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11 Applications of Physiotope Mapping in the Cuesta Landscape of Luxembourg

A.C. Seijmonsbergen, L.H. Cammeraat and A.M. Kooijman

Abstract

Digital physiotope maps combine multi-source abiotic information, and can be used to assess derived characteristics such as natural hazards and type of forest community. Physiotopes are spatially explicit functional landscape units that stratify landscapes into distinct units, resulting from the interplay between geological, geomorphological and soil processes. Boundaries of the physiotopes in the cuesta landscape of Luxembourg are based on geological boundaries, geomorphological processes boundaries and key indicators of soil forming processes which are supplemented by quantitative topographic land surface parameters such as slope angle. A physiotope map is presented for an area near the village of Bigelbach, which reflects the resource potential of the landscape. We present three derived applications of the physiotope map: a hazard zonation map, a forest community map and a soil erosion vulnerability map. The hazard zonation map is based on weighting and ranking of attributes of the physiotopes, such as process activity, materials, slope angle and forest cover. The derived forest community map strongly reflects the spatial distribution of geological substrate and soils of the main physiotope units along the cuesta. The soil erosion vulnerability map implements the Revised Universal Soil Loss Equation in combination with the physiotope map. The physiotope map content can be extended and updated and its derived products may support landscape conservation and restoration programs, and can be used to monitor temporal changes within a landscape.

11.1 Introduction

A landscape is not merely an environment in which people live, work and travel on a daily basis, it is also a resource which delivers many

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functions, that need to be maintained. Therefore, a landscape is considered one of the key themes of policies for environmental sustainability (Peano and Casatella 2011). Science-based information is necessary to support such sustainability policies, but often comes as fragmented information of only one single component of the landscape. Moreover, long records of changes in soil quality attributes, e.g. the occurrence of erosional features, are lacking. Physiotopes are spatially explicit functional landscape units that stratify landscapes into distinct units, resulting from the interplay between geological, geomorphological and soil processes. Digital physiotope maps may overcome the problem of fragmentation in abiotic knowledge, because they combine multi-source abiotic information of a landscape. To efficiently document the abiotic status of the landscape, integration of multiple information carriers or *environmental indicators* is required.

In contrast to ecotopes (Klijn 1994), the vegetation cover is not included in the spatial delineation of natural physiotopes. Hosting vegetation communities or high biodiversity should be reflected in the resource potential of physiotopes. Resources are here defined as those properties relevant to the development and evolution of abiotic compartments of ecosystems (Parks and Mulligan 2010), as is used in geodiversity research (Gray 2004). Differences in resources are related to differences in soil quality, because contrasting lithology produces different weathering products and soils, under similar climate conditions. Differences in vulnerability to geomorphological process activity may lead to spatio-temporal differences in natural hazards, which are closely linked to physiotope variation in parent material, topographical variation, nutrient content and hydrological properties. On a fine scale, as in the cuesta landscape of Luxembourg, expert-derived inventories on geology and geomorphology can be combined and supplemented with field inventories and information on land surface parameters in a Geographical Information System (GIS).

The cuesta landscape of Luxembourg is an outstanding area for studying geology, soils and geomorphology, due to its contrasting abiotic gradients. The cuesta landscape is the result of a complex development, due to variation in lithology (see Chap. 1), climatic change(s) and variation in soil formation (see Chap. 6), intensity of geomorphological processes (Chap. 5) and in Land Use Land Cover Change (see Chap. 3). In the present cuesta landscape the resulting abiotic patterns can be captured by mapping physiotopes.

Studying relations between the abiotic and biotic part of nature on fine scales, requires in depth representation of physiotopes and thus a transparent workflow and processing steps. Traditional field-based knowledge from geology, geomorphology and soils is the basis for the definition of physiotopes. The detailed scale demands that such fine-scaled abiotic field data has to be included to illustrate fine-scale variations between and within physiotopes. Furthermore, new techniques from the geosciences, such as expert-derived mapping and use of geomorphometric parameters (Hengl and Reuter 2008) are included and integrated in a physiotope geodatabase. For that, multiple data sources are combined, with different formats, extents, cell sizes and of varying quality. The issue of 'scale' should therefore be carefully addressed, so that the resulting physiotope maps are reliable.

Our aim is to present a workflow for physiotope mapping and three applications that use information derived from the physiotope map and its geodatabase. A first case presents a natural hazard map, while in the second case a forest community map is compared to the physiotope map. A third example implements the Revised Universal Soil Loss Equation and an additional land use map to calculate potential annual soil loss. These examples are the results of our long-lasting experience in the cuesta landscape (see Chap. 2) and the outcome of fieldwork by staff and students (see Chap. 12).

11.2 Methods

11.2.1 Physiotope Mapping

Figure 11.1 presents a workflow for preparing the physiotope map (steps 1–9) in which three

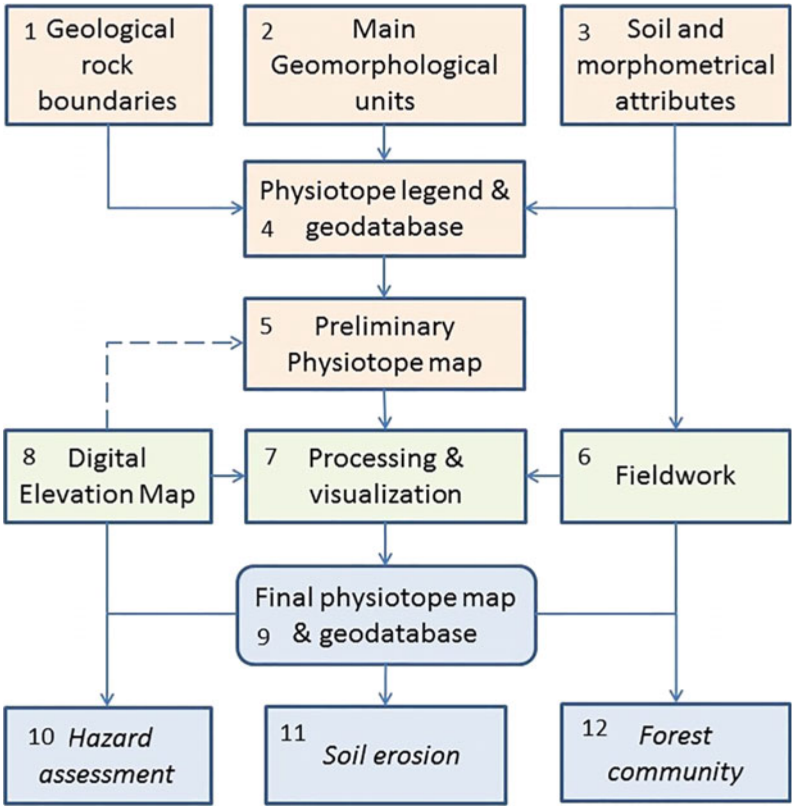

Fig. 11.1 Workflow for physiotope mapping. In *orange* the preprocessing steps, in *green* the analyses and validation, the resulting deliverables are indicated in *blue*

applied maps, the natural hazard map (step 10), the erosion map (step 11) and the forest community maps (step 12) are included. On the highest level, the legend for physiotope map (step 4) is the result of a combination of the main geological units (step 1) derived from the Carte Géologique at scale 1:25.000 of Luxembourg (http://map.geoportail.lu), combined with the main geomorphological units (step 2), as defined by Seijmonsbergen and de Graaff (see Chap. 5), which results in 7 main units: (A) Sandstone Plateau, (B) Sandstone Cuesta, (C) Marl underlain landscape, (D) Dolomite underlain landscape, (E) Fluvial landscape, (F) Aeolian landscape, (G) Colluvial landscape and (H) Other. On a lower legend level, each main unit has been subdivided into smaller units, which are characterized by combinations of geomorphometric, morhodynamic and soil attributes (step 3), which are mainly based on field descriptions. The combination of main legend units and lower level attributes is summarized in Table 11.1. The most important attributes hold information on relative drainage properties, soil type and soil depth, slope form and slope angle, material composition and relative age. This selection has been, during fieldwork experience of over 25 years, recognized as a set of key indicators for physiotope characterization. Many of these parameters can nowadays be calculated from high resolution elevations models, which enhances transferability to other regions, while others, such as soil and material properties, need fieldwork.

In the preprocessing steps (steps 1–5) data are collected (1–3), and a legend and a physiotope geodatabase (step 4) are designed in which a preliminary physiotope map (step 5) is compiled. This pre-field physiotope map contains all the individual map boundaries as well as the supplementary attributes. This allows flexibility to adapt physiotope boundaries and extensions with additional attributes. For the analyses and validation steps (steps 6–9), a hand drilling

Table 11.1 Main and subunits of the physiotope map and the summary of key point observations

	1	2	3	4	5	6	7
(A) Sandstone Plateau	Shallow, well-drained soils in loamy sandy weathered li2, with a Bw (Brunic Arenosol)	Deep, well-drained soils in loamy sandy weathered li2 with a Bw horizon (Brunic Arenosol)	Well-drained acid soils on li2 with an E and a cambic or spodic B (Brunic Arenosol, Podzols)	Shallow (4.1) or deep (4.2) soils having a loamy to clayey B wit pseudo-gley within 30 cm and a texture transition within 50 cm (Stagnosols)	Poorly drained soils with peaty surface layers and/or Histosols		
(B) Sandstone Cuesta	Convex to straight slopes in li2, well-drained shallow stony colluvial cover (Arenosols)	Stepped slopes of varying slope angle in li2 with stony and loamy sandy soils, local colluvial cover (Leptosols, Arenosols)	Slope segments with sandy colluvial deposits of sandstone scree, overlying marls, with intermediate to deep well-drained humus-rich sandy soils (Arenosols)	Strongly dissected slopes, varying thickness of overlying colluvial cover (complex of Leptosols and Arenosols)	Steep, straight and concave foot slopes, predominantly in marl, shallow, well-drained loamy to clayey soils (Regosols)	Irregular landslide topography with cover of large sandstone blocks, characteristic wet areas	Similar to B6, (initial podsolization)
(C) Landscape underlain by marls	Faint ridges with duplex soils or silty upper soil (Planosol, Stagnosol, Luvisol, A-B-C profiles)	Low-angle to medium steep, medium to well-drained straight and concave slopes underlain by marls with or without a shallow colluvial cover (Regosols, A-C profiles)	Faint ridges or straight slopes underlain by marls intercalated with conglomerates, shallow loamy to clayey soils, varying in moisture conditions (Regosol)	Steep fluvial valley slopes, often underlain by conglomerate and sandstone layers. Well-drained clayey to loamy, often gravel-rich stony soils (Regosols)	Faint ridges underlain by Psilonotenschichten (Regosols, Cambisols)	Deep, V-shaped incision underlain by marl (Regosols)	
(D) Dolomite landscape	Horizontal or low angle upper levels underlain by alternating dolomite/marl. Shallow, stone. Loamy to clayey or sandy, well-drained soils (Leptosols and Regosols)	Horizontal or low-angle upper levels of low-angles upper slopes with high silt containing horizons at or close to the surface. Clayey to loamy or sandy, moderately-drained soils (Regosols)	Intermediate steep, instable slopes with intercalated marl layers. Medium to well-drained shallow, loamy to clayey or sandy soils (Regosols)	Intermediate steep stable slopes with intercalated marl layers. Medium to well-drained shallow, loamy to clayey or sandy soils (Luvisols)	Steep upper valley slopes with shallow soils. Stony, well-drained soils (Regosols, Leptosols)	Similar to D4, with mass movement	Deeply incised, steep V-shaped valley slopes

(continued)

Table 11.1 (continued)

	1	2	3	4	5	6	7
(E) Fluvial landscape	Older terraces, deeply weathered soils, distinct Bt horizon. Gravel-rich silty topsoil on clay-rich substrate (C-material >1 m deep), moderately drained (complete Luvisols/Alisols) (A + E + Bt > 1 m) (E1.1)	Older terraces, partly truncated weathered soils. Gravel-rich silty topsoil on clayey substrate (C material). Truncated soil profiles without an E and/or (eroded) Bt. Moderate to well-drained (Regosols, Luvisols, Alisols)	Recent, loamy alluvial soils. Deeply drained soils, with loamy topsoil and local clayey substrate (Fluvisols, Regosols)	Recent, coarse-grained, well-drained sandy to loamy alluvial soils Occasional sedimentary lime-containing layered soils (Arenosols, Fluvisols)	Recent, loamy alluvial and/or recent colluvial alluvial and/or colluvial valley floor. This cover of recent alluvial material overlying poorly drained marls (Gleysol, Regosol)	Organic-rich/peaty valley floor (Histosols)	Older terrace, on Sandstone Plateau
(F) Aeolian landscape	Löss (at least 50 cm thick). Silty grey to brown, well-drained soils (Luvisols)						
(G) Colluvial landscape	Colluvial valley bottom and soils >0.5 m thick (Regosols)	Colluvial foot slopes, including alluvial fans. Deep, well-drained silty to sandy humic soils (Regosol, Cambisols, even Phaeozems), <1 m thick.	Colluvial foot slopes, including alluvial fans. Deep, well-drained silty to sandy humic soils (Luvisols, Gleysols near streams), >1 m thick	Faint ridges, wide divides or shallow valley floors with duplex soils, or with silty topsoil developed in colluvium (Planosol, Stagnosol, Luvisol) underlain by Steinmergelkeuper	Colluvium on slopes, >0.5 m thick		
(H) Other	Built-up area, infrastructure	Excavated, levelled terrain					

campaign is executed in step 6, during which several soil catenas are investigated using standard soil investigation equipment (IUSS 2015). A field form is used to determine additional geomorphometric and soil parameters, which are added to a point feature class, that contains all the point-based observational information. Physiotope field boundaries are updated during fieldwork with the use of a DEM (step 8) and its derivatives, such as a slope map and land use information (land use map, Fig. 11.2). If necessary, small mapping units are aggregated into major units to maintain readability of the final physiotope map. The input of steps 6 and 8 is then processed and visualized in step 7, which results in the final physiotope map (Fig. 11.3) and related geodatabase (step 9). For example, the point observation data are linked to the polygon-based physiotope boundaries. The digital elevation model at 5 m resolution is used to verify homogeneity of physiotope classes, by adding zonal statistical information on e.g. slope angle variations to the physiotope geodatabase.

Applications, such as a hazard zonation assessment, a soil erosion vulnerability and forest community map (steps 10–12), are examples of deliverables derived from data analysis, originally stored in the physiotope map.

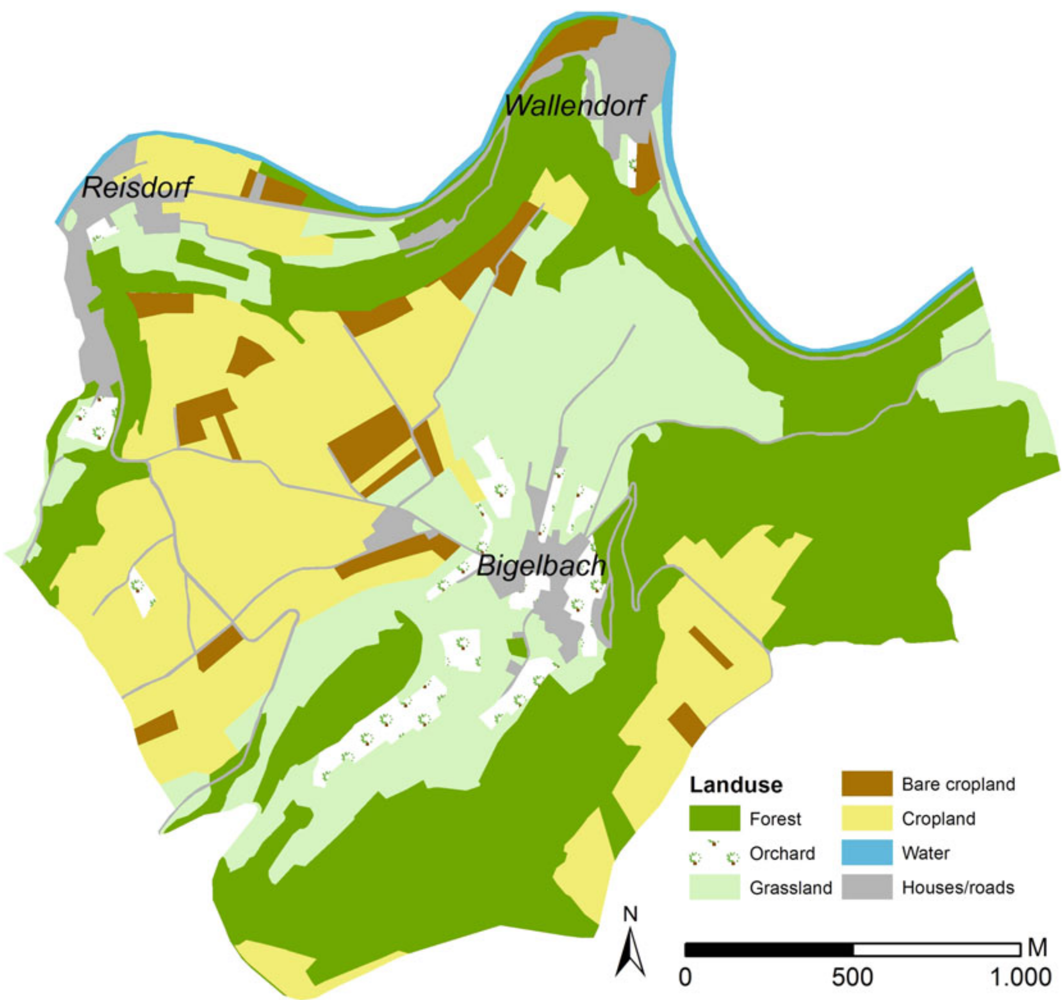

Fig. 11.2 Land use map

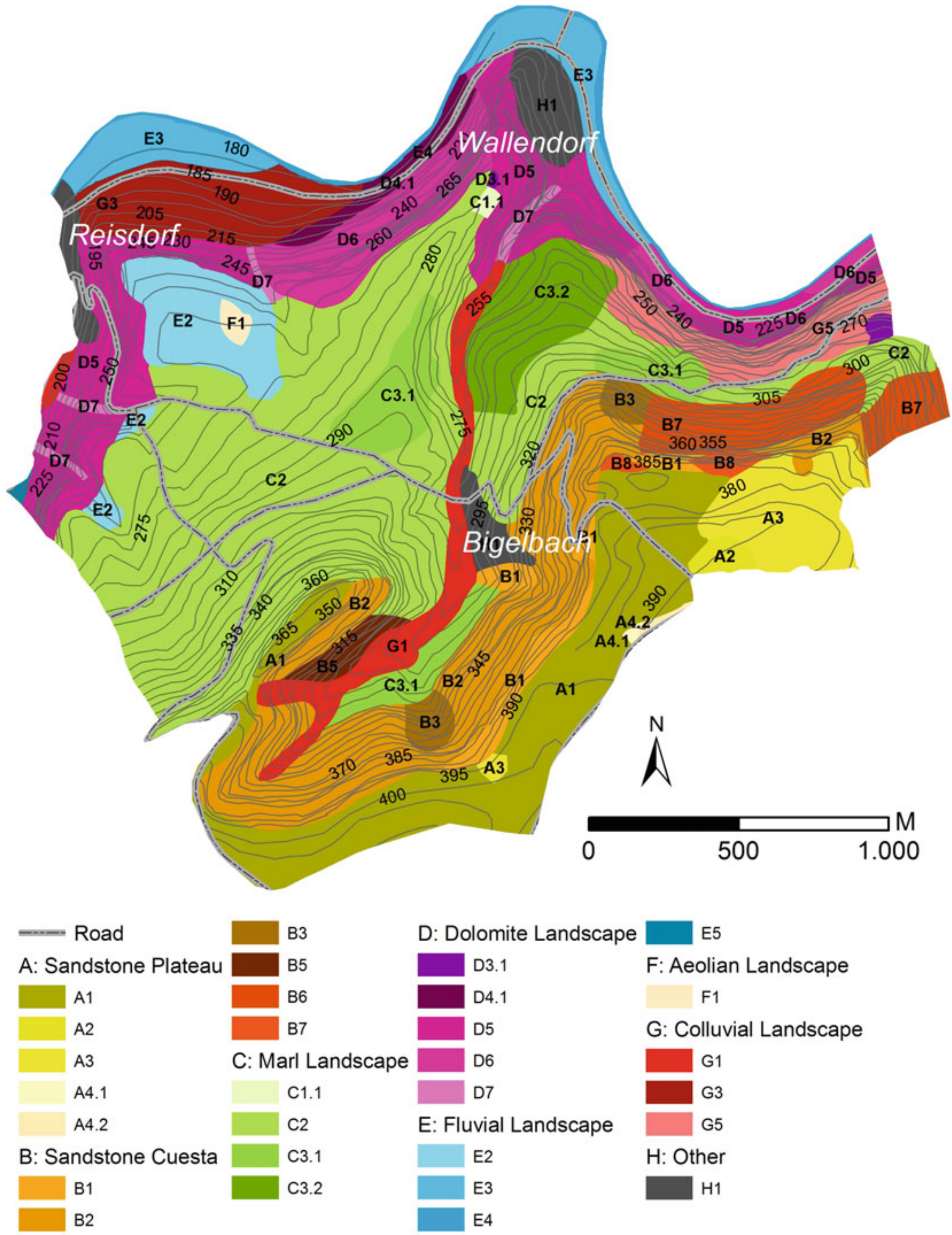

Fig. 11.3 Physiotope map in the surroundings of Bigelbach (after Koene 2012). The explanation and a summary of attribute information of the legend codes is provided in Table 11.1

11.2.2 Hazard Zonation Mapping

A natural hazard zonation map shows the spatial distribution of all hazards in an area, divided into different types of hazards, such as flooding, erosion and mass movements, and their potential impact. Procedures to produce hazard maps are described by e.g. Guzzetti et al. (2012). These techniques can be divided into inventory, heuristic, statistical and deterministic approaches (Soeters and van Westen 1996). Here we follow a combination of an inventory and heuristic approach using a weighted overlay approach. The physiotope map contains information on the spatial distribution of geomorphological processes as well as soil depth. In the heuristic approach, qualitative map combinations are made, in which expert knowledge is used to assign individual weights to a series of parameter maps that can be grouped into hazard classes.

The physiotope map (Fig. 11.2) holds attribute information on material and activity, and is supplemented with land surface parameters calculated from a 5 m resolution DEM. In this example, the physiotope units have been used in a weighted overlay to reclassify the area into zones that are equally endangered by the occurrence of natural hazards. In a weighted overlay procedure, raster maps are weighted and ranked according to their relative importance, which results in a categorization from very low hazard to very high hazard probability. The procedure works well in areas with relative fine-scale, expert-derived spatial information, in combination with quantitative Land Surface Parameters derived from a digital elevation model and field information.

First, from the 5 m DEM, a slope angle map was calculated and reclassified into 7 slope angle classes. Each class has been given a relative importance value (in brackets): <2° (1), 2°–5° (2), 5°–10° (3), 10°–20° (4), 20°–30° (5), 30° (6) −40°, >40° (7). The physiotope map was reclassified into forest (1) and non-forested area (7). The process attributes of the geomorphological map were weighted as follows: weathering (1), flow (2), erosion (3), fall (4), slide (5) and flooding (6). The geomorphological processes were weighted 50%, the slopes angle classes 30%, and the forest map 20%. The weighting and rating system is thus based on the relative importance of various causative factors derived from field knowledge and depends on characteristics of the study area. The resulting outcome is then scaled into 5 classes: very low, low, moderate and high and very high hazard classes. This procedure was done using spatial analyst tools available in ArcGIS10.2(ESRI@).

11.2.3 Forest Community Mapping

Forest community maps subdivide the present forest land cover in homogeneous forests, according to their dominating type of plant community, which has, in general terms, clear correlations with the abiotic habitat factors (see Chap. 8). The physiotope map provides the abiotic basis for mapping forest communities. For forest community mapping, additional information is necessary on forest boundaries and forest composition. The present forest boundaries are dictated by two important factors: slope angle and land-use and land cover practice. Most forest boundaries are the same as in 1777 (Ferraris LeComte 1777). The recent forest boundaries, or changes in forest type, such as planted pine trees, have been mapped by a combination of image classification (Google Earth imagery) and topographic map interpretation (1:20.000 scale topographical maps), in combination with field checks, which offers a thorough basis for the forest community maps. The point observation data provided sufficient supplementary data to classify the forest cover into forest communities, in accordance to Niemeyer et al. (2010), van der Werf (1991) and Kooijman and Smit (Chap. 8).

At each site, plant species presence and abundance was counted in a standard grid of 10 m × 10 m, so that statistical analysis between vegetation and the abiotic parameters assigned to the physiotope map could be made. A first clustering based on species presence was made using TWINSPAN (Hill 1979). A series of additional attributes was distinguished and assigned to forest communities. For this, tree cover, shrub cover, herb cover, moss cover, litter cover, bare soil cover, thickness of the ectorganic layer, the F, H and Ah/Ap horizons, humus type (mor, moder, mull) and rooting depth were estimated at each point observation site. Borders between forest communities have been checked in the field.

11.2.4 Soil Erosion Mapping

Physiotope maps hold information on soil texture, organic matter content, structure and permeability. Together with additional rainfall and land use information, an erosion assessment was made. The Revised Universal Soil Loss Equation (RUSLE: Wischmeier and Smith 1978, and Renard 1997) was applied to calculate annual soil loss, according to:

$$A = R * K * LS * C * P \qquad (11.1)$$

where A = annual soil loss in tons ha^{-1} year^{-1}, R = rainfall-runoff erosivity in MJ mm ha^{-1} h^{-1} year^{-1}, K = erosion sensitivity factor based on texture and organic matter (Renard et al. 1997; Panagos et al. 2014), LS = Slope length factor (unitless), C = crop factor (based on Morgan 2005) and P = supporting practice, which was in this case set constant to 1.

For each input parameter, a map was constructed showing the spatial distribution of the variables. Processing was done with an ArcMap toolbox, which used 10 m cell size raster maps as input.

Rainfall erosivity data are derived from Panagos et al (2014) for Luxembourg at 645 MJ mm ha^{-1} h^{-1} year^{-1}. The K-factor was determined for each of the physiotope units, by using data taken from Cammeraat et al. (2009), van den Broek (1989) and Van Zon (1980), the slope factor LS was calculated from a 10 m DEM, which was originally digitized from the topographical maps 1:5.000, while C values are taken from literature (Morgan 2005). Since the K factor also depend on organic content of the soils and the C factor is based on land use, a detailed land use map was prepared by using the 1:20.000 topographical map, Google Earth air photo information, and field checks. The land use map (Fig. 11.2) and physiotope map (Fig. 11.3) and were intersected in ArcMap, and the newly resulting units were assigned the appropriate K and C-values in the attribute (Table 11.2). The toolbox then combined the maps into calculated soil loss.

11.3 Results

11.3.1 The Physiotope Map

The physiotope map (Fig. 11.3) presents the spatial distribution of physiotopes around the village of Bigelbaach. The uppermost zone at approximately 400 m altitude is the Sandstone Plateau (A-units), which is here dominated by physiotopes A1 and A2, respectively shallow and deep well-drained soils developed in loamy to sandy weathered Luxembourg Sandstone Formation (li2), and characterized by Brunic Arenosols. Locally, loamy weathering residues of former river deposits are present, which have been indicated as A4. In other places, well-drained sandy soils have developed on the li2 with a B horizon with brunic or spodic qualities, classified as either brunic Arenosol or Podzol and are indicated as A3.

The Sandstone Cuesta (B-units) is, in its upper part, dominated by convex to straight slopes developed in li2 mostly with well-drained Arenosols in a stone-rich colluvial cover. In places, landslides have caused major slope instability, causing fast alternating fine-scale patterns of irregular topography, with wet areas (unit B6) and initial soil forming processes. The green colors are indicative for marl underlain landscapes, mostly developed on low ridges (C1) on which Planosols or Stagnosols may have developed under forest (not present in the area depicted by Fig. 11.3). On low angle or medium steep slopes (C2/3-units), mostly under agriculture, Regosols are commonly developed. The transition towards the dolomite underlain landscape (D-units) shows a transition in physiotopes characterized by steep slopes and alternations of

Table 11.2 Metadata of parameters used for the RUSLE model

RUSLE factor	Unit	Arable	Grass	Forest	Average Luxemb.
R	MJ mm ha^{-1} h^{-1} $year^{-1}$	674.5	674.5	674.5	674.5
C	(−)	0.25–0.38 (0.215)*	0.162 (0.091)*	0.001 (0.0011)*	–
K	Mg h ha ha^{-1} MJ^{-1}	0.012–0.073	0.009–0.058	0.006–0.031	(0.0392)*

In ()* the national average values as given by Panagos et al. (2015a, b)

marl layers, in general with well-drained clayey to sandy Leptosols and Regosols.

The fluvial landscape (E-units) include depositional fluvial landforms which can be separated into older terraces, such as the E2 unit of the Eebierg (see also Chap. 5) on which Regosols, Stagnosols, Luvisols and Alisols occur in gravel-rich silty topsoil on a clayey substrate, and younger fluvial deposits, mainly younger recent alluvium, on which clayey to loamy alluvial soils have developed (Fluvisols, Arenosols and Regosols).

Local remnants of loess are present on the old terrace of Eebierg (unit F), while the colluvial landscape (G-units) predominate in the smaller tributary valleys such as those of the Bigelbach stream (G1), indicating that deposition of colluvial material from surrounding slopes has been relatively important, and could not be transported by the fluvial system. The soils are mostly well-drained silty to sandy-loamy humic soils (Regosols).

11.3.2 The Natural Hazard Map

The natural hazard map is shown in Fig. 11.4. Very high hazards do not occur in this area, but high hazard activity may occur along the steep cuesta and valley slopes. Especially the area of the Hansche Schlaff with steep slopes and high mass movement (see Chap. 5 for detailed geomorphological descriptions) stands out as a hotspot of high hazard. Along the valley slopes of the Sauer River distinct zones of high hazard (flooding) occur. The relatively steep slide area of the Schaedbierg is depicted as a local high risk area as well. Most of the area however, has been classified as very low to low and moderate hazard, mainly reflecting a combination of low-angle slopes and flow-type processes on agricultural land. Although the resulting hazard map does reflect a choice on relative weighting and ranking of the input parameters, boundaries are not likely to change a lot when applying different settings.

11.3.3 The Forest Community Map

Seven forest typologies have been mapped in the area around Bigelbach (Fig. 11.5). In broad terms, the forest types follow the major subdivisions of the physiotopes, and the zones of relative steep slopes, although some deviations occur. The physiotopes on the Luxembourg sandstone plateau are dominated by Fago-Quercetum forests and fragments of former production forests (Leucobryo-Pinetum; van de Werf 1991). The N to NE facing slopes of the sandstone cuesta are covered by Luzulo-Fagetum forests in the upper parts, and Galio odorati-Fagetum in the lower parts (Niemeyer et al. 2010). The larger part of the marl underlain landscape is here non-forested, due to the low angle slopes on which farm and cropland is present. The physiotopes developed in de dolomite underlain landscape (D-units) are dominated by the Carici-Fagetum (steeper slopes) and the Hordelymo-Fagetum forests, as well as local patches of planted pine and spruce. The correspondence between physiotopes and forest communities in this area is so good, because especially the deciduous forests are relative undisturbed. After selective thinning of the forest every approximately 30 years, natural succession takes over without further management. This

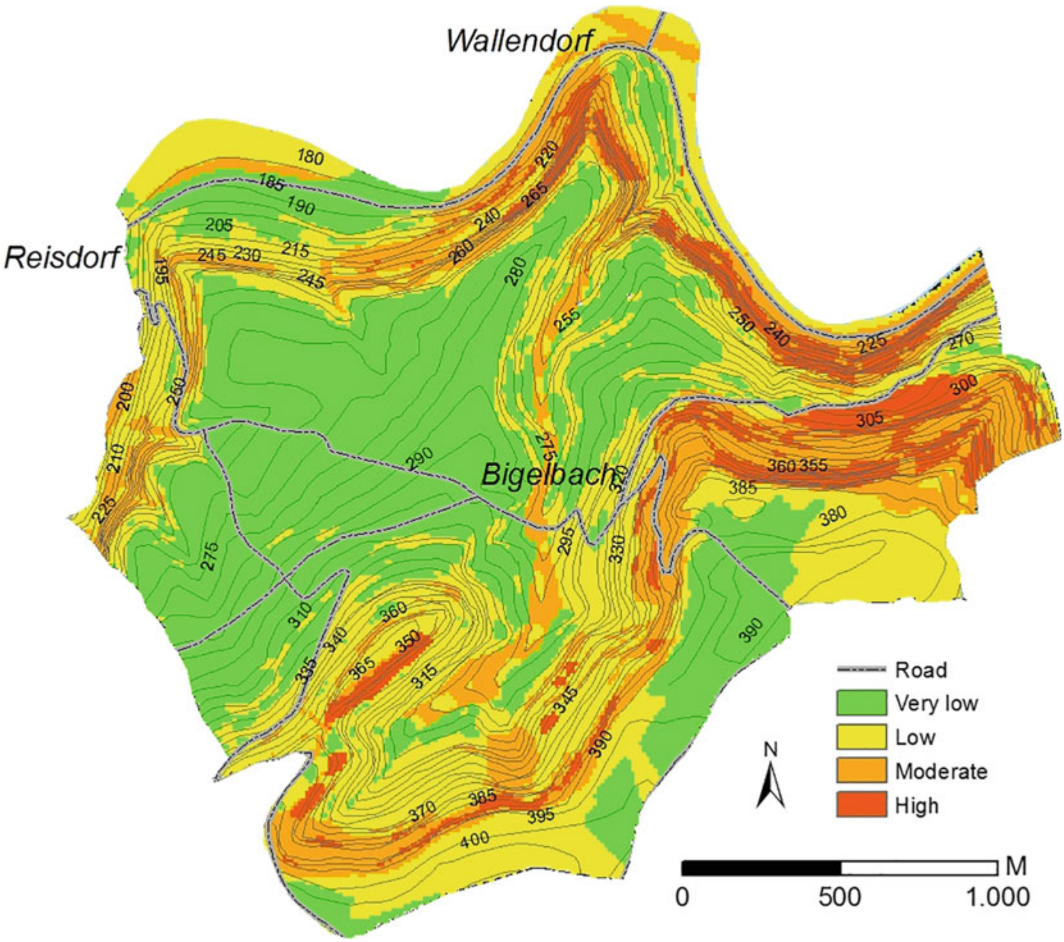

Fig. 11.4 Hazard map of the Bigelbach area, after field data provided by Brock (2012)

promotes the development of vegetation communities that are strongly related to the physical and chemical properties of the soils (physiotopes) of the forested areas.

11.3.4 The Soil Erosion Vulnerability Map

The soil erosion vulnerability map as shown in Fig. 11.6 has been classified into six units from very low to extreme erosion vulnerability. It basically shows that most of the studied area has a (very) low erosion vulnerability. The dark green areas on the map are mainly forests on the steep cuesta front and the deep river incision of the Sauer river, and forests protect the soil relatively well. For the arable soils, vulnerability levels are much higher, especially on sloping areas. The meadow areas show mostly low to moderate vulnerabilities. It is not possible to give actual soil erosion values, as the model is not validated, but the actual erosion levels can more or less be deduced from literature. Under agricultural practice on Keuper substratum, the water erosion rates on a catchment scale are in the order of 1.5–2.5 ton ha^{-1} $year^{-1}$ (e.g. Imeson and Vis 1984; Van Hooff and Jungerius 1984). This is in accord with recent modelling work of Panagos et al. (2015c) for the whole of Europe with a spatial resolution of 500 m × 500 m, who showed an average rate of 2.07 ton ha^{-1} $year^{-1}$

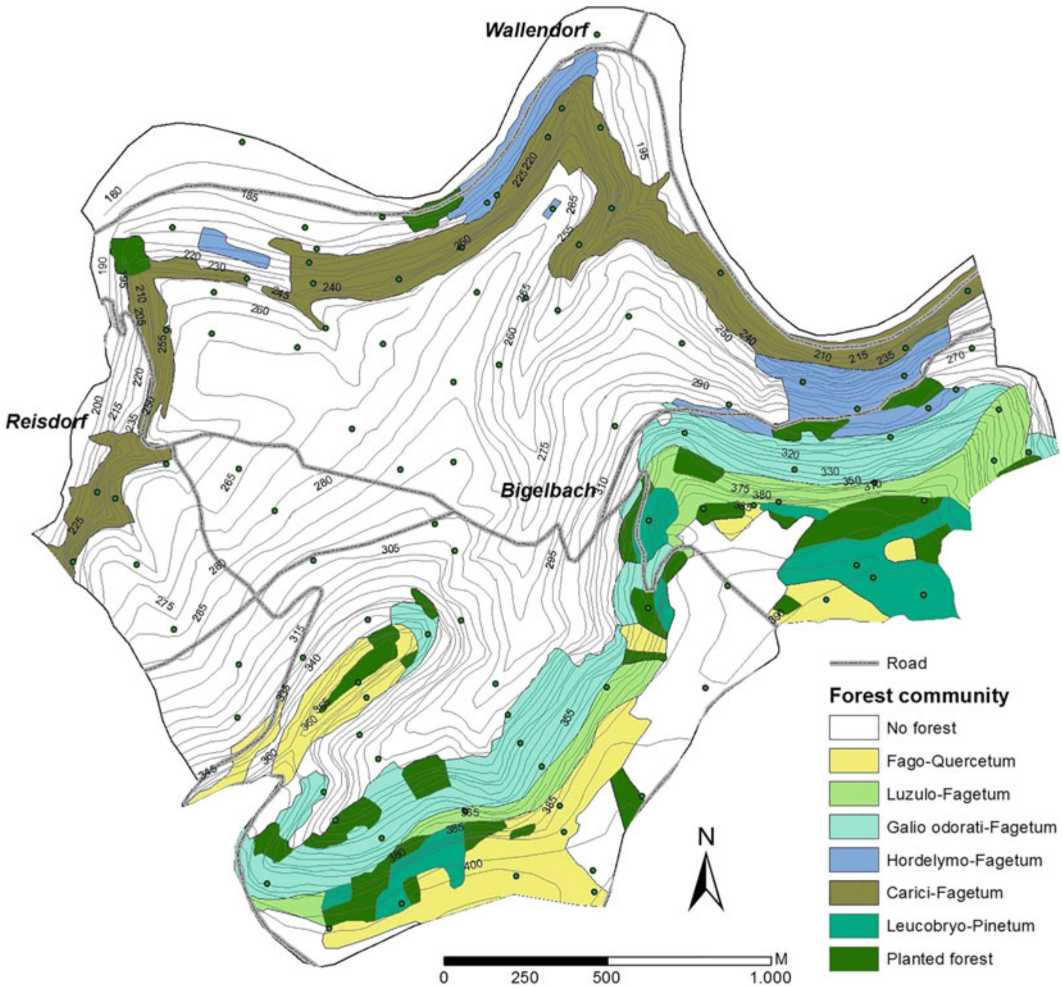

Fig. 11.5 Forest community map in the surroundings of Bigelbach (after field data by Oosterhuis 2012)

for the whole of Luxembourg, and a mean of 4.54 ton ha^{-1} year^{-1} for arable fields and even higher values (6.19 ton ha^{-1} year^{-1}) in Luxembourg for areas which are managed without 'good environmental condition practices'. For forest, values are generally lower, but also depend on the substratum. For Luxembourg Sandstone hillslopes on the cuesta front Van Zon (1980) measured soil loss of 0.010 ton ha^{-1} year^{-1}, but this was much higher for the Keuper substratum, where values ranged between 0.30 and 0.77 ton ha^{-1} year^{-1} (Imeson and Vis 1984; Duijsings 1987 respectively).

At a finer scale, erosion rates can be much higher or lower than at a 500 m × 500 m or a catchment scale. The combination of GIS and high resolution DEMs and land use information, as shown here, makes it possible to give estimates of erosion at much finer scales, e.g., to pinpoint erosion hotspots, where the chance is high that rill or gully erosion might occur (see red areas on Fig. 11.6). The prediction of erosion hotspots can be further improved by also including high spatial resolution data of organic matter in the RUSLE models, as organic matter is one of the important factors determining erodibility (K-factor; see f.i.

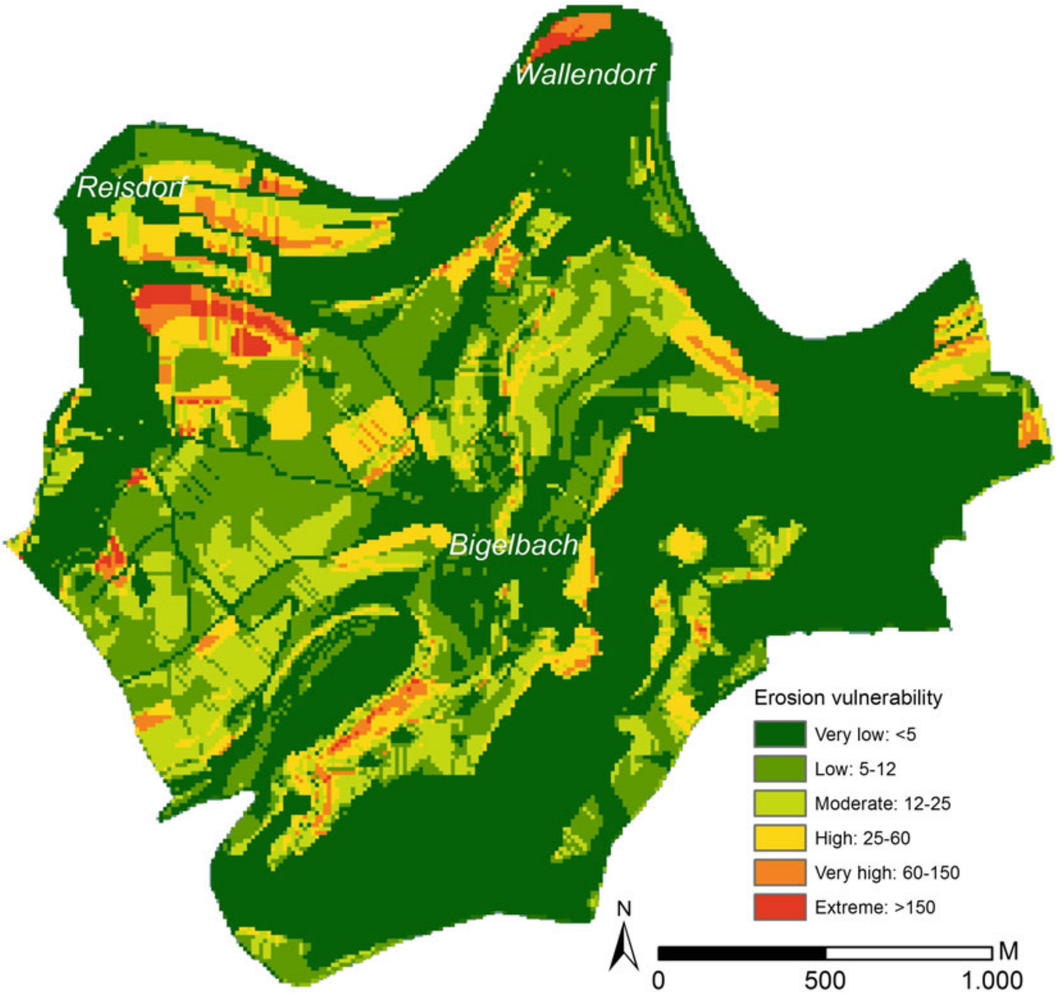

Fig. 11.6 Modelled RUSLE-based erosion vulnerability classes

Panagos et al. 2014). Recent work shows that air-born spectrometry can be successfully used to predict organic matter in bare soils, which was also tested in Luxembourg (Denis et al. 2014). The combination of high resolution physiotope maps derived from fieldwork, remote sensing data on land use and organic matter, high resolution DEMs derived from LIDAR data and high resolution GIS based modelling is an important and rapidly expanding field that can contribute to predict erosion hotspots. This can help to design improved management practices or to implement mitigation measures at exactly at the location where it is needed.

11.4 Conclusions and Outlook

We presented a workflow for digital physiotope mapping, based on integration of multiple data sources and together forming spatially explicit functional landscape units. These landscape units are characterized by a set of key abiotic parameters from geology, soil, geomorphology and topography, which can be extended according to need, data availability and fieldwork effort. The Bigelbach area has currently no very high hazards. However, if land management changes, deforestation on currently moderate and high hazard areas may increase the hazard class to very high hazard. The selection and the weighing and ranking thresholds remain the full choice of the earth scientist and is closely related to the landscape type, in this case the Luxembourg cuesta. Therefore, attention should be given when applying the workflow to other environments.

We further conclude that, on a fine-scale, physiotope mapping is a powerful means to represent integrated qualities of the cuesta landscape. The physiotope map is not only a solid basis for generating natural hazards and erosion maps with little additional information, but may better explain the distribution of forest community maps in the light of geological substratum, geomorphological development and soil quality potential.

The physiotope has grown from an initial, hand-drawn interpretation of a landscape unit to a digital GIS-based landscape unit, that contains a wide variety of abiotic information layers and measurements, which can be used in a wide variety of applications upon the end-user's request. The data processing workflow is mainly based on GIS-based procedures and can therefore be automated, in order to monitor changes in the status of physiotope boundaries and its content. In this way, conservation measures can be supported or validated, or the effect of disturbances in a landscape studied. The popularity and availability of high detailed LiDAR-based elevation data will further improve the physiotope mapping, not only promoting more accurate delineation of mapping units, but also offering more statistical insight in fine scale variations of the landscape. For example, the mean or standard deviation in slope angle for a certain physiotope unit of a 1 m slope angle map can easily be calculated using zonal statistics and may add to discriminate physiotopes and their properties on finer scales. The integrated character of physiotopes enables also new possibilities to study the impact of climate change and land use change, especially with regard to agriculture, and to predict hazard zones with regard to slope stability and soil degradation. High resolution multi- or hyper-spectral orthophoto imagery may reveal better spatial information of soil chemical properties such as mineral content. Through remote sensing imagery and automated workflows, upscaling of fine-scale information to larger areas will become common practice.

Combining the physiotope maps with high resolution DEM's, and remote sensing data on land use and organic matter contents opens up a field where soil erosion hazards can be pin pointed to the real problem areas. This has important implications for land use management and mitigation of soil erosion.

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