

Accessibility mapping as a tool for measuring rural deprivation

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Introduction

One of the problems in any rural landscape is the accessibility of services to the local population. These services may be schools, health clinics, post offices, telecommunications, shops and any other public or private service. In urban areas these are nearly always within easy walking distance and access to them is only restricted by their cost and a person's ability to pay.

In rural areas, almost by definition, access to services is also restricted by the remoteness of their location. Access is often measured by quoting straight line distances from services to potential users. In the UK for example, access to broadband internet connections has for some time been restricted to households within a 5km radius of a telephone exchange, which has excluded large areas of the rural countryside. Figure 1 shows how long it would take to travel to schools in a region, if it was possible to travel directly to them in a straight line at a steady speed of 30 kph.

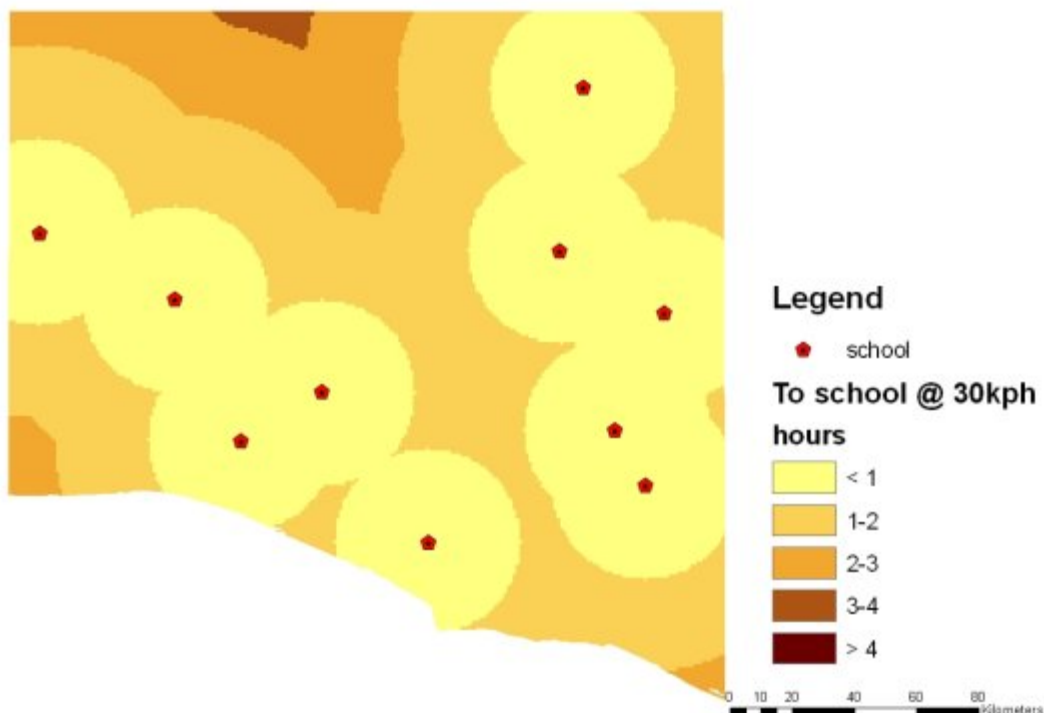


Figure 1 Straight line times of travel to schools in an area, assuming a steady speed of 30 kph

In reality it is impossible to travel like this. Travel is usually confined to roads or tracks, and speed is anything but constant. In poor areas, travel may have to be on foot, or restricted to poor quality public transport network. The important measure of remoteness from a service is not the physical distance to it, but the

time it takes to reach it. A hospital which is within sight on the far bank of a dangerous river is far more inaccessible than one 10km away on the same side. It will also take far longer to travel 5km on a rough dirt road than 20km on a paved highway. It takes longer to walk than to drive. Access to services in the rural environment is restricted both by cost and by accessibility travel times. A much more accurate picture of accessibility mapping is given in figure 2, showing the shortest times to travel to a school taking these factors into account.

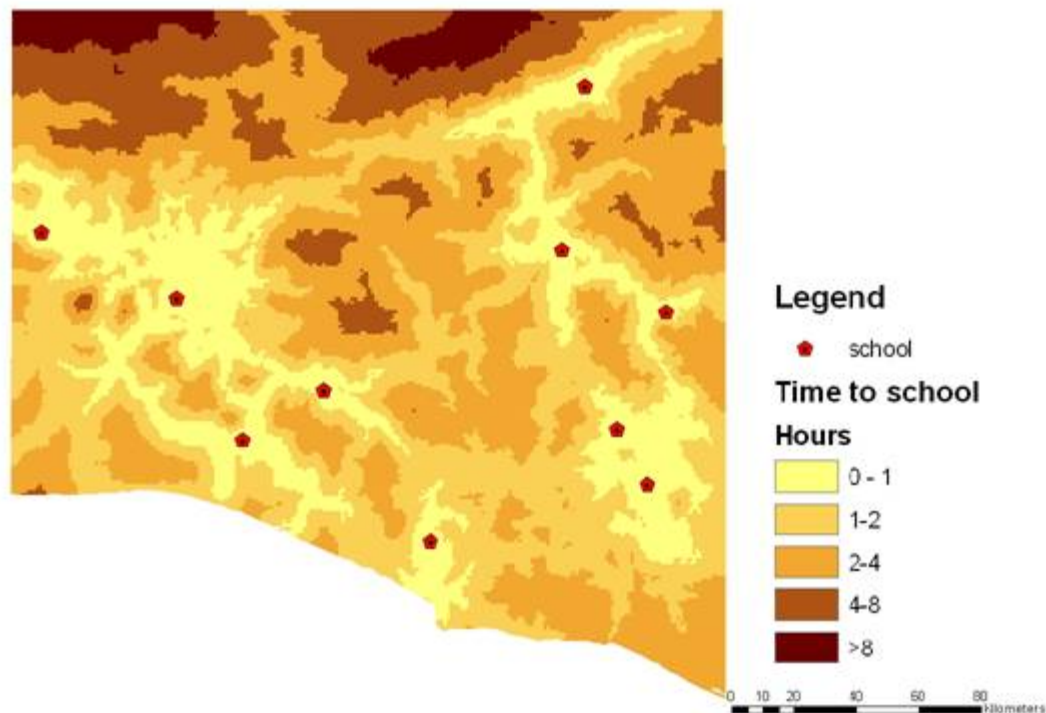


Figure 2 Shortest travel times to a school allowing for road networks and varying speeds of transport

This paper sets out to describe how these travel times as shown in figure 2, may be modelled in a geographical information system (GIS) to produce accessibility maps as measures of rural service deprivation.

Data requirements

Almost any type of geographical feature which might influence travel time can be incorporated into an accessibility model. However, so many assumptions have to be made about how quickly people can move through the landscape, that it is counter productive to use too many datasets. At best the model can only give approximations and comparisons and should not be treated as significantly precise or accurate.

In the case study given here, it is assumed that travel will primarily be along roads and that travel times will be influenced by the quality of the roads and the steepness of the land. In order to produce the accessibility map, the following data sets will be needed:

- Road map, showing categories of road
- DEM or a derived slope map of the region
- Target features: places of interest that people will travel to or from. In this case study there are two types of targets:
 - Settlements: location of centres of population
 - Services: the location of features such as schools, hospitals, and anything else of interest.

Additional data that might be added to the model are landcover, if a significant amount of travel will be off road, and rivers, if these are used for transport or are significant barriers to land transport i.e. they could both increase or reduce travel times. If there are definite barriers to travel, such as large bodies of water or national boundaries, these should be added to the model. None of these additional features are considered in this case study, which simply intends to show the principles of the technique.

Figure 3 shows the basic distribution of the datasets in the case study region (this is an area around the borders of Guatemala, El Salvador and Honduras. The villages, roads and slope are true features, the services targets are hypothetical.)

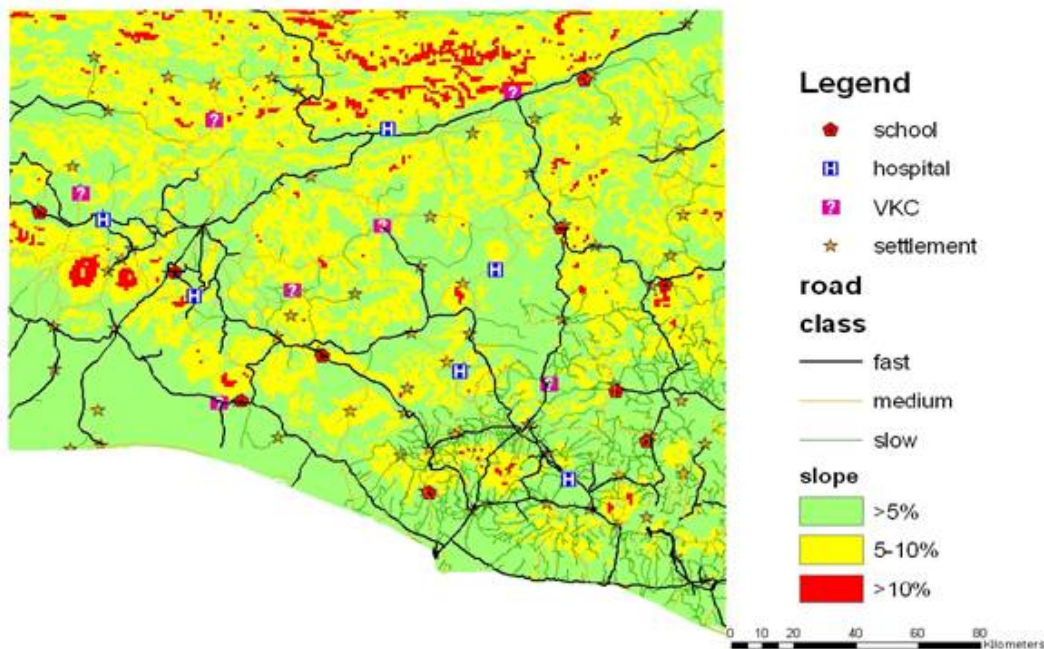


Figure 3 Basic data sets used for this case study. These are based on data from Central America but the service targets (schools, hospitals and VKC) are hypothetical.

Data type and projection

Vector data for roads and targets can be used, but the accessibility model is generated as a raster surface map, a collection of equal sized cells in a grid covering the study area. All vector data sets will have to be converted to rasters. All datasets must be projected on a common equal-area projection for the calculated travel times to be anything close to real times. (This is not so critical for small study areas or areas near the equator.)

The resolution of the raster (the size of each cell) is important as it relates directly to travel time. The times used are those required to move either directly or diagonally across one cell of the raster at any location. How the resolution is incorporated into the calculations will vary depending on the algorithm of the geographical information system (GIS) used to build the model.

Creating a cost surface

The core of the accessibility model is a cost surface (also called a friction surface) for the region being studied. This is a raster map of the whole region in which the values in the raster cells are equal to the time it takes to cross directly through that cell. If the cell represents part of a fast road, the time will be very short. If it represents steep open land, it may be very large. (If there are barriers in the model, these can be represented by cells with values several magnitudes larger than even the highest non-barrier cells or, in some GIS, they can be defined as barriers to the travel time calculations.) Once the cost surface is created, it can be used for any number of travel time scenarios by defining the location of target features on the surface, and then calculating the cumulative *least* travel time to the *nearest* target from every cell on the map. This process is described under *Creating an Accessibility Map* below.

The basic travel cost surface

In this case study only roads and slope are used as data inputs to the cost surface to keep the process simple and clear. In a real study, barriers to travel such as lakes and borders should be included and some experimental work done to determine genuine travel speeds for people in the study area.

Creating the road and land travel time map

The vector road map from CIAT defines 3 classes of road, (figure 4) major roads, minor roads and tracks.

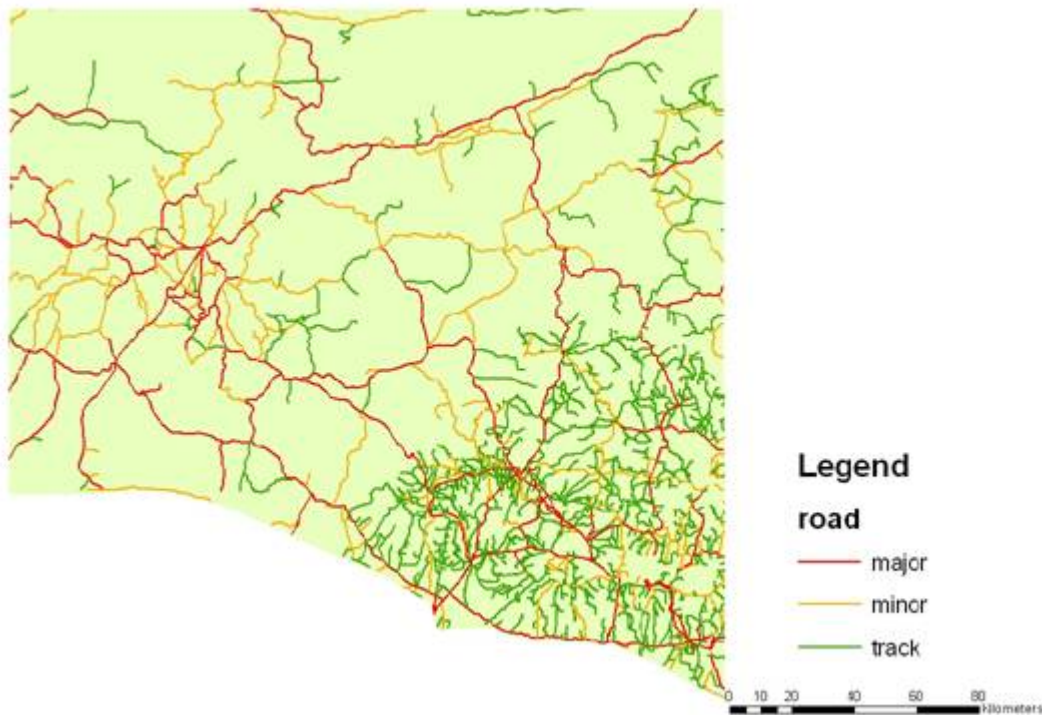


Figure 4 the road network in the case study area

The road network is clearly very unevenly distributed, which will have significant influence on the general accessibility of different locations. What speed can people travel over a road? Deciding this is very subjective and variable. Someone with a private car can travel rapidly over a metalled highway. Someone walking will not travel at significantly different speeds on any type of road. Someone relying on a bus service will be dependent on bus timetables, reliability and their ability to pay the fare. The speed will also be influenced by the steepness of the road, its straightness and even the prevailing weather. This is an area where values can be varied to see how sensitive the model is to different speeds.

For this case study the following speeds are assumed, but without any experimental justification.

- Speed over non-road surfaces 5 kph
- Speed on a track 10 kph
- Speed on a minor road 30 kph
- Speed on a major road 60 kph

Experimenting with walking, draught animal, cycling and vehicular speeds can give an indication of the accessibility to services for different affluence levels in the local society. It should be possible to create travel cost surfaces for poor people and affluent people, and these may be very different.

Note that a single speed is used for travelling over non-road surfaces, i.e. all of the spaces between the roads. The model could

be further refined by using a landcover map and assigning different speeds for travelling through each type of landcover, but this is probably assigning too much detail to the model to be realistic.

The road map is now converted to a raster with a specified cell size. In this case study, cell size is 1km x 1km. The cells are reclassified to show the time to travel across each in minutes (figure 5.)

- Non road 12 minutes
- Track 6 minutes
- Minor road 2 minutes
- Major road 1 minute

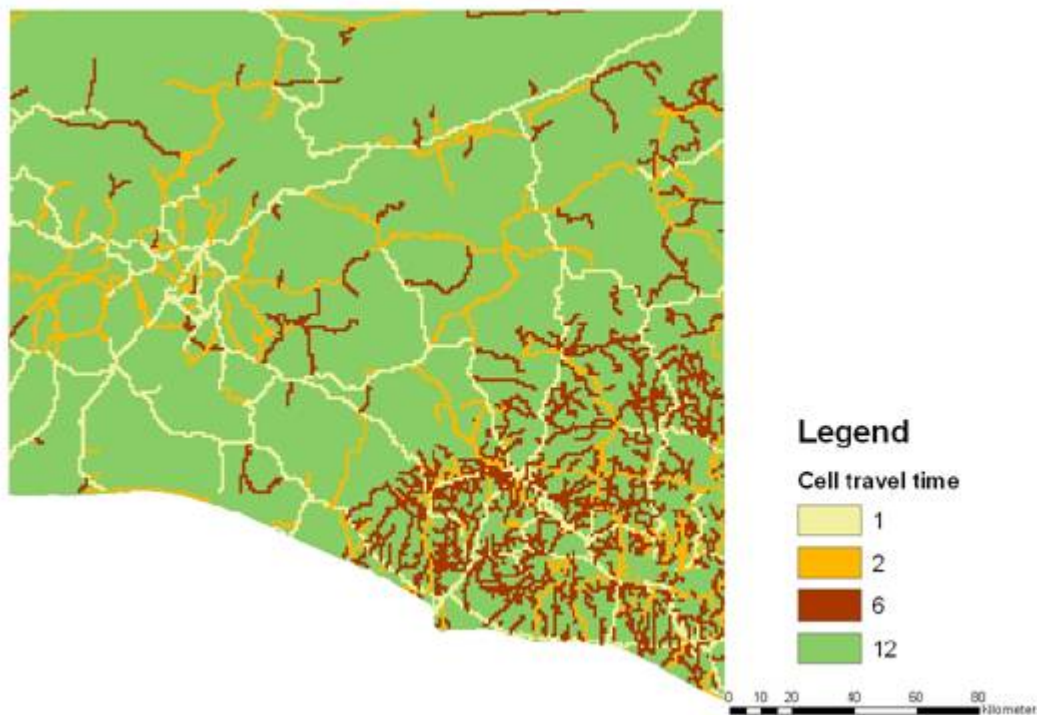


Figure 5 Time to travel across a 1 km cell at any location on the map

This basic cost surface assumes that there are no other impediments to travel. To better reflect reality it needs to be modified to allow for the effect of slope on speed of travel.

Creating the slope factor map

A slope map at the same resolution as the land/road travel time map needs to be created. This can be done from a digital elevation model (DEM) or elevation point data set. It is still important not to be too precise and detailed as the model cannot justify this. For this case study, a slope map was derived from a DEM and classified into three categories of slope:

- 0-5%
- 5-10%
- >10%

The assumption is then made that below 5%, slope has no influence on travel time, between 5 and 10% it doubles travel time and over 10% it increase travel time fivefold. Again, it is worth experimenting with different values to see how sensitive a particular landscape is to these factors. In this case study, very little land is steeper than 10% (figure 6)

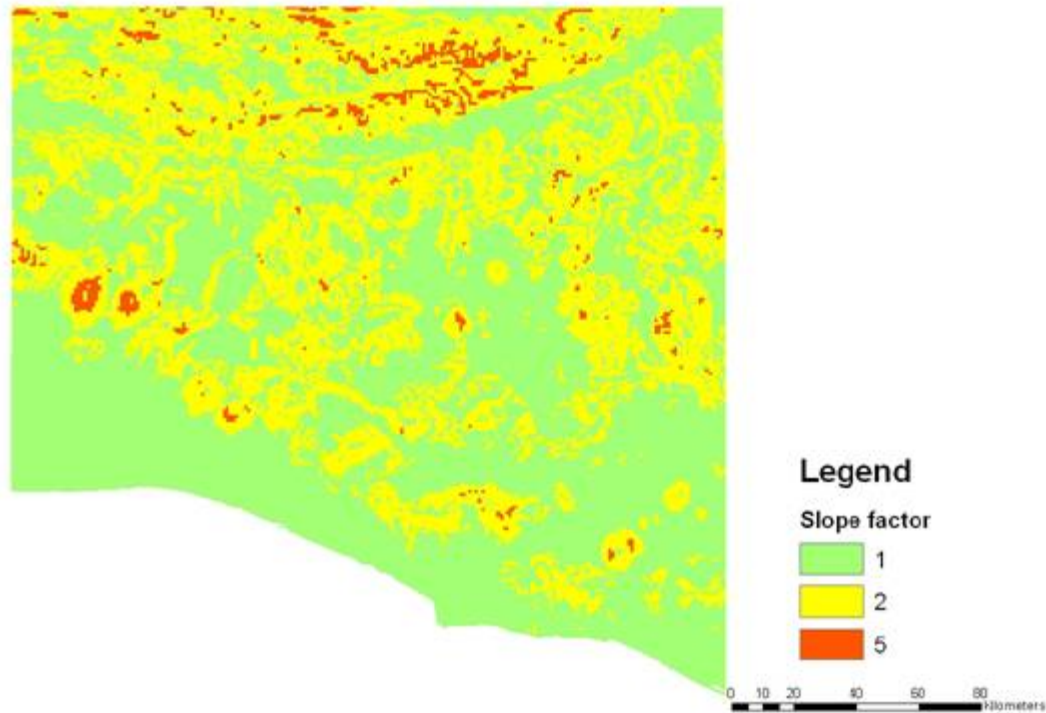


Figure 6 The factor by which slope increase travel time in each cell

Generating the basic travel cost surface

The final cost surface is created by using simple map algebra. This may be implemented in different ways with different GIS. Put simply, a new raster map is generated in which the value of each cell is the product of the equivalent cells on the land travel time map and the slope factor map. Thus, if the travel time in a cell is 12 minutes and the slope factor is 2, the total travel time will be 24 minutes across that cell. The range of cell travel times will be from 1 (fast road, flat ground) to 60 (no road, over 10% slope) (figure 7)

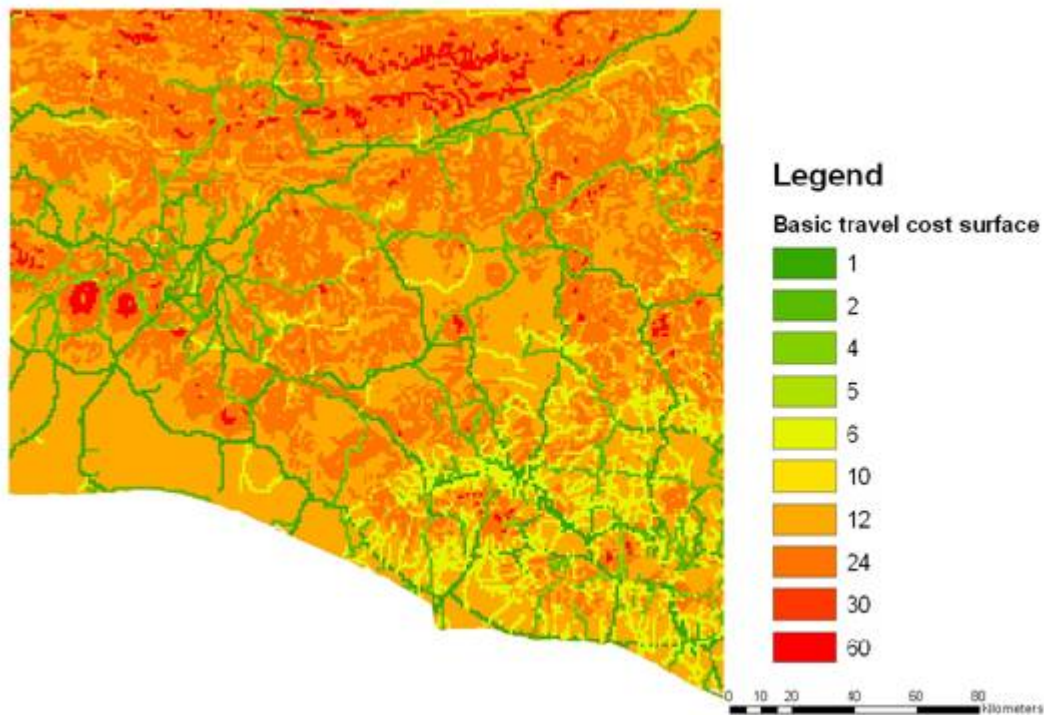


Figure 7 The basic travel cost or friction surface, showing how many minutes it takes to cross any cell, as influenced by road type and slope

Creating an accessibility map:

Having now produced a cost surface, it is possible to generate accessibility maps to any target locations within this region. Targets can be vector points, but some GIS programs will produce a better result if they are rasterised first. In this first example, the accessibility to schools is examined (figures 8 and 9)

The exact algorithm used to generate the accessibility map can be written by the user, but most GIS contain a basic *least cost distance* tool. This will work outwards from each specified target, calculating the least cumulative cost moving from the targets to any cell in the raster and using those least costs to generate a new raster, the accessibility map. This raster can contain large, floating point numbers and it is necessary to reclassify it for use. In this case study, using *ArcGIS 9*, the raster resolution was 1000 and so the values were divided by 60,000 to account for the resolution and give time in hours rather than minutes. This output was further reclassified in to a simple five level ordinal scale for clarity.

Travel time to school

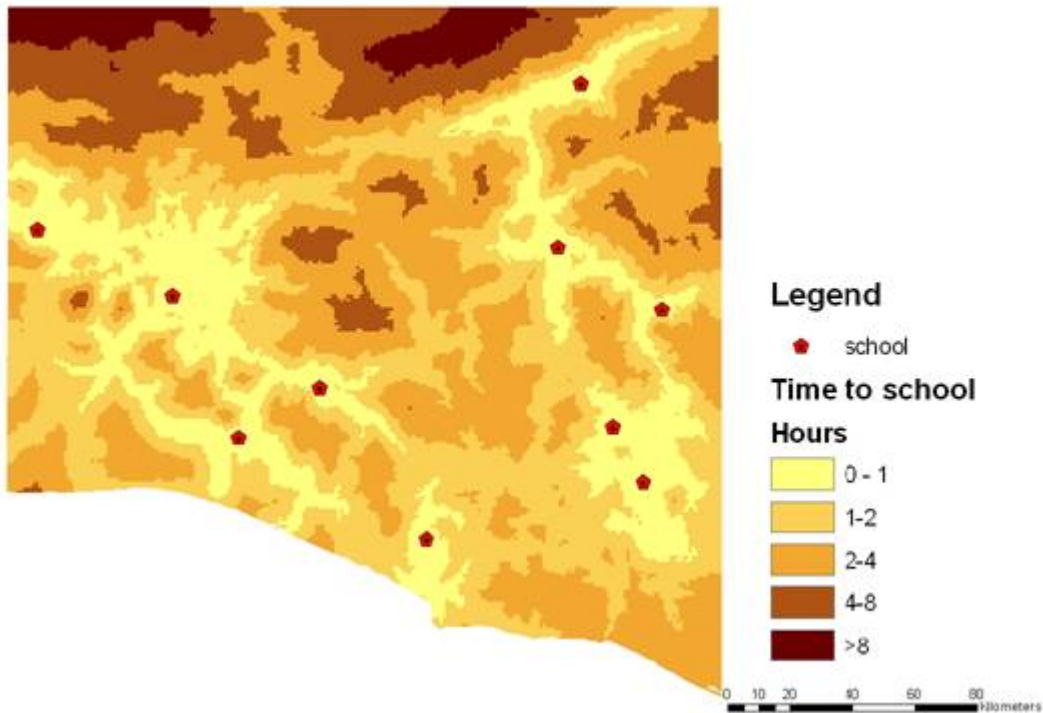


Figure 8 The time to travel to the nearest school

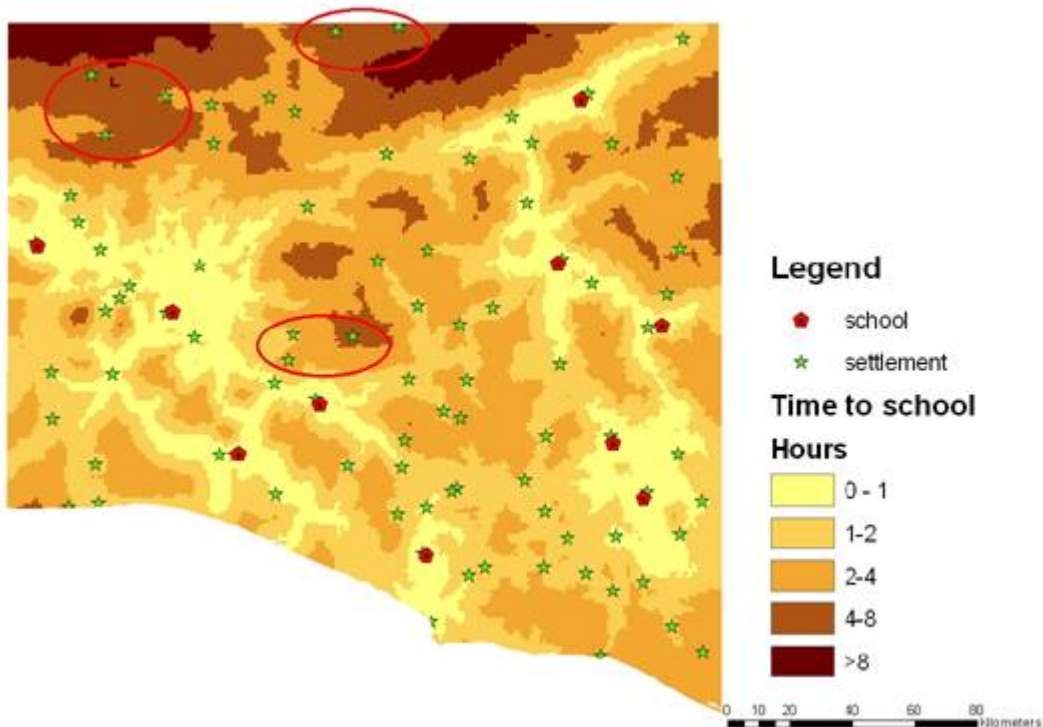


Figure 9 Settlement locations have been overlain and the villages most remote from schools outlined. The most inaccessible land areas are uninhabited and so are not a social problem.

This basic school accessibility map shows that straight line distances bear little or no relationship to how accessible somewhere like a school really is. It also shows the overriding influence of the road network on accessibility (Figure 10).

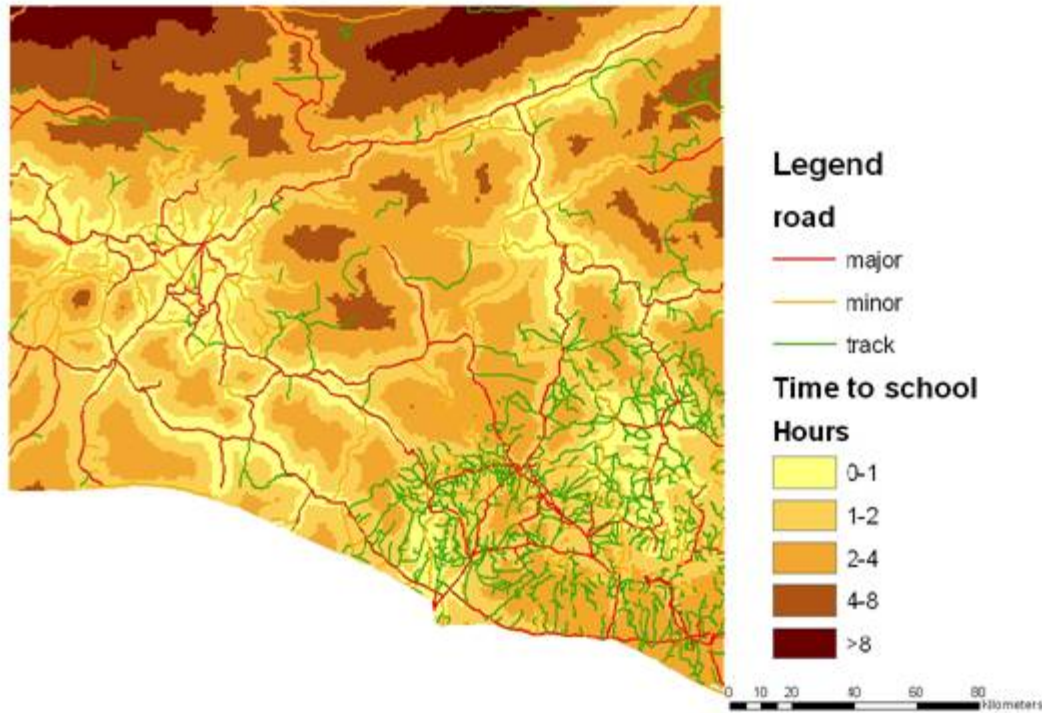


Figure 10 School accessibility map overlain with road network.

Time to hospitals and village knowledge centres

Exactly the same process can be used to generate accessibility maps to any chosen target or groups of targets. The next two examples shows travels times to regional hospitals and to information resources at Village knowledge Centres (VKC) (figures 11 and 12)

In all three cases shown, the distribution of the targets are different and the accessibility maps also differ. However, the gross underlying pattern is similar and is largely determined by the road network, which is to be expected. This also indicates that the model is fairly robust and not overly sensitive to changes of inputs.

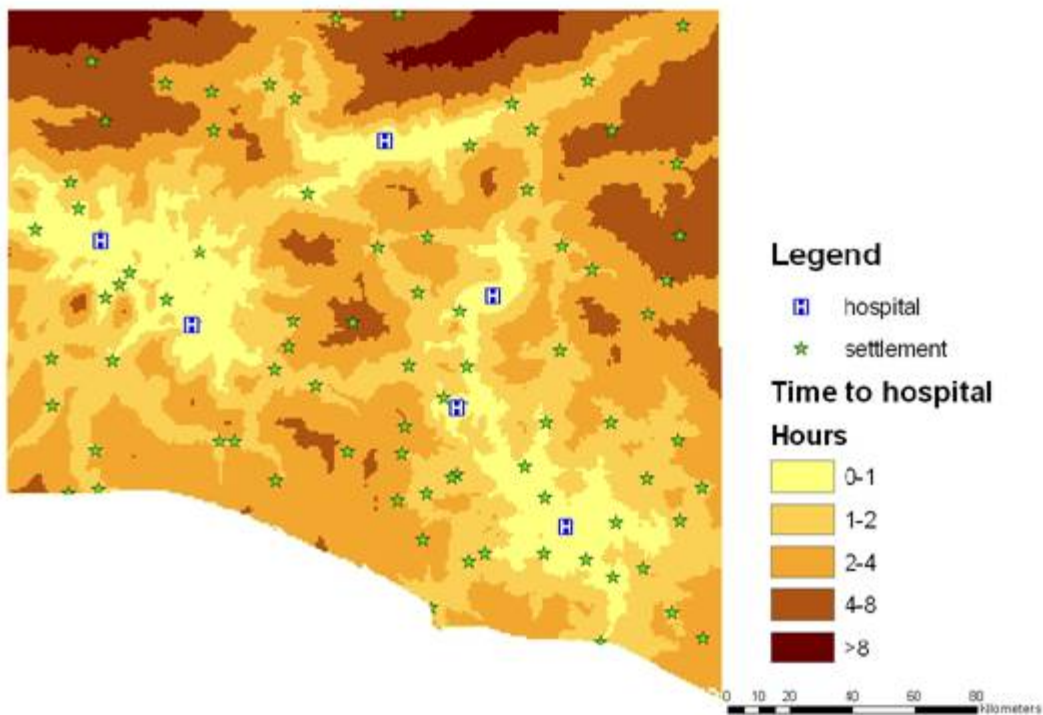


Figure 11 Hospitals have a different distribution to schools and so the accessibility map is different, although still heavily influenced by the road network.

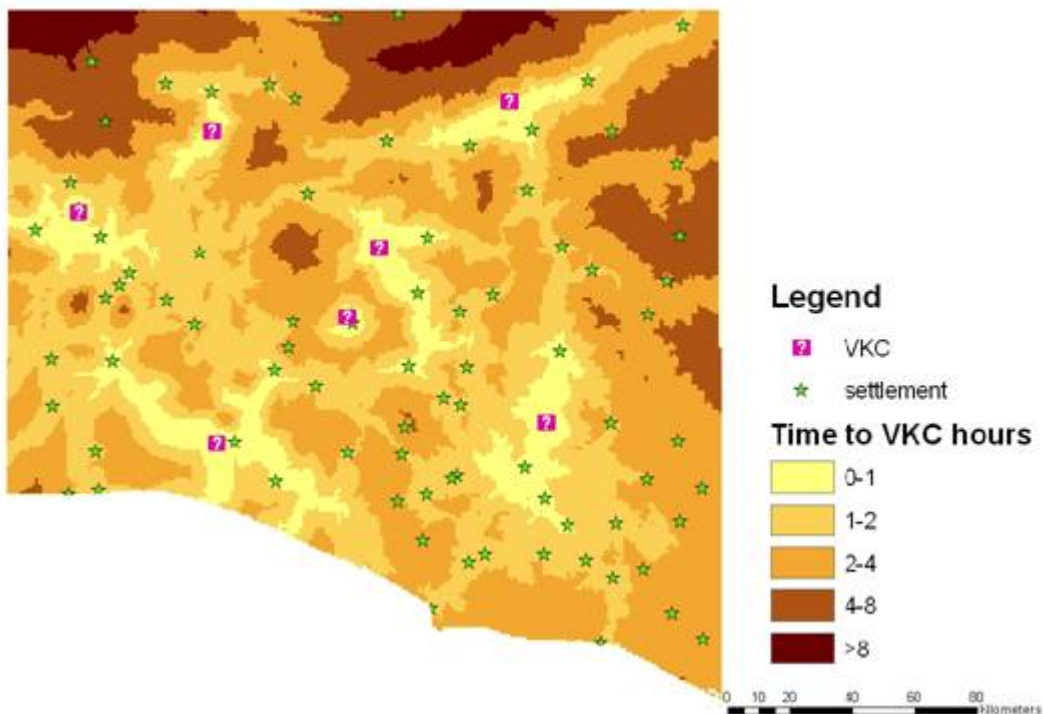


Figure 12 Accessibility to village knowledge centres (VKC)

Identifying deprivation

These three examples show that it is possible to map out areas of good and bad access to specific targets, with an indication of the travel times involved in reaching them. It is also possible to combine any number of such maps to get an overview of the general quality of access to all services, which will give a good indication of general service provision or deprivation in different locations. This can be done either by simple aggregation of the maps, or by using a weighted overlay function where some services, say hospitals, are deemed more important than others.

Simple aggregation to determine relative quality of access

In the first case, the travel time maps are all reclassified to a common fixed interval ordinal range, as a summation of travel times to different services would be quite meaningless. In this case the total travel times are reclassified on a simple ordinal scale of 1-5, representing best to worst. The three maps are then averaged together to give a final output of average quality of access to all three services, ranging from best - worst (figure 13)

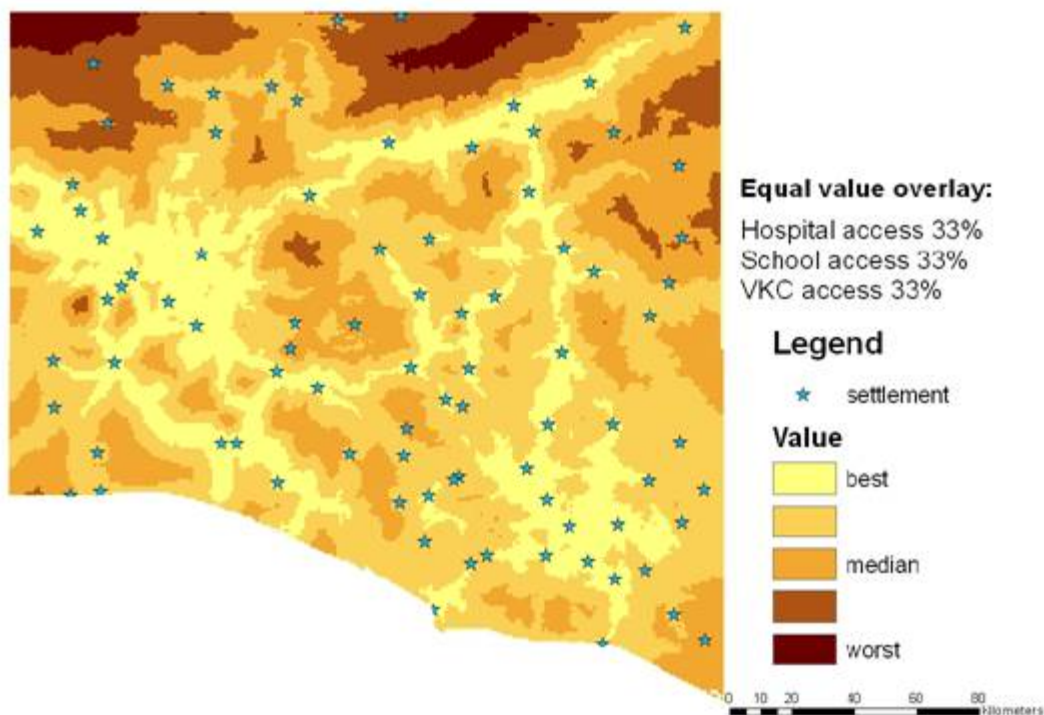


Figure 13 Aggregate service map showing the average quality of access to three different services

Weighted aggregation of maps

It may be the case that some services are considered of more importance than others. Access to hospitals is important to all members of society, whilst access to schools is only important to one portion. It is possible to aggregate the classified maps using a weighted overlay algorithm where each map is given an express weighting to specify its importance. Two examples are given here, first where hospitals are deemed most important (figure 14 overleaf) and secondly where schools are given priority (figure 15 overleaf). These are subjective determinations and must be treated with great caution.

These maps show differences, but the general distribution of access quality does not vary greatly between them. This means that in this case study, the distributions are not too sensitive to variations in these subjective choices. This would indicate that the model, whilst very simple, is also quite robust and so could be a useful tool for decision making.

Scenario modelling

Accessibility maps can be used in a number of ways as aids to development decision making.

- They can be used simply as a means of identifying areas of deprivation, as shown above.
- They can be used in "What if" scenario modelling, where new service targets are added, the model rerun and the resultant changed accessibility maps evaluated.
- They can be used in "exploratory scenarios" where a deemed ideal distribution of accessibility is defined, independent of the model, and then new service targets added to the model in an attempt to produce an approximation of this ideal distribution.

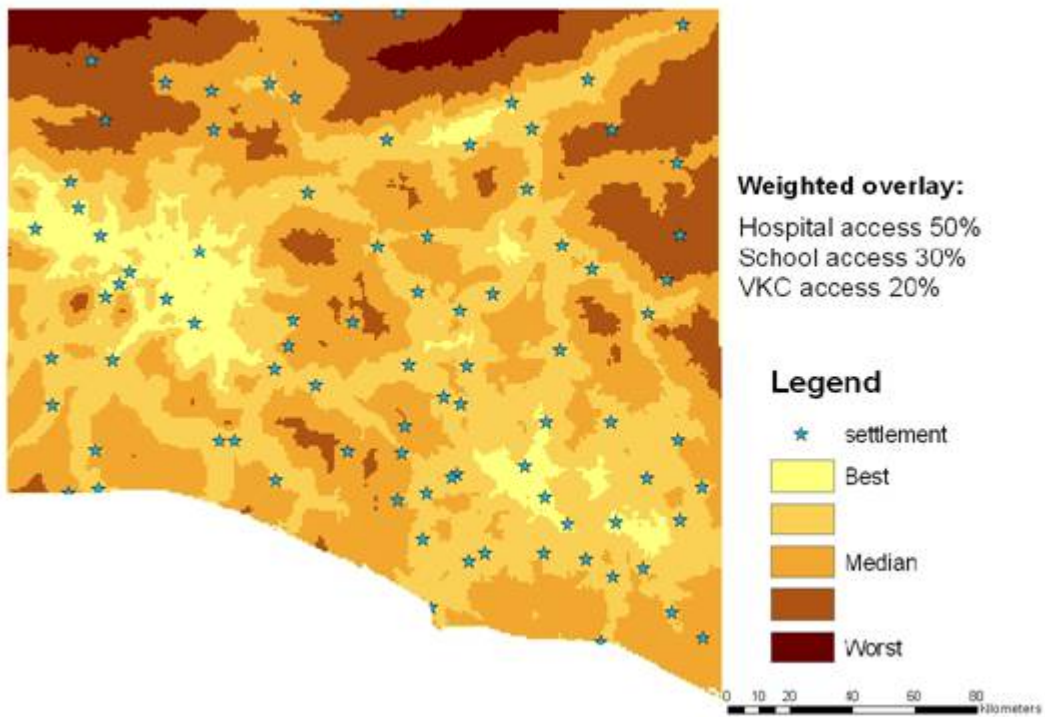


Figure 14 Weighted aggregation: Hospitals 50%, Schools 30%, VKC 20%

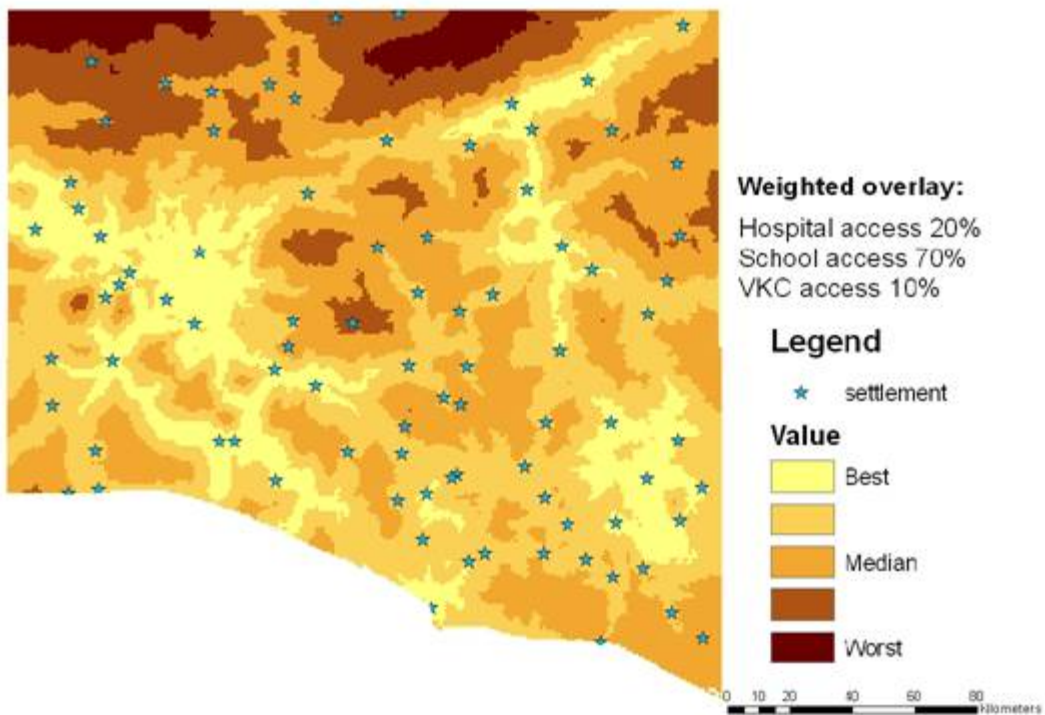


Figure 15 Weighted aggregation, Hospitals 20%, Schools 70%, VKC 10%

Accuracy of the accessibility model

As in all spatial modelling, the quality and accuracy of both inputs and outputs must always be borne in mind. These physical attributes are further qualified by the subjective content of the model, such as speed of travel, impact of slope, permeability of barriers and so on. Accessibility maps can only be indicative at best, and will not give accurate numeric results. However, in rural locations with relatively restricted transportation systems, they can give a very good indication of areas of temporal remoteness which can inform development decision making processes.

A further important limitation of the model comes from the edge effect of the map. Any targets outside of the model area will have no influence on the model at all, but may be very important services in reality. In the examples shown, the northern areas generally have the worst accessibility. However, if there was a school just north of the edge of the *map*, this could mean that service provision in this area was in reality quite good (figure 16). Edge effects should be minimised by taking the model right up to real natural boundaries, such as the sea coast or possibly national borders, or well beyond the extent of the study area, so that it is not unduly influenced by the map edge effect. Values anywhere near the edges must be treated with caution and tested against local knowledge of the area.

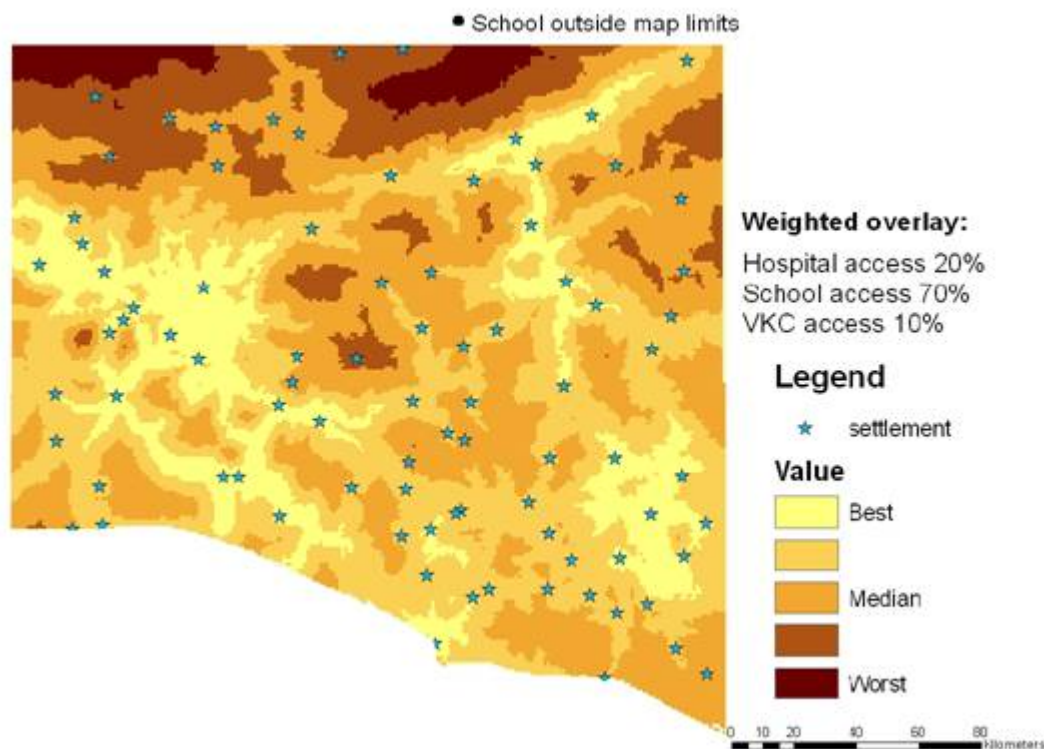


Figure 16 A school just north of the map boundary does not influence the access model, but will in reality be an important local service

Conclusion

The most important component of the accessibility map model is the travel time cost surface. Once created, this can be quickly used to model any number of accessibility scenarios. The ease of this process means it must be used with care and circumspection. Where it is easy to create maps, it is also easy to create maps which show any desired outcome, however unrealistic it may be. This "looking for patterns" approach can be very tempting and is often deceptive. It is far better to make decisions about location of services based on knowledge of the landscape and populations within it and then to model the results of those decisions to see their impact, rather than to play with the model with the hope that a good decision will happily drop out of it.

References

CIAT (2006) *Accessibility Analyst* <http://www.ciat.cgiar.org/access/> (accessed Mar 15, 2006) The data used in this case study was taken from this CIAT website which is gratefully acknowledged.

The examples given in this paper were modelled in *ArcGIS 9.1 Spatial Analyst* which has a full cost distance mapping toolkit.