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Determination of water body structures for small rivers using remote sensing data

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ABSTRACT

The diversity of habitats in water bodies like rivers is characterised by the status of morphological and hydrological conditions. The good ecological status of water bodies is claimed in the European Water Framework Directive. For the assessment of this status the hydro-morphology is one of the most important supporting components for the classification of the ecological status of water bodies. Therefore the periodical monitoring is a mandatory measure in the scope of the European Water Framework Directive. Regarding the so called overview-method of the LAWA (German Working Group on water issues of the Federal States and the Federal Government represented by the Federal Environment Ministry) the use of remote sensing data and remote sensing methodologies becomes more important. Therefore remote sensing data on different scales (satellite, aerial photographs) as well as other topographic information (ATKIS) and a high resolution DTM are merged into an integrative process of analysis using remote sensing and GIS methodology. The analyses are focused on two parameters. First, a detailed landuse classification based on LANDSAT satellite data is performed for whole catchment of a small river. The results show significant increase of urban areas close to the river. The second analyses deals with the determination of river curvature and introduces the use of a quasi-continuously representation of the river. An additional challenge is the chosen study area of a low mountain range river. While large rivers are clearly visible in remote sensing data, the usability and transformation of the well-established algorithms and workflows to small rivers need a further substantial research.

Keywords: European Water Framework Directive, LANDSAT, river monitoring, curvature, water body structures, land cover classification

1. INTRODUCTION

At the end of the 20th century a consistent and integrative water policy became necessary. Especially in the last two decades the condition of water bodies had to be stated as ecological poor. At that time, for example in many German rivers the limits for nitrate as well as for phosphorus, defined by the LAWA (German Working Group on water issues of the Federal States and the Federal Government represented by the Federal Environment Ministry), were exceeded.¹ Because the more than 30 separate legal regulations in the member states of the European Union could not fulfill the needs of water body management of for example often border crossing rivers, the European Parliament passed the Water Framework Directive (2000/60/EC) in 2000.^{2,3}

1.1 The European Water Directive – 2000/60/EC

The European Water Directive (2000/60/EC) comprises essentially on two key aspects. On the one hand it deals with the definition of collective environmental objectives and on the other hand the member states commit themselves to transfer their water bodies into a "good status". The "*Good surface water status*" means the status achieved by a surface water body when both its ecological status and its chemical status are at least "good" (Article 2(18)). In addition it is also the objective of the European Water Directive that the condition of the European water bodies does not deteriorate.³ It becomes apparent that the European Water Directive distinguishes between a chemical and an ecological status of a water body. The latter is defined by biological,

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physical-chemical and morphological components of quality. The accurate weighting of the individual parameters to each other is described in detail in Annex V of the European Water Directive.

The most important instrument for an implementation of the European Water Directive is represented by the monitoring of surface water bodies. The composed river basin districts are analysed regarding their components of quality. The same does apply for the examination of man-made impacts a water body. The results of the mapping of a water course forms the basis for the development of a management plan.

Without a doubt the biological condition of a water body is according to the European Water Directive the most important parameter for qualitative evaluation. However physical-chemical and hydromorphological components of quality have also an influence on the biological status. This means that without a near-natural or natural water body structure no near-natural or natural flora and fauna habitats may develop. Therefore a good ecological status may not develop. The following hydromorphological quality elements have an impact on the biological quality of rivers:³

- Hydrological regime:
 - quantity and dynamics of water flow
 - connection to groundwater bodies
- River continuity
- Morphological conditions:
 - channel patterns
 - river depth and width variation
 - flow velocities
 - structure and substrate of the river bed
 - structure of the riparian zone

Besides the other quality elements (biological, physicochemical) the displayed elements are an inherently part of the quality assessment.

Article 13 of the European Water Directive requires the implementation of management plans and these in turn require an inventory of water bodies. Since more than 100 years the saprobity system developed by Kolkwitz and Marsson⁴ is available for the evaluation of biological stress of a water body and is still valid in a modified form today.⁵

The German Working Group on water issues of the Federal States and the Federal Government represented by the Federal Environment Ministry (LAWA) introduced an area-wide and consistent mapping approach, which was developed for small and medium sized water courses. Due to the federal structure of Germany this approach serves as a general principle for the implementation on the level of the Federal States.⁶ In this context two mapping procedures can be distinguished. On the one hand the on-side procedure and on the other hand the overview procedure. On the basis of the three compartments bottom, riparian zone and land the on-site approach serves primarily the mapping of structures of small and medium sized water courses which provide a catchment area of 10-100 km². The subordinated six main parameters are divided into 25 individual parameters.

At first the evaluation is carried out for the individual parameters and subsequently for the main parameters by calculating the average according to the bottom-up principle on the basis of an index system. Due to the high expenditure of time that is connected with this procedure, it is restricted in terms of usability.⁷ Compared to this, the overview procedure was designed by the LAWA for water courses that feature catchment areas of more than 100 km². For this purpose methods of remote sensing are applied, a ground truthing is only performed as an exceptional case.

The evaluation is carried out just as the on-site procedure by means of a 7-level evaluation scale and is performed with a different weighting of the individual parameters. The results of an investigation in 2004

demonstrate that 14 % of the surface water bodies will reach the environmental goals of the European Water Directive. For about 26 % the achievement is questionable and about 60 % will not meet the guidelines of the European Water Directive.⁸ Based upon this fact and according to an up-to-date investigation in 2013, the investigation of hydromorphological parameters may still represent an important part of an overall assessment of water courses.

1.2 Determination of water body parameters using remote sensing

The use of remote sensing in context with water as an object of research has been attracting attention in recent years. The fields of applications are manifold and range from investigations that deal with erosion (e.g. the physical properties of water)⁹ to studies of chlorophyll concentrations in surface waters¹⁰ or the analysis of algae blooms in lakes.¹¹ A detailed presentation of challenges, progress and future directions using remote sensing is well described by Palmer et al. (2015).¹²

Referring to the determination of the quality of water body structure exists a series of comparative investigations of different methods of collecting data.^{13–17} Zumbroich et al. (2012) summarise that the usage of geodata for the description of water body structures is hardly used and predominantly restricted to visual interpretation of aerial imagery. They designed a semiautomatic procedure within the HYDRA-Project for mapping water bodies on the basis of TerraSAR-X and RapidEye satellite imagery. With the help of the developed reduced set of parameters they were able to achieve sufficiently accurate results.^{18, 19}

In this context the following research shall demonstrate how different remote sensing data sets are able to support the determination of quality of water body structure of small water bodies. Therefor a workflow is presented that determines the curvature of a water body assuming that sections of the water course are covered by vegetation in that way that the course of the river is not visible in remote sensing imagery anymore. In addition to the extraction of the centerline an approach is introduced that visualizes the curvature of a water body independently of the length of the chosen section of the water course. Furthermore it is demonstrated, how in comparison to the investigations of Zumbroich et al. (2012) land use in the catchment area of a small water course is prone to change over a period of more than 20 years.¹⁸

2. METHODOLOGY

2.1 Study Area

A small river with an catchment area of less than 100 km km² was chosen as study area. Therefore only the on-site procedure of the LAWA is applicable. The selected Lockwitzbach has its source in the Eastern Ore Mountains and forms, after an run length of about 23.8 km, a tributary of the River Elbe in the eastern part of the city of Dresden (Germany).²⁰ The whole catchment area of the Lockwitzbach was used for the multitemporal research. Only the last ~8.1 km of the lower water course were taken into account for the investigation of curvature. This part of the river features a very heterogeneous structure and is shaped by sections that are not visible. For this reason the Lockwitzbach is particularly suited for the provided research.

2.2 Used Data and Data Preprocessing

2.2.1 LANDSAT Data

Eleven data sets, which were collected between 1990 and 2014 by the LANDSAT Satellite System, were acquired for the multitemporal analysis. This period was chosen due to the political transformation in the eastern part of the Federal Republic of Germany at the beginning of the 1990s that rise the expectation that there will be distinct changes in the catchment area (cf. Fig. 1).

Figure 1. LANDSAT Timeline

Preprocessing of the data was done in two steps. The conversion from digital numbers (DN) to radiances for all LANDSAT datasets provided by the USGS was carried out using the ENVI Atmospheric Correction Module FLAASH. Correction of atmospheric influences was realised by considering atmospheric models, aerosol models as well as information about aerosol optical depth (AOD). The following parameters were used for all data sets:

1. Atmospheric Model: Sub-Arctic Summer (SAS)
2. Aerosol Model: Rural
3. Aerosol Optical Depth (AOD): varied

Determination of Aerosol Optical Depth Values for all data sets after the year 2002 was carried out with the help of NASA's Giovanni Portal,²¹ which uses the MODIS Atmosphere product MOD08 for the calculation of the AOD value. This value is transformed into the horizontal visibility:²²

$$V = \frac{3,912}{\beta} \quad \beta = \frac{AOD}{2} \quad (1)$$

FLAASH implements a method for the computation of AOD and visibility values that is based on the work by Kaufman et. al. (1997).^{23,24} This method uses the spectral band in the range of $2.1 \mu m$ and the spectral band in the range of $0.66 \mu m$. The calculation is performed using dark pixels that exhibit a reflectance value ≤ 0.1 in the spectral range of $2.1 \mu m$ as well as the ratio between the reflectances of dark pixel in the range of $0.66 \mu m$ and $2.1 \mu m$.^{23,24} This step is realised for all data sets that were collected before 2002.

Due to the objective of a multitemporal analysis it is mandatory that all data sets share the same reference system. Though the data sets are provided in the same reference system by the USGS there is a need for verifying the co-registration between these data sets. Co-registration was performed pairwise using the latest data set (2014) as a reference inside the Image Registration Workflow of the ENVI 5.0 Software Package.²⁵ To prevent changes of the original reflectances nearest neighbour resampling was chosen. With the help of the workflow between 21 and 90 tie points for each pair of data sets were automatically detected for co-registration. The results reveal that residuals are almost in the range of zero (< 0.5 px). On the basis of the selected resampling method no image transformation was necessary. The last step was the creation of spatial subsets based on the catchment area of the Lockwitzbach.

2.2.2 Orthophotos / Digital Elevation Model / ATKIS Data

Digital orthophotos with a ground sample distance of 0.2m were acquired for the determination of curvature of the Lockwitzbach. All data sets were provided by the Staatsbetrieb Geobasisinformation und Vermessung Sachsen (GeoSN). The collection of these data sets was carried out during a flight in the year 2014. Each data set consists of four spectral bands in the visible part of the electromagnetic spectrum and the range of near infrared. Since these data sets were only used for extraction of geometrical objects no further preprocessing e.g. radiometric corrections was carried out.

Furthermore, a Digital Elevation Model (DEM) of the catchment area was acquired with a spatial resolution of 2m. Height accuracy (2σ) is referred to 0.2m by GeoSN. In addition data of the Amtlichen Topographisch-Kartographischen Informationssystemen (ATKIS) was used.

2.3 Methods of Multispectral Classification

Different techniques of multispectral image analysis can be used for classifying LANDSAT scenes. Several tests have been conducted showing that object-based image analysis does not perform very well. Due to this fact a conventional pixel based classification method was chosen. On the basis of a selection of suitable training samples the maximum-likelihood classification considers variance as well as covariance of each class. Assuming a Gaussian distribution of the pixel values of the training samples the position of a class inside the feature space is completely described by the mean vector and the associated covariance matrix. These functions allow the computation of membership probabilities for each pixel to every available class. The assignment of a pixel to a class occurs where membership probability is at its peak.²⁶

Five classes to describe land use were extracted on the basis of separability of classes. These classes were used as basis for the multitemporal data analysis.

1. Water
2. Urban Areas / Settlements
3. Agricultural Area (Fallow Land)
4. Meadows and Agricultural Areas (Cultivated Land)
5. Forest

The selection of training samples took place using the whole catchment area. The number of chosen pixels per class usually exceeds 1,200 to 1,300 pixel. Classification of the eleven LANDSAT scenes was performed on the basis of these training samples (cf. Sec. 2.2.1).

The assessment of classification quality is realised by means of one of the most common methods. The error matrix or also known as confusion matrix compares the results of classification with reference measurements. This procedure is done on a category-by-category basis. The reference measurements are determined by a manual/visual classification for a well defined number of reference pixels. These reference pixels are distributed by a stratified random approach. Based on the matrix different descriptive measures can be obtained. The *overall accuracy* is the number of correctly classified pixels in relation to the total number of reference pixel. Furthermore two additional measures can help to assess the accuracies for each individual category/class. The *producers accuracy* is defined as the relation between the number of correctly classified pixels in each category and the number of reference pixels used in this category (error of omission). On the other hand the *users accuracy* is defined as the relation between the number of correctly classified pixels in each category and the number of pixels classified in the appropriate categories or classes (error of commission).²⁶ As sample size for the reference measurements a number of 200 pixels is chosen. Additionally, for the interpretation of the mentioned accuracies it is important to consider the probability that the right classification of a reference pixel is random. To take into account these cases the Cohen's Kappa coefficient²⁷ combines the relative measured matches with the hypothetical probability of chance agreement.²⁸ The Kappa coefficient ranges between 0 and 1. An assessment of this coefficient is made by Landis and Koch (1977).²⁹ They defined a Kappa value > 0.81 as an almost perfect agreement, 0.61 – 0.8 as substantial, 0.41 – 0.6 as moderate, 0.21 – 0.4 as fair and Kappa values of 0 – 0.2 as slight agreement. For Kappa values lower than 0 there is no agreement.²⁹

2.4 Determination of River Curvature

The determination of curvature of the Lockwitzbach is based on a multi-level approach, that uses different types of data (cf. Sec. 2.2.2).

1. Multiresolution segmentation of Orthophotos
2. Determination of depth contour and buffering
3. Filling of gaps based on visual interpretation of Orthophotos
4. Determination of river centerline
5. Determination of curvature

The segmentation of ortho imagery was carried out with the help of the eCognition Developer 8 software. This software offers diverse methods to create image objects. The multiresolution segmentation was chosen to generate the objects. Single image elements are merged with their neighbours as long as an increase in heterogeneity is small. If heterogeneity exceeds a threshold value no further merging is performed. This parameter is also called the scale-parameter.³⁰ The scale-parameter itself can be weighted by radiometric (colour) or geometric (shape) homogeneity whereas shape is described by compactness and smoothness.³¹ The developed segmentation approach uses four levels with different scale-factor (cf. Table: 1).

Table 1. Parameters of Image Segmentation

	Level 1	Level 2	Level 3	Level 4
Scale Factor	30	50	70	90
Shape	0.1	0.1	0.1	0.1
Colour	0.9	0.9	0.9	0.9
Compactness	0.1	0.1	0.1	0.1
Smoothness	0.9	0.9	0.9	0.9

The shape as well as the colour-parameter were the same for all segmentation levels. The colour-parameter was ranked higher since a large amount of small scale spectral extrema can be found in all scenes. Urban areas, vegetated areas and water bodies can be found next to each other. In addition linear urban objects such as streets and roofs to those linear forms of the channelised watercourse. The utilisation of the weighting parameter shall not provide generalisation of water bodies and urban objects. Smooth objects are generated if the shape parameter uses a lower weighting of *compactness*. The produced segmentation levels were exported to a shapefile for further merging to generate one single watercourse polygon in ArcGIS.

Segmentation results show that there is no continuous watercourse polygon available. Structures crossing the watercourse such as bridges on one hand and overhanging vegetation that narrows the width of the stream on the other hand are responsible that not all sections of the Lockwitzbach are visible in the imagery. Detected gaps are filled with the help of the Digital Elevation Model, that was derived from airborne laserscanning data. Despite overhanging vegetation height information is available which is one advantage of the DEM. The computation of the bathymetric contour line is performed with the help of the *Hydrology Toolset* of *ArcGIS*. Therefore the following tools were used in the given order:

- *Fill*: fills sinks in a surface raster to remove small inconsistencies in the data^{32,33}
- *Flow Direction*: creates a raster of flow direction from each cell to its steepest downslope neighbour^{32,34,35}
- *Flow Accumulation*: creates raster of accumulated flow for each cell, it is also possible to apply a weighting factor^{32,33,35}
- *Raster Calculator*: $\text{Con}(\text{"flowaccumulation Raster"} > n, 1)$ with $n = 5,000$

A buffer of 2 m was applied to the bathymetric contour line to extract a second watercourse polygon. It was not possible to complete the watercourse polygon even with the help of the bathymetric contour line because of the spatial resolution of the DEM as well as dense riverine vegetation. However these vegetated areas demonstrate structures on several locations that allow the detection of the watercourse using visual image interpretation.²⁶ The remaining parts of the watercourse were connected manually where the curvature prior and subsequent of a

section can indicate the curvature gradient of the missing segment. River segments that were detected with the help of the presented methods were merged.

The extraction of the river centerline was performed using the *Polygon to Centerline* Tool that is implemented in ArcGIS. This Tool uses Thiessen polygons to extract the centerline of the Lockwitzbach as a polyline.³⁶ The objective of the following investigation is described by the extraction of a dynamic and quasi-continuous representation of curvature for different extents of watercourse segments. For this reason the extracted centerline was divided into sections of equal length (1 m) using the *Divide line by length* Tool (ArcGIS). On the basis of the derived list of coordinates ($P_l(X_l, Y_l)$) the curvature of the watercourse at location l of run length could be extracted using the following algorithm:

$$\frac{k_l}{\overline{P_{l-n}P_{l+n}}} = \frac{2 \cdot n}{\overline{P_{l-n}P_{l+n}}} \quad n = 1 \dots \frac{max}{2} \quad (2)$$

$$\overline{P_{l-n}P_{l+n}} = \sqrt{(X_{l-n} - X_{l+n})^2 + (Y_{l-n} - Y_{l+n})^2} \quad (3)$$

As demonstrated the curvature is determined with the help of a moving window approach. The size of an individual segment ranges from 1 m to half the length of the watercourse.

Therefore curvature k on location l of the watercourse is determined as the ratio of its real length and the shortest distance between beginning and end of the segment. The location l is defined as the center of a given segment. Thereby a quasi-dynamic analysis is carried out by shifting the examined segment size ($2 \cdot n$) in steps of 1 m. Simultaneously the size of the given segment is gradually scaled up until the size of the whole watercourse is reached. This results in the computation of a curvature value for the entire watercourse.

3. RESULTS

3.1 Results of the Multitemporal LANDSAT Classification

3.1.1 Maximum Likelihood Classification

Because of the small width of the Lockwitzbach and the geometric resolution of the LANDSAT satellite system it was not possible to detect the river body itself (cf. Fig. 2). By means of visual interpretation of the classification results it becomes clear, that especially in the surrounding of the lower reaches of the Lockwitzbach changes in land use and land cover are detectable in the course of the last 24 years. It has been found that in already populated areas a further densification has taken place. On the other hand also new developed areas were found in the river basin. The results show also changes between *Fallow Land* and *Cultivated Land*. In contrast to the detected changes of urban areas, it has to be mentioned that this kind of land use change can probably reduced to the fact that the used LANDSAT data set were recorded at different times in a year. Therefore it is not possible to derive a basic trend regarding the development of *Fallow Land* and *Cultivated Land*. The results of a detailed quantitative analysis are presented in chapter 3.1.2.

The analyses of classifications accuracy assessment show high Overall Accuracy (OA) values between 87% and 91,5% over all analysed time intervals (cf. Table 2). Furthermore it is visible that the results of the chosen workflow lead to an constant level of classification accuracy. These findings are confirmed by the related Kappa coefficients. Thus it can be expected that the correct assignments of reference pixel are not randomly. But there are still differences if the analyses are focused to certain landuse classes. In particular mismatches between the *Urban Areas* and *Fallow Land* are noticeable. These mismatches may be caused by construction of new buildings. In this case already existing construction sites can also be both, *Urban Areas* or *Fallow Land*. In addition an incorrect classification also occurs between *Cultivated Land* and *Forest*. This applies for both, young growing trees and also other low vegetation.

Figure 2. Landuse Classification Results of LANDSAT Data (1990-2014)

Table 2. Results of Accuracy Assessment [%]; PA: Producer Accuracy, UA: User Accuracy

Date	Overall Accuracy	Kappa Coefficient	Urban Areas [PA/UA]	Fallow Land [PA/UA]	Cultivated Land [PA/UA]	Forest [PA/UA]
10.06.2014	88.0	0.82	100 / 71.7	88.8 / 82.7	83.3 / 95.2	89.8 / 91.6
15.05.2013	87.0	0.80	96.6 / 65.9	56.6 / 100	90.7 / 92.6	93.0 / 90.9
26.05.2011	91.5	0.86	96.4 / 71.0	84.2 / 94.1	90.0 / 96.1	95.3 / 97.6
10.07.2010	88.0	0.81	100 / 63.4	57.8 / 84.6	91.6 / 95.1	85.7 / 94.7
28.07.2005	91.5	0.87	96.5 / 84.8	95.2 / 93.0	90.0 / 93.1	87.1 / 91.8
18.06.2002	91.5	0.86	96.0 / 80.0	88.4 / 82.1	90.9 / 95.2	92.3 / 97.3
13.09.1999	87.0	0.80	82.6 / 63.3	90.6 / 87.8	87.6 / 92.0	85.0 / 91.8
10.08.1998	87.5	0.82	95.4 / 80.7	94.7 / 75.0	74.3 / 98.3	100 / 97.5
28.06.1994	89.0	0.79	83.3 / 68.1	75.0 / 71.4	90.7 / 94.4	93.7 / 93.7
08.08.1992	90.0	0.83	83.3 / 45.4	100 / 94.4	87.8 / 95.5	90.3 / 96.5
24.05.1990	87.5	0.79	92.8 / 72.2	92.8 / 72.2	81.9 / 98.0	100 / 81.8

3.1.2 Landuse Change Detection – 1990-2014

The goal of the European Water Frame Directive is to achieve the good ecological and chemical status of surface waters. As explained in chapter 1.1 this also includes the condition of the riparian zone of the river and the whole catchment. For this reason a change detection analysis for a buffer zone of 150 m on the left and right side of the Lockwitzbach was performed to determine significant long term trends in this area (cf. Fig. 3).

Figure 3. Results of Change Analysis for a buffer zone of 150 m on the left and right side of the Lockwitzbach (1990-2014)

The results show a significant increase of *Urban Areas* in the investigated areas from about 40 % to over 50 %. As already mentioned above it is not possible to find a final interpretation of the visible trends of *Fallow Land* and *Cultivated Land* because of the different times of data acquisition.

3.2 Results of Determination of Curvature

Figure 4 shows the complete and quasi-continuous image of curvature of the lower reach of the Lockwitzbach. It is obvious, that the value of curvature does not only depend on its position of the river but at some positions also on the size of the segment which was used for the calculation of curvature. Thereby the image of curvature allows different interpretations primarily based on the visible artefacts.

Figure 4. Quasi-continuous image of curvature of the lower reach of the Lockwitzbach

1. In the range of 2,000 - 2,700 m the values of curvature depend very much on the size of the used river segment. The values of curvature exceed 1.8 for segment sizes beyond 700 m. In contrast to the conventional method of determining the curvature of rivers, defined by the LAWA (stepwise analysed 100 m segments), it can be determined that the curvature in this parts of the river is twice as large.
2. Contrary to the explanations above it is also possible that higher curvature values occur for smaller river segments. That is the case for example near the river length of about 6,700 m.
3. The results also show triangle structures in white and grey (cf. Fig. 4). These structures provide information about the position and size of straight reaches of a river. This kind of information may be useful to estimate an optimal size for a river segment without the risk to lose valuable information about the curvature of the river.
4. In this context it is obvious that the resulting "edges" in curvature (eg. close to $l=200$ m) should be avoided to be used as positions for the start or end point of a river segment. In this case it will not be possible to determine the curvature between the two segments before and after such a point.
5. In the upper part of figure 4 it is visible that for the use of large river segments no further differentiation of curvature is possible. Therefore it can be stated that values of curvature tend towards a threshold value. This value characterises the whole analysed reach of the river. For the Lockwitzbach this curvature value is approximately 1.5 above a river segment size of about 2,500 m.

Representations as displayed in Figure 4 may contain a lot of useful information about the structure of a river, depending on the character of the analysed river.

4. DISCUSSION AND CONCLUSION

In Germany the assessment of rivers is based on a given scheme provided by the German Working Group on water issues of the Federal States and the Federal Government represented by the Federal Environment Ministry

(LAWA). As mentioned, the methods of the overview approach of the LAWA are only usable for large river basins ($> 100 \text{ km}^2$).

The results of the performed land use analyses show essentially two things. First it was shown that the determination of land use information is possible. The results of the related quality assessment show that the quality of the extracted information fulfil the requirements of a land use classification with overall accuracies of about 90 %. Even if the water body is not visible in the used satellite data of the LANDSAT system, the obtained land use information along with administrative data (e.g. ATKIS) allows the localisation of a specific land use class regarding to the river. Furthermore it was shown, how valuable the high temporal resolution of remote sensing data can be. Regarding the land use, it could be proven that there is a significant increase of urban areas. Referring to the level of 1990 this denotes an increase of about 35 % in the close environment (150 m left and right) of the Lockwitzbach.

Additionally, the added value of a quasi-continuous representation of the river curvature was shown. It has to be distinguished between the provision of the river polygon using different remote sensing data and methods and determination of river curvature itself. By means of the mentioned workflow it could be demonstrated, how it is possible to extract a river polygon if it is not visible in satellite data or orthophotos. Based on a multi-stage process the fragmentary river polygon could successive filled. The alternative use of other administrative data, e.g. ATKIS, is not recommended. A comparison between ATKIS and the river extracted from remote sensing data has shown significant differences.

Furthermore the determined image of curvature which is based on the extracted river polygon enables an easy to use and quasi-continuous assessment of river curvature. For example, it shows the impact of the segment size as well as of its position along the river for the calculation of curvature. It is obvious that the dimension of variability can lead to a diverging valuation regarding the standards of the LAWA. Therefore the quasi-continuous image of curvature is able to support the assessment of rivers based on river segments.

In summary it has to be noted that a final assessment of a river will not be possible only on the basis of the two chosen parameters. Of course an integrative assessment of a river needs the use of a complete set of water structure parameters in line with the standards of the LAWA. The presented analyses show, how methods of remote sensing and geoinformation sciences can also contribute to the assessment of small rivers. Primarily the high temporal resolution of several systems or the use of new and very flexible UAV (unmanned aerial vehicle) technology promises a growth of importance of remote sensing and GIS methodology regarding the assessment of small rivers.

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