Jul 11th, 5:50 PM - 6:10 PM

Analysing the error potential of administrative data in determining the sinuosity of small rivers

Pierre Karrasch
TU Dresden, pierre.karrasch@tu-dresden.de

Sebastian Hunger
TU Dresden

International Environmental Modelling and Software Society (iEMSs)
8th International Congress on Environmental Modelling and Software
Toulouse, France, Sabine Sauvage, José-Miguel Sánchez-Pérez, Andrea Rizzoli (Eds.)
http://www.iemss.org/society/index.php/iemss-2016-proceedings

Analysing the error potential of administrative data in determining the sinuosity of small rivers

Pierre Karrasch[a*], Sebastian Hunger[a]
*Chair of Geoinformatics, TU Dresden (*pierre.karrasch@tu-dresden.de)*

Abstract: According to the European Water Framework Directive the member states are committed to prove the good ecological status of all water bodies. These requirements are verified by a regular monitoring. Especially the use of remote sensing data and methods of applied geoinformatics and statistics can be recommended for the monitoring of several hydromorphological parameters. At the same time for some single parameters basic geodata provided by local authorities are available (e.g. river centrelines). In this study the quality of these basic geodata is compared with self-extracted results using different remote sensing data sources (CIR-orthophoto, digital terrain model). The results reveal a mean deviation of approximately 3 m regarding the true course of the chosen test water body. But also deviations of up to 20 m occur. Especially in sections of strong river sinuosity these deviations particularly increase. Furthermore it can be shown that the use of low quality river centrelines can have a direct impact on the determination of parameters of the water body structure. It can be demonstrated that with regard to the single parameter of sinuosity the assessment of a stretch of water tends to underestimation.

Keywords: European Water Framework Directive, River Sinuosity, Data Quality

1 INTRODUCTION

Since the year 2000 the European Water Framework Directive commits the member states of the European Union to achieve the good qualitative and quantitative status of all water bodies by 2015. 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)). Especially the ecological status of a water body is defined by biological, physical-chemical and morphological components of quality. Annex V of the European Water Directive describes in detail the weighting of the individual parameters to each other. Although the biological condition of a water body is the most important, the remaining components of physical-chemical and morphological conditions could have a direct impact on the biological status.

The current development demonstrates that this goal could not be reached and the period is extended to 2027. The whole assessment of water body qualities is based on different strategies of water monitoring. Therefore it is crucial to develop and provide a set of methods to determine the multitude of parameters at a high quality level. Remote sensing data in conjunction with methods of geoinformatics and statistics promises, primarily in the field of the morphological components, the availability of quality information of water bodies or its surrounding environment. Referring to the use of remote sensing data for the determination of water body structures a series of studies were able to demonstrate their added value (Raven et al. 2002, Balestrini et al. 2004, Kamp et al. 2007, Šipek et al. 2010, Scheifhacken et al. 2012, Zumbroich et al. 2012, Klemenjak et al. 2012). In Germany the Working Group on water issues of the Federal States and the Federal Government (LAWA) provides an area-wide and consistent mapping approach. This approach is established especially for small and medium sized water courses (Patt et al. 2004). Furthermore this approach distinguishes two mapping procedures; the on-side method as well as the overview method. For the latter one the use of remote sensing data is recommended for water courses that feature catchment areas of more than 100 km². In this case a ground truthing is only performed as an exceptional case.

Regardless the considered parameters, the final assessment of river quality always depends on the quality of the underlying data. In this context the following research shall demonstrate the influence of different data sources for the determination of the parameter *sinuosity*. The sinuosity is one of several parameters of the hydromorphological component of river quality. It has a major impact to the flow velocity on different positions in the river and thus to the flora and fauna in an aquatic ecosystem. Therefore it can be expected that the parameter of sinuosity can have an effect to the ecological component of river assessment. The calculation of this parameter is carried out on the centreline of the river. Generally these data were provided by local public authorities. In many cases the comparison of the course of a river (e.g. in orthophotos) with the river centrelines of the authorities shows partly a significant positional shift.

Currently no detailed information about the frequency and dimension of such errors or deviations are available. Consequently the impact on the determination of water body structures regarding the European Water Framework Directive (parameter: sinuosity) is unknown. It is expected that this phenomenon occurs mainly for small rivers which form the largest proportion of a water course network. Because of its very heterogeneous structure, the river Lockwitzbach is chosen.

2 METHODOLOGY

2.1 Concept of Analysis

The analysis concept is based on the comparison of the two different river centrelines. The first one is provided by a local authority, the Saxon State Office for Environment, Agriculture and Geology (LfULG). The second centreline is determined using remote sensing data. The analysis starts with the determination of the river centreline by a combined approach using CIR-orthophotos and the information of a digital terrain model (section 2.2). After that the actual comparison between both river centrelines is performed. This stage can also be divided into the determination of a metric positional shift and a detailed statistical analysis of this measure (section 2.3). In order to describe the impact of these positional shifts on the river sinuosity their determination is explained in section 2.4.

2.2 Determination of River Centrelines

Besides the river centreline which is provided by the Saxon State Office for Environment, Agriculture and Geology a second line is extracted using different remote sensing data. The use of CIR-orthophotos in conjunction with an object-oriented and segment-based classification algorithm allows to separate the visible river polygons. All these calculations are performed with the software eCognition Developer 8 on different levels of segmentation (Karrasch et al. 2015). The results of this classification reveal that it is not possible to extract one continuous river polygon. The reason for this could be bridges over the river or the vegetation on the banks covering the river from both sides. Therefore in these areas a digital terrain model (DTM) with a geometric resolution of 2 m is used to find the channels. With the help of the ArcGIS hydrology toolset (Fill, Flow Direction, Flow Accumulation, Raster Calculator) it is possible to find the course of the river in areas where it is not visible (Karrasch et al. 2015). Finally, missing parts were digitized manually using methods of the visual image interpretation (Lillesand et al. 2004). Visual interpretations methods as well as an on-site ground truthing indicate that the accuracy of river detection is much better as if the administrative river centreline is used. For all river sections available as polygons the river centreline is calculated with the ArcGIS Polygon-To-Centerline Tool. This tool uses Thiessen polygons for the extraction of centrelines (Dilts 2015).

2.3 Comparison of River Centrelines

The comparison part is divided into two stages. In the first stage the distance between a point on the extracted river centreline (section 2.2) and the centreline provided by the Saxon State Office for Environment, Agriculture and Geology is calculated as a metric measure. For this purpose points are generated on the remote-sensing based river centreline in 1 m intervals using the ArcGIS tool *divide line by length* (Jones 2013). Since the direction of a point cannot be clearly defined, it is specified as the bisector line of the two segments originating in that point (cf. Figure 1).

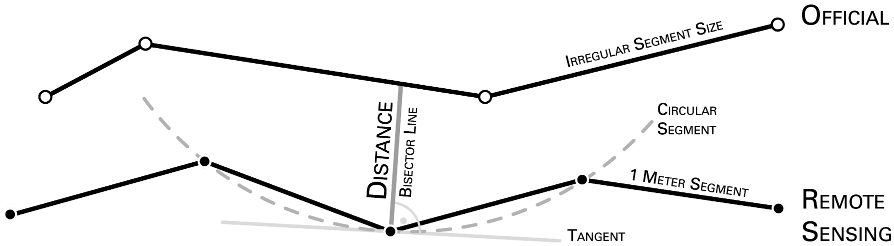


Figure 1. Concept of Determination distances between administrative river centreline and self-extracted river centreline using remote sensing data

The point of intersection between the bisecting line and the official river centreline and the basic point on the generated river centreline are the inputs for the calculation of the positional shift (distance) at this point on the river centreline based on remote sensing data. This procedure will be iteratively performed for all points on the river centreline.

In the second stage a detailed statistical analysis of the distances is performed. These distances could also be interpreted as deviations of the official river centreline from the true river course. This includes particularly descriptive statistical measures as well as analyses about the statistical distribution of the deviations. In order to estimate the error potential if the provided river centreline is used for further analysis, e.g. the determination of river body structures, the relation between the rivers sinuosity and the deviation is analysed in detail as a case study. Furthermore the impact to the classification (parameter: sinuosity) of the river regarding the European Water Framework Directive is determined.

2.4 Determination of River Sinuosity

The calculation of sinuosity is, in accordance with the requirements of the LAWA, performed for small and medium rivers with fixed segment sizes of 100 m. The value of sinuosity can be represented as the ratio between the true length of a river segment and the Euclidian distance between the start and end point (5 Classes; Class 1: sinuosity > 1.5; Class 2: 1.5 ≥ sinuosity > 1.1; Class 3: 1.1 ≥ sinuosity > 1.05; Class 4: 1.05 ≥ sinuosity > 1.02; Class 5: sinuosity ≤ 1.02). The impact of the position of a 100 m segment on the river centreline regarding the value of sinuosity is described by Karrasch et al. (2015). For this reason a quasi-continuous approach of sinuosity calculation is recommended, which allows a variable segment size and variable segment position (Karrasch et al. 2015). Figure 2 shows the basic workflow of a quasi-continuous determination of river sinuosity.

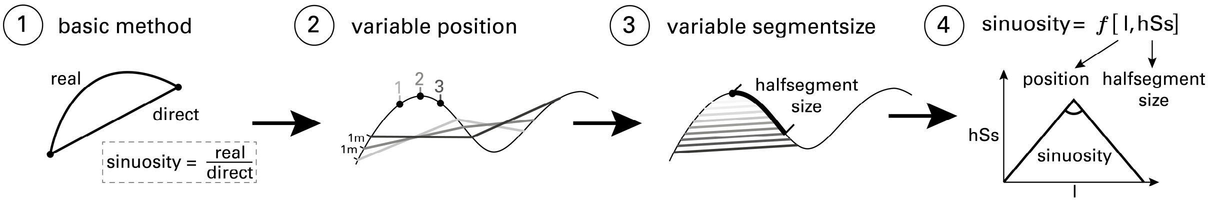


Figure 2. Concept of Quasi-continuous determination of river sinuosity

This kind of determination river sinuosity allows a detailed interpretation regardless of a particular river segment size or their position on the river course.

3 RESULTS

3.1 Positional shift of river centrelines

The initial point of the analysis is the river centreline provided by the LfULG. A first visual interpretation of its distances regarding the self-extracted line demonstrates the dimension of deviation. It is visible that there are strong local differences in the course of the analysed river (cf. Fig. 3).

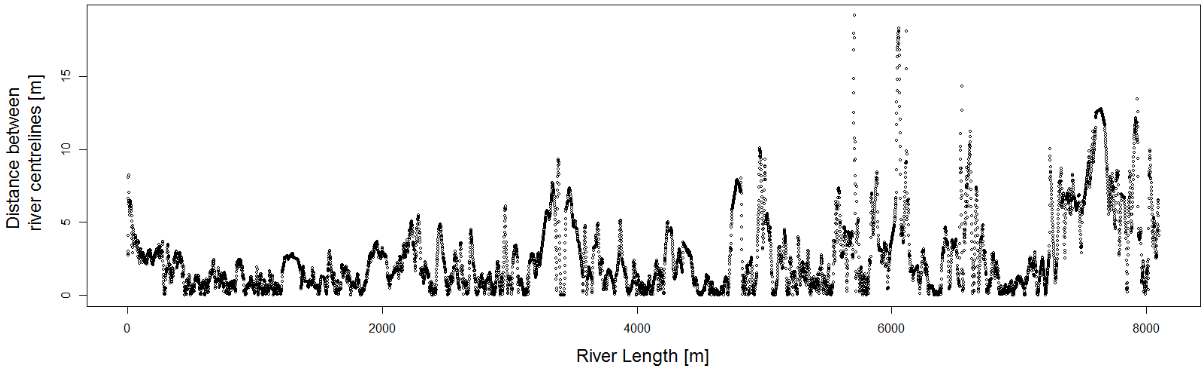


Figure 3. Distances between administrative river centreline and self-extracted river centreline using remote sensing data for the lower reach of the river Lockwitzbach

It should be pointed out that the majority of the deviations is in the range of less than 5 m. Based on the mapping precision of ATKIS data (Official Topographic Cartographic Information System) of 3 m (ADV 2015) it can be assumed that all deviations above this level are clear errors in the data basis.

The histogram of distances of the both river centrelines (cf. Fig. 4) shows, that the frequency of large deviations decrease successive. The second statistical illustration of a boxplot shows that more than 25 % of data are above the already mentioned threshold. In terms of the determination of water body structures these deviations are of particular interest. From a statistical point of view all deviations greater than 7.5 m have to be classified as outliers. The maximum deviation is larger than about 19 m. These large deviations have two main reasons. At first in the areas where vegetation fully covers the river, the manual digitization of the river fails. And second, in areas where the river shows high sinuosity values in some cases the level of generalisation during the process of digitisation is too high for an accurate geometric modelling of the river course.

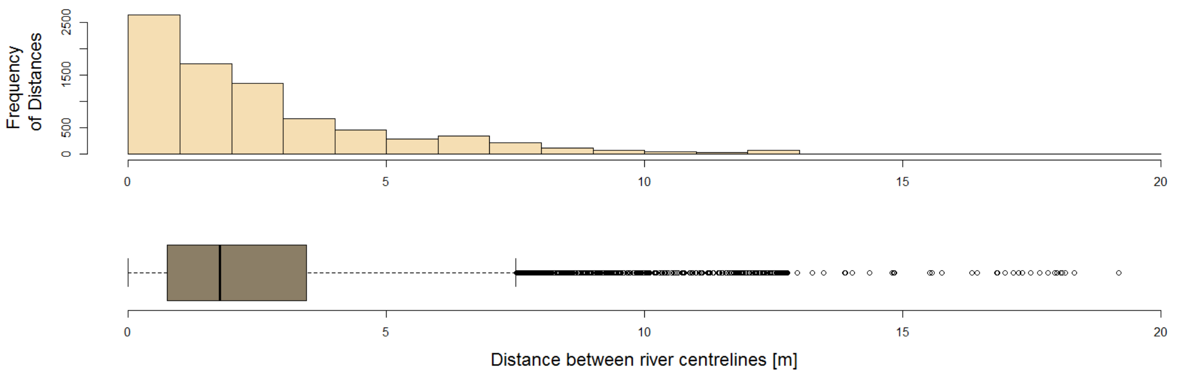


Figure 4. Distribution of distances between administrative river centreline and self-extracted river centreline using remote sensing data

A high frequency of small deviations is present because of the high level of spatial discretisation of the river centreline of only 1 m and the occasional intersection of the both lines. In these areas of intersection small deviations are much more frequent. For increasing the significance of the results it is necessary to analyse the reasons and impacts of these deviations regarding different river describing parameters. The parameter of river sinuosity seems to be a suitable indicator.

3.2 Relation between Positional shift and sinuosity

The calculation of the river centrelines extracted from remote sensing data is performed in accordance with the methods presented in section 2.3 as well as the explanations by Karrasch et al. (2015). As shown in Figure 5 (left), the variable river segment sizes in combination with the quasi-continuous approach demonstrate the behaviour of river sinuosity independent of the position or size of a stretch of water.

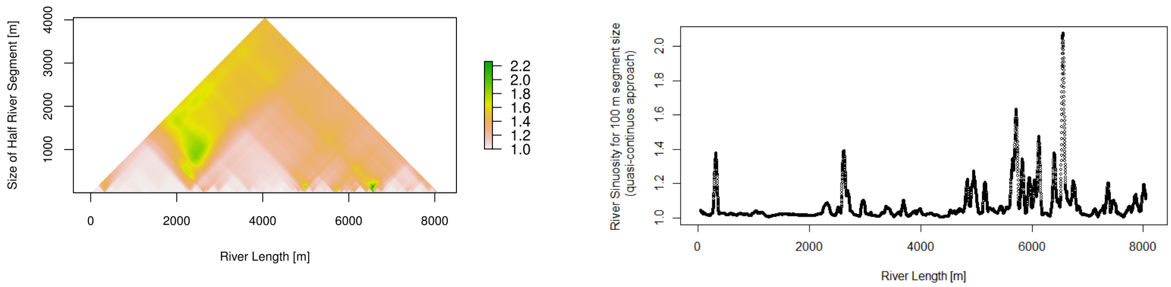


Figure 5. left: Quasi-continuous image of sinuosity of the lower reach of the Lockwitzbach (Karrasch et al. 2015); right: quasi-continuous sinuosities for a river segment size of 100 m of the lower reach of the Lockwitzbach

For analysing the dependence of the positional shift regarding the sinuosity, the choice of a fixed segment size is necessary. Due to the fact that the German Working Group on water issues of the Federal States and the Federal Government (LAWA) recommended a segment size of 100 m for all further analyses this length is also chosen. In contrast to this directive the analysis is performed using the quasi-continuous approach with a length of discretisation of 1 m. This information is extracted from the complete matrix of sinuosity (Figure 5, left) and displayed separately (Figure 5, right). This approach allows a comparison of the calculated river sinuosity and the distances between the river centrelines (positional shift). Figure 6 displays this correlation as a scatterplot.

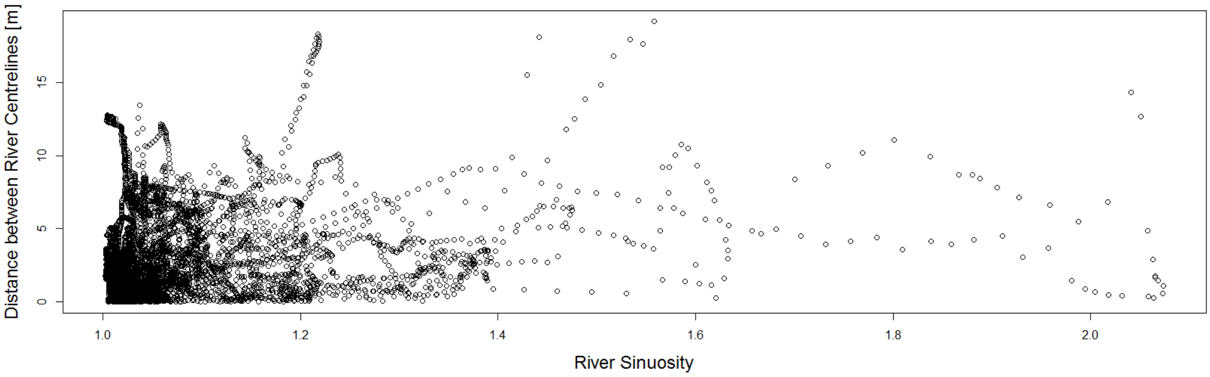


Figure 6. Scatterplot of river sinuosity and distances between river centrelines

The distribution of the pair of variates indicates a typical pattern, as would be expected for data which are measured along a trajectory. This is especially true when the spatial data density is very high. It must also be noted that a general correlation between river sinuosity and the positional shift between the river centrelines cannot be confirmed. The rank correlation coefficient (Spearman) for not normal distributed data returns a value of $\rho=0.213$. That means that only a small part of the overall variance of the distances can be explained by the sinuosity. Nevertheless the distribution of the pair of variates in Figure 6 implies that the mean value of distances and its statistical spread increase for higher sinuosity values.

For this reason the analyses are performed separately for different ranges of sinuosity. Therefore a separation of sinuosity values according to sinuosity classes is possible. This formation of sinuosity classes can be performed in different ways. For example with equal sinuosity differences, uniformly distributed in accordance with the frequency of occurrence of certain sinuosity values and finally according to the valuation classes of the standardised river assessment as realised by the LAWA (5 Classes; Class 1: meandering (sinuosity>1.5); Class 5: straight (sinuosity≤1.02)). The latter option of class formation shows that the probability to assign a river segment into a class of high sinuosity (class 1) is considerably less than a class of smaller sinuosity (class 5; cf. Figure 7).

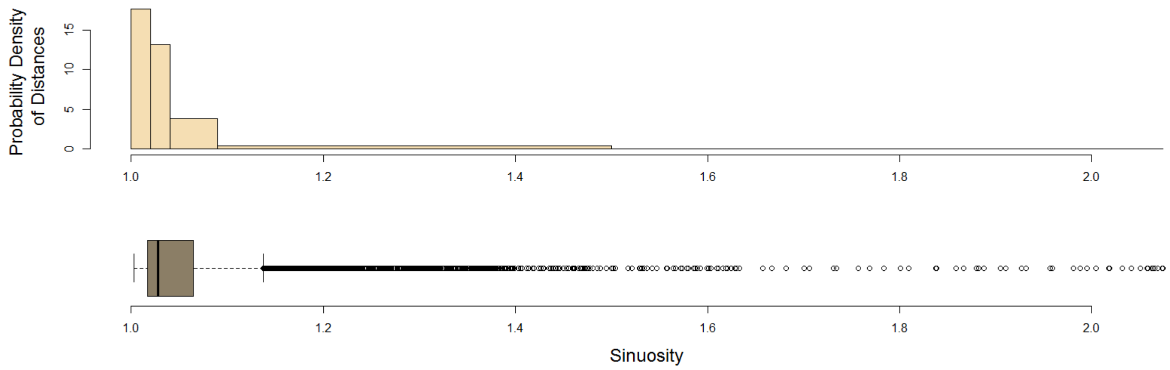


Figure 7. Probability Density of distances between administrative river centreline and self-extracted river centreline using remote sensing data in terms of different classes of river sinuosity

Figure 7 also indicates that after the classification of sinuosity values the major part of it belongs to the classes with smaller sinuosity (class 5). For analysing the distances between the river centrelines within the classes of sinuosity their statistical distribution and spread is calculated (cf. Figure 8).

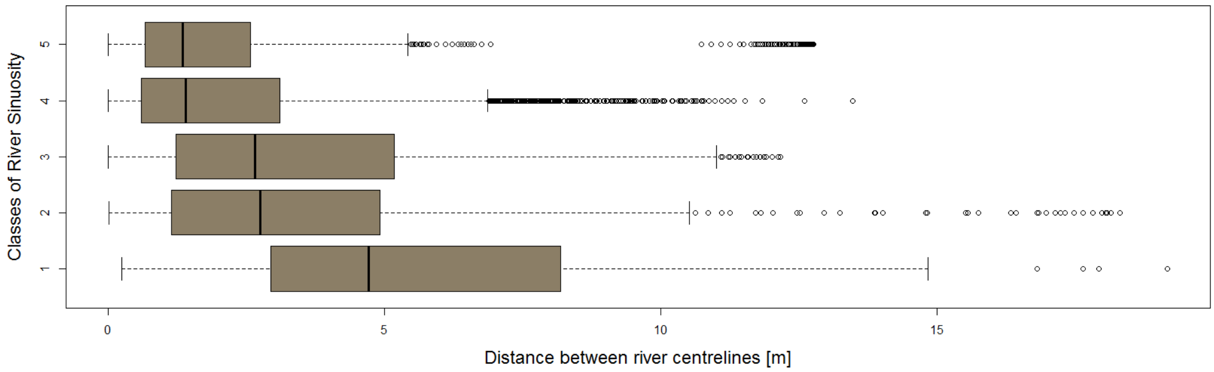


Figure 8. Distribution of distances between administrative river centreline and self-extracted river centreline using remote sensing data in terms of different classes of river sinuosity (Class 1: meandering (sinuosity>1.5); Class 5: straight (sinuosity≤1.02))

The distinction of distances in classes of sinuosity shows different effects. In spite of the low correlation values of all pairs of variates (sinuosity, distance), dependencies of distances and sinuosities are visible. It is clear that the median value of distances arises (about 5 m) with increasing sinuosity (e.g. class 1). Concurrently the statistical spread also increased which is particularly visible on the interquartile range (IQR). The same applies for the whiskers of the boxplot. Furthermore it is also clear that the number of statistical outliers is higher for classes with smaller sinuosity (class 5).

4 DISCUSSION

4.1 River centrelines

The determination of river centrelines is based on a multistage workflow using different data sources (CIR-orthophotos, DTM), remote sensing methodology and methods of applied geoinformatics. The results indicate, that the quality of self-extracted river centreline is significantly higher than the provided administrative one. Nevertheless it must also be mentioned that the self-extracted river centreline using remote sensing data can contain errors. This is especially true for the areas where the river is covered by vegetation. For determining the river centreline the depth contour line of the digital terrain model has been used. Already the visual comparison of the river centreline with the available digital orthophotos shows that the self-extracted line corresponds to the river course to a significant higher degree than the administrative line.

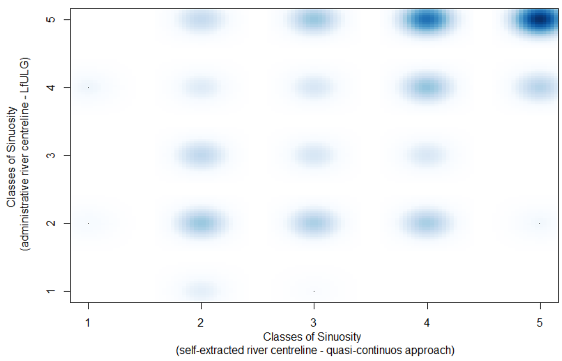
4.2 Positional shift and Sinuosity

The results of section 3.1 and 3.2 show that the deviations between the used river centrelines can vary widely. Partly these values are clearly higher than the expected deviation of a manual digitization. It is important to note that the administrative river centreline is the basic geometric information of a river. It forms the basis for all other parameters of the river monitoring which is performed as a part of the European Water Framework Directive. The assignment of single parameters to river segments contains errors or affects the calculation of several parameters directly. In addition to the river sinuosity, which is analysed in this study, also further parameters can be affected. These may include the river width variation or the characterisation of the bank structures.

Although no general correlation between the distances of the analysed river centrelines and the river sinuosity could be detected, an increase of this positional shift and its variance in classes with a high sinuosity values (e.g. class 1) shows, however, that especially in these areas the operator of a manual digitization tends to more generalisation than in straight sections of the river.

4.3 Impact to the determination of river sinuosity

As shown the river polygons form the basis for the determination of different parameters of water body structure. For this reason the example of river sinuosity shall show the impact of different river centrelines for the assessment of this parameter. In this case it is not sufficient to calculate the difference of sinuosity. Rather it is necessary to compare the results of the classification of sinuosity. Figure 9 shows the result of this comparison. The determination of sinuosity classes takes place for the self-extracted river centreline as well as for the administrative river polygon with a fixed river segment size of 100 m and the already mentioned quasi-continuous approach of calculation river sinuosity.



Classes of Sinuosity (self-extracted river centreline - quasi-continuos approach)	Classes of Sinuosity (administrative river centreline - LfULG) 1	2	3	4	5
1	0,0%	2,3%	0,0%	4,4%	0,0%
2	90,0%	35,8%	50,0%	9,6%	5,7%
3	10,0%	28,8%	25,8%	12,3%	10,8%
4	0,0%	30,1%	24,2%	44,9%	31,7%
5	0,0%	3,1%	0,0%	28,8%	51,7%

Figure 9. left: Assessment of river segments comparing the administrative river centreline and the self-extracted river centreline using remote sensing data; right: Relative shift of the assignment to sinuosity classes in accordance to the sinuosity classification using administrative data

The comparison of classification shows both underestimations and overestimations of the classified parameter of sinuosity. It is clearly visible, that the assessment of a river in accordance to its sinuosity tends to underestimation. Across all sinuosity classes only 45.3 % of the river segments are assigned to the same class. 18.2 % of the segments are evaluated worse, 36.5 % better as on the basis of the administrative river centreline provided by the Saxon State Office for Environment, Agriculture and Geology (LfULG). It is noticeable that there are partly shifts in the rating by more than one grade. This is interesting, especially in the areas where a shift to class 2 (“good ecological status”) could be shown. At this point it becomes apparent that the aim of the European Water Framework Directive has been achieved, but due to the rigid methodology (fixed 100 m river segments) it cannot be detected.

It needs to be critically assessed that the performed analyses don’t permit statements regarding the assessment of the whole water network. The results refer to a well-defined river section of the Lockwitzbach. It is chosen because all sinuosity classes are present in this river section. Many of the larger deviations, caused by generalization during the digitizing of orthophotos, are available in areas were large sinuosity values are present. Therefore a general tendency to underestimation of quality can be expected.

5 Summary

The assessment of the european water courses according to the regulation of the European Water Framework Directive requires a continuous monitoring of all water bodies and their environments. In the case of the determination of hydromorphological parameters the results of the presented study show the impact of data quality using the example of river centrelines provided by the Saxon State Office for Environment, Agriculture and Geology (LfULG). At the same time the results also show what impact the use of these data can have on the determination of parameters of the water body structure. The presented case study showed that the assessment of river sinuosity tends to be worse, in contrast to the current conditions.

Based on these findings it must be recommended that the data base of water courses (river centrelines) used for the mapping and assessment of water bodies should be reviewed immediately. Furthermore the currently used methodology, using fixed 100 m stretches of water, should be revised in favour of a more continuous approach especially for small and medium rivers (Karrasch et al. 2015).

ACKNOWLEDGMENTS

This study was conducted as part of the project *Bootmonitoring*. The project *Bootmonitoring* is funded by the Federal Ministry of Education and Research (Germany; FKZ:033W039A).

REFERENCES

Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland (ADV), 2015. Digitales Basis-Landschaftsmodell. Produktblatt.

Balestrini, R., Cazzola, M., Buffagni, A., 2004. Characterising hydromorphological features of selected italian rivers: a comparative application of environmental indices, In: Hering, D., Verdonschot, P., Moog, O., Sandin, L., eds., Integrated Assessment of Running Waters in Europe, Developments in Hydrobiology 175, pp. 365-379, Springer Netherlands.

Dilts, T., 2015. Polygon to centerline tool for arcgis. (http://www.arcgis.com/home/item.html?id=bc642731870740aabf48134f90aa6165)

Jones, S., 2013. Divide Line By Length Add-in. (http://www.arcgis.com/home/item.html?id=d5d27ee47330434b9a96b91136a0118f)

Kamp, U., Binder, W., Hölzl, K., 2007. River habitat monitoring and assessment in Germany. Environmental Monitoring and Assessment 127(1-3), pp. 209-226.

Karrasch, P., Henzen, D., Hunger, S., Hörold, M., 2015. Determination of water body structures for small rivers using remote sensing data. Proc. SPIE 9637, Remote Sensing for Agriculture, Ecosystems, and Hydrology XVII.

Klemenjak, S., Waske, B., Valero, S., and Chanussot, J., 2012. Automatic detection of rivers in high-resolution SAR data. Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal 5(5), pp. 1364-1372.

Lillesand, T. M., Kiefer, R. W., Chipman, J. W., 2004. Remote Sensing and Image Interpretation. John Wiley Sons, Inc., 5. ed..

Patt, H., Jürging, P., Kraus, W., 2005. Naturnaher Wasserbau - Entwicklung und Gestaltung von Fließgewässern, Springer Verlag, 2nd ed.

Raven, P., Holmes, N., Charrier, P., Dawson, F., Naura, M., Boon, P., 2002. Towards a harmonized approach for hydromorphological assessment of rivers in europe: a qualitative comparison of three survey methods, Aquatic Conservation: Marine and Freshwater Ecosystems 12(4), pp. 405-424.

Scheifhacken, N., Haase, U., Gram-Radu, L., Kozovyi, R., Berendonk, T., 2012. How to assess hydromorphology? A comparison of Ukrainian and German approaches, Environmental Earth Sciences 65(5), pp. 1483-1499.

Šipek, V., Matoušková, M., Dvorák, M., 2010. Comparative analysis of selected hydromorphological assessment methods. Environmental Monitoring and Assessment 169(1-4), pp. 309-319.

Zumbroich, T., Waske, B., Klemenjak, S., Meier, G., Nienhaus, I., Lange, P., 2012. HYDRA - Gewässerstruktur-Monitoring mit TerraSAR-X und RapidEye. tech. rep., Universität Bonn.