MINERAL POTENTIAL MAPPING – A NEW SPATIAL DECISION SUPPORT TOOL FOR INDUSTRY AND PLANNERS

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ABSTRACT

The initial search for the optimal location for a mineral extraction site is complex, involving the consideration of geology, environment, market, transport and other factors. This research used a geographical information system (GIS) as a spatial decision support tool to combine all of these aspects and to map the potential for aggregates extraction in the East Midlands region of England. The methodology, developed as part of an MSc research project, takes the concept of 'Mineral Potential Mapping' to a further stage. It moves beyond simple mapping of the extent of mineral resources to examine the potential of an area to be suitable for mineral extraction.

Geological units were ranked according to their relative suitability for use as aggregates. The degree of constraint imposed by various environmental designations was assessed and mapped. The potential market for aggregates was evaluated using change in population density, proximity to urban areas, housing targets and priorities for highway improvements. Distances to main roads were also examined, together with the presence of bird strike risk zones. All these aspects were weighted using expert opinions and combined to produce maps showing the distribution of extraction suitability.

Such maps represent a useful decision-making tool for both Mineral Planning Authorities and quarry operators. Although the project focussed on aggregates extraction in the East Midlands region of England, the methodology developed could be used for any other region, and potentially for other minerals.

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INTRODUCTION

When considering the optimal location for a new mineral extraction site there are many factors that need to be taken into account, including the existence and quality of the mineral resource, the location and degree of constraint imposed by a wide range of environmental designations, the distance to the market and access to transport infrastructure. As a consequence, the initial 'land search' process can be complicated.

Many of the factors included in this process have a spatial dimension and, therefore, a geographical information system (GIS) could be a useful tool to assist in identifying suitable locations for aggregates extraction. The aim of this research project was to identify the main factors that should be included in a GIS-based decision support tool and to develop a suitable method to incorporate these factors into a map showing the potential for an area to be suitable for aggregates extraction. This tool could then be used by the industry themselves during the early stages of their land search process, or by Mineral Planning Authorities (MPAs) to identify or prioritise preferred locations as part of their Mineral Development Frameworks.

The research shown here used the East Midlands region as a study area, which includes the counties of Derbyshire, Nottinghamshire, Lincolnshire, Leicestershire and Northamptonshire, the unitary authorities of Rutland and the cities of Leicester, Nottingham and Derby, plus the Peak

District National Park. However, the methodology that has been developed could also be applied to other regions.

Mineral Potential Mapping

The methodology known as 'mineral potential mapping' has been used for many years to predict the most likely locations in which various minerals and metals might be found. For example, a case study by Bonham-Carter (1994) aims to predict the occurrence of gold in Nova Scotia, Canada. With mineral or metal exploration there are a number of different factors to consider, which vary depending on the particular mineral in question, but might include remote sensing information, soil samples, chemical samples from water bodies, etc. These factors are brought together spatially and used to predict where the ore body might be located.

The methodology has also been used to identify areas with good quality aggregates resources, for example, in Austria (Pfleiderer et al., 2007), Canada (MEMPR, 2007) and the USA (MDNR, 2008). However, the majority of these studies have concentrated entirely on the geology, i.e. rock types suitable for use as aggregates, and only rarely have additional social or environmental factors been incorporated into the methodology. Examples where such factors have been considered include a study in Ireland which incorporated a measure of the market (Lally, 2008) and research in Spain that contained some environmental factors (Lamelas *et al*, 2006).

Including social, environmental and other relevant factors into the methodology converts it from a process that maps the potential of an area to contain a mineral, into 'extraction suitability mapping' which identifies and ranks locations based on their appropriateness for extraction.

Mineral Planning In England

Planning is the system by which decisions are made on the future shape of the nation's cities, towns and countryside. Mineral planning is one aspect of the planning system and aims to ensure an adequate and steady supply of minerals is provided to support the prosperity and quality of life of the UK (DCLG, 2012), whilst at the same time recognising that mineral extraction does potentially result in some negative impacts such as dust, noise and visual intrusion.

Mineral planning in the UK is a 'plan led' system, whereby the national Government establishes policies (DCLG, 2012) and guidance on overall provision and these are subsequently cascaded down to local areas where individual planning decisions are taken[1]. As part of this process each Mineral Planning Authority will develop a plan[2] which includes 'site allocations'. These are specific locations where applications for aggregates extraction will be considered in future, although there is no presumption in favour of extraction and the full application and permitting process is still followed. An application for planning permission to extract aggregates from land outside these allocations is very unlikely to succeed.

The sites included in these local development plans are, in general, suggested by the extractive industries themselves, although unused sites from the previous plan are also usually considered (e.g. Nottinghamshire C.C., 2005). Each Mineral Planning Authority will then assess the identified sites against their particular policies and criteria to produce their plan containing sufficient sites to meet their perceived needs. The research established the key criteria used by the extractive industries during the process of identifying new sites and these included: the potential market for the minerals, the local geology, obvious constraints to extraction, transport links and land ownership. As many of these factors as possible were included in the development of the GIS tool.

DATASETS

[1] Although there have been changes to the system in the time between the research and this paper the basic principle remains the same.

[2] The precise name of these documents has changed over time but the basic principle remains the same, i.e. to identify specific locations where mineral extraction would be considered acceptable.

The research identified five factors to include within the GIS tool, although one of the benefits of the methodology is the ability to add or remove factors and adjust the importance weights as necessary, thus allowing different assumptions and policies to be incorporated. These five factors are described and illustrated below.

Mineral Resources

Since minerals can only be extracted from where they occur it is, therefore, obvious that the location and quality of resources is a primary factor to be included in this tool. The British Geological Survey (BGS) has mapped the geology at the surface of the UK over many years and their digital dataset for mineral resources (BGS, 2006) was used as the basis for this first factor, supplemented by the digital geological map product known as ‘DiGMapGB-50’ (BGS, 2008).

Primary aggregates are extracted either as hard rock (e.g. limestone or granite) or as sand and gravel, and for mapping purposes it is easier to consider these separately. The suitability of a hard rock deposit for use as crushed rock aggregates depends on its physical properties such as its resistance to abrasion, to crushing or to polishing and its degree of water absorption. These quality factors are incorporated into the tool by applying scores to particular rock types, with 10 being applied to the most suitable rocks and 1 to rocks which are less suitable but which are still used for low specification aggregates. Table 1 contains the scores developed in this research for aggregates resources, and Figure 1 is a map of the crushed rock resources in the East Midlands region with the scores applied.

The suitability of deposits of sand and gravel for aggregates depends primarily on their particle size distribution rather than their geological composition, in particular the ratio of sand to gravel and the quantity of ‘fines’ (silt and clay). This particle size distribution is often a reflection of the environment of deposition, e.g. whether the sand and gravel was deposited by a river, the wind or glaciers. Again these quality factors are incorporated using scores for different types of deposit as shown in Table 2, where the different depositional environments are shown as geological categories. Figure 2 is a map of the sand and gravel resources in the East Midlands region with the scores applied.

Environment

In the UK, areas of land which are considered to be particularly important are often protected using one or more environmental designation. For the purposes of this research the term ‘environment’ includes designations which have been utilised to protect or preserve nature, landscape or cultural heritage. Clearly the presence of these environmental designations has the potential to act as a constraint to the extraction of minerals and, therefore, it is important to incorporate these into the GIS tool.

There are a considerable number of environmental designations in the UK and the degree of protection afforded by them varies widely (Steadman et al., 2004). Consequently, the degree of constraint imposed on other land uses by these designations also differs significantly. It was not possible, nor appropriate, to incorporate every possible type of designation into the tool, but the most significant ones are included. In addition, many of them are not mutually exclusive, with some individual areas having up to 10 different designations. In this tool, where there are overlaps, the designation imposing the highest constraint has been used. The digital datasets were obtained from Natural England, English Heritage or the RSPB via the MAGIC website (MAGIC, 2009).

To reflect the degree of constraint on mineral extraction, the designations were scored such that the areas most favourable to extraction, i.e. those without any designations, were scored 10 whereas areas where extraction would not be possible were scored 0. These scores were determined using expert opinions obtained via a questionnaire, combined with details of the level of statutory protection (i.e. international, national or local) and details of land ownership. The environmental designations used in this research are shown in Table 3, together with the scores that have been applied. Figure 3 is a map of the designations in the East Midlands region with the scores applied.

Market
Aggregates have a high place value, i.e. transport costs represent a significant proportion of the selling price, and consequently the closer a quarry is to its market the more competitive its product price will be. However, predicting and mapping the level of demand in the market is complex and contains a high degree of uncertainty. In an attempt to do this, however, four indicators were incorporated into this research: change in population density, proximity to urban areas, housing targets and road improvement priorities.

The change in population density was calculated using data from the 2001 census, obtained via the Casweb website (Casweb, 2001), and the Office for National Statistics 2007 mid-year population estimates (ONS, 2008). When considering the market for aggregates, changes in population density were considered to be more important than population density by itself because the provision of infrastructure often lags slightly behind as population increases.

Urban areas were defined in the research as cities, towns and villages greater than 100 hectares in size. Proximity was mapped according to distance from the boundary of these urban areas, with closer distances scoring higher. Clearly a quarry could not be located directly inside an urban area due to lack of space and, therefore, the area within the boundaries scored low.

It is important to include some measure of the future market, rather than just the current demand, because it takes some time for a proposed quarry site to progress through the planning system. Consequently, the remaining two indicators were included as a prediction of where the market for aggregates might increase in the coming years. Both the housing targets and road improvement priorities were taken from the Regional Spatial Strategy (RSS) for the East Midlands (GOEM, 2009) which was still in place at the time of the research.

Each of these individual indicators were mapped and scored such that the area closest to each of the market areas for aggregates was scored 10 and the areas furthest way scored 1. These four maps were then combined into a single map of the potential market for aggregates and the scores averaged; the resulting map is shown at Figure 4.

Transport
In an environmentally acceptable area, even the very highest quality aggregates deposit is of little worth unless it can be transported to the market. Almost 90 per cent of all aggregates are delivered entirely by road (QPA, 2008) and consequently the proximity to the network of major roads is of vital importance when identifying the optimal location for a new quarry.

In practice, accessing the public highway is more complicated than mere proximity because of planning rules which outline where and how a new entrance can be constructed. However, for the purpose of this research it was considered reasonable to simplify this factor by using proximity buffers within the GIS, as shown in Figure 5. Each buffer is 2 km across. The definition of what constitutes a major road was arbitrarily classified as including all motorways and those A-roads which have one, two or three digit numbers, e.g. A1, A14 or A511.

Bird strike risk zones
Birds, particularly flocks of large birds, represent a hazard to aircraft because striking them can cause damage, particularly to engines. Multiple strikes can lead to engine failures with potentially catastrophic consequences. Aircraft in the process of take-off or landing are particularly vulnerable because their lower elevations mean they are more likely to encounter birds, and because the high thrust requirements cause engine fans to rotate at especially high speeds with severe damage thus being more likely (CAA, 2003).

Although Civil Aviation Authority (CAA) regulations accept that “mineral extraction itself does not attract birds”, the voids created by mineral extraction can fill with water, are sometimes used for landfill sites, or can be restored in other ways specifically to benefit wildlife and these will attract birds (CAA, 2007). Certain airports, e.g. the East Midlands Airport, are designated as ‘officially safeguarded aerodromes’ around which are 13 kilometre bird strike risk zones. Within these zones planning authorities are required to consult the CAA and the airport operator on any proposed development that might attract birds. Although other airfields may not be officially safeguarded, their presence represents an additional consideration for MPAs and it was, therefore, considered appropriate to include this factor in the research, albeit with a lesser importance than some of the other factors.

IMPORTANCE WEIGHTS

Not all of the datasets described above are of equal importance when deciding on new potential locations for aggregates extraction. This is incorporated into the GIS tool using importance weights which are applied to each factor. In order to avoid introducing a subjective element to the research, and to ensure these weights were impartial, a questionnaire was used to gain expert opinions from the aggregates industry. The responses to this questionnaire were used to derive the relative importance of different elements and the resulting weights were multiplied by the scores within each of the input maps.

The resulting datasets, with their weighted scores, were then combined together and the scores multiplied, which ensures that an area that scored 0 on any factor remains 0 in the final output maps. The diagram at Figure 6 illustrates the process.

One advantage of using a GIS to assist with this decision-making process is the ability to perform multiple iterations based upon different importance weightings, or indeed different quality scores, for the different layers. This enables a variety of scenarios to be easily assessed.

RESULTS

The research resulted in two final maps for the East Midlands region of England: hard rock resources (Figure 7) and sand and gravel resources (Figure 8).

The highest scoring areas for crushed rock aggregates are predominantly located in Leicestershire. Most of these are based on good quality hard rock (i.e. igneous rock or Carboniferous limestone) outside any environmental designations. The next category includes both Permian dolomite, which scores lower on resource quality but higher on market factors, and Carboniferous limestone located outside the national park in Derbyshire, which scores higher on resource quality but lower on distance to market.

For sand and gravel the highest scoring areas are mainly located along the course of rivers where many of the river terrace and sub-alluvial deposits are found. These have a scored well in terms of resource quality, but are also close to the market for aggregates and frequently have good access to the road network.

Comparison of the most suitable locations predicted by this GIS tool, shown of these result maps, with the location of current and recently worked out quarry sites (for example as displayed in Harrison et al., 2002) show a good correlation. This suggests that the methodology developed during this research represents a robust model that has integrated the majority of important factors and weighted them appropriately.

CONCLUSIONS

Aggregates are essential materials for building and maintaining the physical infrastructure on which a modern society depends. Mineral Planning Authorities have to balance conflicting requirements to ensure sufficient planning permissions for aggregates extraction are granted to meet society’s needs while at the same time protecting the environment that people value highly. A transparent methodology for selecting the optimal locations for quarries would clearly be beneficial.

From the perspective of the aggregates industry, searching for suitable land to bring forward to the Authorities is a complex process requiring consideration of many different factors including geology, environmental sensitivities, the potential market and access to suitable transport. A methodical approach for identifying locations, weighing the different criteria for each and thereby ranking them in order of suitability would be valuable.

The methodology developed during this research aims to meet both these requirements using GIS as a spatial decision support tool. The key factors that should be incorporated were identified during the research; a methodology was developed to manipulate the available datasets, to weight them according to their relative importance and to combine them together to produce the final result maps. These final maps (Figures 7 and 8) identify the most suitable areas for aggregates extraction in the East Midlands region of England. These include many locations where quarries are already operating, thereby indicating that the methodology is robust. The method of reaching these results is itself important because it provides a transparent methodology that could be used to reassure an often sceptical public.

The ability within the GIS model to adjust scores, and/or importance weights, means that the methodology is easily adaptable to local circumstances and can be used to simulate various scenarios. Consequently it has the potential to be very useful as a tool to support the necessary spatial decisions made by planners and industry.

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FIGURES & TABLES

Score	Geological category
10	Igneous and metamorphic rocks
9	Carboniferous limestone
6	Carboniferous dolomite
5	Permian dolomite
2	Sandstone
2	Jurassic limestone
1	Chalk
1	Ironstone

Table 1. Scores developed to indicate the suitability of different hard rock types for use as crushed rock aggregates, with 10 representing the most suitable rocks and 1 the least suitable (0 represents no mineral extraction is possible). These are based on the rock types present in the East Midlands region of England and may need to be adjusted if the methodology is used in other regions.

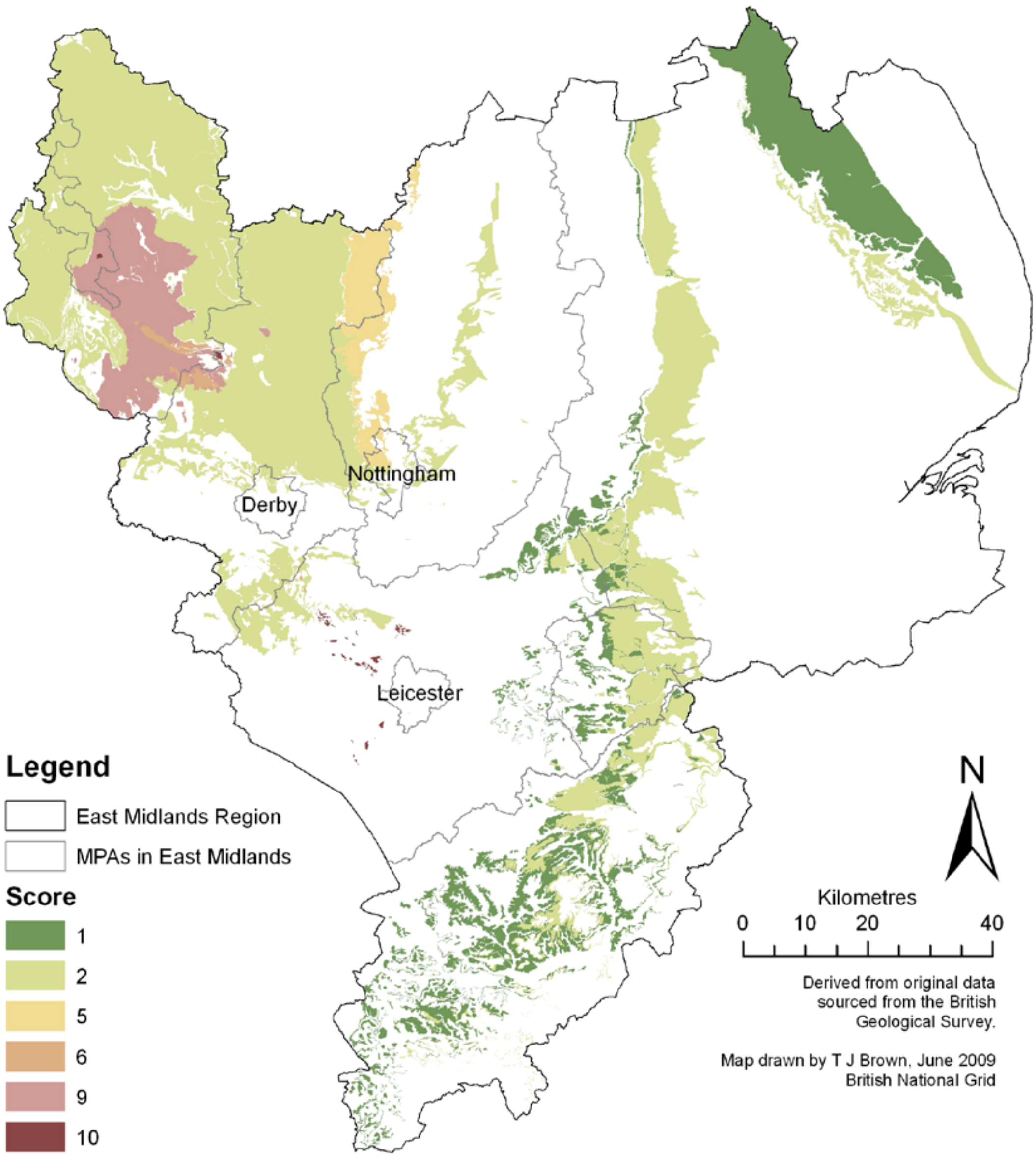

Figure 1. Map of the East Midlands region of England showing the locations of hard rock resources, with the suitability scores applied.

Score	Geological category
8	River terrace and sub-alluvial deposits
7	Glaciofluvial deposits
5	Bedrock conglomerate
2	Bedrock sand
2	Blown sand
1	Beach deposits

Table 2. Scores developed to indicate the suitability of sand and gravel deposit types for use as aggregates, with 10 representing the most suitable deposits and 1 the least suitable (0 represents no mineral extraction is possible). These are based on the deposits present in the East Midlands region of England and may need to be adjusted if the methodology is used in other regions.

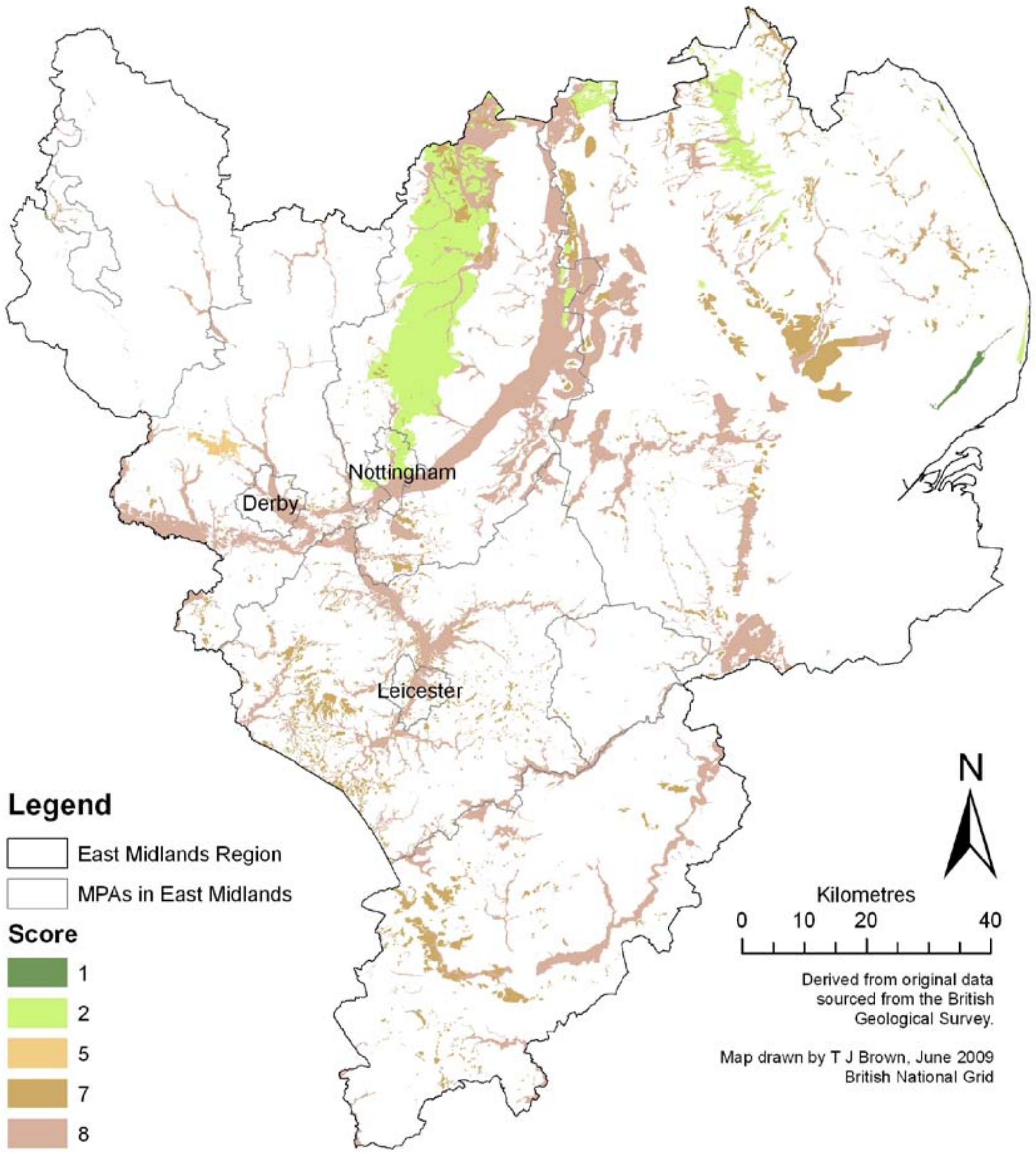

Figure 2. Map of the East Midlands region of England showing the locations of sand and gravel resources, with the suitability scores applied.

Score	Name of Designation
0	World Heritage Sites
1	Special Area of Conservation (SAC)
2	Ramsar Site
2	Special Protection Area (SPA)
2	National Park
3	Scheduled Ancient Monument
3	Area of Outstanding Natural Beauty (AONB)
3	National Nature Reserve (NNR)
3	Site of Special Scientific Interest (SSSI)
5	National Trust owned land
6	RSPB reserve
7	Local Nature Reserve (LNR)
7	Important Bird Area
8	Registered Park or Garden
8	Registered Battlefield
9	Ancient Woodland
10	No environmental designation

Table 3. Scores developed to indicate the degree of constraint imposed on mineral extraction by selected environmental designations.

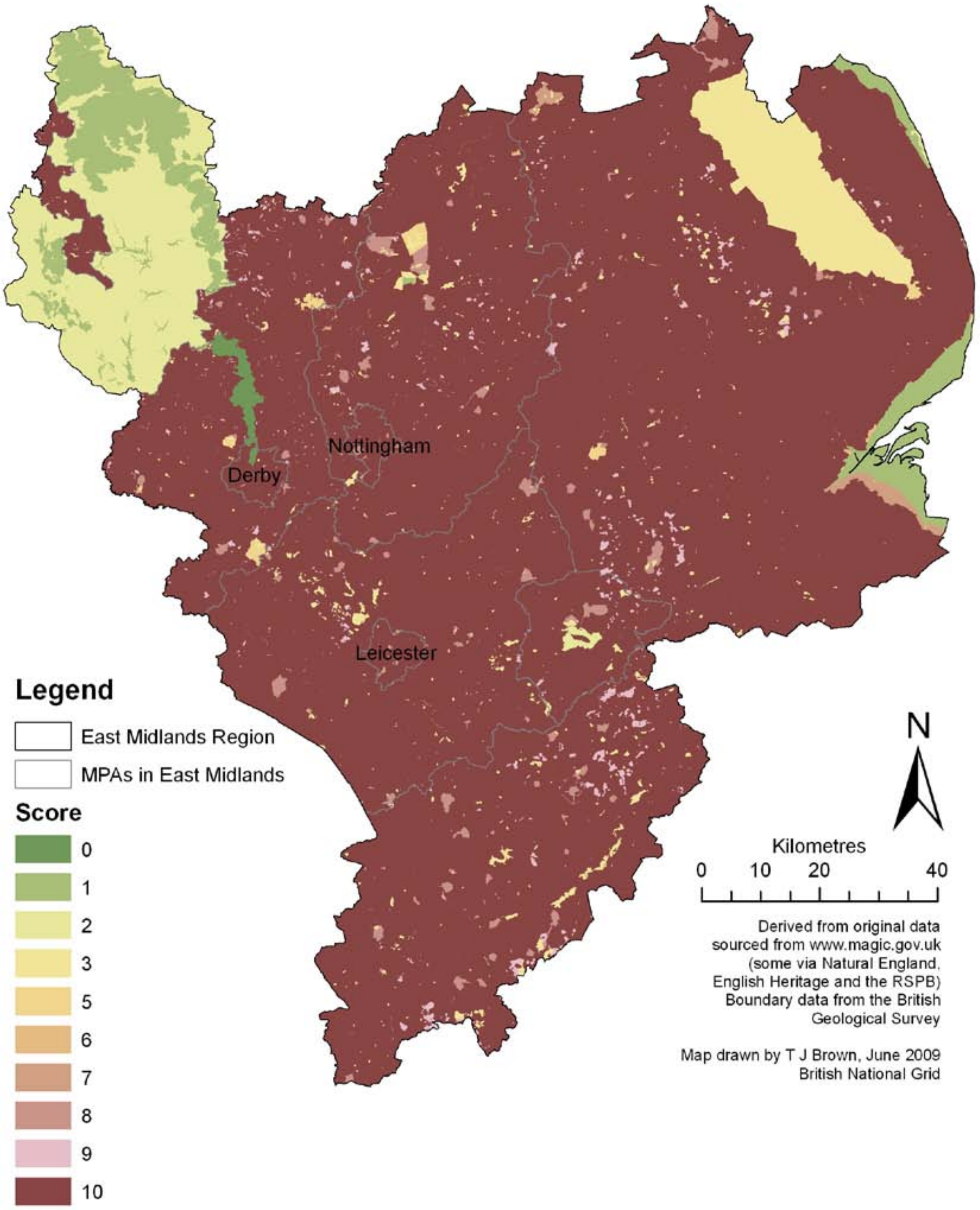

Figure 3. Map of the East Midlands region of England showing the environmental designation scores applied.

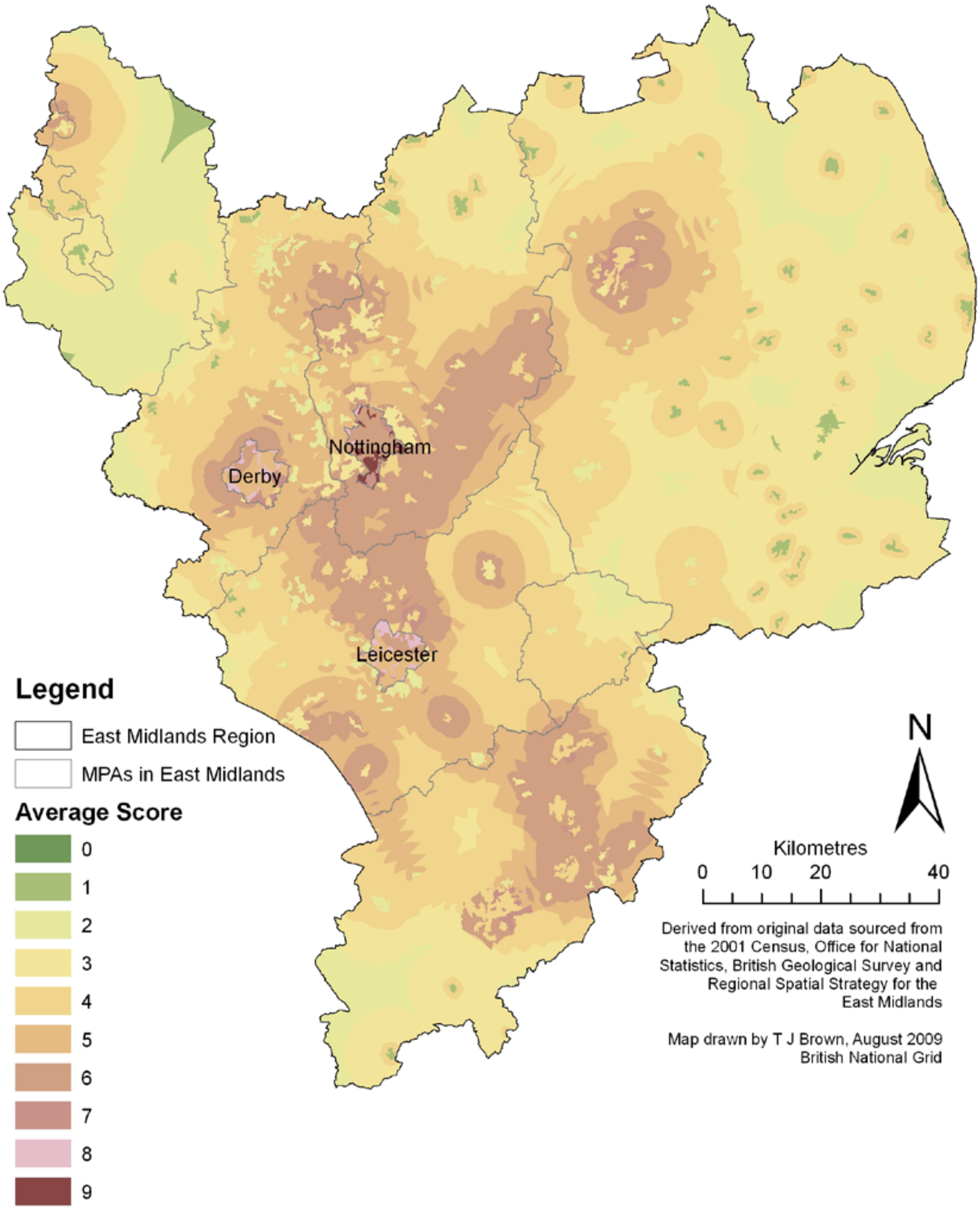

Figure 4. Map of the potential market for aggregates in the East Midlands region of England, obtained using an average score from change in population density, proximity to urban areas, housing targets and highway improvement priorities.

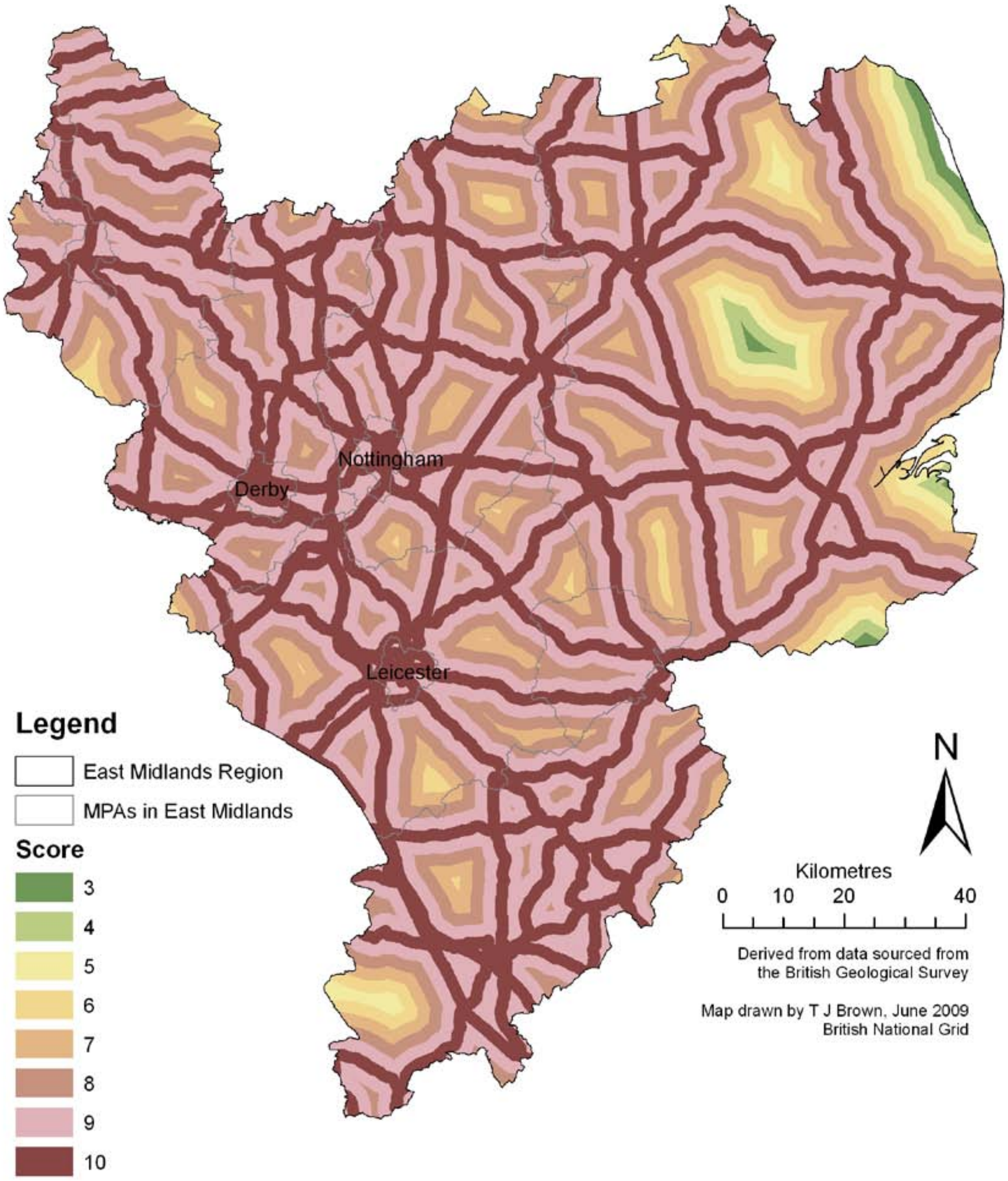

Figure 5. Map of the East Midlands region of England showing proximity buffers for the major road network, scored by proximity.

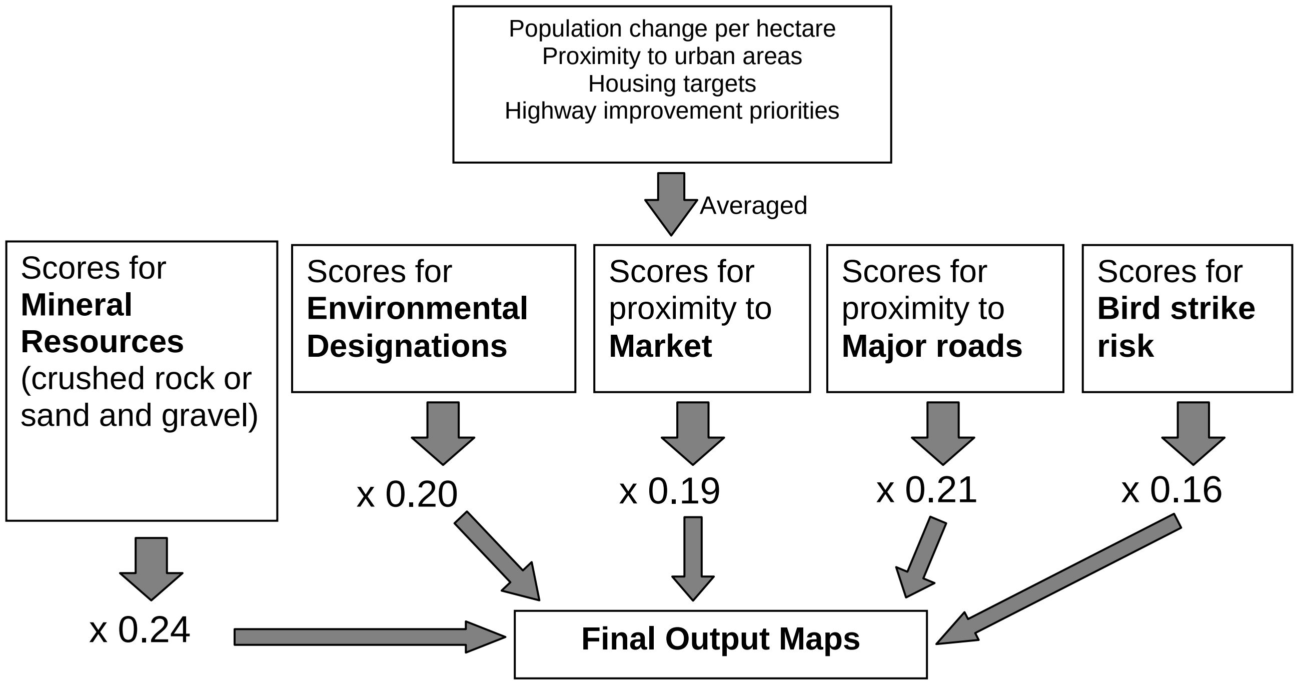

Figure 6. Diagram showing how the various datasets used in the decision-support tool are multiplied by their importance weights and incorporated into the final result maps.

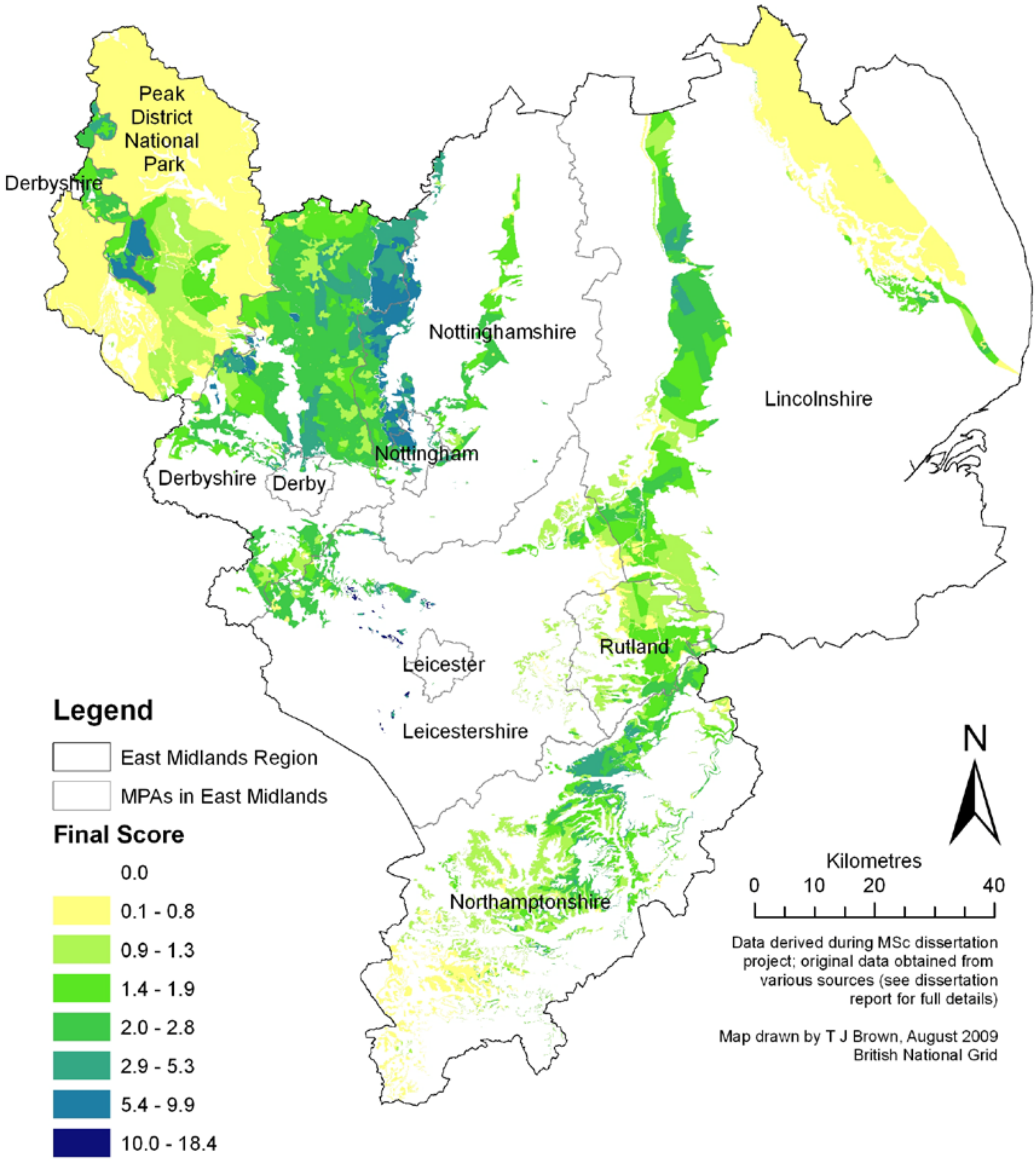

Figure 7. Final map showing the hard rock resources of the East Midlands region of England, ranked by suitability for aggregates extraction.

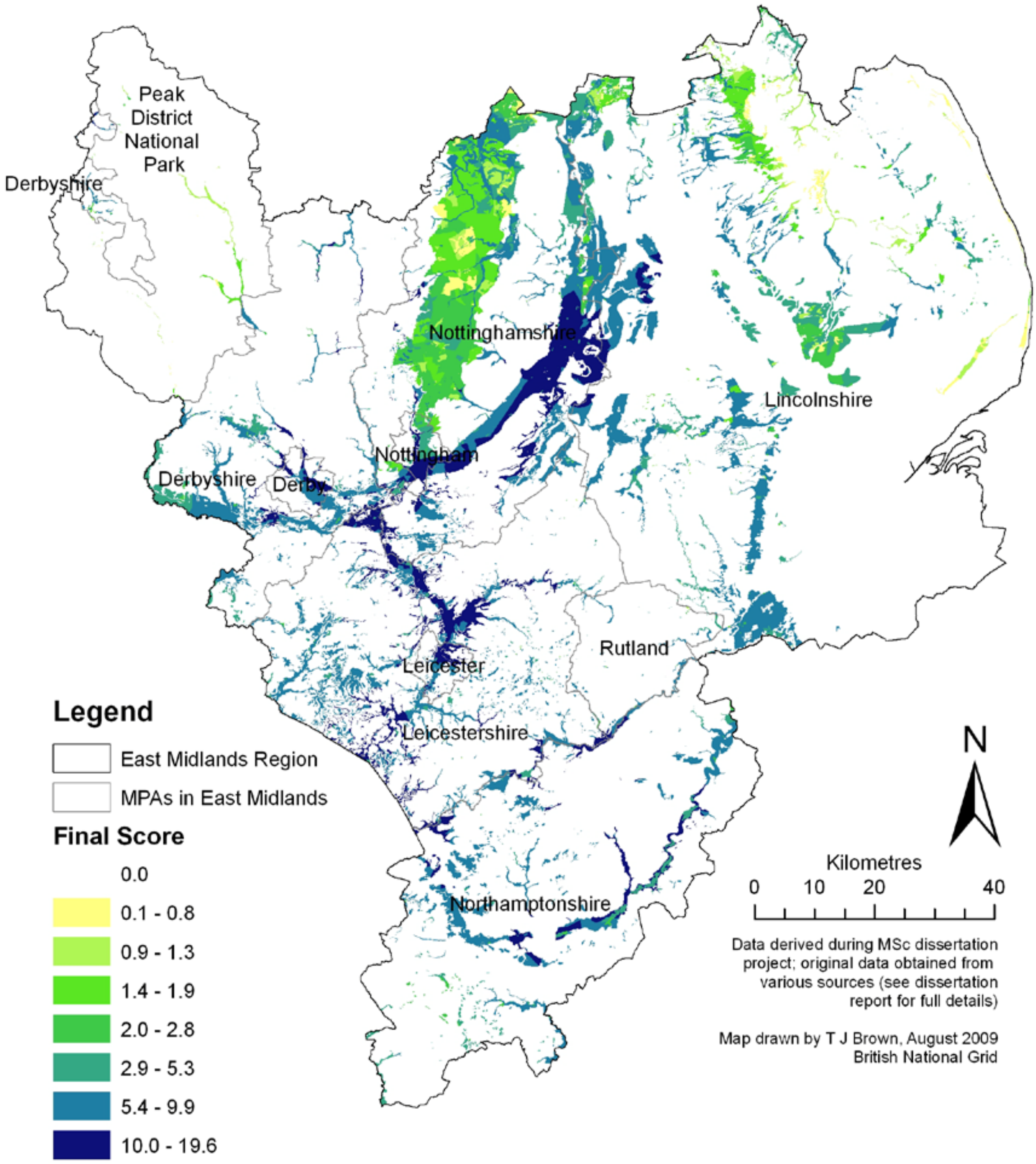

Figure 8. Final map showing the sand and gravel resources of the East Midlands region of England, ranked by suitability for aggregates extraction.