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A procedure for deriving qualitative contaminant attenuation maps from land type data

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Abstract

A procedure is presented for deriving qualitative contaminant attenuation maps from available soils information. Unfortunately, in South Africa, no soil map with national coverage exists at a scale larger than 1:2 500 000. However, 1:250 000 land type maps, which depict areas of relatively uniform soil pattern, are available. The spatial distribution of each soil type within a land type is not mapped and thus the position of each unique soil type is not known. However, the percentage of land covered by each soil type is quantified. The approach adopted here was to use land type data to derive soil characteristic maps per land type. Using Geographic Information Systems, the soils characteristic maps were then combined with reported contaminant attenuation characteristics from the literature to obtain a qualitative indication of the attenuation potential of a group of contaminants in a given land type. For example, the average clay content map was used to generate the attenuation potential of cation forming contaminants. The higher the clay content, the higher the contaminant attenuation potential. For attenuating anion forming contaminants, sesquioxide content plays a primary role. In general, the higher the sesquioxide content, the higher the contaminant attenuation potential. Thus the iron content map was used to depict the attenuation potential for anion forming contaminants. These qualitative contaminant attenuation maps can be used for regional planning purposes. From the maps, areas with soils that have favourable attenuation properties for a given contaminant or group of contaminants can be identified. To pinpoint sites with the required properties, further detailed investigations of target areas would need to be undertaken. It is concluded that land type maps can be used in lieu of soil maps, to identify areas with favourable contaminant attenuation properties for more detailed investigation. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Soil maps; Contaminants; Attenuation; GIS

1. Introduction

South Africa has limited water resources that are unevenly distributed. Some areas are already experiencing water stress, and competition among various activities for use of water has become more intense, requiring better management of the resource. It is recognised that with increased human settlement and economic development, a range of undesirable waste products are generated, which often enter the environment. These waste products can cause pollution of groundwater resources, thereby increasing water scarcity. Once polluted, cleaning up of groundwater is difficult and expensive. Protection strategies should, therefore, be put in place to prevent contamination from occurring, with the primary focus on areas most vulnerable to pollution.

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Vulnerability assessments can be used to provide preliminary information and criteria for decision-making concerning management of water resources and land use as related to groundwater protection. In its broadest context, groundwater vulnerability refers to whether or not an underlying aquifer will be contaminated as a result of activities at the land surface (National Research Council, 1993). There are a number of approaches used to assess the vulnerability of groundwater to pollution (Barber et al., 1993; National Research Council, 1993; Vrba and Zaporozec, 1994). Most of these methods emphasise physical flow processes that affect transport of solutes in the subsurface. They do not directly address characteristics of contaminant attenuation. However, it is known that during infiltration through soils, many contaminants are naturally attenuated. An evaluation of the protective properties of soils is, therefore, one of the most important tasks for vulnerability assessments (Andersen and Gosk, 1987; Breeuwsma and van Duijvenbooden, 1987; Lemme et al., 1990).

In South Africa, the importance of soils information in vulnerability studies has been recognised. Although many ad hoc soil surveys producing maps at a range of scales have been undertaken for a variety of purposes, no soil map with national coverage exists at a scale larger than 1:2 500 000. However, land type maps, which depict units of land that have a uniform climate, terrain form and soil pattern, have been mapped for the whole country (Land type Survey Staff, 1987). These maps contain information that can be used to derive generalised soil characteristic maps per land type.

In this paper, we report on a methodology that was developed to derive soil characteristic maps from land type data (Sililo et al., 1999). These maps were then combined with contaminant attenuation characteristics in a Geographic Information Systems (GIS) framework to produce a qualitative indication of the attenuation potential of a given group of contaminants in a given land type.

2. Development of methodology

2.1. Land type maps

In South Africa, land type maps were designed to assist in assessing agricultural potential. The procedure followed in mapping land types was described by the Institute of Soil, Climate and Water (Land type Survey Staff, 1987) and is shown schematically in Fig. 1. The first step involved collecting and studying existing information and maps, including satellite imagery, relevant to the terrain, soils and climate of a given area. After an orientation excursion, areas called terrain types, each displaying a marked uniformity of terrain form, were delineated. The soils within each terrain type were then identified and areas known as pedosystems, each displaying uniform terrain and soil pattern, were delineated. The soil composition of a terrain type was described by detailing which soil series of the Binomial System (MacVicar et al., 1977) occur on each terrain unit and by giving an estimate of the area of each soil type on a given terrain unit. A separate map showing climate zones was then drawn. This was superimposed upon the pedosystem map to arrive at a map of land types. On completion of these steps, the land type boundaries were transferred from the 1:50 000 to the 1:250 000 maps. Finally, an inventory of each land type was compiled in terms of terrain, soil and climate parameters. An example of a land type map is shown in Fig. 2. The latter also depicts the area which was used here as an example for deriving contaminant attenuation potential maps from land type data.

2.2. Deriving soil characteristic maps from land type data

Of major interest to the assessment of contaminant attenuation potential is the soils information available

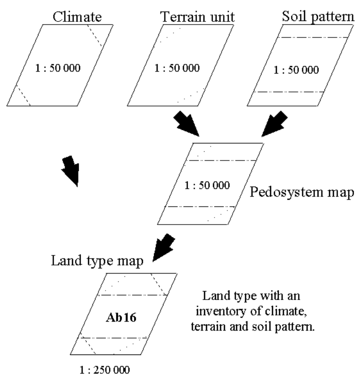

Fig. 1. Procedure followed in mapping land types.

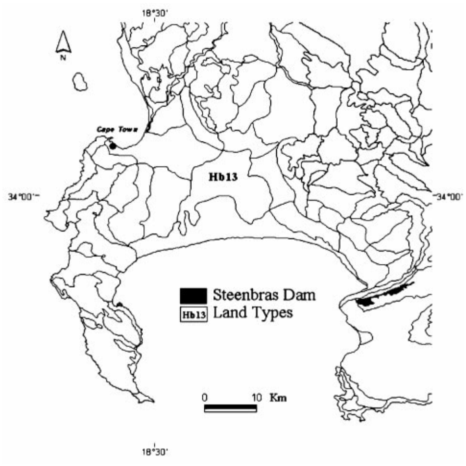

Fig. 2. An example of a land type map.

Table 2
An example of the soil series per land type. A^* — non-soil land classes (pans, streambeds and coarse deposits), R^+ — rock

Land type	Class				Soil series as a % of land type
	CEC	OM	Fe	Clay	
Ab16	1	1	2	1	19.30
Ab16	2	1	1	1	4.35
Ab16	2	1	1	2	8.51
Ab16	2	1	1	2	1.00
Ab16	2	1	2	2	2.35
Ab16	3	1	1	3	4.35
Ab16	3	1	2	3	3.95
Ab16	3	1	3	3	41.60
Ab16					5.15 A^*
Ab16					9.44 R^+

per land type. The spatial distribution of each soil type within a land type is not actually mapped and thus the position of each unique soil type is not known. However, the percentage of land covered by each soil type is estimated. For each soil type within each land type, the following soil property information, inter alia, is either given, or can be derived from modal profile analytical data: Cation Exchange Capacity (CEC); Organic Matter (OM); Fe (sesquioxides); and clay percentage. For each of these characteristics, the measured values were grouped into classes by the Institute of Soil, Climate and Water as shown in Table 1.

The first step in deriving soils information maps involved generating an attribute database for each land type. This was effected by assigning attribute values to each soil within a land type, according to the soil property classes as defined in Table 1. The percentages of soils with similar attributes were then added to obtain the percentage occurrence of each unique soil type within the land type as shown in Table 2. Pans, stream beds and coarse deposits are excluded and the percentage of such occurrences is denoted by *A*. Similarly, the occurrence of rock outcrops, denoted by *R*, was also excluded.

From Table 2, it can be seen that, for example, land type Ab16 contains eight different soil types and the areal percentages of these soil types per land type are also listed. However, the geographic position of the soil types within the land type unit is not known. To represent the soil characteristics spatially, area weighted averages were calculated. An example of the database file created for clay content per land type is shown in Table 3. Such database file and map coverages were generated for clay content per land type (Fig. 3) and iron content per land type (Fig. 4).

2.3. Qualitative contaminant attenuation maps

The soils information maps generated above were used to obtain a qualitative indication of the

Table 1
The class subdivisions of each land type parameter

CEC class	cmol (+)/kg	OM class	%C	Fe class	%	Clay class	%
1	0–2	1	0–2	1	0.0–0.5	1	0–6
2	2–4	2	2–10	2	0.5–2.5	2	6–15
3	4–8	3	> 10	3	> 2.5	3	15–35
4	> 8					4	35–55
						5	> 55

Table 3
Area weighed averages and ranges of clay content per land type

Land type	Area weighted average of clay class	Range of clay classes
Ab16	2.31	2
Ab18	2.49	3
Ab21	2.89	2
Ab22	2.51	3
Ab23	2.9	2
Ab24	2.9	2
Ab26	2.91	2
Ac15	2.6	1
Ac17	2.72	2

attenuation potential of cation and anion forming contaminants as described below.

2.3.1. Cation forming contaminants

For attenuating cation forming contaminants, clay content plays a primary role. Fuller (1978) found that clay-rich soils were very effective in attenuating these contaminants, while sandy soils were ineffective. Thus clay content can be used to obtain a qualitative indication of attenuation potential of cation forming contaminants. The higher the clay content, the higher the attenuation potential.

Three classes of contaminant attenuation potential were calculated according to the clay content classes

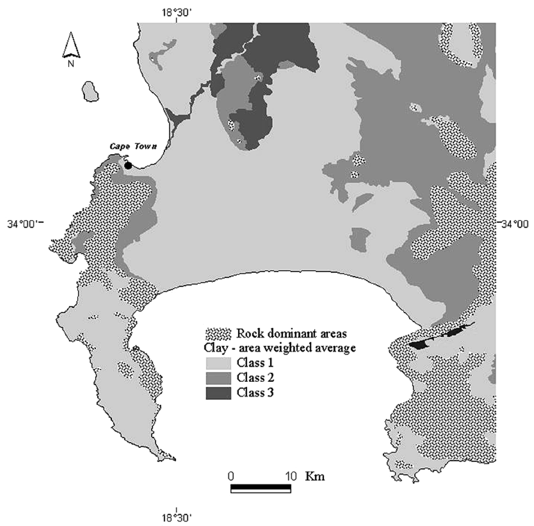

Fig. 3. A map showing average clay content per land type.

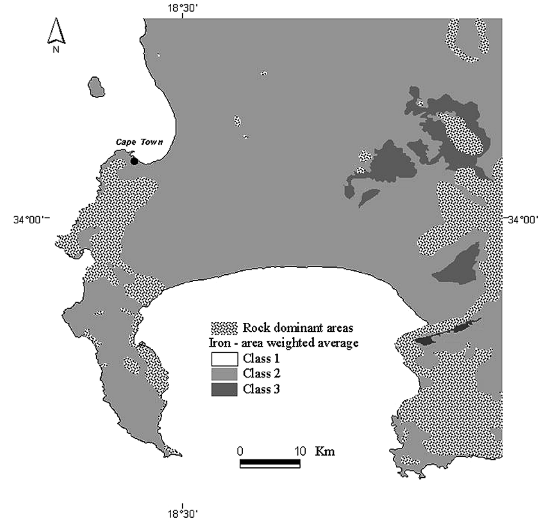

Fig. 4. A map showing average iron content per land type.

per land type (Table 4). Attenuation Class I generally indicates a relatively low attenuation potential; Attenuation Class II intermediate attenuation potential; and Attenuation Class III a relatively high attenuation potential. In practical terms, what this means is that the likelihood of finding soils with high attenuation potential for cation forming contaminants is higher in land types with Attenuation Class III than in land types with Attenuation Class I classification. Fig. 5 shows a map generated from data in Table 4.

2.3.2. Anion forming contaminants

For attenuating anion forming contaminants soil hydroxide (Fe) content plays a primary role (Fuller, 1978). In general the higher the soil hydroxide content, the higher the attenuation of anion forming contaminants.

Iron oxide content was used to determine the

Table 4
Attenuation potential classes of cation forming contaminants assigned according to clay content

Clay class per land type	Attenuation class
1–2	I
2–3	II
3–4	III

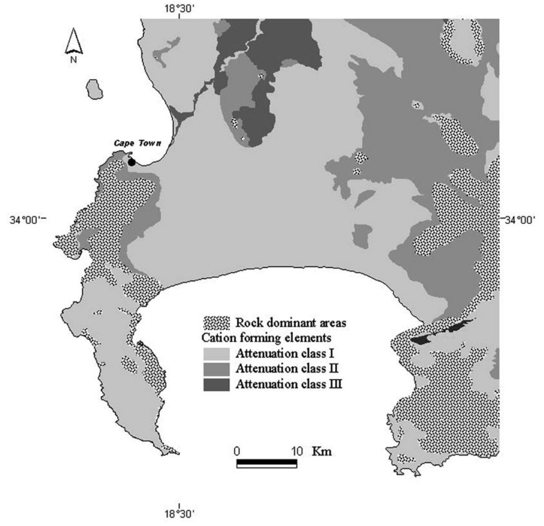

Fig. 5. A map showing attenuation potential classes of cation forming contaminants.

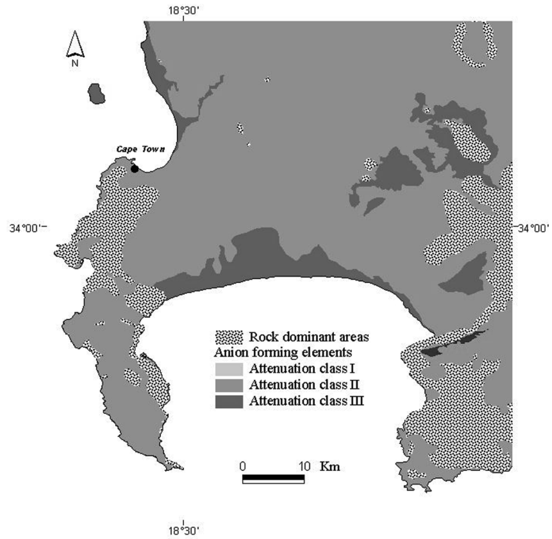

Fig. 6. A map showing attenuation potential classes of anion forming contaminants.

qualitative attenuation potential of anion forming contaminants as shown in Table 5. The map generated using these data is shown in Fig. 6.

3. Discussion

As described above, determination of soil characteristics relevant to the behaviour of percolating pollutants is one of the most important tasks in vulnerability assessments. When the geographical distribution of soils is known, an assessment can be made with regard to areas with high or low attenuation potential for a given contaminant. In the absence of soils maps, the methodology developed here for using land type data to derive soils characteristic maps was found to be useful. Using GIS, the soils characteristic maps could be combined with contaminant attenuation characteristics to obtain a qualitative indication of the attenuation potential of a group of contaminants in a given land type. Such maps can be used for land use planning purposes to give a broad overview of favourable and unfavourable areas for certain human activities. From the maps, areas with soils that have favourable attenuation properties for a given contaminant or group of contaminants can be identified. To pinpoint sites with the required properties, further detailed investigations of target areas would need to be undertaken. For example, the maps can be used to identify areas for more detailed investigation for siting waste disposal facilities. The maps can also be used in combination with geological and hydrogeological maps to assess groundwater vulnerability to pollution.

Table 5
Attenuation potential classes of anion forming contaminants assigned according to iron oxide content

Iron oxide class per land type	Attenuation class
1–1.5	I
1.5–2.5	II
2.5–3	III

4. Conclusions

It has been demonstrated that land type data can be used in lieu of soil maps to derive soil characteristic maps. The latter can then be combined with contaminant attenuation characteristics to obtain a qualitative indication of the attenuation potential of contaminants in a given land type. A limitation of using land type data stems from the fact that the exact spatial distribution of soils within the land type is not known. These maps can, therefore, not be used for site specific work. They can, however, be used for regional planning purposes to identify areas with favourable contaminant attenuation properties for more detailed investigation.

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