Assessment of landscape pattern and landscape functions by application of GIS and remote sensing

Angela Lausch
Department of Applied Landscape Ecology
UFZ – Centre for Environmental Research Leipzig-Halle, Germany

Abstract

Open-cast mines, one of mankind's most radical interventions in landscapes, are now serving as the basis of new biotopes and land-use structures. In the region south of Leipzig (western Saxony), lignite surface mining has scarred several hundred square kilometres. Mining began in the mid-19th century and reached its peak in the 1980s. Its sharpest impact on the landscape was the almost complete destruction of river wetlands. Nowadays, many of the landscape functions destroyed in Leipzig's southern region are undergoing regeneration. This still 'unstable' landscape offers a unique opportunity to test the suitability of landscape structural indicators for landscape functions. One important function in the region south of Leipzig is the capacity of the landscape to filter out contaminants from the watercourses. Studies conducted in the open-cast mine river (Pleisse) demonstrate that there is an extraordinarily high level of contaminants. These contaminants are assisted by piping as well as by any straightening of the watercourse. As a result of structural alterations along the watercourses it is no longer possible to re-divert the watercourse's structure into the original riverbed. Changes to the biotope and land-use structures alongside the rivers can serve to enhance the watercourses' retentivity. The aim of this paper is to show ways in which structural landscape criteria in models can be integrated for the analysis of contaminants entering rivers.

Research into landscape structures in the region south of Leipzig is based on an analysis of spatio-temporal analysis of landscape structures.
1 Introduction

The studies carried out in the waters of the Pleisse demonstrate that there is an extraordinarily high level of contaminants from both point and areal sources. The report on the quality management of the Pleisse [1], as well as the investigations conducted by Baumgartner and Liebscher [2], show that the landscape's hydrological capacity for retaining contaminants has been diminished by anthropogenic influences, for example, such as sealing and river widening. However, infrastructural and commercial land-use factors are reducing the possibility of large-scale renaturalisation of the river wetlands that still currently exist and the areas bordering the diverted Pleisse. In addition to dismantling the piping and reversing the river straightening, changes to the biotope and land-use structures along the river would be conceivable to minimise the contaminants entering the Pleisse. Therefore, the type of biotope and land-use structures alongside the Pleisse should be examined and whether these might contribute to the retention of contaminants entering the watercourse in order to make subsequent recommendations on changes in the land use. For this, suitable spatio-structural indicators that characterise the biotope and landscape structure have to be found first. After that the biotope and landscape structure types characterised by the spatio-structural indicators should be investigated to see which of them would contribute to the retention of contaminants.

At the forefront of research into characterising the landscape structure are the approaches of the landscape ecologists Forman and Godron [3], Turner [4] and Turner and Gardner [3] for calculating landscape metrics (LSMs). LSMs are calculated according to data filed in GIS, complemented by data from remote sensing. LSMs can be applied as indicators, by which the patterns, composition and configuration of sections of the landscape are analysed, described and quantified.

The objective of this paper is to describe the landscape stretching 500 metres wide along both sides of the Pleisse by means of landscape metrics, and to compare them for sections of the river. The intention is to highlight the significance of a formalising and integrating landscape description by means of LSMs. Their potential importance for detecting sections of river threatened by diffuse contaminants requires a separate investigation.

2 Historical development of the southern region and the course of the river

The first evidence of lignite mining in central Germany dates back to the years 1671 (Meuselwitz-Rositz), 1698 (Geiseltal) and 1882 (Lieskau near Halle) (Regional Planning Association for Western Saxony [7]). The region south of Leipzig was characterised chiefly by agriculture at the beginning of the last century, but with the increasing shortage of fuelwood supplies at the start of the 19th century and the expansion of an efficient railway network, widespread
economic change was underway. Coal mining, which had up to then been concentrated locally in deep mining operations and small pits, was followed in the 1920s by the opening up of the "real large-scale open-cast mines" [6]. The space requirements resulting from this led to a widespread change in the landscape, the complete destruction of the natural landscape structure, the landscape functions and important spatio-functional relationships. During this process the water balance in the area was subjected to particularly drastic changes. The massive transformation of the watercourse network (the shifting and shortening of river courses), the destruction of the Pleisse wetland as well as large-scale lowering of the groundwater brought about radical ecological consequences, the extent of which is hard to ascertain. Comparisons of the watercourse network in the years 1944 and 1994 in the region south of Leipzig, as well as their proportion by area (see Figure 1), clearly demonstrate the extent of the change in the landscape.

Figure 1: a) analysis area: “open-cast mining landscape in the region south of Leipzig”, b) catchment area of the Pleisse watercourse, c) 500-metre buffer zone around the watercourse

3 Establishing the diffuse impact of contaminants on watercourses

Establishing and modelling spatially dynamic processes requires a complex approach on the basis of essential indicator data. Geographic information and remote sensing can offer important complementary tools for ascertaining, integrating, analysing and modelling spatial objects. From this it is possible to derive model parameters. In addition to area statistics, the density of individual biotope types and spatio-structural quantities represent important characteristic
values that should be considered in models for the impact of contaminants in watercourses.

3.1 Area statistics

When examining land use and representing spatio-temporal changes, it is necessary to record the surface cover of the analysis area at different time intervals. With the aid of data evaluated from satellite images (the classification of spot-XS data), it is possible to make specific statements about the area for the region south of Leipzig, which are included as model parameters in the evaluations. To enable process monitoring of the overall region, the use of multi-temporal analyses of remote sensing data is required. Therefore the changes in the biotope and land use of the analysis area for the period from 1990 to 1996 were the subject of a multi-temporal examination with the aid of satellite image evaluations. By integrating the landscape development concept for the year 2020, statements can be made concerning future areal development beyond the 1996 period.

The proportions of and changes to important biotope and land-use elements in the region south of Leipzig and the Pleisse catchment can be seen in figure 3. For the land-use categories of copses, broadleaf woodland and water in the period from 1990 to 2020 an increase in area was recorded, whereas for the category "open land without vegetation" (open-cast mines) a sharp reduction in the proportions by area was ascertained.

Figure 2: Analysis of the areal distribution of important biotopes and land-use elements as well as their change over time for the region south of Leipzig and the Pleisse catchment
3.2 Density analyses

In addition to the methods deployed in land-use analysis, the evaluation of land-use density and its changes represents another method of assessing the transformation of landscape elements and landscape structures in the analysis area. For the analysis area of the region south of Leipzig, the densities for the spatio-characterising land cover categories of “open land without vegetation”, copses, woodland and built-up areas were established for the period from 1990 to 1996. In this process the areal proportion of the object categories for the reference area was established for one hectare and classified according to density. The following breakdown of density categories was applied here:

- density category 1 (>0 to 20 % / ha),
- density category 2 (>20 to 40 % / ha),
- density category 3 (>40 to 60 % / ha),
- density category 4 (>60 to 80 % / ha),
- density category 5 (>80 to 100 % / ha)

For the object category “open land without vegetation” a massive decrease in density category 5 was recorded for the region south of Leipzig within the period 1990 to 2020. From the analyses available about open land density it is possible to conclude that there has been a succession of vegetation as well as recultivation of the open-cast mine landscape, and important hypotheses concerning the impact of contaminants in watercourses can be formulated.

3.3 Spatio-structural quantities

The research branch of quantitative landscape ecology, pioneered by North American landscape ecologists such as Forman & Godron [3], Turner [4], Turner & Gardner [5], was founded in the 1980s and 1990s and developed new methods of analysing and characterising the structure of the landscape. Based on the landscape definition of Forman & Godron [3], the mosaic or structure of a landscape is described by means of landscape metrics or spatial structure metrics. Structure metrics comprise the analysis of the shape, pattern, complexity, configuration and composition of landscape elements or patches, the land-use category and the landscape. Numerous studies emphasise the importance of spatial structure metrics for issues concerning landscape ecology and remote sensing techniques are used to record them (Krummel et al. [7], Koch and Lausch [8], Lausch and Thulke [9], Herzog et al. [10]). Approaches in examining structural landscape and eco-functional relationships can be found in the publications of Gartner & O’Neill [11]. However, no approaches have so far been developed for integrating spatio-structural quantities for the analysis, evaluation and modelling of contaminants entering watercourses. Therefore the indicators proposed in Figure 3 merely represent an approach for this. They are based on the following considerations:

1. Distances and intervals (Nearest neighbour distance): In addition to the purely spatial recording of areas, known as patches, examination of the minimal Euclidean distance that exists between the watercourse and the neighbouring patches (e.g. agricultural land) is of primary importance.
2. Distances, intervals and area sizes (Proximity index, PROXIM): In addition to the distances of watercourses and patches, the inclusion of the patch size is a further aspect that should be considered.

3. The shapes of patches (Shape index): In evaluating the shape of patches the aim is to integrate quantitative values for the shape of individual patches, as well as establishing area data. Therefore the contaminants in areas of the same areal proportion but different in shape, and therefore in areal proportion to the watercourse (e.g. broad side or narrow side), must be differentiated between in the model.

4. Patch measurements such as mean patch size (Mean patch size, MPS), largest individual patch (Largest patch index, LPI): Patch measurements, such as the mean patch size or information on the largest individual patch, represent additional parameters for quantifying individual patches, alongside the use of patch data. For example, the mean patch size (e.g. agricultural land) can give important pointers to the way individual patches are sliced up and spatially configured. Patches that are small on average with an integrated boundary have a larger buffer effect against contaminants than is the case with sections of the landscape with stretches of land that are large on average.

5. Individual patch density (Patch density, PD): The density of individual patches represents a fundamental aspect of the landscape structure. For instance, statements about the number of individual agricultural patches (plough land) per standard patch can support the quantification of contaminants.

6. Edge measurements such as total edge length (Total edge, TE) and edge density (Edge density, ED): The evaluation of absolute lengths and edges and the edge length per standard patch allow quantitative statements to be made about individual watercourse sections, e.g. about meander, riparian copses and hedges.

7. Contrast measurements such as the edge contrast index (Edge contrast index, edgecon): Numerous ecological processes are dependent on contrast or existing gradients and therefore have to be included in model calculations. For example, the type of bank stabilisation with respect to the watercourses represents a quantitative contrast that should be differentiated according to the type of formation.

4 Analysis of the structural quality categories of the Pleisse

Evaluating the structural quality of watercourses is still a relatively new method of describing the properties of rivers. The watercourse sections of the Pleisse were therefore classified into four main categories of anthropogenic impact according to the criteria of longitudinal development, cross section and the riverbanks and environment [1]:
### Structural Quality Categories (SQC)

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<th>Structural Quality Categories (SQC)</th>
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<tr>
<td>SQC 1</td>
<td>natural to near natural</td>
<td>scarce to slight impact</td>
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<tr>
<td>SQC 2</td>
<td>partially near natural</td>
<td>moderate to clear impact</td>
</tr>
<tr>
<td>SQC 3</td>
<td>partially denaturalised to denaturalised</td>
<td>noticeable to bad damage</td>
</tr>
<tr>
<td>SQC 4</td>
<td>unnatural</td>
<td>excessively bad damage</td>
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**Figure 3: Spatio-structural metrics for the quantitative evaluation of landscape structures on watercourses**

These structural quality categories (SQC) were examined in the current analysis regarding their spatio-structural features. To standardise the area analyses, a buffer of 500 metres (radius) around the watercourse section of each SQC was set up. The calculations of the spatio-structural metrics (data base: biotope and vegetation mapping for Saxony for the year 1994) of these patches was carried out on a raster basis with a resolution of 10 metres / pixel.

The areal proportions of the biotope and land-use categories of the structural quality categories clearly show the predominance of mixed broadleaf woodland, cultivated grassland and still water for SQC 2, whereas for SQC 4 arable land, fallow arable land, residential areas and broadleaf woodland are predominant.

Further analyses of the spatio-structural characteristics can be seen in Figure 4 as well as in Table 1 to Table 4. Owing to a lack of comparative values, the values of the spatio-structural analyses of the three structural quality categories examined were compared with each other as relative values. The following results were achieved:

For the SQC 2 ranges, areas in the land-use class commercial grassland have a mean PD as well as high values for LPI and MPS. In contrast, for the grassland areas of SQC 4 only small values for LPI and MPS were recorded.
The large scale of the grassland areas in SQC 2 is based on the relatively extensive wetland areas still intact here, whereas the grassland areas in SQC 4 clearly bear the marks of more intensive agricultural use. In contrast, for the arable areas in SQCs 2 and 4 a contrary trend was recorded. The arable areas in SQC 2 have a high PD, however with respect to the large-scale plough land areas in SQC 4 there are only relatively small-scale arable areas here (a low MPS).

Figure 4: Analyses of the spatio-structural quantities for patches in the structural quality categories (SQC) 2 and 4 in the years 1994 and 2020.
In the spatio-structural analyses of the land-use category of broadleaf woodland, a low PD with high LPI and MPS are indicated by the presence of large-scale woodland areas, whereas only relatively low LPI and MPS values were recorded for SQC 4. Here, comparable to the land-use category of grassland, there are also large stretches of broadleaf woodland in SQC 2, whereas in the sections of SQC 3 a fragmentation of the mixed broadleaf woodland is noticeable.

Table 1. commercial grassland

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SQC = structural quality category of the watercourse, x = year 1994

Table 2. arable land / fallow arable land

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Table 3. broadleaf woodland

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SQC = structural quality category of the watercourse, x = year 1994

Table 4. open-cast mine

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<th>SGK 3</th>
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SQC = structural quality category of the watercourse, x = year 1994
5 Summary and prospects

The study of the spatio-structural quantities of landscape elements represents an aspect of process research in landscape ecology that is still seldom used. With the new methods of information processing, which support the rapid and efficient processing of large amounts of data, it is possible to conduct analyses concerning the landscape pattern and structure. The modelling of contaminants entering the watercourse requires a complex approach. This paper has pointed out the significance of spatio-structural quantities for modelling contaminants in watercourses by taking the Pleisse as an example. Current models should therefore take particular account of aspects of the landscape pattern, the configuration and distributions of landscape elements.

References


