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The role of disaggregation of asset values in flood loss estimation: a comparison of different modeling approaches at the Mulde River, Germany

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1 Introduction

Economic appraisals of probable flood losses are a crucial issue for estimating the effectiveness of flood-protection measures within the scope of cost-benefit analyses (Olsen and others 1998; Beyene 2000; Ganoulis 2003; Penning-Rowsell and others 2005; Rose and others 2007). Due to the scarcity of public budget funds, it is of particular importance to determine whether the expected reduction in flood damages justifies the required investments for protection measures (MURL 2000). Furthermore insurance and reinsurance companies depend on information on the probable maximum loss (PML) of their portfolios to guarantee their solvency in case of an extreme flood event (Kron 2005).

The demand for reliable loss estimation methodologies and models has once again been revealed during and after the widespread floods in August 2002 that hit major parts of the catchments of the rivers Elbe and Danube causing tremendous damage in many parts of Central Europe (e.g. Thieken and others 2006a). The 2002 flood was an extreme event, i.e. with a discharge return period of 150-200 years at the Saxon reach of the river Elbe and 200-400 years at the rivers Mulde and Freiberger Mulde (ICPER 2004; for a description of the event see Ulbrich and others 2003; Engel 2004). In Germany alone, 21 people were killed and total losses were estimated to 11.6 billion euro (Munich Re, 2007). As a consequence numereous political and scientific activities have been initiated (e.g. EU 2007; Merz and others 2007; Pichler and others 2009).

The calculation of probable flood losses requires numerous input data sets which are merged in depth-damage functions (e.g. Wind and others 1999; Penning-Rowsell and others 2005), depth-damage ratio functions as used in HEC-FDA or HAZUS-MH (e.g. Hydrologic Engineering Centre 1998; Scawthorn and others 2006) or more complex loss models (e.g. Blong 2003; Thieken and others 2006b). Such functions and models describe building damage due to one or more flood hazard parameters like inundation depth, velocity or flood duration. They often distinguish building types and uses. The resulting damage is expressed either in absolute monetary values (e.g. depth-damage-functions in Penning-Roswell and others 2005) or as a ratio of the total asset value of the affected object (e.g. in HAZUS-MH as shown in Scawthorn and others 2006). The estimation of losses on the basis of relative loss function or relative loss models therefore requires additional data on the exposed asset values in the area of investigation (Fig. 1). This approach is commonly chosen if losses of various asset portfolios, e.g. in case of a reinsurer, are to be estimated.

In order to obtain the necessary data on the amount and the spatial distribution of the exposed valuables micro-, meso- and macro-scale approaches can be distinguished (Meyer 2005): Micro-scale analyses calculate and distribute the asset values on the basis of single properties (e.g. Reese, Markau and Sterr 2003; Penning-Rowsell and others 2003). In contrast meso- and macro-scale methods use aggregated information on the elements at risk that can be easily procured from official statistics, e.g. the number and the total value of all residential buildings within a municipality.

The chosen scale does not only depend on the size of the study area, but also on the goal of the investigation, the availability of necessary data and on time, money and manpower resources (Messner and Meyer 2006). Since great effort and considerable expenses are required to map single elements at risk like residential buildings, companies or streets, micro-scale methods are rarely applicable on a regional or (inter)national level. Furthermore due to reasons of privacy protection information on asset values of single properties are difficult to obtain. On the other hand the use of exposure data at spatially aggregated and coarse areal unit levels leads to a spatial mismatch between hazard and exposure data (Chen and others 2004) within loss analyses. In contrast to the official information on the exposed valuables, hazard estimates like water depth or inundation area are commonly modelled at a spatially explicit raster level. While macro-scale approaches simply assume an equal spatial distribution of the provided valuables over the whole administrative area, within meso-scale studies the different valuables are disaggregated to one or more corresponding land use categories to achieve a more realistic distribution. In general, disaggregation is defined as a process of transferring the value of a (statistical) variable from a coarse spatial level to a lower spatial level by means of ancillary information (Meer and Mosimann 2005; Wenkel and Schulz 1999). As far as mapping is concerned disaggregation is also addressed as dasymetric mapping or regionalisation (e.g. Chen and others 2004; Meyer 2005).

Different disaggregation methods have already been developed and applied in former studies concerning not only loss estimation for various natural hazards, but particularly mapping of population density (e.g. Eicher and Brewer 2001; Gallego and Peedell 2001; ICPR 2001; Mennis 2003; Chen and others 2004; Meyer 2005; Merz and others 2006; Thieken and others 2006c). In these studies topographic maps, satellite or land use and land cover (LULC) data sets have been proved suitable for disaggregation purposes since their information reveal an explicit relation to population and therefore as well to asset distribution.

Although some studies focus on the comparison of different disaggregation techniques with regard to population distribution (e.g. Fisher and Langford 1995; Martin and others 2000; Eicher and Brewer 2001), the influence of variably disaggregated asset values on flood loss estimation has been analysed in very few publications (e.g. Meyer 2005). Scientific research is mainly focussed on the development of suitable loss functions and models (e.g. Blong 2003; Dutta and others 2003; Penning-Roswell and others 2005) or on the quality of hydraulic modelling (e.g. Gall and others 2007; Apel and others 2009). Therefore, the objective of this paper is the application and evaluation of several common disaggregation methods in the framework of flood loss estimation. In this context especial attention is payed to the suitability of two kinds of ancillary LULC data commonly used for loss estimations in Germany. The study exclusively examines losses to residential buildings, including losses to fixed inventory (i.e. heating and sanitary facilities). Mobile inventory like furniture is not considered. As case study region, 21 municipalities were chosen at the river Mulde in Saxony, Germany (Fig. 2), which had been severely affected during the extreme flood in August 2002.

The results of the method comparison are supposed to contribute to a significantly increased accuracy of loss estimation. They are not only restricted to the case study region and the applied models and data, but have a generic character.

The paper is organized as follows: First, all data and methods used for the disaggregation of residential assets values (Section 2) and the subsequent estimation of associated losses during the 2002 flood (Section 3) are described. Both steps include independent validation methods, respectively. In Section 4 the major results are presented combined with a quality assessment of all applied disaggregation methods and loss models. Finally, conclusions are drawn and issues interesting for further research are elaborated (Section 5).

2 Disaggregation of residential building assets

Residential building assets were disaggregated in six different ways using two kinds of LULC data as ancillary information and three core methods of disaggregation (see Table 1). Fig. 3 illustrates the basic steps of any disaggregation procedure using Geographic Information Systems (GIS). Before combining the two input data layers with an INTERSECT tool, the ancillary LULC data set is usually generalized, reducing the number of considered classes by aggregation. Then, a number of selections and calculations are performed on the attribute table of the preliminary output layer to assign disaggregated values to the LULC polygons. To this end the use of external assumptions or data sets to determine weighted coefficients for the different LULC classes is very common, but not obligatory. For example, it could be roughly defined to assign 70 percent of the aggregated value to urban, 20 percent to agricultural and woodland and 10 percent to forested land uses classes (Eicher and Brewer 2001).

Before describing the different disaggregation methods in detail, all key input data used in this paper are presented.

2.1 General input data

Residential building assets were taken from the work of Kleist and others (2006). In this approach, information on standardized construction costs for residential buildings in Germany were combined with census data about the building stock and the living area per community. The calculated values represent the total replacement costs (value as new) for buildings in the reference year 2000 per municipality and therefore had to be transferred to the year 2002 by means of the construction price index (Statistisches Bundesamt 2004). For loss estimations referring to the year 2002, for example, the original assets have to be slightly corrected by a factor of 0.999. They include assets of fixed inventory (i.e. heating and sanitary facilities). Assets of mobile inventory like furniture, machines and instruments are not considered.

For an assessment of economic flood losses, i.e. in the framework of cost-benefit-analyses, the asset values further have to be corrected to depreciated values, e.g. by taking the building age and the state of maintenance into account (see van der Veen and Loigtmeijer 2005 or Messner and others 2006 for a discussion). However, in this study, the financial repair costs were estimated as these costs were also documented in the loss adjustment reports of the flood 2002 that were used for validation.

With the objective of assessing the quality of the different disaggregation methods a parallel disaggregation of the *residential building number* was conducted using census data on municipality level by INFAS GEOdaten (2001).

As mentioned before, disaggregation is carried out with the help of ancillary information, in this case LULC data. To also evaluate the influence of the LULC data on the disaggregation process, two different vector data sets were used: on the one hand ***C**ORINE (CoORdination of INformation on the Environment) **L**and **C**over data (CLC)* for Germany (DLR–DFD and UBA 2000) - funded by the German Federal Environmental Agency and by the European Union – and on the other hand the *digital basic landscape model (Basic DLM) from the German ATKIS (Authoritative Topographic Cartographic Information System)* (BKG

GEODATENZENTRUM 2005). The CLC data set gives a European wide overview of land use in 44 classes reflecting the land use pattern in the year 2000 (Mohaupt-Jahr and Keil 2004). The data evaluation is based on satellite imagery interpretation with a defined minimum size for different areas (25 hectares), so CLC areas show a high degree of generalization. In contrast, the ATKIS Basic DLM distinguishes 190 object types which were taken from analogue topographic maps on a scale of 1:10,000 to 1:25,000 and hence contain more detailed information on the current land use. As an example Fig. 4 illustrates the differences for residential land use classes between the ATKIS and the CLC data set.

Although in Germany the ATKIS Basic DLM is predominantly used for disaggregation purposes within flood loss estimations (HYDROTEC 2001, 2002; Meyer 2005; Reese and others 2003), all three core disaggregation methods were likewise performed with CLC data. The underlying rationale is that CLC data show some important advantages concerning data availability and handling: CLC data can be obtained not only for the German territory, but for whole Europe making transboundary analysis easier and more reasonable (e.g. Rhine Atlas of the ICPR 2001). Moreover, CLC data are assumed to be more homogeneous since data processing was highly standardised while the rules for assignment of some land use classes (e.g. areas of mixed use) differ between different German Federal States in the ATKIS Basic DLM. Grabbert (2006), for example, examined differences of the area ratio between the ATKIS object types “residential areas” (2111) and “areas of mixed use” (2113), which are considered to contain areas for residential purposes. He noticed that whereas this specific area ratio is almost equal in the federal state of Bavaria, “residential areas” are hardly found in Saxony and Saxony-Anhalt.

2.2 Binary method (C1, A1 and A1+)

With the binary method, 100% of the residential assets are assigned to exclusive land cover classes that are considered inhabitable and thus contain residential assets. No data is assigned to land cover types classified as forest, meadows or water. Using CLC data (the appropriate disaggregation method is further referred to as method C1) we defined the following land cover classes inhabitable, following the *Rhine-Atlas* of the ICPR (2001): “continuous urban fabric” (CLC code 111) and “discontinuous urban fabric” (CLC code 112). In line with former studies by MURL (2000) and Meyer (2005) the following object types were chosen from the ATKIS Basic DLM: “residential areas” (ATKIS code 2111) and “areas of mixed use” (ATKIS code 2113). The appropriate disaggregation methods are further referred to as method A1 and method A1+.

The major advantage of this common method is its simplicity. The reclassification of the land use data into two classes, one for inhabitable and the other for uninhabitable areas, is only followed by a simple recalculation of asset densities $d_{CLC,c}$ and $d_{ATKIS,c}$ within the inhabitable land cover area of each municipality:

$$d_{CLC,c} = \frac{r_c}{A_{CLC,c}} \quad \text{(1a)} \qquad \text{and} \qquad d_{ATKIS,c} = \frac{r_c}{A_{ATKIS,c}} \quad \text{(1b)}$$

where $d_{CLC,c}$ = residential building asset density within CLC-inhabitable area in municipality *c* [EUR/m²], r_c = residential building asset value in municipality *c* [EUR], $A_{CLC,c}$ = inhabitable area in municipality *c* from CLC [m²], $d_{ATKIS,c}$ = residential building asset density within ATKIS-inhabitable area in municipality *c* [EUR/m²], $A_{ATKIS,c}$ = inhabitable area in municipality *c* from ATKIS [m²]. Uninhabitable areas receive an asset density of 0 EUR/m².

The major weaknesses of the binary method are the unrealistic hypotheses that all areas classified as inhabitable in a municipality have a homogeneous population and asset density and furthermore that all areas classified as uninhabitable in a municipality contain no population and residential assets. Particularly when LULC data of coarse resolution like the

CLC are used, uninhabitable land cover classes, like agricultural or industrial areas, often contain some population and residential assets, too.

To counteract the first problem an advanced binary method (method A1+) on the basis of ATKIS land use data and additional census data on the level of constituencies was applied. Number and size of a constituency within a municipality depend on the population density since a constituency unit consists of about 500 households (or 1000 inhabitants). The approach A1+ is geared to the works of the MURL (2000) and Meyer (2005). Unfortunately, method A1+ can only be applied for nine of the 21 communities under study (see Table 1 and Fig. 2) since only larger, densely populated communities are further subdivided into more than one constituency. For these communities census data on the level of constituencies (INFAS GEOdaten 2005), that contain - amongst others - information on the total number of residential buildings, was used during the disaggregation process. Incorporating these data into the recalculation of the residential asset densities, different residential building densities within a municipality can be taken into account. The procedure is as follows: First, a mean asset value for residential buildings is calculated for each municipality by dividing the asset value from Kleist and others (2006) by the number of residential buildings in the municipality (INFAS GEOdaten 2001). Then the asset density $d_{ATKIS,s}$ within the inhabitable land use area can be estimated for each constituency:

$$d_{ATKIS,s} = \frac{r_{B,c} \times z_s}{A_{ATKIS,s}} \qquad (2)$$

where $d_{ATKIS,s}$ = residential building asset density within ATKIS-inhabitable area in constituency s [EUR/m²], $r_{B,c}$ = mean asset value for residential buildings B in municipality c [EUR], z_s = number of residential buildings in constituency s, $A_{ATKIS,s}$ = inhabitable area in constituency s from ATKIS [m²].

2.3 Empirical sampling method (C2 and A2)

To counteract the problems associated with the binary approach, an empirical sampling method, developed by Merz and others (2006) on the basis of a dasymetric mapping approach of Mennis (2003), was applied. The method traces back to the three-class method described by Eicher and Brewer (2001). There, a weighting scheme is used to assign a given percentage of population or census data to each land cover class within a municipality. However, there are two major weaknesses of this method: the weights are subjectively determined and the method assumes a uniform distribution of land cover, i.e. it does not account for the actual area that is covered by each land cover class within a given census district (Eicher and Brewer 2001; Mennis 2003). Mennis (2003) proposes an algorithm that overcomes the second problem. In addition, Merz and others (2006) use detailed empirical data of the built environment to determine appropriate weights. Thus, the subjectivity in assigning a percentage of the asset value to a given land cover class can be mitigated.

According to Mennis (2003), the weights of each LULC class in a municipality are composed of two factors: the building density fraction and the area ratio. The building density fraction describes how many buildings are (on average) located in a specific land cover class. The area ratio considers whether the percentage of a specific land cover class in a municipality is underrepresented in an area or not. In the following the basic working steps of the empirical sampling method are outlined.

For the **CLC-based version** (further addressed as method C2), the 44 CLC classes were aggregated into six main classes (according to Eicher and Brewer 2001; Gallego and Peedell 2001) (see Table 2). Then the boundaries of these aggregated classes were intersected with the areas of residential buildings included in the ATKIS basic DLM. Unfortunately, ATKIS building data are currently only available for the federal states of Mecklenburg-Western Pomerania and Saxony-Anhalt. As the results in Table 2 reveal, only 60% of the residential buildings are located in the settlement areas of the CLC data set, whereas approximately one third fall upon areas classified as arable land. This is particularly due to small villages and single (farm) houses that are smaller than 25 hectares and that are thus not mapped in the CLC data set as settlement areas.

For the disaggregation process, the distribution weights were generalised as shown in Table 2. These percentages are further addressed as residential building density fraction d_i of a land cover class *i*.

Strictly speaking, these estimated building density fractions are only valid for communities where the area percentages of the aggregated land cover classes conform to the percentages of area within the original investigation area (in this case Mecklenburg-Western Pommerania and Saxony-Anhalt), namely: 4% settlement areas, 1% industrial and commercial areas, 61% arable land, 11% pastures and meadows and 23% forest and natural vegetation. This occurrence, of course, is rarely the case. Therefore a second factor, the area ratio $a_{i,c}$, was determined:

$$a_{i,c} = \frac{n_{i,c}}{n_{i,total}} \qquad (3)$$

where $a_{i,c}$ = area ratio of land cover class *i* in municipality *c* [-], $n_{i,c}$ = percentage of area of land cover class *i* in municipality *c* [%], $n_{i,total}$ = percentage of area of land cover class *i* in the investigation area [%].

Afterwards the residential building density fractions can be adjusted for each municipality using the respective area ratio. The resultant variable, the total fraction $f_{i,c}$ of land cover class *i* in municipality *c* (no unit), is defined as:

$$f_{i,c} = \frac{d_i \times a_{i,c}}{\sum_{i=1}^{6} \left(d_i \times a_{i,c} \right)} \qquad (4)$$

Finally the asset densities $d_{i,c}$ can be assigned to the CLC classes:

$$d_{i,c} = \frac{f_{i,c} \times r_c}{A_{i,c}} \qquad (5)$$

where $d_{i,c}$ = residential building asset density within land cover class *i* in municipality *c* [EUR/m²], r_c = residential building asset value in municipality *c* [EUR], $A_{i,c}$ = area of land cover class *i* in municipality *c* [m²].

For the **ATKIS-based version** (further addressed as method A2), the following object types were extracted from the original LULC data set: “residential areas” (ATKIS code 2111), “industrial and commercial areas” (ATKIS code 2112), “areas of mixed use” (ATKIS code 2113), “areas of special uses” (ATKIS code 2114) and “recreational areas” (ATKIS code 2202). Spatial data analysis revealed that buildings are exclusively located within these five areal classifications. The procedure of method A2 is basically the same as for method C2. Table 3 shows the calculated residential building density fractions d_j for the chosen ATKIS object types *j*. Comparing the density fractions of Table 2 and 3 vast differences between areas defined here as residential become evident. This is due to the coarse resolution of CORINE Land Cover data that does not allow further differentiation within areas of urban character. Thus, most of the areas of ATKIS object type “areas of mixed use” are included in the CLC classes “urban fabric”.

2.4 Regression method (C3)

As a third approach, a regression-based method was performed. Gallego and Peedell (2001) developed a disaggregation model for the distribution of census population on the basis of the CLC data set for whole Europe. Thieken and others (2006c) applied the results to improve the spatial modelling of asset values in Germany assuming that the population distribution directly reflects the distribution of residential asset values. Thus, the residential building asset density $d_{i,c}$ of land-cover class *i* in municipality *c* can be described as follows:

$$d_{i,c} = (U_i \times W_c) \times d_{cap,c} \times 100 \qquad (6)$$

where $d_{i,c}$= residential building asset density $d_{i,c}$ of land-cover class *i* in municipality *c* [EUR/m²], U_i= quasi-median population density per land cover class *i* [Inhabitants/km²], W_c= adjustment factor for municipality *c*, $d_{cap,c}$= per-capita residential building asset in municipality c [EUR/Inhabitant]. The derivation of the necessary input data is further explained in the following:

The per-capita residential building asset was derived from the estimates of Kleist and others (2006) and the population figure on municipality level (INFAS GEOdaten 2001).

The quasi-median population densities were calculated by Gallego and Peedell (2001) for six aggregated CLC classes (Table 4). The quasi-median population densities result from regression analyses assuming that the ratio between the population density of two given land-cover classes is the same for any municipality. To differentiate this assumption, Gallego and Peedell (2001) further distinguished three types of communities (strata), so that the ratio is only homogeneous inside each stratum. The distinction was realised by comparing the population density of a municipality with the population density at the corresponding regional level using official statistical data of the European Union. As a result, high density communities (stratum 1), medium density communities (stratum 2) and low density communities (stratum 3) were defined (for details see Gallego and Peedell 2001).

Starting with a set of initial regression coefficients provided by the European Environment Agency (EEA), Gallego and Peedell (2001) performed an iterative algorithm to optimise the coefficients by minimising the disagreement between the retrieved and the known communal population. The resulting quasi-median population densities are shown in Table 4.

To determine the asset density $d_{i,c}$ by *equation 6*, one still needs to multiply the quasi-median-population density with an adjustment factor W_c to ensure that the total population of a given municipality will be correctly estimated by this approach. The adjustment factor is calculated by the ratio of the officially reported population figure of that municipality (INFAS GEOdaten 2001) and the predicted population figure within the municipality using the general coefficients U_i:

$$W_c = \frac{X_c}{\sum_i A_{i,c} \times U_i} \qquad (7)$$

where X_c = officially reported population figure in municipality c (INFAS GEOdaten 2001),

$A_{i,c}$ = area of land cover class *i* in municipality *c* [m²].

Due to missing regression analyses for ATKIS land use classes, the regression method was only performed on basis of the CORINE land cover data (further addressed as disaggregation method C3).

2.5 Validation

With the objective of assessing the quality of the different disaggregation methods all approaches except for method A1+ were validated using census data of the residential building number on municipality and the subordinate constituency level by INFAS GEOdaten (2001, 2005).

First, the residential building number on municipality level was disaggregated with the methods C1, A1, C2, A2, and C3 as described in the previous sections. Then, the disaggregated data sets were used to estimate the total number of residential buildings in the subordinate constituencies. The official number of residential buildings per constituency is also provided by INFAS GEOdaten (2005). Thus, the error of the building number per constituency can be estimated and analysed statistically. Method A1+ was excluded from this validation since the census data on constituency level were already used for the disaggregation process itself (see Table 1).

As mentioned in section 2.2 census data on constituency level were only suitable for nine of the 21 communities in the study area. Furthermore, these data refer to the year 2005, whereas the census data on municipality level reflect the situation in 2001. A comparison of both values revealed minor changes in most of the communities, but an unacceptable increase in residential buildings of more than 17% for two of the nine communities. Therefore, the validation was only applied to the remaining seven communities (see Fig. 2). To allow a comparison with the data of 2005, adjustment factors for the disaggregated values of 2001 were calculated. Thus, a sample of 114 constituencies was available to validate the applied disaggregation methods (see Table 1).

3 Flood loss estimation

In order to shed some light on the influence of the chosen disaggregation method within the scope of flood loss estimation, losses to residential buildings were estimated for the flood event in August 2002.Three relative loss functions were applied, which are commonly used in Germany. Additionally, losses were also calculated with the help of a relative rule-based loss model. Before describing the approaches in detail, the required input data are presented.

3.1 Input data

Since relative loss models were applied, the residential asset values disaggregated with the methods C1, A1, A1+, C2, A2 and C3 served as input data for the loss estimation. Furthermore, information on the flooded area and the inundation depths are required. In this study, data of Grabbert (2006) were used, who transformed 2002 flood discharges of several gauges at the river Mulde into inundation depths of a 25 m resolution by hydraulic transformation. Cross profiles at the gauging stations were constructed with the help of a digital elevation model and the gauge datum as well as the rating curves of the gauges to derive stage-discharge relationships including the floodplain for each gauge. By intersecting the calculated water levels of 2002 with the digital elevation model inundation depths were obtained. The method is described in more detail by Rodda (2005).

Inundation depths by Grabbert (2006) were only available for 19 of the 21 investigated communities (see Table 1 and Fig. 2).

3.2 Methodology for flood loss estimations

Three different types of relative loss functions were used, which had been developed and applied in flood action plans or risk mapping projects in Germany (MURL 2000; ICPR 2001; HYDROTEC 2001, 2002). These functions consider the inundation depth as the single factor that influences the quantum of loss. Additionally, losses were also estimated with the multifactorial loss model FLEMO$_{ps}$ (Büchele and others 2006; Thieken and others 2006b). Fig. 5 shows the loss ratio curves for all four calculation approaches.

MURL (2000) calculate the loss ratio of residential buildings by the equation $y = 0.02x$ where x = water level [m] and y = loss ratio [-]. For water levels of more than 5m the loss ratio is set to 0.1 (i.e. 10%). ICPR (2001) estimate the loss ratios of residential buildings by the relation $y = (2x^2 + 2x)/100$. For some flood action plans HYDROTEC (2001, 2002) used the root function $y = (27\sqrt{x})/100$. In the latter two models, loss ratios > 1 were set to 1.

In contrast to these three depth-damage functions the loss model FLEMO$_{ps}$ calculates the loss ratio at residential buildings for five classes of inundation depths, three distinct building types and two categories of building quality leading to a stepped range of loss ratios. Information on building type and quality were taken from census data of INFAS GEOdaten (2001), which were classified by cluster analysis (see Thieken and others 2006b).

The loss calculation was realized using ArcView GIS 3.3 to transfer all input information into raster data sets. While a resolution of 25 m was regarded sufficient for the CLC-based methods C1, C2 and C3, the ATKIS-based datasets of method A1, A1+ and A2 required a finer resolution of 10 m to reflect the higher degree of information. After the grid cell information had been resampled, loss ratios and finally the absolute residential building loss [EUR] per municipality were estimated with the help of a script developed in MatLab 7.0.4. Altogether, in this paper loss estimates are distinguished for six disaggregation methods and four loss functions/models.

3.3 Validation

To evaluate the quality of the loss estimations, the loss estimates per municipality were compared with official repair costs, which have been well documented by the Saxon Relief Bank (SAB 2005). After the flood event in August 2002 a huge damage compensation program was released by the German government putting the SAB in charge of the loss adjustment and management in Saxony. According to the loss compensation guidelines (SMI 2002), costs for repairing or replacing damaged household contents and/or damaged outside facilities (e.g. fences, plants) were excluded from the compensation. Therefore, the eligible repair costs almost represent the total residential building loss. Both, validation data and modelled losses do not represent economic losses, but the financial costs and can therefore be compared.

4 Results and discussion

4.1 Distribution of residential assets

The results of the disaggregation were visualized in the form of maps that allow first conclusions about the characteristics of the applied methods. As an example, Fig. 6 shows the spatial distribution of the unit building asset [EUR/m²] in the municipality of Wurzen for all applied disaggregation methods.

Due to higher resolution and differentiation of land use, settlement patterns and agglomeration areas and therefore asset distribution are highlighted in more detail by the ATKIS-based approaches A1, A1+ and A2 than by the CLC-based methods C1, C2 and C3. Furthermore, the binary methods C1, A1 and A1+ result in relatively large areas without any assigned assets, since these areas were defined as uninhabitable. Method A1+ takes different residential building densities within the inhabitable area into account, so that the distribution of the residential building asset value could be further differentiated than with the method A1. In contrast to the binary approach, the more complex methods C2, A2 and C3 prorate the asset values to several LULC classes leading to less area without any asset share.

The empirical sampling methods C2 and the regression method C3 result in a similar distribution pattern with minor differences in regard to area boundaries, which are due to the different reaggregation of the original CLC classes in the beginning of the disaggregation process.

4.2 Validation of the disaggregation methods

For all disaggregation methods besides method A1+ a statistical quality assessment as described in section 2.5 was performed , i.e. the estimated residential building numbers of 114 constituencies were compared with the building numbers provided by INFAS GEOdaten (2005). Table 5 lists common error statistics for the analysed disaggregation methods. The mean bias error (MBE) reveals that over- and underestimation of the residential building number is equally present in all applied methods, i.e. there is no tendency of a general error in either direction. Both, the mean absolute error (MAE) and the root mean squared error (RMSE), decreased significantly by disaggregation in comparison to the uniform distribution without disaggregation. This decrease amounts to 42-43% regarding the CLC-based methods. The application of the ATKIS-based methods A1 and A2 leads to an even higher reduction by 64 and 58%, respectively. The MAE and the RMSE suggest that there is no significant difference in quality between the three CLC-based methods. The ATKIS-based binary method A1 shows a lower MAE and RMSE in contrast to the empirical sampling method A2.

The MRE amounts to 10% and less for all disaggregation methods. However, some more interesting results arise from the frequency distribution of the MRE for all 114 constituencies (Fig. 7).

A uniform distribution of the number of residential buildings without any disaggregation produces considerable underestimation in half and considerable or even extreme overestimation in another third of all considered constituencies. The application of any of the five disaggregation methods helps to reduce the number of both underestimated and overestimated constituencies. Highest reductions can be achieved by the ATKIS-based disaggregation methods A1 and A2, leading in both cases to satisfactory estimations in more than two thirds of all constituencies.

Regarding the CLC-based disaggregation methods, the binary method C1 is slightly outperformed by the more complex methods C2 and C3. If method C1 is used, an underestimation of the residential building number of 100% (MRE) is caused in several constituencies. These constituencies are considered completely uninhabited, although they do contain some settlement areas. This is due to the low resolution of the CLC data set, neglecting land use areas smaller 25 hectares. Therefore, the residential building number is underestimated by 100% in all constituencies characterised by small settlement patterns (e.g. single farms or tiny villages), exclusively (Fig. 4). This problem is solved by using the disaggregation methods C2 or C3 since they consider more than two CLC classes as inhabitable and assign a certain percentage of the residential building number to agricultural and forested land cover classes as well.

On the other hand all three CLC-based methods suffer likewise from a considerable and extreme overestimation in many constituencies. This can be explained by another major weakness of the CLC data set caused by its low resolution: If several smaller areas of the same land use class (e.g. residential areas) are situated close to each other, but separated by areas of other land use classes (e.g. rivers of less than 100m width, national roads, industrial areas), the small areas will be aggregated into a single big area (Fig. 4). This led to an overestimation of the residential area and therefore as well of the number of residential buildings in some constituencies, irrespective of the chosen CLC-based disaggregation method.

It is obvious that overestimation can only be reduced significantly by the use of land cover data with a higher resolution. However, even the best performing ATKIS-based method A1 still produces some overestimation in 16% of all constituencies. This might be explained by two aspects. At first, the chosen ATKIS object type "areas of mixed use" (ATKIS code 2113) covers not only residential areas, but also rural built-up areas with agricultural and forestry plants as well as areas used for administrational and commercial purposes within cities. Hoping to resolve this shortcoming, method A2 considers another three ATKIS object types as relevant for residential uses and derives appropriate percentages of the residential building number. Surprisingly, this more sophisticated method A2 does not further improve, but even decreases the accuracy of the estimation compared to the binary method A1. This might be due to regional differences of the derived percentages (Table 3), especially in industrial and commercial areas, but also due to the heterogeneity of the most relevant ATKIS object type "areas of mixed use" (ATKIS code 2113). Whereas "areas of mixed use" within city centres usually contain residential buildings combined with small shops and enterprises, "areas of mixed use" in rural areas can be characterized as undeveloped areas with few residential buildings and agricultural and forestry plants.

Another reason for the overestimation of building numbers by the ATKIS-based binary method A1 might be that different building densities within the communal residential area are not considered. For example, there is a big difference between loosely built one-family-house-areas in the outskirts and densely built multi-storey building areas in the city centre. Therefore, method A1+ was developed leading to a higher degree of differentiation, especially within the inner-city residential area (Fig. 6). Unfortunately, this method could not yet be properly validated due to a lack of even more detailed building data on the micro scale within the constituencies.

4.3 Influence on estimated flood losses

The disaggregated asset values were used to estimate residential building losses that occurred during the flood event in August 2002 as described in section 3. Absolute losses to residential buildings [EUR] were calculated by four loss models for 19 communities using asset values disaggregated by methods C1, A1, A2, C2, C3 and for seven communities using asset values disaggregated by method A1+. Since the official repair costs in the study area (SAB 2005) vary in a wide range between about 100,000 Euro (municipality of Ebersbach) and 77,000,000 Euro (municipality of Eilenburg), the relative error was chosen to assess the influence of different disaggregation methods and different loss models on the quality of loss estimation. The box-and-whisker diagrams in Fig. 8 show the respective error ranges. For purposes of clarity extreme values and outliers are only shown up to a relative error of 700%, while the number of values higher than 700% (X) have been added below the diagram.

It is obvious that the large errors and especially the wide error range that occur if no disaggregation of the asset values is performed can be decreased with any of the chosen disaggregation method and for all loss models. The application of method A1 leads to the highest containment. Second best are the results of the loss estimation based on asset values disaggregated by the empirical sampling method A2. The loss estimations on the basis of the three CLC-based disaggregation methods C1, C2 and C3 show no significant difference.

Thus, in summary, the results of our former validation based on the building numbers (section 4.2) can be corroborated.

Besides, specific characteristics of the different loss functions and loss models become evident. The MURL-function constantly underestimates the flood losses by 50% and more in all communities and hardly shows any reaction to differently disaggregated asset values. This can be explained by the gently rise of the linear curve of this function (Fig. 5), where differences in the inundation depth have little influence on the results. Apel and others (2009) observed similar underestimations of losses using the MURL-function and draw the conclusion that the MURL-function, developed for applications at the river Rhine, is not suited for an application in the Elbe catchment.

The ICPR-function and the loss model $\mathrm{FLEMO_{ps}}$ show similar results. In general, both tend to slightly underestimate the losses. However, the error does not reach the same extent as the MURL-function. Apel and others (2009) noticed that the additional consideration of the damage influencing factors contamination and precaution within the advanced loss model $\mathrm{FLEMO_{ps}}$+ led to better results when estimating the residential building losses of the 2002 flood in a test municipality at the river Mulde. However, due to missing information on these additional influencing factors in the study area, the results of Apel and others (2009) could not be verified here.

The HYDROTEC-function shows a significant tendency to overestimate the residential building losses due to the 2002 flood in our study area. However, in combination with the disaggregation method A1 an overestimation of about 100% occurs in two communities only. Furthermore the position of the median indicates a balance of over- and underestimation for this combination.

In order to examine a further increase in the quality of the loss estimation based on asset values disaggregated by method A1+, which uses census data on constituency level, residential building losses were calculated for seven communities (Table 1). Due to the small number of observations the following results can only offer a first tendency and should be validated in future research. For purposes of clarity extreme values and outliers are only shown up to a relative error of 100%, while the number of values higher than 100% (X) have been added below the diagram.

The box-and-whisker-diagrams in Fig. 9 illustrate an even stronger containment of the variance of the relative error when using the disaggregated asset values of method A1+ in comparison with method A1. Thus, the general characteristics of the loss models described above become even more evident. The ATKIS-based extended binary method A1+ seems to be the most suitable approach for residential building asset disaggregation for flood loss modelling. However, since this evaluation is only based on six communities, further validation and research is necessary.

In summary, it has to be concluded that the use of disaggregated asset values increases the quality of flood loss estimations, especially when applying ATKIS-based disaggregation methods. However, the difference between the estimated residential building losses and the official flood repair costs is still very high in many of the analysed communities. Since loss estimation represents a complex process, which requires numerous input data, different reasons can be identified for this high uncertainty: First of all, the simple loss functions of the MURL, the ICPR and HYDROTEC do not consider other influencing factors besides the inundation depth. Even the more complex loss model FLEMO_{ps} disregards the influence of important factors like contamination and precaution. Secondly, the inundation depths of the 2002 flood provided by Grabbert (2006) are based on a straightforward calculation method, not considering any hydrodynamic features like flow direction, flow velocity or shear resistance. Dike breaches, which played an important role at the river Mulde during the flood event in 2002, were neither incorporated. Therefore, future analysis should include more detailed hydraulic modelling. At last, the quality of any loss estimation can only be assessed by reliable official loss data. Since flood losses are hard to record directly, they have to be estimated via compensation and insurance payments, donations and other financial aids keeping an uncertainty which can not be neglected. However, standard procedures are rare for this task.

5 Conclusions

In order to assess the quality of different disaggregation methods within the mesoscale flood loss estimation, six disaggregation methods were successfully applied, using European CORINE land cover data and data from the German ATKIS digital basic landscape model to distribute residential building assets. As one result, maps illustrating the residential building density can be presented. They reflect the varying degree of differentiation between the applied methods. These maps can be used as input data for the estimation of building numbers and assets at risk. The results of the disaggregation processes were validated with the help of census data on the constituency level.

From the validation it has to be concluded that the common ATKIS-based binary method (A1) leads to the most accurate asset distribution. There is some evidence that the additional use of building data on the constituency level (method A1+) might result in even lower uncertainties. However, the latter method can only be applied in larger, densely populated communities which are further subdivided into several constituencies. Thus, the extended binary method A1+ is not applicable to many sparsely populated rural areas in Germany. Due to the coarse resolution of the CORINE land cover data all CLC-based disaggregation methods result in higher errors than the ATKIS-based methods. However, the CLC data set has two important advantages in comparison to the ATKIS data set that legitimate its use for disaggregation purposes: It is easier to incorporate in a Geographic Information System and it can be obtained not only for the German territory, but for whole Europe making transboundary analyses easier and more reasonable. This is important with regard to the new EU flood directive (EU 2007).

In regard to the complexity of the different disaggregation methods it has to be stated that the development and application of more sophisticated and time-consuming algorithms like the empirical sampling and the regression method did not lead to a significantly higher degree of accuracy in the distribution of residential building assets. Nevertheless it might be worth analysing the influence of empirically based disaggregation methods for other sectors like industry, trade and commerce since binary methods on the basis of CORINE and ATKIS land cover data are difficult to apply to these sectors.

Concerning the influence of the different disaggregation methods on the quality of flood loss estimations, the containment of the error variance can be described as the main effect of any disaggregation approach. Thus, the specific characteristics of the different loss functions and loss models become more evident. The degree of containment depends on the choice of the disaggregation method and corroborates the results of the validation on basis of building numbers. The estimated building losses imply that more effort should be put into the consideration of other loss-influencing factors like building type and quality, degree of contamination or precautionary measures within the loss models.

Finally, is has to be concluded from this case study that the estimation of residential building losses still suffers from a high uncertainty, even when the best disaggregated asset values are used. Future research may, therefore, lead in two directions: First, the incorporation of micro-scale building data within the disaggregation process (method A1+) should be further analysed and validated. Secondly, the different disaggregation methods should be applied and assessed for buildings and inventory of other sectors like industry, trade and commerce, agriculture and forestry or the service sector. Additionally, further research should include the development of more sophisticated and transparent loss and hydraulic models. Thus, an important contribution to an all-encompassing flood loss estimation would be made.

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Tables

Table 1: Overview of the applied disaggregation methods and number of samples (municipalities or constituencies) for disaggregation, validation and loss estimation

disaggregation method	abbr.	LULC data set	number of municipalities (*constituencies*) used for		
			disaggregation	validation of disaggregation	loss estimation
no disaggregation	-	-	21	7(*114*)	19
binary method	C1	CORINE Land Cover	21	7(*114*)	19
	A1	ATKIS Basic DLM	21	7(*114*)	19
	A1+	ATKIS Basic DLM	9	-	7
empirical sampling method	C2	CORINE Land Cover	21	7(*114*)	19
	A2	ATKIS Basic DLM	21	7(*114*)	19
regression method	C3	CORINE Land Cover	21	7(*114*)	19

Table 2: Percentages of areas of residential buildings per CORINE land cover class in two German federal states and generalized weights for the disaggregation procedure (building density fraction)

CORINE land cover class	**CLC-Code**	**Saxony-Anhalt**	**Mecklenburg-Western Pommerania**	**Generalised building density fraction d_j**
Residential areas	111, 112	61,7%	53,9%	60%
Industrial and commercial areas	121, 122, 123, 124	6,0%	1,6%	4%
Arable land	211	25,3%	35,0%	30%
Pastures and meadows	231, 243	2,8%	4,7%	4%
Forests and natural vegetation	311, 312, 313, 321, 322, 324	2,0%	2,7%	2%
Other land cover types	all others	2,2%	2,0%	0%
Sum	---	100,0%	100,0%	100%

Table 3: Percentages of areas of residential buildings per ATKIS object type in two German federal states and generalized weights for the disaggregation procedure (building density fraction)

ATKIS object type	**ATKIS-Code**	**Saxony-Anhalt**	**Mecklenburg-Western Pommerania**	**Generalised building density fraction d_j**
Residential areas	2111	4,20%	18,64%	13%
Industrial and commercial areas	2112	19,22%	2,11%	11%
Areas of mixed use	2113	73,49%	76,75%	74%
Areas of special use	2114	3,00%	2,46%	2%
Recreational areas	2202	0,09%	0,05%	0%
Sum	---	100,00%	100,00%	100%

Table 4: Quasi-median population density U_i per CORINE land cover class and municipality (modified from Gallego and Peedell 2001)

CORINE land cover class *i*	**CLC-Code**	**Quasi-median population density U_i [Inhabitants/km^2]**		
		Stratum 1	Stratum 2	Stratum 3
Continuous urban areas	111	1445.9	947.4	0
Urban areas	112, 121, 122, 123, 124, 141, 142	619.1	622.4	0
Arable land	211	10.2	17.4	32
Permanent crops, heterogeneous agricultural areas	221, 222, 242	15.4	30.9	69.3
Pastures	231, 243	5.1	11.3	22.8
Forest & natural vegetation	311, 312, 313, 321, 322, 324	3.3	5.2	8.6

Table 5: Error statistics for five applied disaggregation methods, showing the discrepancy between the estimated and the reported number of residential buildings in 114 constituencies

Error measures	**Disaggregation method** **no**	**C1**	**C2**	**C3**	**A1**	**A2**
minimum of the absolute difference	-316	-282	-310	-201	-166	-197
maximum of the absolute difference	742	387	456	431	212	303
range of the absolute difference	1058	669	766	632	378	500
mean absolute error (MAE)	140	81	80	79	51	59
mean bias error (MBE)	0	0	0	0	-1	0
root mean squared error (RMSE)	190	109	110	108	69	82
mean relative error (MRE) [%]	9	0	10	9	7	10

Figures

Fig. 1: Basic elements of relative flood loss estimations

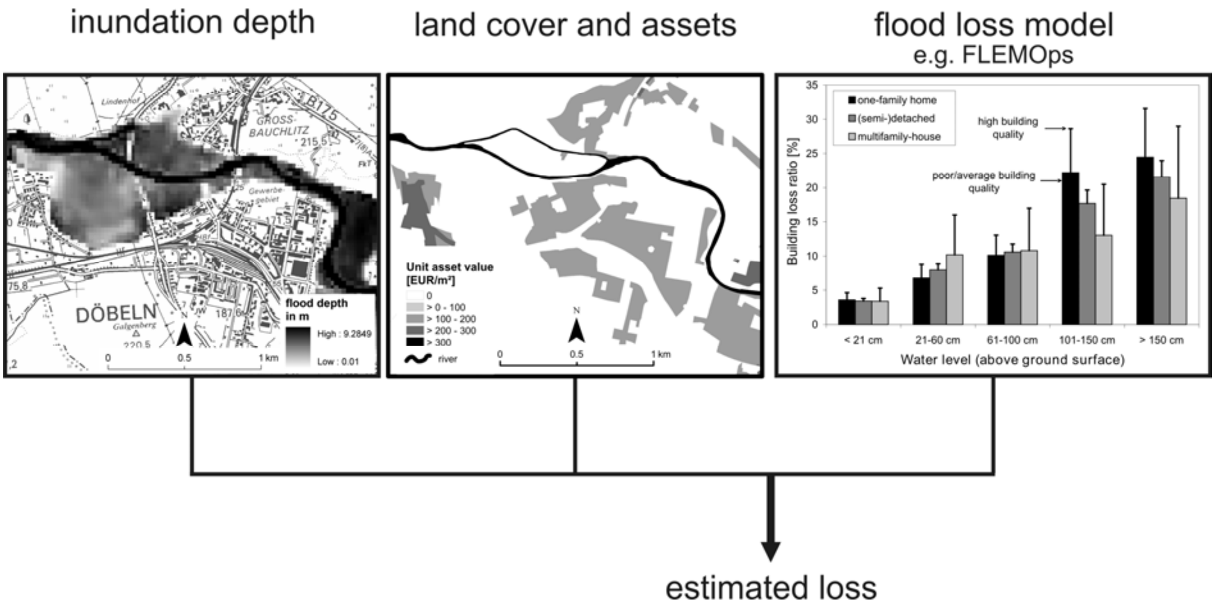

Fig. 2: Location of the study area and spatial distribution of the applied methods

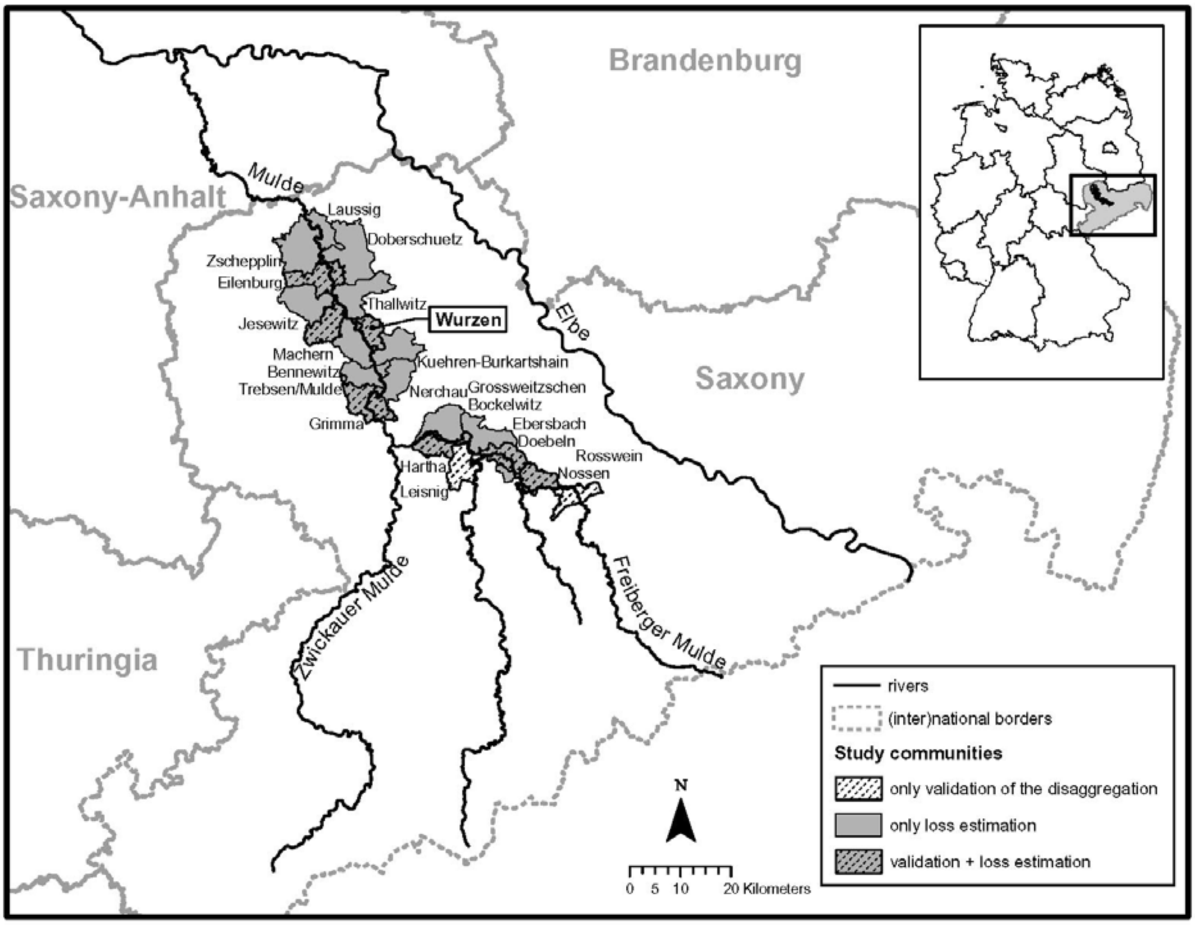

Fig. 3: General flowchart diagram for disaggregation processes (modified from Hultgren 2004)

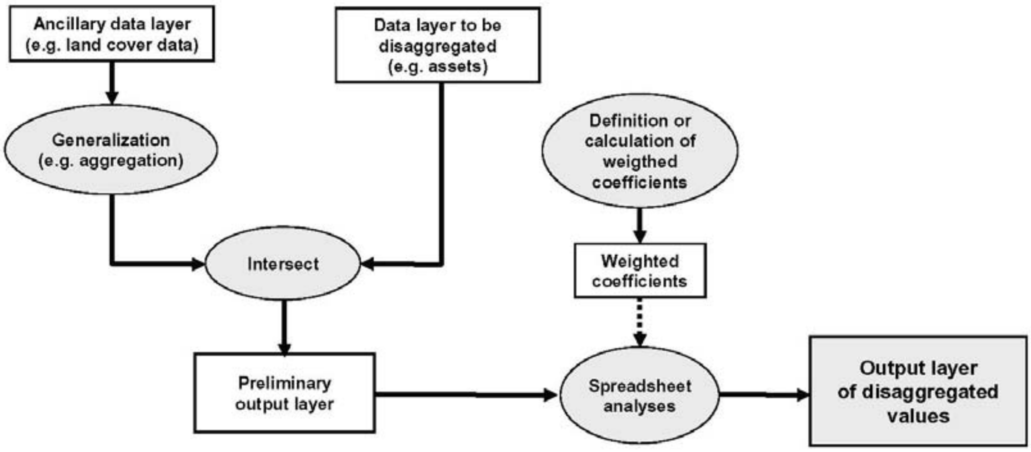

Fig. 4: Comparison of the residential area of the ATKIS- and the CLC data set (detail of the municipality of Hartha)

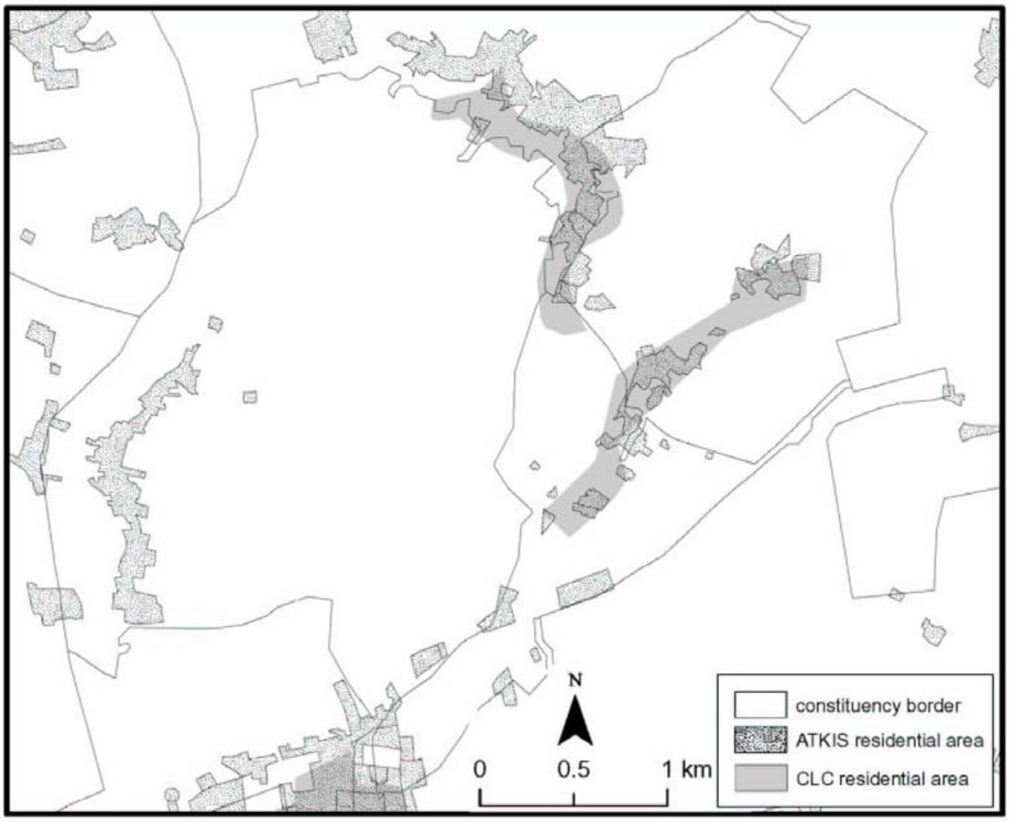

Fig. 5: Loss ratio curves of different meso-scale loss functions and the meso-scale loss model FLEMOps

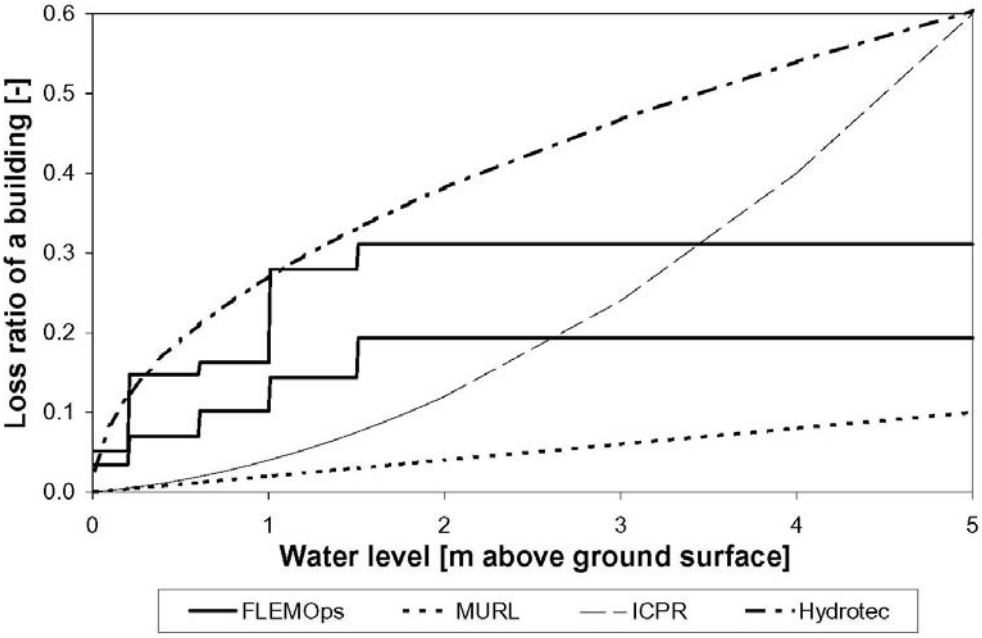

Fig. 6: Unit residential building asset values [EUR/m²] in the municipality of Wurzen as a result of the six applied disaggregation methods using either CORINE land cover (C) or ATKIS basic DLM (A) as ancillary data (see Fig. 2 for geographical position)

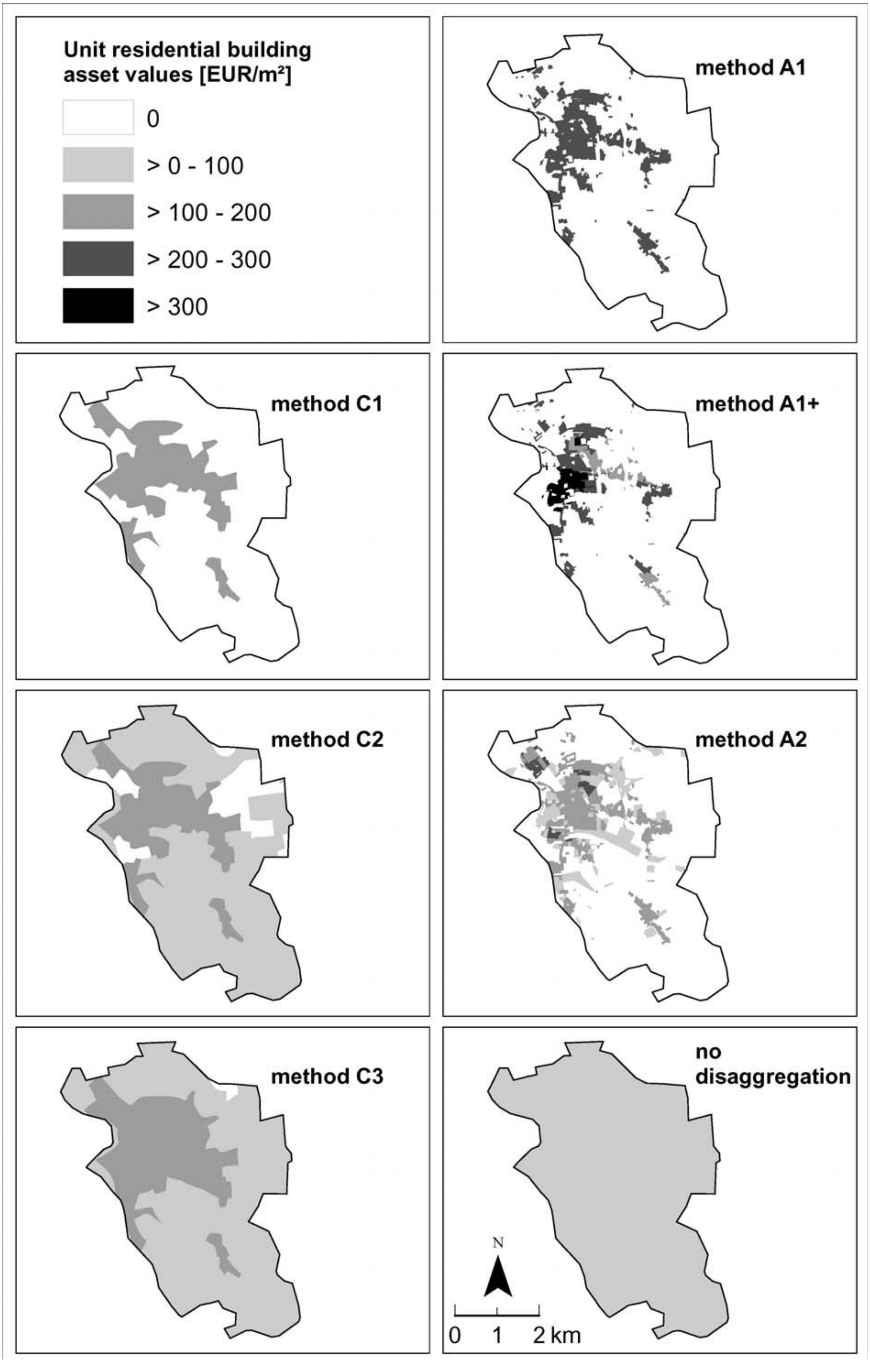
Unit residential building asset values [EUR/m²]
0
> 0 - 100
> 100 - 200
> 200 - 300
> 300
method A1
method C1
method A1+
method C2
method A2
method C3
no disaggregation
N
0
1
2 km

Fig. 7: Frequency distribution of the mean relative error (MRE) of the residential building number in 114 constituencies; white: estimation satisfactory (-49% ≤ MRE ≤ +49%); grey: considerable under- or overestimation (-99% ≤ MRE ≤ -50% or +99% ≤ MRE ≤ +50%); black: extreme under- or overestimation (MRE = -100% or MRE ≥ +100%). Figures indicate the absolute number of constituencies with satisfactory estimation, underestimation and overestimation, respectively

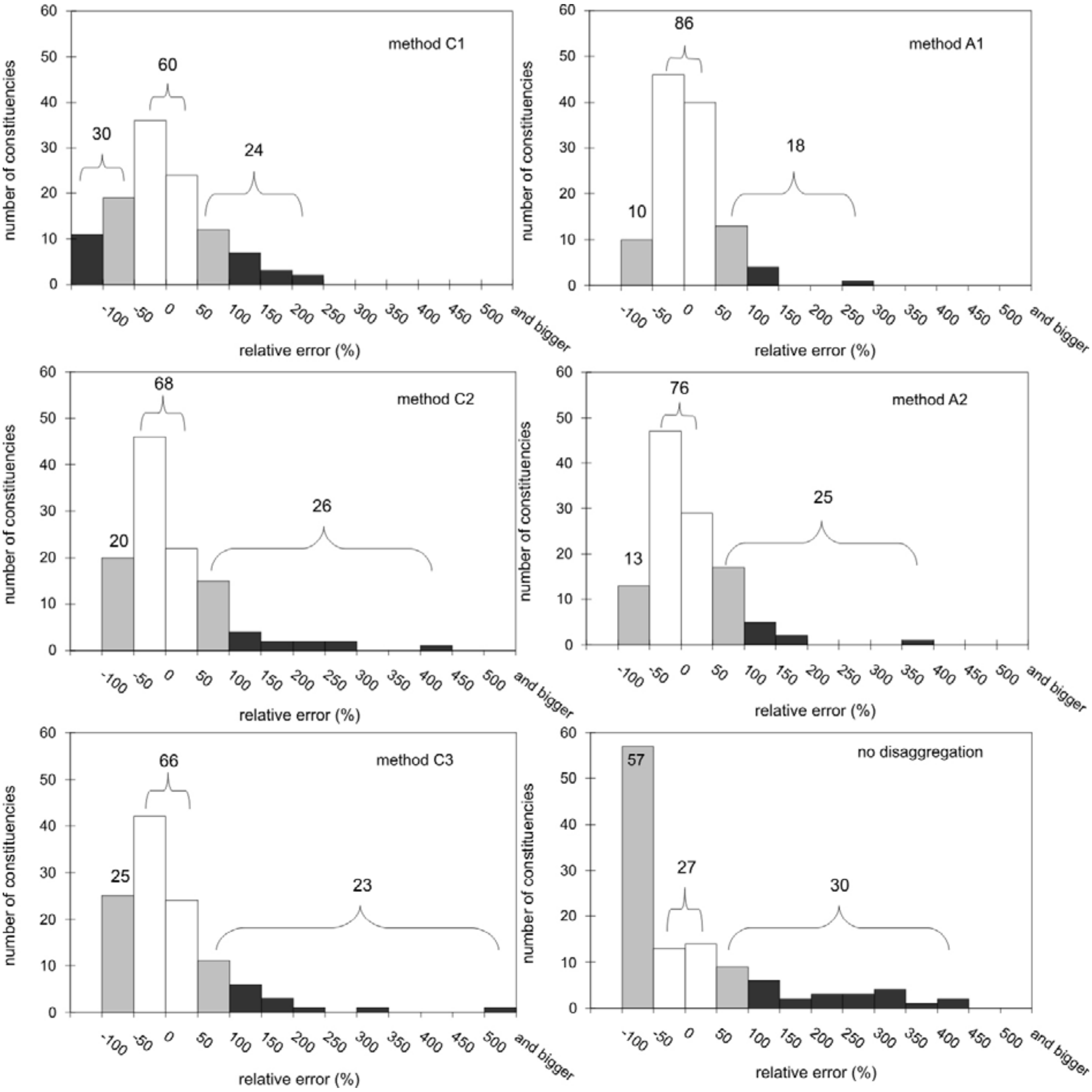

Fig. 8: Relative error [%] of the estimated losses for different disaggregation methods and loss models (*= extreme value, o = outlier). X indicates the number of outliers and extreme values excluded from display for purposes of clearity

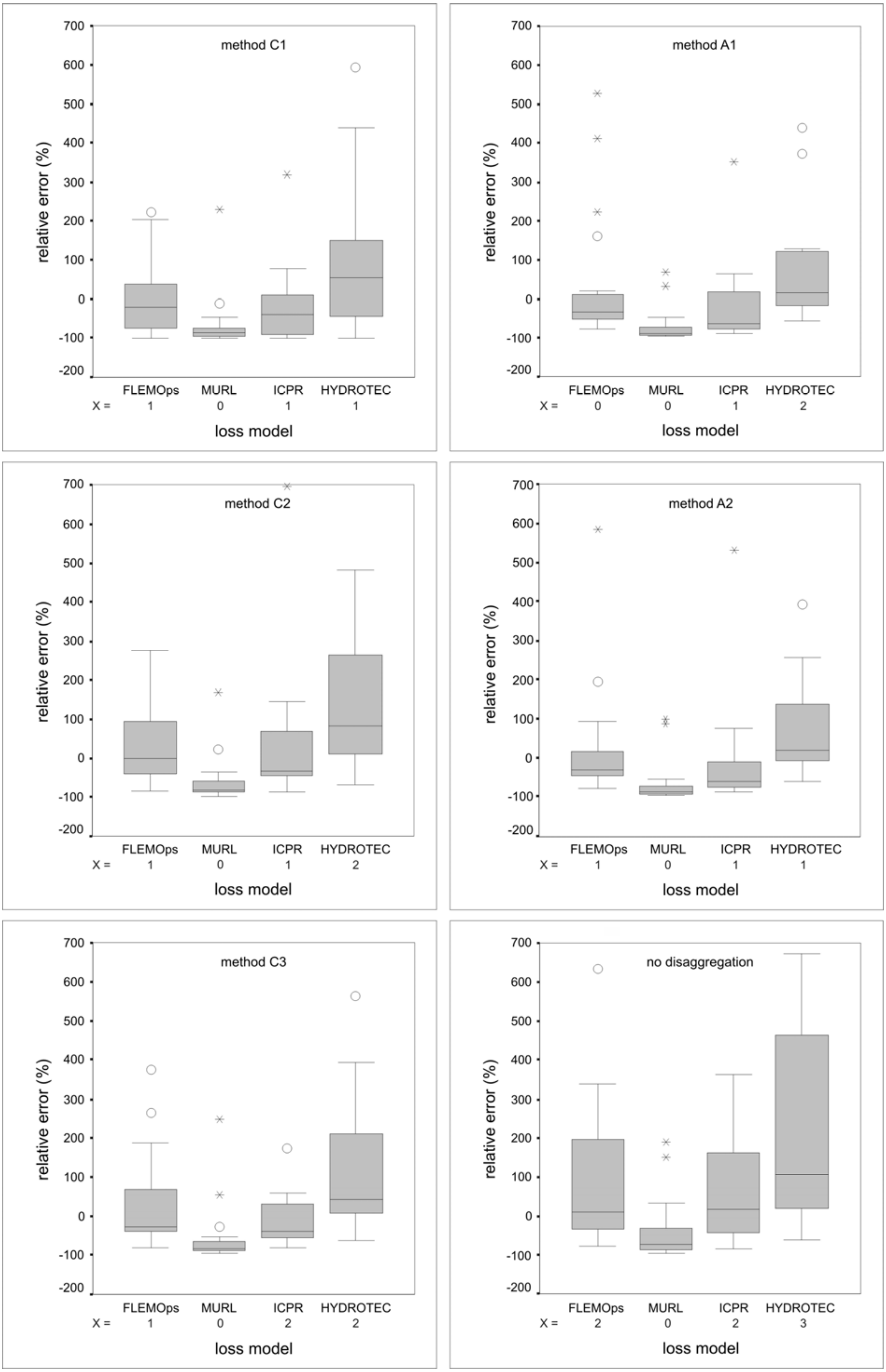
method C1
method A1
method C2
method A2
method C3
no disaggregation
relative error (%)
700
600
500
400
300
200
100
0
-100
-200
FLEMOps
MURL
ICPR
HYDROTEC
loss model
X = 1 0 1 1
X = 0 0 1 2
X = 1 0 1 2
X = 1 0 1 1
X = 1 0 2 2
X = 2 0 2 3

Fig. 9: Relative error [%] of the estimated losses for the disaggregation methods A1 and A1+ (*= extreme value). X indicates the number of outliers and extreme values excluded from display for purposes of clearity