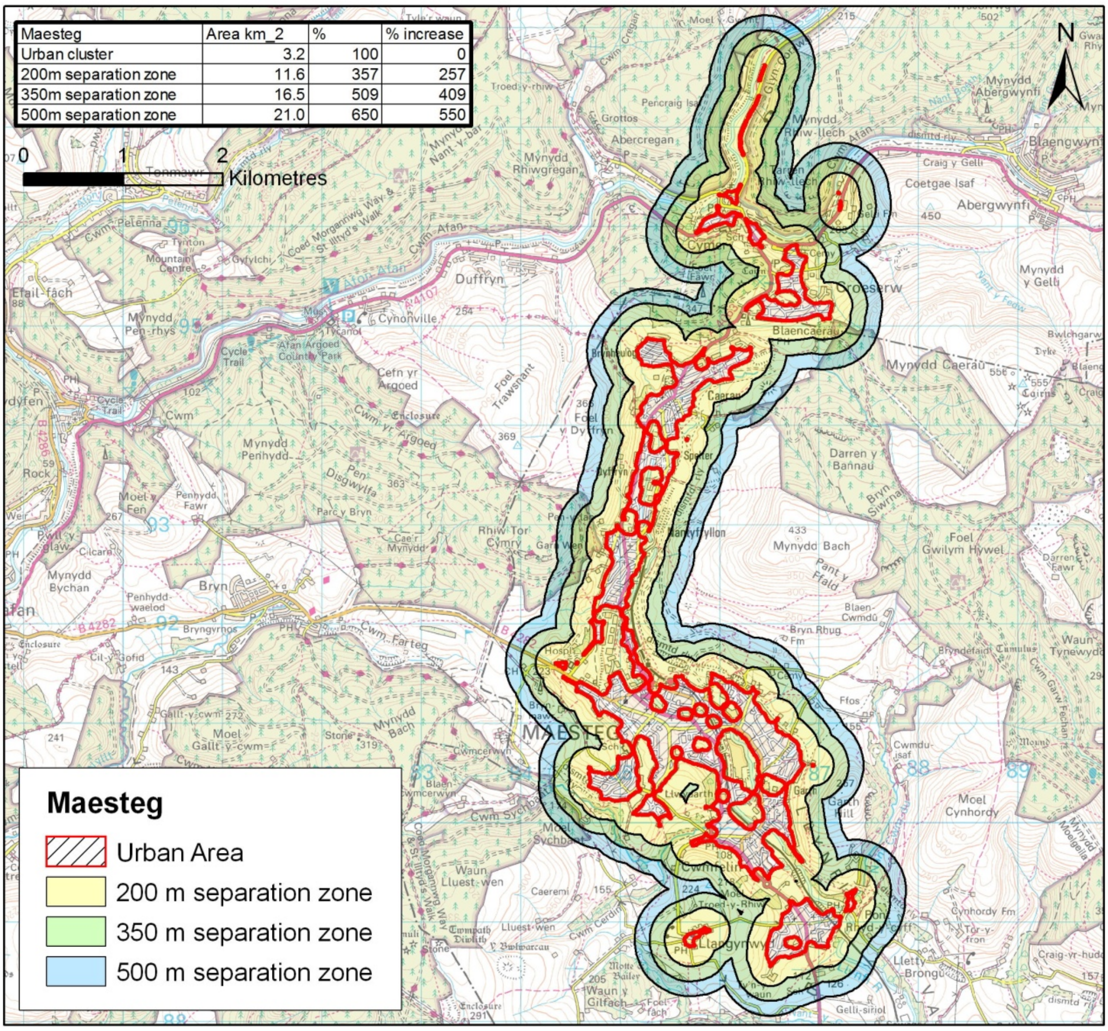


Figure 41 Urban area of Maesteg with separation zones at 200, 350, 500 metres

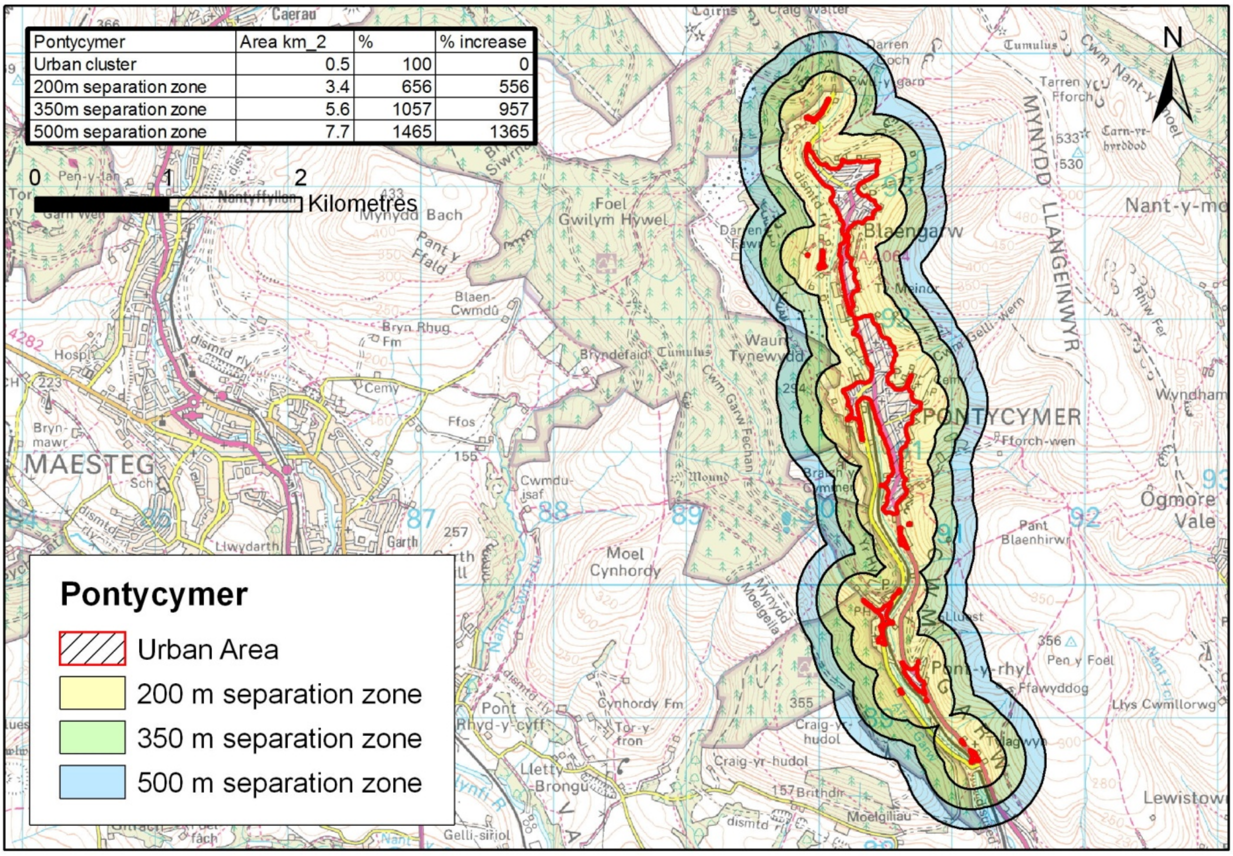


Figure 42 Urban area of Pontycymer with separation zones at 200, 350, 500 metres

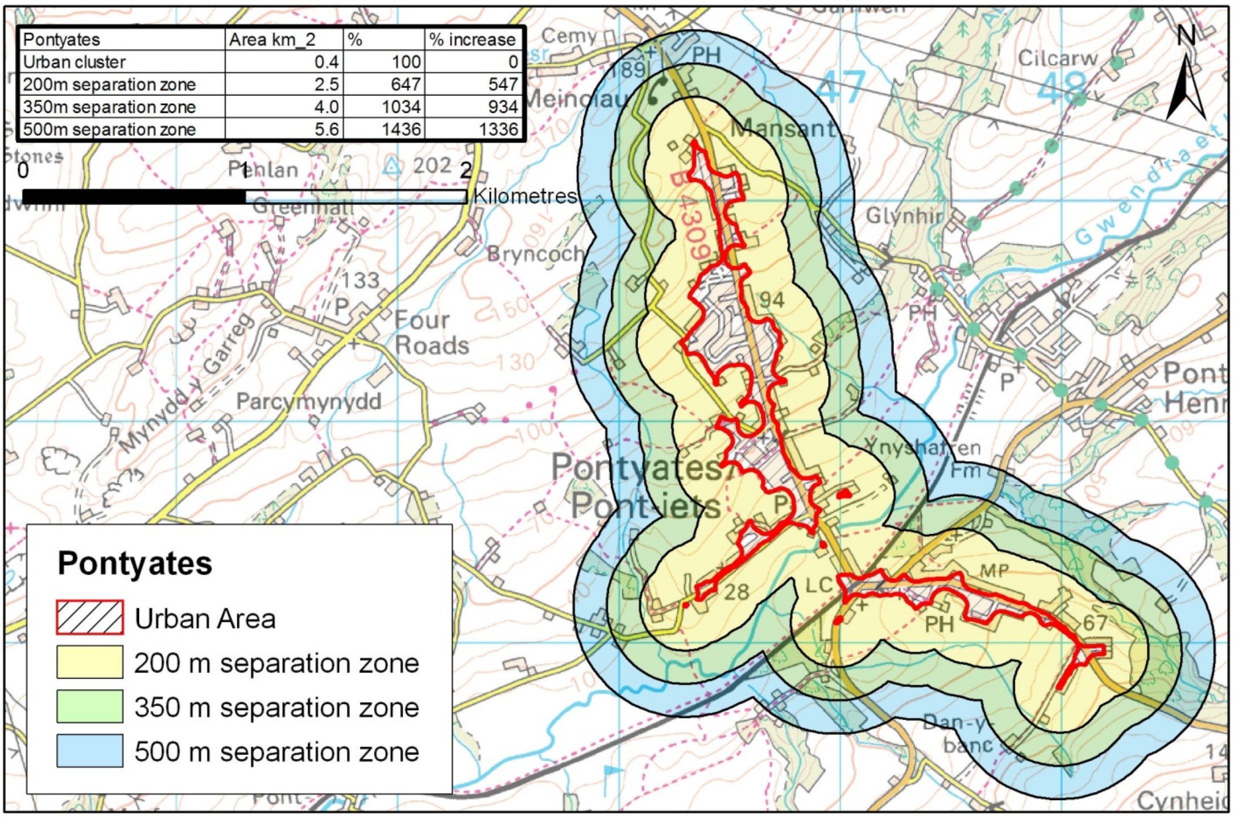


Figure 43 Urban area of Pontyates with separation zones at 200, 350, 500 metres

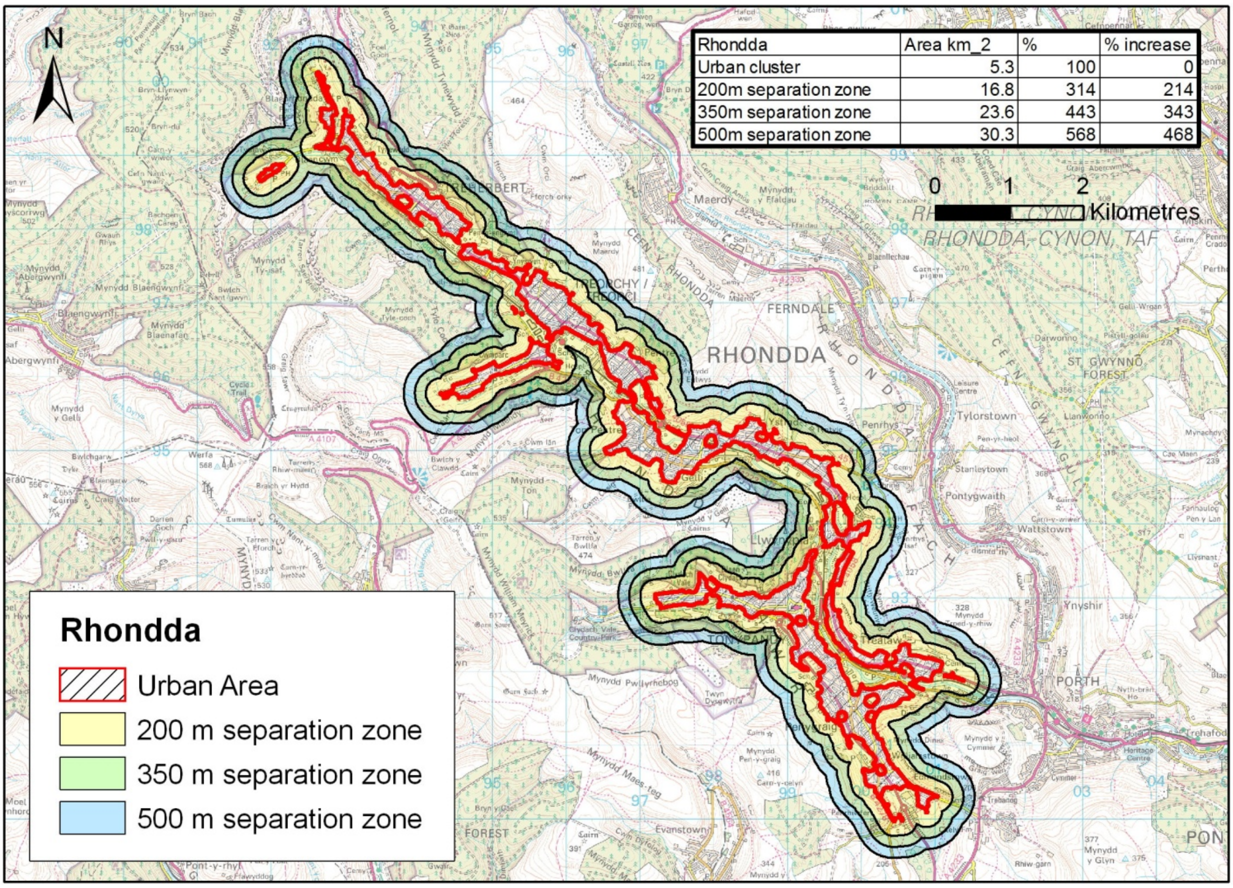


Figure 44 Urban area of Rhondda with separation zones at 200, 350, 500 metres

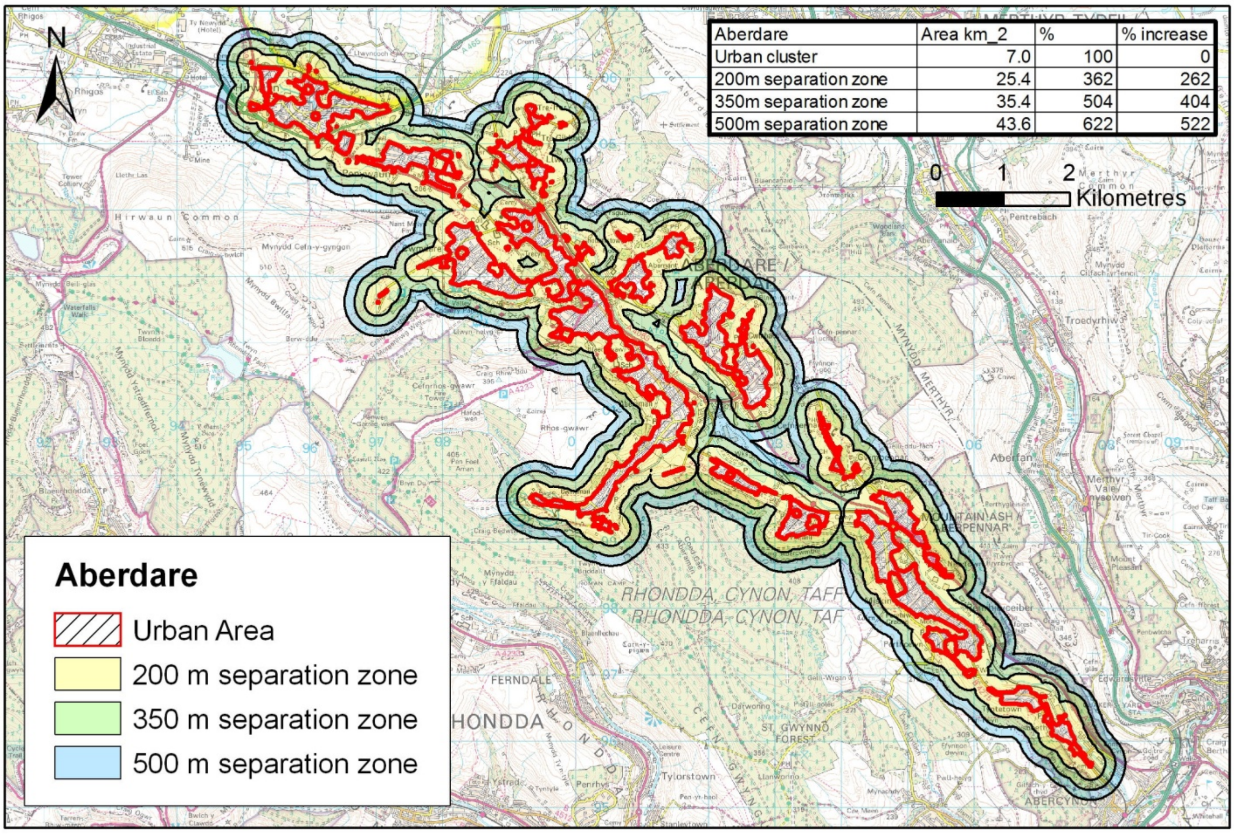


Figure 45 Urban area of Aberdare with separation zones at 200, 350, 500 metres

Appendix 3 Determining urban areas and their separation zones

The Ordnance Survey's large-scale vector dataset, MasterMap®, is (Figure 46) was used to identify the settlements within the coalfield areas.

In MasterMap® Buildings (in orange) for separate polygons; the yellow areas are classified as General Surfaces – Multi Surfaces and the green areas are 'General Surfaces Natural'.

Figure 46 Example of the Ordnance Survey (OS) MasterMap® Topographic layer

In order to identify settlement areas, it was necessary to distinguish whether a property forms part of a settlement or whether it is an isolated property. This was best answered by defining a minimum separation distance between properties. A property that is separated from any other property by a distance greater than the minimum separation distance was classified as isolated. The Welsh study (Lott *et al.* 2006) set a separation distance of 100 metres (i.e. 50 m from each property) which was in line with that defined for other similar projects in the UK (e.g. Ordnance Survey AGENT project – (Revell, 2004), and Statistics Norway project (Schoning, 1997). Figure 47 shows how this methodology identifies isolated buildings in a small area within the Midlands Coalfield.

Having identified settlement clusters, the OS Address-Point® dataset was used to identify which clusters contained ten dwellings. For this study, as in the two previous BGS studies (Jones, 2006a and Lott *et al,* 2006), an urban area is defined as a settlement of ten or more properties. However, in rural areas where farms often have several outbuildings settlement clusters were being erroneously classified as urban. To eliminate this, address points were utilised. Only those address points with a relevant urban definition were used (see Appendix 6 for full listing). Finally, removal of the building separation distance (i.e. the original 50 m GIS buffer from each property) produced a dataset that defined the edges of urban areas (Figure 48). The resultant urban clusters match well against the urban areas within OS 10 K raster topography (Figure 49).

The buildings extracted from MasterMap® are shown in red. The pink zone is the 100 m separation zone. Small settlement clusters are formed but most of these would be eliminated as they each have less than 10 buildings.

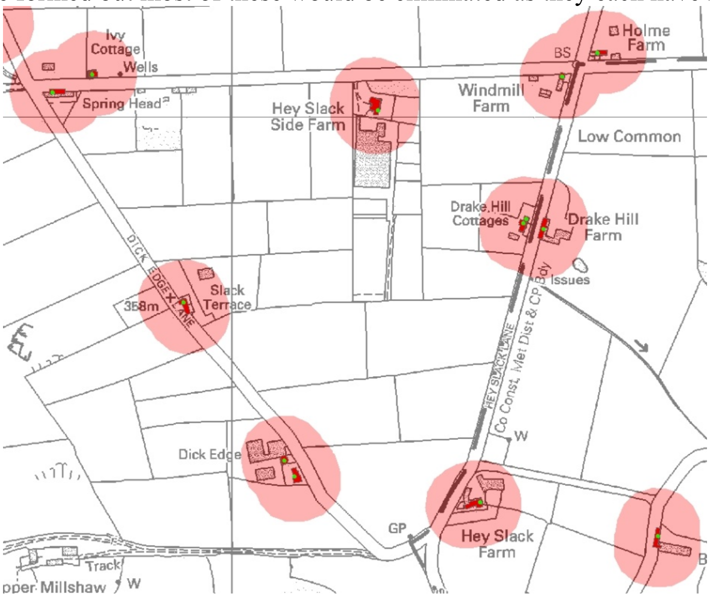


Figure 47 Rural area showing clusters defined by 100 metres separation

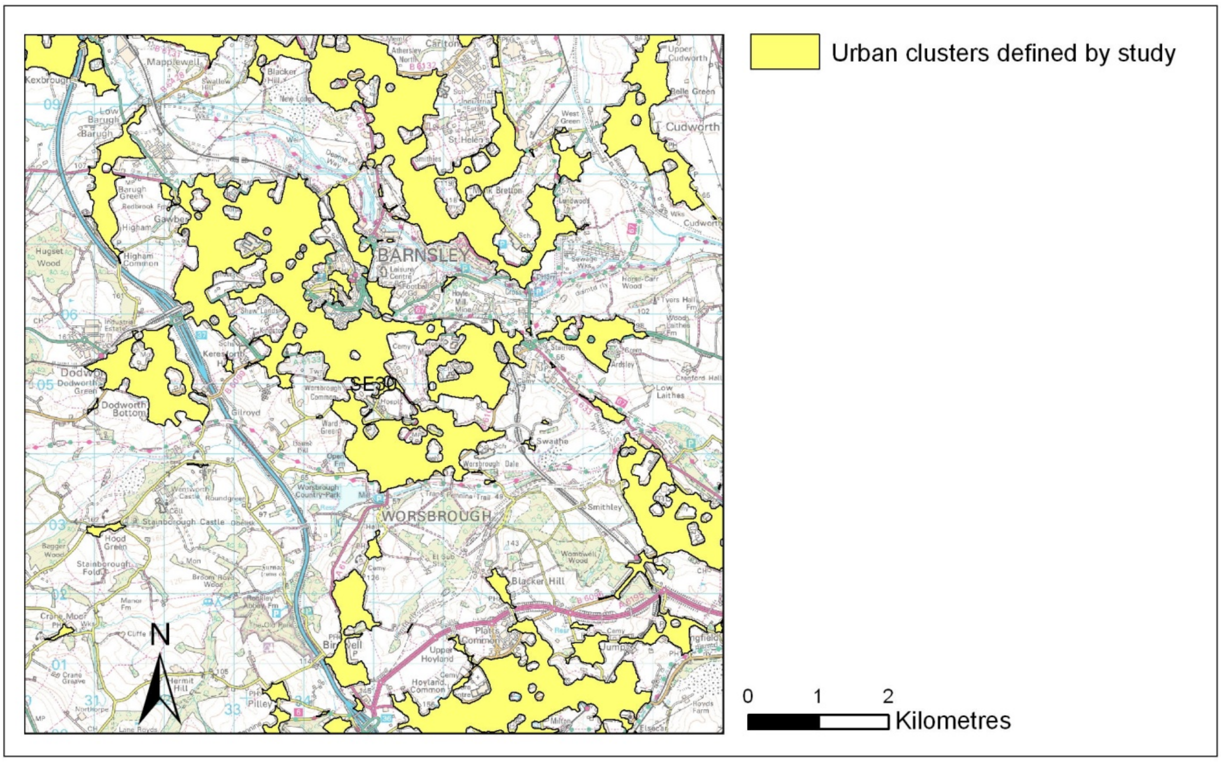


Figure 48 Urban clusters defined by this study for SE30 tile of the Midlands Coalfield

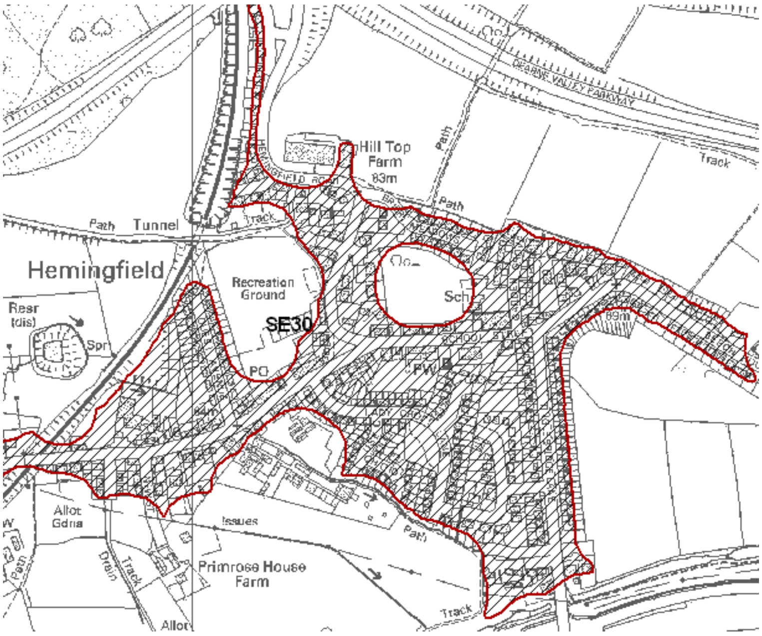


Figure 49 Part of SK30 tile in Midlands Coalfield showing the close match between the urban area defined by this study (red line) compared with the OS 10 K raster topographic map

There are a number of limitations of this methodology:

- Where there are areas with no (or few) addressable buildings within the urban area (e.g. such as playing fields, parks etc) they tend to produce small 'non-urban' polygons within what is essentially an urban area. However, the use of separation zones will eliminate most of these areas.
- Large building complexes and industrial sites such as power stations, waterworks, chemical works, hospitals, cemeteries and schools generally occupy large areas, but they typically have less than 10 address points associated with them and hence do not always classify as part of the defined settlement areas. If they were required to be included then further processing of the data would be needed.

GIS Methodology

The following methodology was used to define settlements and their separation zones:

1. The MasterMap® data files for all 100 km national grid squares covering the Midlands Resource area were extracted into an ESRI file geodatabase using Feature Manipulation Engine (FME) software.
2. All buildings (FeatureCode='10021') were extracted from OS MasterMap® then clipped to the Midlands area shapefile to create a smaller subset making data manipulation easier. This also ensured that any urban areas that continue across the boundaries were included in the analysis. The curtilage of the properties are not identified in the MasterMap® dataset so were not included in the analysis.
3. Buildings were spatially joined to the OS Address-Point® dataset and only those buildings where BaseFunction had an urban attributed feature code (See Appendix 6 for list) were extracted. This created a dataset of only urban buildings.
4. These buildings were buffered by 50 m (i.e. a separation distance of 100 m) to generate clusters of buildings.
5. Individual building buffers were dissolved to formulate the clusters where buildings are within 100 m of each other.

6. OS Address-Point® data was joined spatially to the dissolved clusters so each had a count of address points within it.
7. The building clusters with 10 or more addresses were selected to produce urban clusters.
8. The buffer effect from the building clusters was removed by using a negative buffer (-50 m) producing a dataset that defines the edge of urban areas or clusters.
9. The urban clusters were then buffered by 200, 350, and 500 metres. This creates the separation zones described in Chapter 4.
10. The urban clusters and their separation zones were then clipped to the Midlands Coalfield study area.

This methodology was then repeated for the South Wales Coalfield.

Appendix 4 Methodology to analyse settlement patterns

Nearest Neighbour Analysis

NNA is a simple spatial statistical technique first used by plant ecologists to analyse the locations of different plant species in relation to each other. It is a technique designed to offer a more objective method of describing settlement patterns and has been subsequently used by geographers to describe the pattern of settlements.

Nearest Neighbour Analysis (NNA) is based on the following formula:

$$Rn = 2\bar{d}\sqrt{\frac{n}{A}}$$

Where:

Rn = the nearest neighbour statistic

$\bar{d}$ = the mean observed nearest neighbour distance (km)

n = the total number of points

A = the total area (km^2)

The range of Rn values and the settlement pattern the value corresponds to are outlined in Figure 50 below.

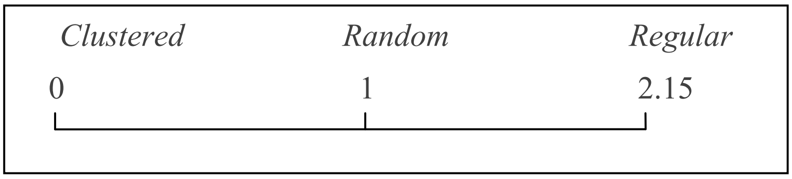


Figure 50 Range of *Rn* values to determine settlement pattern in Nearest Neighbour Analysis

GIS methodology

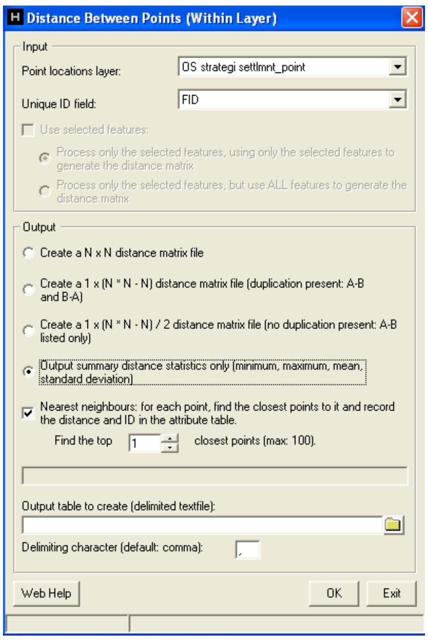


Figure 51 Interface for distance between points (within layer) tool

In order to generate the nearest neighbour index Rn for each of the study areas, the area of the coalfield was determined and the OS Strategi® settlement points within each of the study areas were obtained. Each settlement was given a unique identifier and the '*Distance Between Points (within Layer)*' tool from within the suite of Hawth's Analysis Tools for ESRI ArcGIS (Figure 51) was used (see http://www.spatialecology.com/htools/) to calculate the nearest neighbour for each settlement. The results were then collated and divided by the total number of points to find the mean distance for the nearest neighbour ($\bar{d}$). The relevant values were then incorporated into the NNA formula and the statistic Rn determined.

ESRI ArcGIS *average nearest neighbour distance* tool

ESRI ArcGIS 'A*verage Nearest Neighbour Distance'* tool was also applied to the study areas. This statistical technique measures the distance between each settlement and its nearest neighbour. The index is expressed as the ratio of the observed distance divided by the expected distance (expected distance is based on a hypothetical random distribution with the same number of features covering the same total area). If the index is less than 1, the pattern exhibits clustering. If the index is greater than 1, the trend is toward dispersion (refer to ESRI ArcGIS Help Documentation).

As the average nearest neighbour function is very sensitive to the Area value, the minimum enclosing rectangle around the settlement points was used for each study area (i.e. default area). This is in line with the manually calculated NNA described in above.

Limitations of using Nearest Neighbour Analysis

The statistical technique has a number of limitations. Although summarised below, these are discussed in more detail on page 9 in Hornby and Jones (1991) and on page 373 in Waugh (1990).

1. The size of the area is important – comparisons are only valid if each area chosen is of the same size (hence comparing the like-for-like areas).
2. If the area chosen is too large it can lower the R*n* value and exaggerate the degree of clustering.
3. If the area chosen is too small it can increase the R*n* value and exaggerate the degree of regularity.
4. Repeating the analysis but including different thresholds for settlement size may produce different results. Deciding upon the limit for the settlement size of settlements to include in the study is, therefore, important. For this coal study settlements (and their centres – see point 5 below) as determined by OS Strategi® settlement points were used.
5. Determining where the centre of a settlement is also needs careful consideration as the location of the 'dot' representing the settlement could alter its nearest neighbour depending on where the 'dot' is located.
6. The boundary of the study area is important as the nearest neighbour of settlements close to the boundary may actually be on the other side of the boundary. This study tried to compensate for this by using an area slightly larger than the shallow coal resource extent (e.g. the red line study area outlines shown in Figure 1 and Figure 4) to ensure that all the true nearest neighbours for those settlement within the shallow coal resource area were identified.
7. The use of the term 'random' may easily be taken to imply a chance distribution of settlement. In reality, this may not be the case.

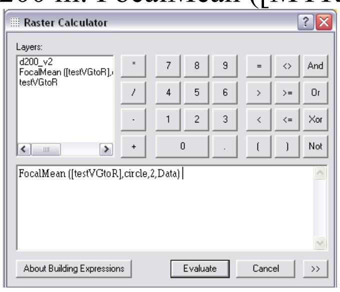
Appendix 5 Methodology to analyse settlement morphology

In 2001 the then Department of Transport, Local Government and the Regions (DTLR) commissioned a wide-ranging review of the definitions of urban and rural areas in use for policy purposes and statistical reporting. The review covered both England and Wales and involved consultation with over twenty-five Government Departments and sections within them (Bibby and Shepherd, 2001). The methodology used also examined residential densities and compared density profiles of settlements as a means of typifying settlements and enabling, via a set of rules, a classification of settlement types. The rate at which density changes away from the 'focus' cell is a function of local settlement structure. Thus in a conurbation, where densities are sustained at (say) 30 dwellings to the hectare over a broader area, such falls will not occur, whereas for a village in an area of hamlets and isolated dwellings, the density 'fall-off' will be marked. 'Density profiles' can thus be created using a series of different area or 'window' sizes. In other words, density profiles can be created by calculating densities at a series of fixed scales - in our case 200 m, 400 m, 800 m and 1600 m - around each cell (Bibby and Shepherd, 2001).

Bibby and Shepherd's methodology has been applied to the two study areas examined in this report in order to classify settlement types within the coalfields and compare and contrast their settlement density profiles, and the morphology of these profiles.

To replicate this methodology OS MasterMap ® address points were used and the following series of steps were implemented:

1. A vector grid (100m by 100m grid cells) was created for the region. This was achieved using Hawth's Analysis Tools for ESRI ArcGIS with the shapefile extent of study area used as an input layer. (see http://www.spatialecology.com/htools/)
2. A 'Point in Polygon' analysis to count the OS address points falling within each grid cell was conducted using the suite of Hawth's Analysis Tools for ESRI ArcGIS (see http://www.spatialecology.com/htools/). This generated an attribute [PNTPOLYCNT].
3. The vector grid was then converted to a raster using the Arctoolbox 'features to raster' tool using field [PNTPOLYCNT] and cell size 100. This generated a raster showing the number of address points falling within each raster cell (i.e. density).
4. Raster calculator was used to conduct the following equation for the density profile at 200 m: FocalMean ([MYRASTER],circle,2,Data).



5. The calculation was then made permanent by right clicking layer and selecting 'data/make permanent'. The permanent file was made into an ESRIgrid and labelled according to the density performed e.g. d200.
6. Stages 4 and 5 above were then repeated for d400 - 4 cells, d800 - 8 cells and d1600 - 16 cells.

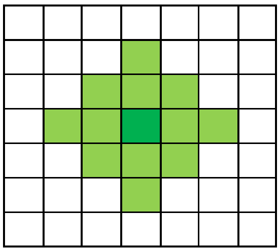
Information about creating density profiles using 'Focal Mean'

The tool in ESRI ArcGIS uses the following formula:

FocalMean ([testVGtoR],circle,2,Data) - where:

- FocalMean is the operation: Finds the mean of the values for each cell location on an input raster within a specified neighbourhood and sends it to the corresponding cell location on the output raster.
- [testVGtoR] is the input raster.
- circle is the shape of the neighbourhood.
- 2 - is the radius (in cells) that the circle will span.
- DATA — Specifies that if a NoData value exists within a neighbourhood, the NoData value will be ignored. Only cells within the neighbourhood that have data values will be used in determining the mean value.

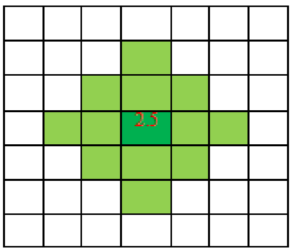
The search neighbourhood will look like this:



The dark green cell is the focus cell.

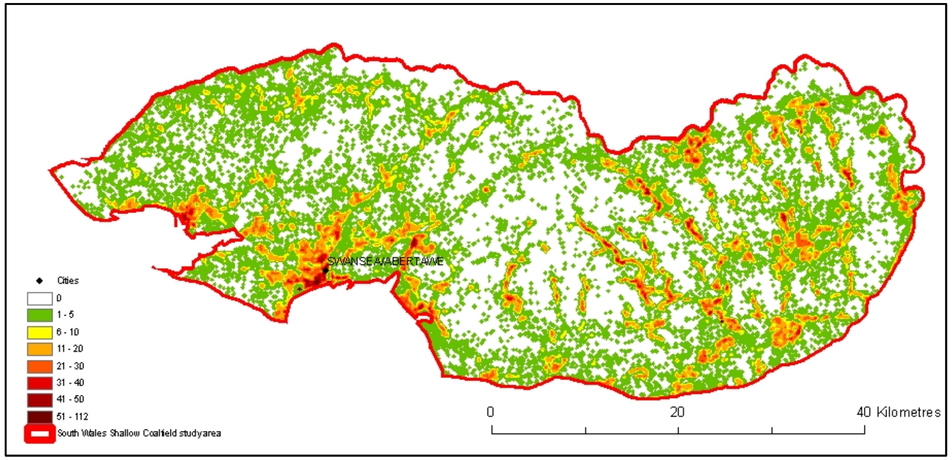
2	2	5	6	8	9	0
1	4	2	2	3	3	2
2	4	3	4	1	1	1
3	3	3	3	1	1	1
3	2	3	2	2	2	1
2	3	4	5	3	2	2
1	0	1	2	3	4	2

To calculate the density at the focus cell using the 200m density profile the following calculation is performed: (2+ 3+4+1+3+3+3+1+1+3+2+2+5) /13 = 2.5

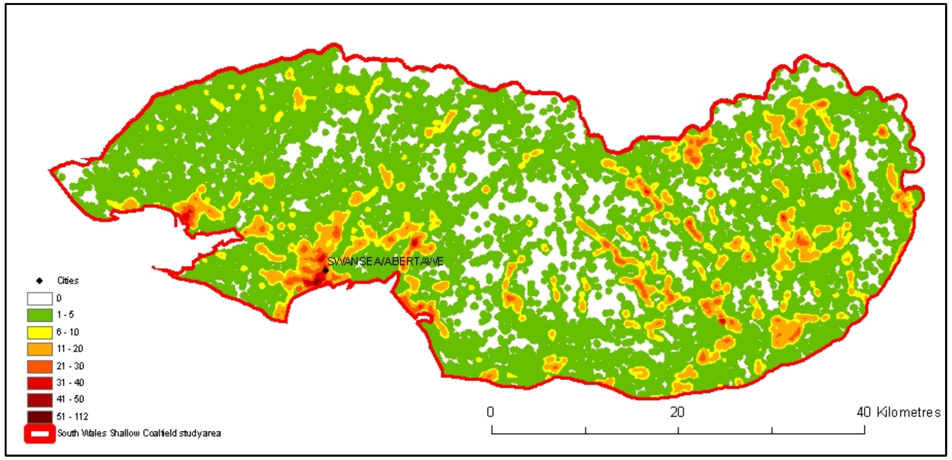


This calculation is conducted on each cell.

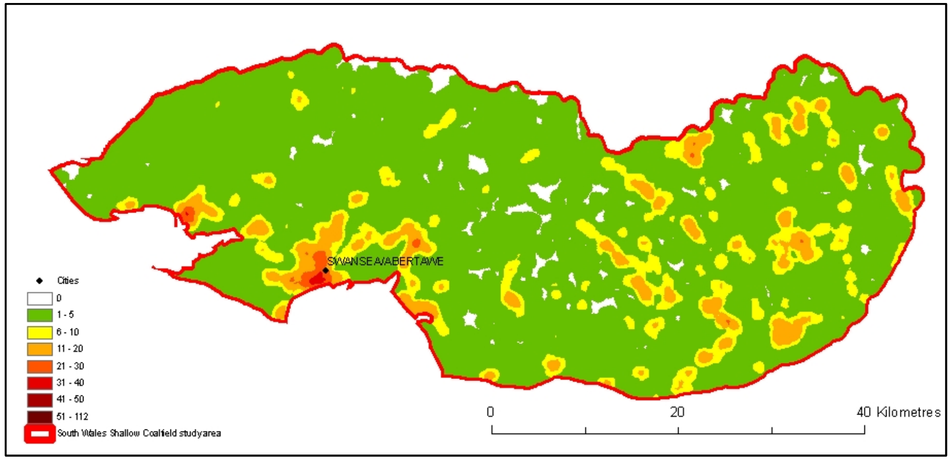
The results of the density profiles for the two study areas are shown in Figure 52 and Figure 53.



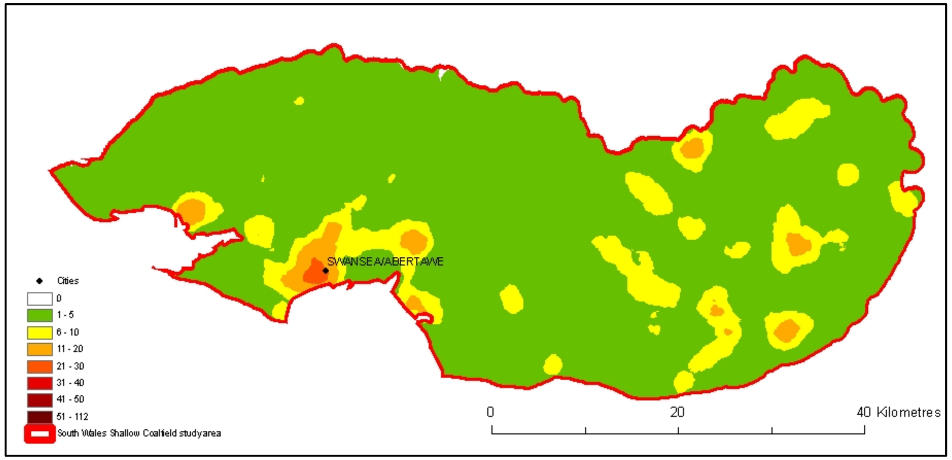
a) D200



b) D400

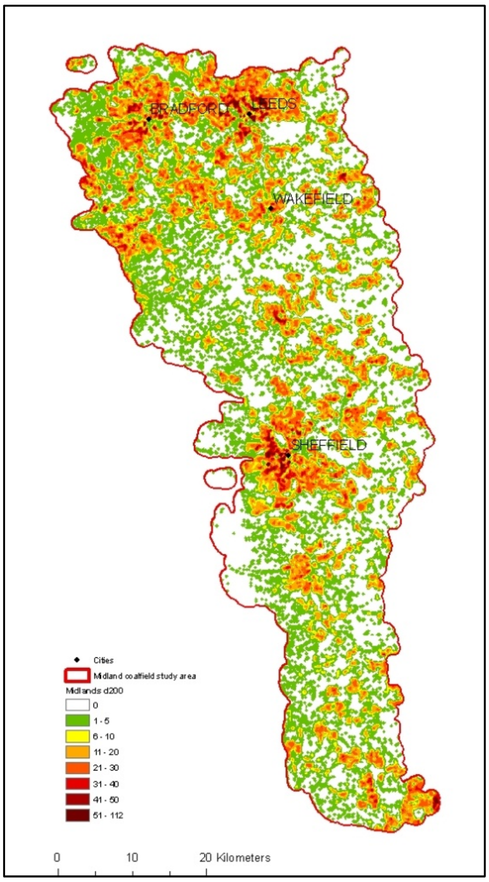


c) D800

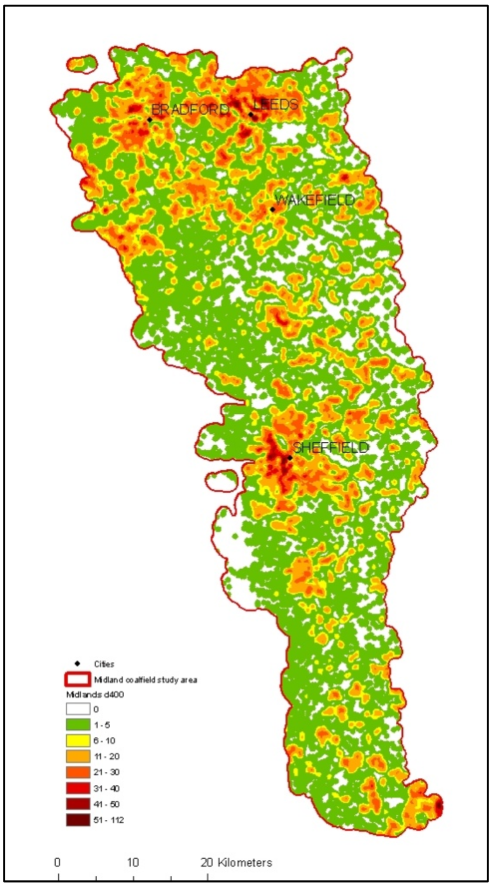


d) D1600

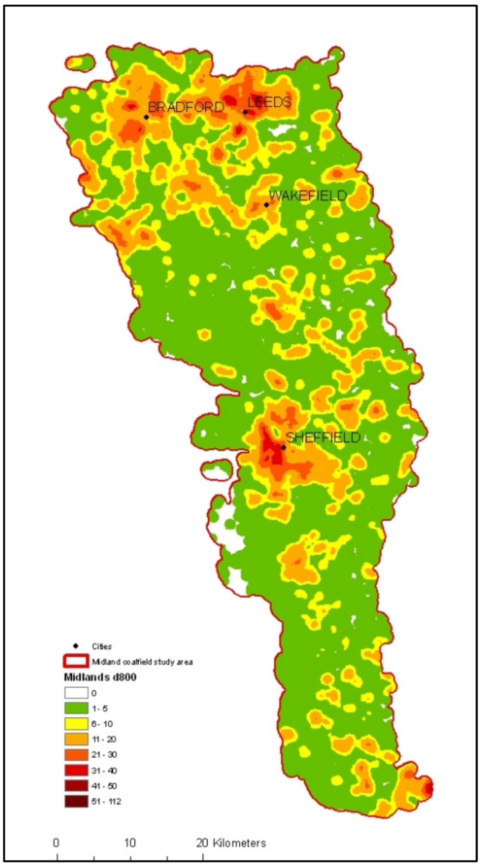
Figure 52 Density profiles for Area 1 in South Wales Coalfield



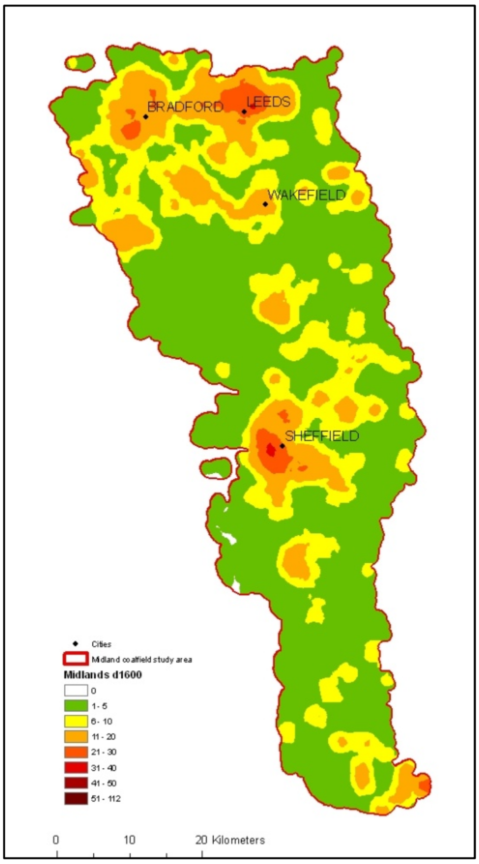
a) D200



b) D400



c) D800



d) D1600

Figure 53 Density profiles for the Midlands Coalfield

Classifying settlements based on their density profiles

In order to classify each 100 m raster grid square according to settlement type the rules Bibby and Shepherd (2001) employed in their study were followed. These rules were based on the density profiles generated for each of the study areas. Each rule was incorporated into the ArcGIS 'Raster Calculator' to calculate a new raster layer showing where the rule was true or false and thus typifying the settlement type. The rules used are shown below and were completed in the order outlined.

Rule 1

D800 > 8 then 'Small town or urban area'

Rule 2

[RASTER d400] > 8 & [RASTER d800] < 4 then 'Fringe (urban, town)

Rule 3

[RASTER d800] > 2.5 & [RASTER d800] > (2.5 * [RASTER d1600]) then' Small town'

Rule 4

[RASTER d800] > 4 & [RASTER d400] > 4 & [RASTER d800] < 8 then 'Fringe (urban, town)'

Rule5

[RASTER d800] < 8 & [RASTER d400] > 8 then 'Small town'

Rule 6

[RASTER d800] > 0.18 & [RASTER d400] > (2 * [RASTER d800]) & [RASTER d200] > (1.5 * [RASTER d800]) then 'Village'

Rule 7

[RASTER d1600] > 1 & [RASTER d400] > (1.5 * [RASTER d800]) & [RASTER d400] < (2 * [RASTER d800]) & [RASTER d200] > 0 then 'Village envelope (in peri urban)'

Rule 8

[RASTER d1600] > 1 then 'Peri-urban zone'

Rule 9

[RASTER d1600] <= 1 & [RASTER d800] >= 15 then 'Village envelope'

Appendix 6 OS Address Points

The following are the 'BaseFunction' attributes within the OS Address-Point® dataset that have been deemed urban. These are used to create the urban settlements layer in the methodology described in Appendix 3.

ALMSHOUSE
BARRACKS
CHILDRENS HOME
CONVENT
DWELLING
GUEST HOUSE
HM PRISON
HM YOUNG OFFENDERS INSTITUTION
HOSPICE
HOSTEL
HOTEL
INN
MANSE
MARRIED QUARTERS
MOTEL
NURSES HOME
NURSING HOME
POLICE HOUSE
PUBLIC HOUSE
RESIDENTIAL CENTRE
RESIDENTS CENTRE
REST HOME
RETIREMENT HOME
VICARAGE

References

BIBBY, P., & SHEPHERD, J., (2001) Developing a new classification of urban and rural Areas for policy purposes – the methodology. http://www.statistics.gov.uk/geography/downloads/Methodology_Report.pdf accessed March 2010.

DEPARTMENT OF COMMUNITIES AND LOCAL GOVERNMENT (DCLG). (2006). Minerals Policy Statement 1: Planning and Minerals. CLG. Wetherby, DCLG Publications: 35pp.

HORNBY, W. F. & JONES, M. (1991) An Introduction to Settlement Geography. *Cambridge University Press*. 145pp.

JONES, N.S., (2006a) A pilot study to show the effects of separation zones around urban areas on opencast coal resources for the SK47 area, North Derbyshire, UK. *British Geological Survey Commissioned Report* CR/06/158 22pp.

JONES, N.S. (2006b). Coal Resource Appraisal Maps: methodology and datasets used. *British Geological Survey Commissioned Report*, CR/06/159N. 19pp. http://nora.nerc.ac.uk/7456/1/CR06159N.pdf

LOTT, G.K., JONES, N.S., ADLAM, K.A., GARCIA-BAJO, M.., WILLIAMS, N., COOPER, R. & LINLEY, K. 2006. Safeguarding Opencast Coal Resources in the Welsh Coalfields. *British Geological Survey Commissioned Report* CR/06/175.

NATURAL ENGLAND (2008) East Midlands Region Landscape character assessment, section 4, group 9 coalfields. http://www.naturalengland.org.uk/Images/section4-group9_tcm6-14497.pdf

REVELL, P. 2004. Building on Past Achievements: Generalising OS MasterMap® Rural Buildings to 1:50 000. ICA Workshop on "*Generalisation and Multiple representation*", 20-21 August 2004, Leicester. http://ica.ign.fr/Leicester/paper/Revell-v2-ICAWorkshop.pdf

SCHONING, P. 1997. Land use statistics for cities and urban settlements in Norway, Conference of European statisticians, work session on Geographical Information systems http://www.unece.org/stats/documents/1997/09/gis/18.e.pdf

SCOTTISH GOVERNMENT. February 2010. Scottish Planning Policy. ISSN 1741 1203. http://www.scotland.gov.uk/Resource/Doc/300760/0093908.pdf

WAUGH, D. (1990) Geography and Integrated Approach. Surrey, UK: *Thomas Nelson and Sons Ltd*. 593pp.

WELSH ASSEMBLY GOVERNMENT. January 2006. *Minerals Planning Policy Wales Minerals Technical Advice Note 2 (Wales) Coal.* The National Assembly for Wales. http://wales.gov.uk/docs/desh/policy/090120coalmtanen.pdf

WELSH ASSEMBLY GOVERNMENT. January 2009. *Minerals Planning Policy Wales Minerals Technical Advice Note 2 (Wales): Coal. Consultation Draft.* The National Assembly for Wales. http://wales.gov.uk/consultation/desh/2006/coalmtan/consultation.pdf;jsessionid=K72bMh1L3p9Yy2NJKnFhn2wSvnYs15YfG6vmCGLqmjrx36GC3NKL!-616133670?lang=en&status=closedf