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Using geographic and cartographic principles for environmental assessment and risk mapping

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Abstract

The National Institute of Public Health and the Environment (RIVM) is a research institute that provides the Dutch government with information for policy making on environment and public health. Policy support requires special care in choosing the right model, since the policy question or policy problem should been addressed by exactly the right answer. From the scientific point of view the answer has to be both scientifically correct and suitable to policy considerations. The translation of scientific model results to a political decision maker taking considerations in all the stages of spatial modelling: the input of the data, the algorithm modelling and the post-processing models. The output of a model is often conveyed in a map. Maps have strong visual impact and wrong use of some cartographic techniques can lead to wrong interpretations of the message to be conveyed. To realize the potential and impact of maps, it is useful to learn some basic principles of cartographic communication and map design. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Cartography; Spatial modelling; GIS; Risk mapping

1. Introduction

The National Institute of Public Health and the Environment (RIVM) is a research institute that provides the Dutch government with information for policy making on environment and public health. Policy support requires special care in choosing the right model, since the policy question or policy problem should been addressed by exactly the right answer. From the scientific point of view the answer has to be both scientifically correct and suitable to policy considerations [1]. It should be remembered, however, that a political decision is certainly not carried by scientific arguments alone.

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RIVM's environmental surveys are prepared and published every year, e.g. Ref. [2] and there are more and more maps included to visualize spatial information. The introduction of GIS-software at RIVM at the end of the 80s brought easy mapmaking to a wide group of researchers. Anyone who can use GIS and other mapmaking programs, can visualize spatial data. The main departure in map production at RIVM is that each researcher, whether geographically or cartographically trained or not, should be able to produce an acceptable map.

This article deals with modelling considerations for translating scientific model results to a political decision maker. As the output of a model is often conveyed in a map, the paper contains some essential principles of cartography and map design for environmental research. Examples are given of cartographic misinterpretations, which can lead to wrong interpretations of the message.

2. Modelling considerations

2.1. Modelling for policy support

It is usually not too difficult to establish the indicators needed for political decision support. A conceptual model can be derived for those indicators, incorporating a state description, behaviour and evaluation [3]. RIVM's policy supporting maps often contain environmental risk [2], therefore, we here focus on spatial models.

Just as important is the matter how to translate scientific model results to a political decision maker. One of the key elements is to condense information to a sufficiently simple form, to allow a political decision maker fast and easy evaluation [4,5]. Transformations may include aggregations of model results and indicators of value or pattern for large zones or perhaps entire maps. Such transformations need to be used carefully due to steps and considerations contained in three stages of this type of modelling (see Fig. 1):

- the input of data: what do the data represent;
- the algorithm: what behaviour and sensitivity does the model contain;
- the post-processing: what information is retained and what is lost?

This section will briefly discuss each of these three stages.

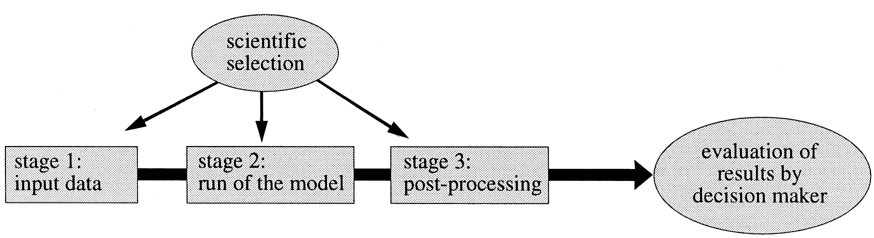

Fig. 1. Stages in policy supporting modelling.

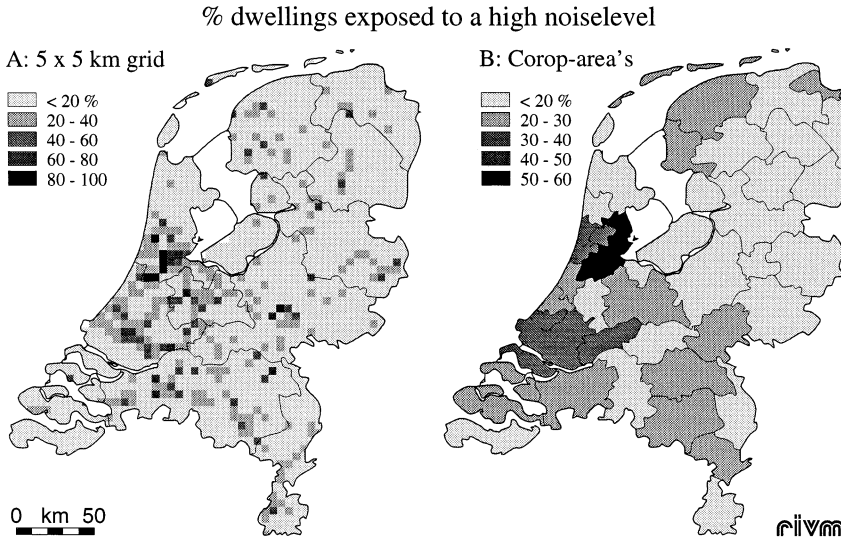

Fig. 2. Impact of areal units on mapping noise pollution in the Netherlands, map A: 5×5 km grids, map B: COROP-areas.

2.2. Data modelling: input

A model can be said to be composed of algorithms and data, so it is crucial to find a perfect match between algorithm and data resolution and content. This is not always as easy as it may seem, since not everything is observed by monitoring networks. Practice in the environmental domain shows that data are used, even when it is perhaps not optimally suited for the model [6].

The most recurring problems with spatial input data are:
1. the areal unit does not fit the problem very well;
2. the value of the areal unit is assumed too homogeneous;
3. the value represents a non-essential feature for the areal unit.

2.2.1. Areal unit

Objects in maps are often bounded by some line. This means that the size and shape of objects are set. Let us assume some dynamic model to assess local problems, like noise. The phenomenon itself spreads over relatively short ranges, within a hundred meters rather than a kilometer. In Fig. 2 an example is shown for dwellings in the Netherlands exposed to a high noiselevel [1]. Map A shows the percentage of dwellings exposed to a high noiselevel per 5 km square grids. The dark grids at the west can be

[1] The exact description of what is meant by a high noiselevel is not important for the examples used in this article. What we like to show is the impact of areal unit and some cartographic principles, the data behind the maps are of no importance. Further information on the research of noise pollution can be found in the work of Miedema [7,8].

explained by the positioning of Schiphol, the national airport. When data are aggregated to, e.g. COROP-units [2] for the benefit of a decision maker, the area is simply too large for accurate assessment and the pattern is different, too. In map B, the impact of the national airport, Schiphol, is spread out over a large region; that the large dark zone, however, is not necessarily valid for all individuals living in that area.

It is impossible to tell whether an areal unit is exactly appropriate for the process presented in the map. There may be several choices and areal units may be modified (as is done in Fig. 2). The resulting pattern may be different, but mean value or spatial structure maybe the same. This modifiable areal unit problem [9] cannot be solved, but can be analyzed.

A further consideration about regions is that some static models are basically one-dimensional, describing a point in space. In most cases regionalization (up-scaling to regional zones) is simply not valid [10].

2.2.2. Single value

Areal unit boundaries are lines, which are often absent in reality. Examples are administrative boundaries, grid cell bounds, but even soil map unit boundaries. A single value for such an area has limited meaning. The municipal fertilizer use is a sensible statistic for fertilizer application per municipality, but it prohibits computation of local fertilizer use, e.g. for individual agricultural fields. The same goes for soil map units.

It can be demonstrated that large variations can occur within a single unit [11] and that variations occur in the gradients which are naturally present at boundaries [12]. These variations are partly due to natural variations: soil is heterogeneous and not all of it is captured in the map. This obviously depends on the original purpose of that map. It may also depend on uncertainties: a single map unit may contain other soil type inclusions, which are ‘unknown’. The variations can be estimated, but at some costs [13]. This fact, of values too homogeneous, goes for many types of data in maps.

2.2.3. Value type

Given the example above about soil units, it may very well be the inappropriate attribute for further modelling. Consider the policy issue of allowing a pesticide, by assessing possible risk. It is important to know any risk spot, regardless of areal unit size or shape. This is known as the worst case approach. If a pesticide leaching model largely depends on organic matter, the worst case approach demands the smallest amount of organic matter anywhere in a zone of interest. However, the map provides only some mean value for that area. The worst case situation can therefore not be assessed directly [14].

2.3. Algorithm modelling

In the case of modelling for policy, the actual indicators needed by the political decision maker may differ from the ones the scientist might want to use. Let us assume that in the preliminary stage detailed, scientific indicators are used.

[2] COROP-units are used for statistical grouping by the Dutch Central Bureau for Statistics (CBS).

The indicators are conceptualized as objects, referring to some state of part of the environment, either in present or in future. Relations between those objects are usually dynamic, but can be modelled in discrete time steps, rendering the individual time step interactions virtually static. This may influence the choice of areal unit input: the more dynamic a model is, the less freedom one has in choosing sizes and shapes for those units [1].

Noteworthy is the dependence of modelling on input data and their aggregation level. Similar to the discussion about too simple values for areal units, the model intricacies can be too much for the data available. Much data have been gathered for specific purposes and have been compiled for a specific presentation. The compilation may very well involve simplifications as with post-processing, thus conflicting with the model's original intention.

2.4. Post-processing models

The scientific modelling results have to be used in a political decision and evaluation process. Post-processing involves simplification and aggregation of results, should allow (or contain) comparisons and correlation's and may involve (multi-criteria) evaluation [4]. van Beurden and Douven [14] exemplify three crucial elements in this post-processing: the type of aggregation, order of activities and cartographic principles. The first two are briefly discussed below, the third element, the cartographic principles, is discussed in Section 3.

The aggregation type should be chosen carefully. Many automated systems allow only a limited set of aggregations, like means or extreme values. On logarithmic or exponential scales, aggregations should be modified.

In many environmental modelling cases aggregations are made of input data (or the input data have already been aggregated) before the model is 'run'. The argument is often computer speed. On the other hand, models are also run on detailed data and results are aggregated later. It is easily demonstrated that results differ in those two approaches, especially when models are dynamic or when values are exponential or logarithmic [14]. However, the latter approach is generally more consistent with the intentions for policy support.

3. Cartographic principles and examples of cartographic misinterpretations

Cartography is a form of communication and can be seen as a form of spatial language for describing locations, discussing places and interpreting two-dimensional arrangements of features [15]. Even bad maps communicate and the question of what a good map is, according to cartographic conventions, is to ask how well it communicates with its users [16]. Important in all fields of mapmaking, is to consider the *message* to be conveyed and the *users* to be reached. To improve the clarity of a map, always answer the following questions first:

1. what is the goal of the map?

2. who will read the map?
3. where will the map be used?

The most important reason to include maps in environmental reports like the National Environmental Outlook is the strong visual impacts maps have. Muehrcke and Muehrcke [17] mention that maps are widely thought to create a more direct, dramatic and lasting impression of the environment than is possible to obtain by other means. To realize the potential and impact of maps, it is useful to learn some basic principles of cartographic communication and map design. As a special type of communication, it does require training. As cartographic rules should be strictly followed, it is necessary to guide researchers with cartographic directions for use.

The basic elements of making a map that fits the message are:

1. the symbology chosen;
2. classes and class boundaries;
3. use of colours;
4. scale and projection;
5. basic map features (e.g. legend, scalebar, title etc.).

The first three elements are also crucial for risk mapping and misuse can easily lead to misinterpretation of the map. These three elements are briefly discussed below. Further information on scale, projection and basic elements can be found in the work of Monmonnier [15].

3.1. Map symbology

Cartographers reduce the world to points, lines and areas. Each of these cartographic elements can be mapped in different ways. Bertin [18] introduced in his book, The Semiology of Graphics, the six visual variables: size, shape, greytone value, texture, orientation and hue (colour differences). Choosing the right symbolization depends on the nature of the phenomena being mapped and on the goal of the map, e.g. shape, texture and hue are effective in showing qualitative differences. For quantitative differences (like amount or magnitude) size is more suited and greytone value is preferred for portraying differences in rate or intensity. Some symbols combine two or more visual variables [19]. In the work of Bartels et al. [20], descriptions and examples are given how each of these visual variables excels in portraying just one kind of geographic difference. The examples in this work show that a poor match between the data and the visual variable can lead to wrong interpretations of the message to be propagated.

3.2. Classes and classbreaks

Most of the maps in RIVM reports are choropleth maps. Choropleth maps portray spatial patterns for regions composed of areal units such as physical–geographical areas, ecological areas but also point data that are aggregated, e.g. by interpolation methods to equal-areal units such as square grids. According to the graphical theory by Bertin [18], a choropleth map is drawn in a number of greyscale values, on a scale from light to dark, representing categories for an intensity. The breaks between the categories can

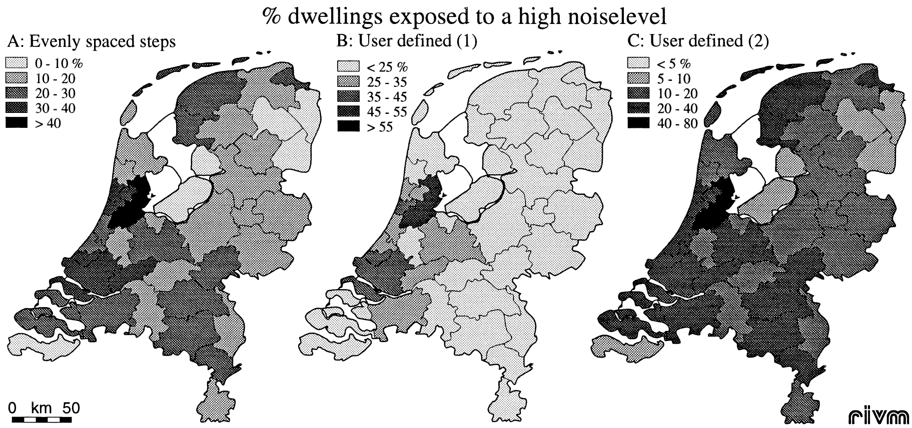

Fig. 3. Comparison of maps using different ranging methods.

have a great influence on the mapped pattern. To understand the importance of classification, it is useful to test the effects of different sets of class breaks from the same dataset.

First the *number of ranges* can influence the interpretation. If too few classes are used, the map may obscure the contour of the data distribution. Too many classes can make it difficult for the mapreader to distinguish among the classes.

Second, and more important for map interpretation, is the *ranging method*. Different classbreaks can lead to radically different interpretations and different spatial patterns. The three maps in Fig. 3, for examples, offer different impressions of the spatial pattern of the dwellings exposed to a high noiselevel in the Netherlands [7,8]. All maps have five classes, portrayed with a graded sequence of greytone area symbols that imply from 'low' to 'high' rates of noise pollution. Map A portrays a balanced distribution, based on evenly spaced steps. This is the most common classification, although the mapmaker has to check whether this distribution conveys the message correctly. Without analyzing the legend, map B gives the impression that there is no heavy noise pollution in the Netherlands. By choosing another classification, see map C, the message is contrary: there seems to be serious noise pollution in the Netherlands. The middle and right maps have both user defined ranges.

The maps in Fig. 3 were developed from exactly the same dataset, but they convey quite different spatial patterns. It shows that a single choropleth map presents only one of many possible views of a geographic variable. The first step in preparing a choropleth map is therefore to explore the dataset and choosing a suitable classification.

3.3. Use of colours

As mentioned before, maps need contrasting symbols to portray geographic differences. Choosing the wrong visual variable can confuse the map user. Among the worst 'offenders' are mapmakers who choose the brilliant rainbow colours of computer

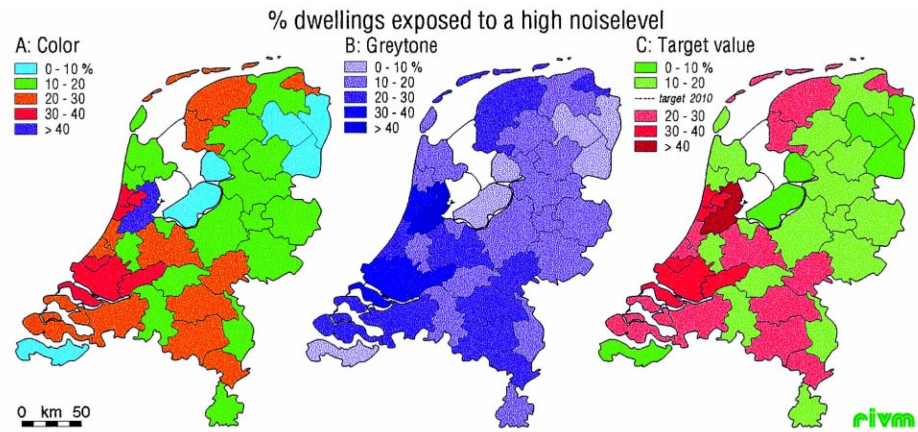

Fig. 4. Comparison of maps using different visual variables and introducing a target value.

graphic systems and using red, blue, green, purple and yellow to portray quantitative differences. In Fig. 4, again the dwellings exposed to a high noiselevel are shown. In map A the visual variable colour (hue) is used to portray the spatial differences. Without analyzing the legend, it is impossible to identify the ‘low’ and ‘high’ areas with heavy noise pollution. According to Bertin’s theory [18] colour is suitable for mapping qualitative differences only. Differences in colour usually fail to portray differences in intensity measures, because spectral hues have no logical ordering in the mind’s eye [7,8], although there are exceptions to this. Map B shows the same data and using the visual variable greytone. Now, in one eye-catch, the mapreader has an impression of the spatial pattern. Even without reading the legend, you can see where the noise pollution is low (light) and high (dark). Imagine, for example, the target value for heavy noise pollution will be set on 20% of the dwellings in the year 2010. In the Environmental Outlook, for example, it has to be clear where the target will be reached and where not. To convey this message the visual variables colour and greytone are combined in map C.

The colours green and red in Fig. 4c are not chosen coincidentally. In western civilization green is associated to ‘save’ or ‘good’, while red is more seen as ‘danger’ or ‘bad’ (think of a traffic light). For a good selection of colour, some basic knowledge of colour characteristics is necessary, because graphic logic, visual perception and even cultural preferences affect the use of colour on maps [19].

4. Conclusions

Based on the examples presented in this paper and the ones known at RIVM, we conclude with the following remarks and recommendations.

- More consideration is needed for input data and matching the data to the model. It is crucial to find a perfect match between algorithm and data resolution and content, because this is of great importance on the output of the model.

- Very special care should be paid to the areal unit, the data content for those units and to aggregation. Policy support requires special care in all stages of modelling.
- GIS-operators and geographers should act as intermediate between data brokers, modellers and policy makers. GIS-users without geographic or cartographic knowledge should be made aware of the relevant design issues and selection criteria that will allow them to produce appropriate cartographic output.
- The first step in preparing a map is to explore the dataset and choosing a suitable classification. The next step is to choose appropriate (but sufficient) colours or greyscale.
- In all fields of mapmaking, consider the *message* to be conveyed and also the *users* to be reached! Maps have a strong visual impact and misuse of the basic principles of cartographic communication can easily lead to wrong interpretations of the message to be conveyed.

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