A GIS tool for the digitisation and visualisation of footpath hazards

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1. Introduction

GIS has gained rapid currency in recent years with outdoor leisure users, who can use packages such as Anquet Maps (www.anquet.co.uk) or Memory Map (www.memory-map.co.uk) to aid planning and visualisation of hiking or cycling routes. Such is the affordability and user-friendliness of today's leisure GIS software that sophisticated tools such as 3D photorealistic fly-throughs, previously confined to expensive commercial GIS, are placed within the grasp of users armed with little more than a home PC and £80 to spare.

Yet for all that these packages empower users with hitherto inaccessible digital geographical data and processing techniques, thereby enabling them to 'get a feel' for a route from the comfort of home, there remains a paucity of information to describe a route's potential hazards. Hazard data, which might include information on uneven terrain, steep slopes or water hazards, would be of great value to recreational walkers, as well as to professionals charged with looking after others in the outdoors (e.g. mountain leaders and school teachers). That such data is not readily available in the current crop of outdoor leisure GIS is remiss, and forms the key deficit that this work seeks to redress.

The aim of this work is to develop a prototype system for storing and visualising footpath hazards within a GIS. The next section briefly identifies the types of hazards that might exist along footpaths, and proposes a method for their digitisation. Section 3 considers how best to visualise hazard data, and presents an algorithm designed to generate hazard density maps at a range of spatial scales. Section 4 concludes by suggesting that the visualisation techniques developed here could be equally well applied to a wide range of other problems.

2. Hazard identification and digitisation

A typical risk assessment for a section of footpath would identify a range of different hazards, which are defined as 'things that have the potential to cause harm'. Hazards can be split into three broad categories (after Long, 2005): 'landscape hazards', such as wet rock or boulder fields; 'timing hazards', such as bad weather or nightfall; and 'people hazards', which include navigational errors or poor decision making. Of these three categories, landscape hazards are the most amenable to storage in a GIS because they can be ascribed real world coordinates; timing and people hazards, by contrast, exhibit strong social and spatio-temporal variation, and so are less well suited to digitisation within a geographic database.

2.1 Footpath hazard examples

The following landscape hazards, illustrated in figure 1, were identified during a risk assessment of the footpath that traverses the Lairig Ghru, a mountain pass in the heart of the Cairngorms National Park, Scotland (see figure 4 below). These hazards were chosen for two reasons: either they increase the risk of a fall resulting in injury (climbing over boulders, for example); or they increase the severity of the consequences of a slip or stumble (compare the consequences of tripping on a flat path against those of tumbling off an exposed drop). It is important to acknowledge that the hazards featured in this project were identified *subjectively*, so that different users' hazard assessments may differ considerably. Furthermore, the ambient conditions during which risk assessment takes place may strongly influence results: consider how a thin layer of ice can render a benign (under summer conditions) footpath far more hazardous.

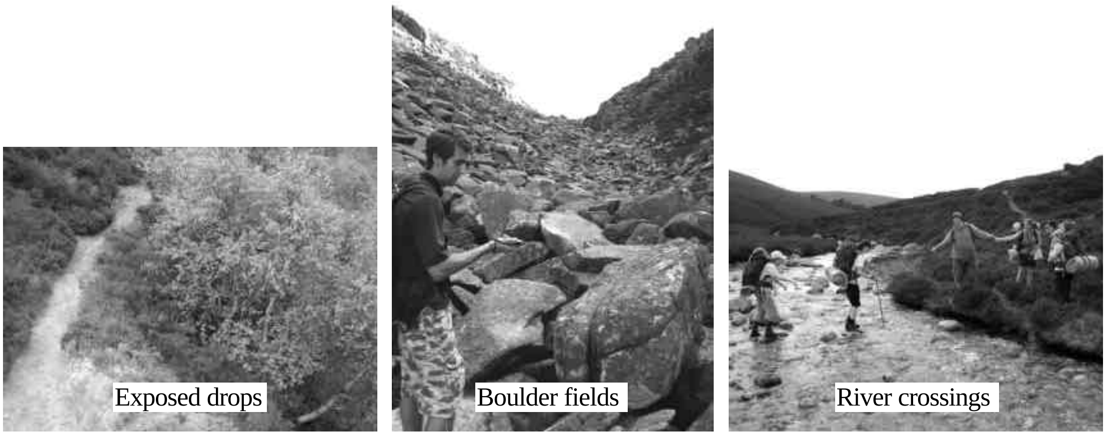

Figure 1. Examples of footpath hazards identified in the Cairngorms during fieldwork.

2.2 Footpath hazard digitisation

Having identified which hazards to record, a formal specification of how to digitally represent them is required. The proposed system, which uses only waypoints from handheld GPS devices, is intended to be as user-friendly as possible, with the ultimate aim that members of the public could contribute to a shared database of footpath hazards. The system comprises two different scenarios, which are presented below:

2.2.1 Short hazards

If the hazard (exposed drop, boulder field or stream crossing) is less than 15 m in length, it should be recorded by a single GPS waypoint, as per figure 2:

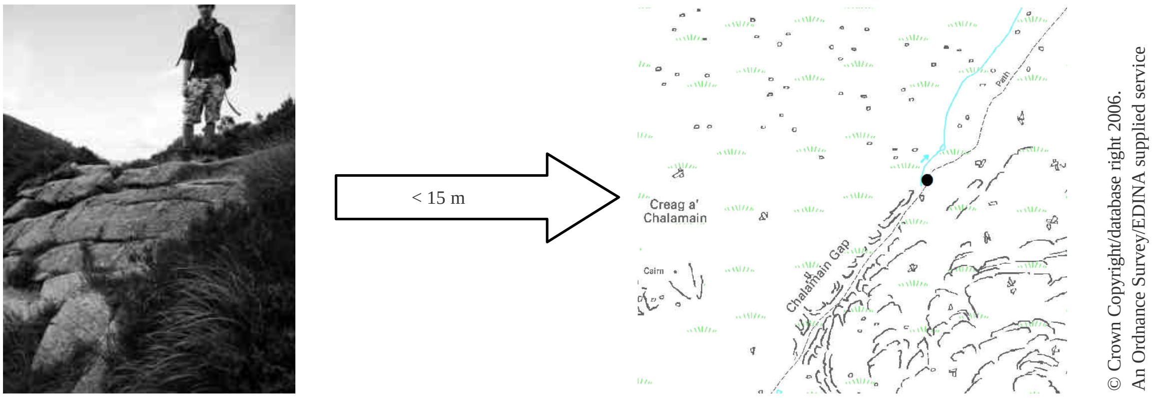

Figure 2. Procedure for presenting hazards less than 15 m long.

2.2.1 Long hazards

If the hazard exceeds 15 m in length, then GPS waypoints should be recorded along the length of the hazard, taken at 15 m intervals, as per figure 3:

Figure 3. Procedure for presenting hazards greater than 15 m long.

2.3 Data Collection

Although longer hazards would be more logically represented in a GIS using one-dimensional lines, most handheld GPS units do not allow the storage of line features with start and end nodes. It is much simpler to generate a point dataset comprised of GPS waypoints. This method of data acquisition was trialled in the Cairngorms National Park during a three day camping expedition in July 2006. The surveyed paths, which total 14 km in length, are indicated on figure 4. GPS waypoints were recorded using a Garmin eTrex Summit, and were subsequently converted to a text file of *x* and *y* coordinates using Garmin's MapSource software. The next section describes how the waypoints were visualised.

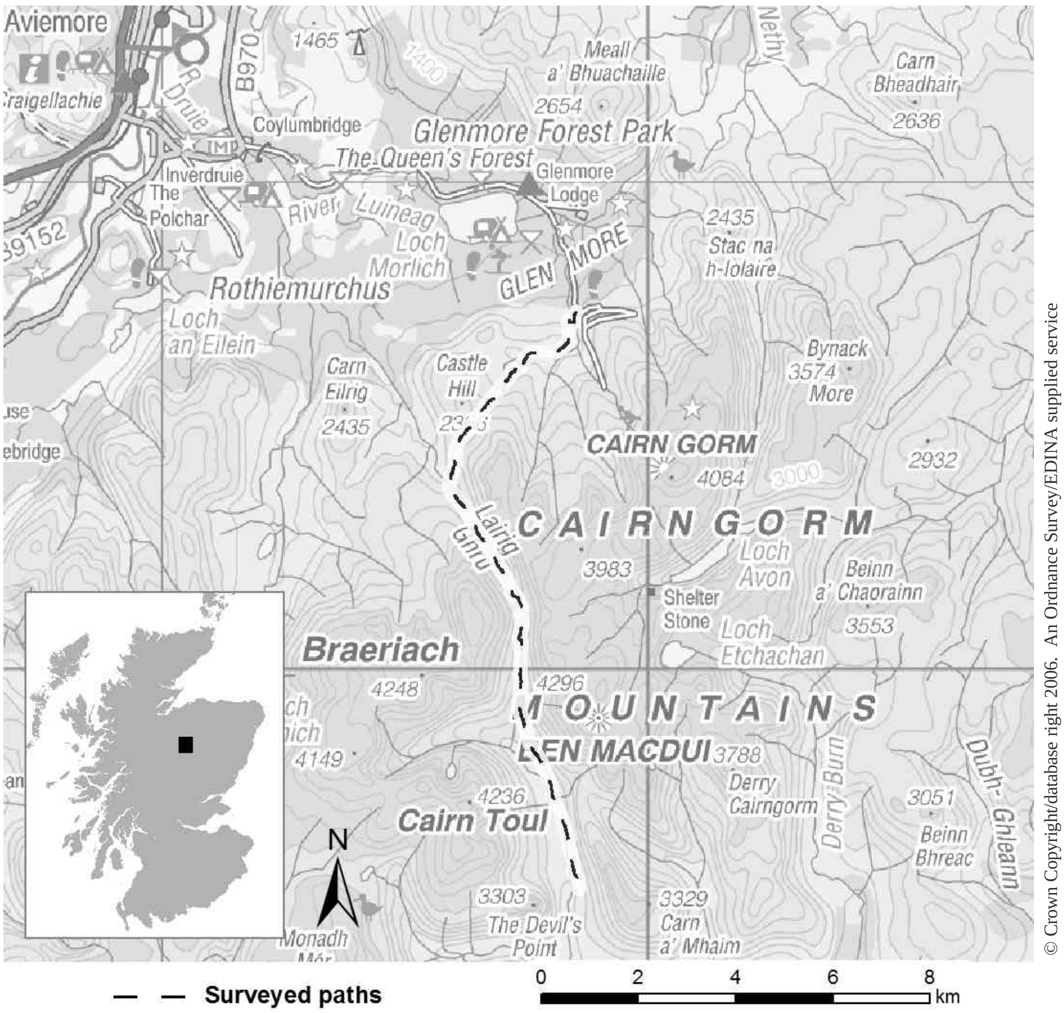

Figure 4. Study area map, showing location of paths surveyed during fieldwork trial.

3. Data visualisation

Recall that the overall aim of this work is to devise a means by which footpath hazard data can be stored in a GIS in order to better inform walkers. This aim is premised upon developing an effective method of cartographic visualisation that would show, at a glance, the relative distribution of hazards in an area. The ability to visualise hazard data at a range of spatial scales would also be advantageous, since expedition planning requires knowledge of a route's overall hazard distribution (small cartographic scale – 1:100,000) as well as locations of individual hazards (large scale – 1:10,000).

A prototype application, which can produce hazard maps at a range of spatial scales, was developed in ArcGIS using Visual Basic for Applications and ArcObjects. The application employs kernel density estimation (KDE) to create a continuous field to represent the density of GPS hazard waypoints (Silverman, 1986). The search radius of ArcGIS 9.1's quadratic distance-weighted kernel function, known as the kernel bandwidth, can be adjusted. This adjustment is the key to tailoring hazard map content in response to changes in viewing scale: increasing kernel bandwidth leads to smoothly varying output rasters, which are better suited to small viewing scales; decreasing bandwidth produces more localised surface patterns, which are best viewed at a large scale (O'Sullivan and Unwin, 2003).

3.1 Map generation

The three stages of hazard map generation are shown below in figure 5. First, hazard waypoints are downloaded from the GPS unit and snapped to footpath vectors. Second, a kernel density surface is created from the GPS waypoints. Third, the original footpath vectors are intersected with the kernel density surface to create a line whose colour is proportional to the incidence of hazards at each location.

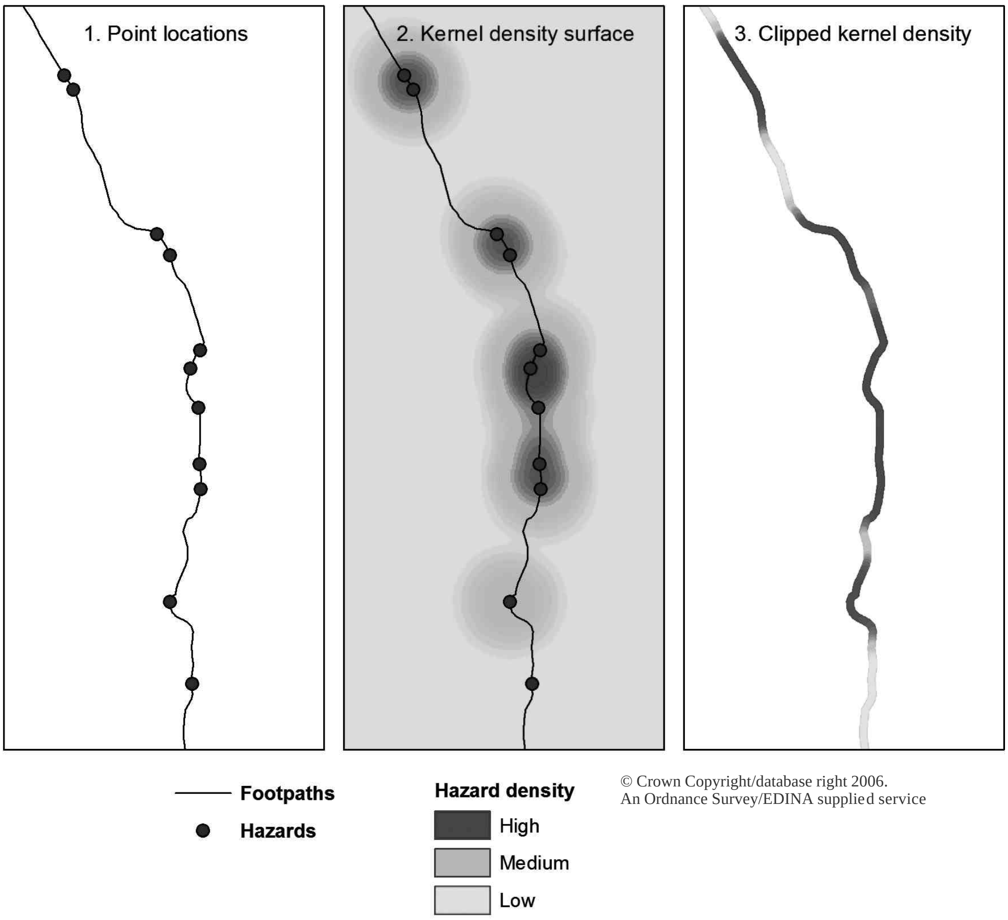

Figure 5. Three stages of hazard map generation, automated by ArcObjects code.

3.2 Altering cartographic scale

By varying the kernel bandwidth (in inverse proportion to the denominator of the map scale, returned by ArcObject's *MapScale* property of the *IMap* interface) it is possible to produce a visualisation appropriate to the scale at which it is viewed. Changing maps' content on the fly to suit their scale, known as automated generalisation (McMaster and Shea, 1992), has long been pursued by geographers. Indeed, for many it is something of a Holy Grail (João, 1998). To be effective, changes between scales must be smooth and progressive, rather than the "quantum leap" steps that result when moving between different map types (Jones and Ware, 2005:859).

Figure 6 presents two maps at different scales (an extent box shows which portion of map 1 (left) is zoomed in on in map 2 (right)). Map 1, which shows the whole study area, uses a coarse kernel bandwidth (600 m). If the same bandwidth were used on map 2 then results would not show any localised detail. Instead, because the cartographic scale of map 2 is increased, a smaller bandwidth is used (50 m). This shows local variation much more effectively. Altering the kernel bandwidth in response to changes in cartographic scale allows users to drill down from small scale overview to large scale detail, without experiencing problems of pixelation (going from small to large scale) or map cluttering (from large scale to small scale). This is of great potential use to a leader, for example, who might initially examine a footpath from a small scale to get an overview of where hazardous sections are located, before zooming in to locate individual hazards more precisely.

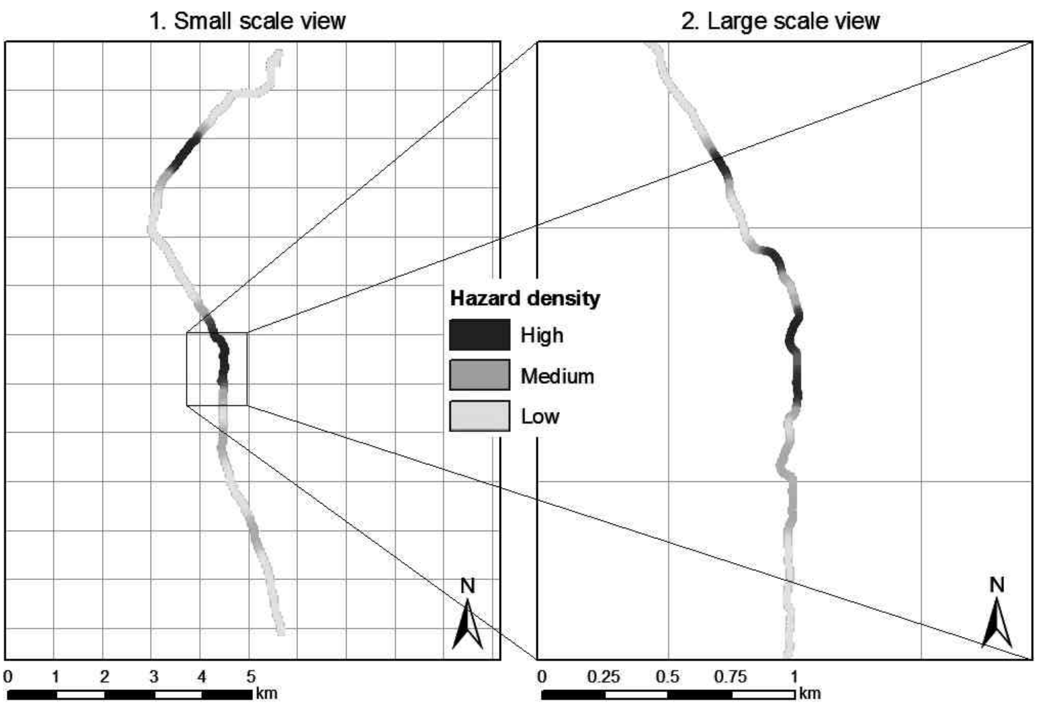

Figure 6. Adjusting kernel bandwidth in response to changes in viewing scale

4. Conclusions

The work presented here offers a robust solution to visualising the number of footpath hazards along a hillwalking route, at a wide range of cartographic scales. The custom ArcGIS tool can in fact be applied to any scenario where the density of point data along a line feature needs to be viewed at different scales. Examples that spring to mind include visualising frequency of accidents along a road network, monitoring the number of wildlife sightings along a stretch of river, or assessing density of point source pollution along a coastline.

As the tool is designed to process simple text files of GPS waypoints, it is possible, in theory, for members of the public to contribute hazard data: any walker equipped with a GPS device could log the locations of prominent hazards, which could then be shared with other users. Over time, a comprehensive hazard database of a region's entire footpath network could be built up.

Future work will be focused towards developing more objective criteria for hazard reconnaissance in the field, and improving the system's ability to cope with temporal hazard data (e.g. increased risks of falling during icy conditions, or at night). A final research challenge concerns how to integrate the hazard density maps with Anquet Maps and Memory Map.

5. References

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