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# The Comparative Analysis of the Adaptability Level of Municipalities in the Nysa Kłodzka Sub-Basin to Flood Hazard

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**Abstract:** A municipality is a basic local government unit (LGU) in Poland. It is responsible for the safety of its citizens, especially in circumstances of flood hazard. A municipality is a unique social-ecological system (SES), distinguished by its ability to adapt to flood hazard. It is impossible to specify the conditions a municipality has to reach to achieve the highest adaptability to flood hazard, however, it is possible to assign a level of adaptability to a municipality, one that corresponds to the position of a given municipality among the population of assessed municipalities threatened by floods. Therefore, a tool was developed to rank municipalities by their adaptability on the assumption that the assessment of municipal adaptability was influenced by 15 selected features. The research was carried out using data from the period of 2010–2016 for 18 municipalities-SESs located in the Nysa Kłodzka sub-basin. It was indicated that municipalities located in the higher course of the river possess higher levels of adaptability. At the same time, the size of a flood stands for each municipality position with regards to the synthetic adaptability index (SAI).

**Keywords:** adaptability; socio-ecological system; flood risk; municipality; Nysa Kłodzka sub-basin

## 1. Introduction

The increasing occurrence of hazardous natural phenomena that have severe consequences, such as floods [1–3], is forcing the development of management tools that help minimize the adverse consequences of such phenomena. These tools may be helpful when making decisions in conditions of uncertainty resulting from the randomness of this hazardous phenomena [4].

Currently, the key role in the analysis of the adaptation of SESs to climate change, including the increasing frequency of natural phenomena such as floods [5], is the assessment of resilience [1,6,7]. Therefore, the flood hazard assessment of a socio-ecological system (Figure 1) is based on the assumption that every system is characterized by the scale of exposure of its elements to floods (as presented on flood hazard maps, etc.,) [8] and its vulnerability to this phenomenon [6,7,9–13]. Floods as a factor that disturbs the functioning of an SES may display diverse intensity at a given probability [2,4,14]. The exposure refers to all elements of an SES that are vulnerable to floods and located in the flood hazard area [4,15]. The sensitivity involves the characteristics (features) of an SES's elements exposed to flood hazard, which make floods a cause of various losses [16,17]. Both the exposure and the sensitivity of the elements of the system at risk of floods affect the scale of potential loss. The vulnerability is a result of the volume of potential flood losses and its resilience influencing the reduction of these losses [17]. In turn, a system's resilience to flood hazard is shaped by its durability, as well as its capability to adapt and to transform (this happens when adverse consequences and the scale of a cataclysm force a system to recreate its basic functions, i.e., to adapt) [18–21].

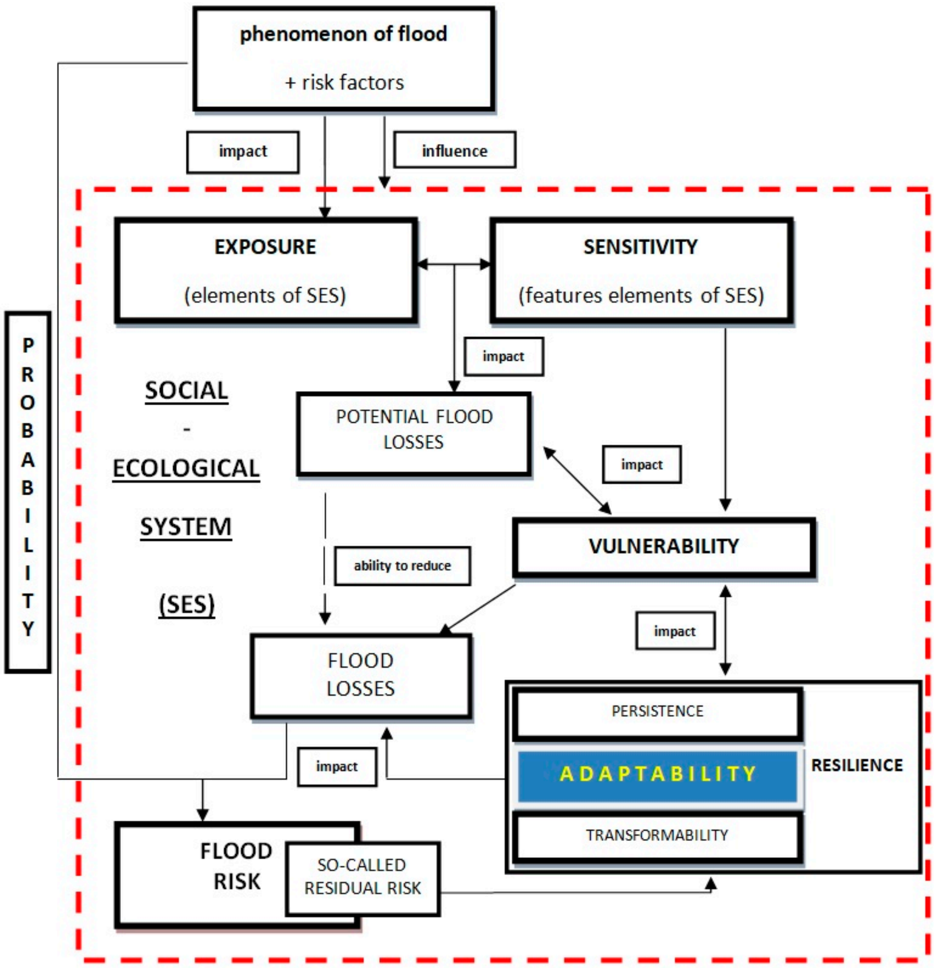


**Figure 1.** Algorithm for assessing the flood risk as a social-ecological system at risk of floods, indicating the role of a system's adaptability in risk reduction. Source: [19].

In Poland, the major natural hazard that may take the form of a cataclysm is a river flood [2,17,19,22]. As indicated by Pniewski and his team, the river flood hazard increases over years, and it is therefore necessary to develop a flood risk management system [2]. Although the last severe floods in Poland took place in 1997, 2001 and 2010, the fundamental flood protection infrastructure has not been restored yet in many regions of Poland, despite strong efforts [17,23]. One can therefore accept the notion that the resilience of the regions of Poland threatened by floods was not sufficient enough to accommodate enormous amounts of flood waters, because the adverse consequences for society and particular sectors of the economy were felt long after the flood waters subsided. This observation questions the state of the adaptability of Polish local government units to flood hazard [17,19].

In Poland, the provisions of the so-called 'flood directive' (i.e., Directive 2007/60/EC) [24] have been implemented since 2010 by the conducting of the Initial Flood Risk Assessment (IFRA), the preparation and public distribution of Maps of Flood Hazard (MFH) and Maps of Flood Risk (MFR) [8] and the introduction of Flood Risk Management by the Polish Parliament (FRMP) [17,24,25]. These documents and the current ongoing work to update them indicate that the national policy on flood risk management, understood as the sequence of decisions and actions (or lack of them) in the field of flood protection, is systematically being formed in Poland [1,23]. The update of IFRA, MFH, MFR and FRMP takes place in six-year planning cycles. Currently the IFRA verification and the MFH and MFR update is in process in Poland. This impacts the identification of areas of new river flood hazard that were not subject to hydraulic modelling in the first planning cycle to designate flood hazard zones [8].

The policy of flood risk management in Poland is implemented on every territorial level and meets the prerogatives assigned to the relevant authorities on the level of state, voivodeship, county and municipality [1,17,23], as well as water management regions [26]. Although the state and regional policy for shaping flood risk is usually carried out within a catchment, it is the municipality, as the basic local government unit in Poland, that is aware of flood risk level in its own territory and has to take up appropriate actions in order to protect itself against an identified threat [12,17,27]. The municipality is undoubtedly the subject (beneficiary) of the state and regional policy that shapes flood risk, but it is also the creator of the local policy on flood risk in its own territory, especially by way of adaptive actions, which are to make it immune to current and expected flood hazards. Disastrous floods cause serious disturbances in the functioning of a municipality as a SES [1,12,17,22]. The system loses its effectiveness and efficiency in terms of achieving its goals. Thus, the municipality-as-SES is supposed to build adaptive capital based on its own resources and shape its capability to adapt to identified and expected disturbances [19,27].

The aim of this article is to present a management tool which enables effective management in municipalities, understood as socio-ecological systems (SES), by way of the process of shaping municipalities' adaptability to flood hazard. The process of a municipality's adaptation to flood hazard may be improved by comparing it to other subjects threatened with flood. Such comparisons may be possible due to the introduction of 15 non-observable statistical features of a municipality-SES which determine its adaptability to flood hazard [19].

The conducted analyzes allowed the research questions to be answered:

Which of the 15 selected statistical features of the municipality-SES that influenced the assessment of adaptability:

1. distinguished the municipalities with the highest and the lowest adaptability assessment?
2. were characterized with the largest or the smallest variability?
3. adopted values distinguishing a municipality that can be a role model for other municipalities.

## 2. Features Which Determine the Adaptability of a Municipality-as-SES to Flood Hazard

It is necessary to highlight that the adaptation of units, such as municipalities and entire water regions, to flood hazard was not analyzed in the FRMP developed in Poland [17]. This means that the Polish Legislator assumed (wrongly, in the authors' opinion) that their adaptability level to flood hazard is the same across the entire area of the country [19]. Yet, it is hard to accept that all municipalities in Poland have comparable resources which they can use to limit the adverse consequences caused by floods, as well as during rebuilding the damage after a cataclysm subsides [16].

When assessing the adaptability level of Polish municipalities, it is necessary to note that:

- The municipality is a socio-ecological system (SES), because it is two interdependent systems, a social system and an ecological system, whose functioning is conditioned by numerous connections [17,19,28]. The aim of such an SES is social development, including the durability of the ecological system. The implementation of this aim can be achieved by shaping the attitudes and social needs and satisfying them, as well as by providing the opportunities to implement ecosystem services [19,29].
- The adaptability of a municipality-as-SES threatened with floods is a (current) capability of the system to limit the adverse consequences of floods. It results from the adaptive potential of the system, that is the quality and quantity of the resources possessed by the system, which are useful for conducting actions in the event of a cataclysm and after it subsides. It also results from the adaptive capability of the system, that is its capability to activate these resources (adaptive potential) [19,29].

- The current adaptive capability and adaptive potential of a municipality-as-SES, and in consequence its adaptability, can be described as the result of a set of SES's attributes/non-observable statistical features [19,29,30]. These features stimulate or break the process of shaping a municipality's capability to keep its effectiveness and efficiency in an event of disturbance (the phenomenon of flood).

Therefore, the catalog of 15 features of an SES have been proposed, and ordered into four categories [19,30]. On the one hand, these features (Figure 2) are a set of determinants which define the effectiveness of the ongoing SES adaptation to floods occurring in the past and expected in the future. These features also constitute a set of information on an SES, which are useful for assessing its current adaptability to flood hazard. Selected statistical features of a municipality-as-SES describe its adaptive potential (the quantity and quality of the resources) and adaptive capability (the capability to activate these resources) [19].

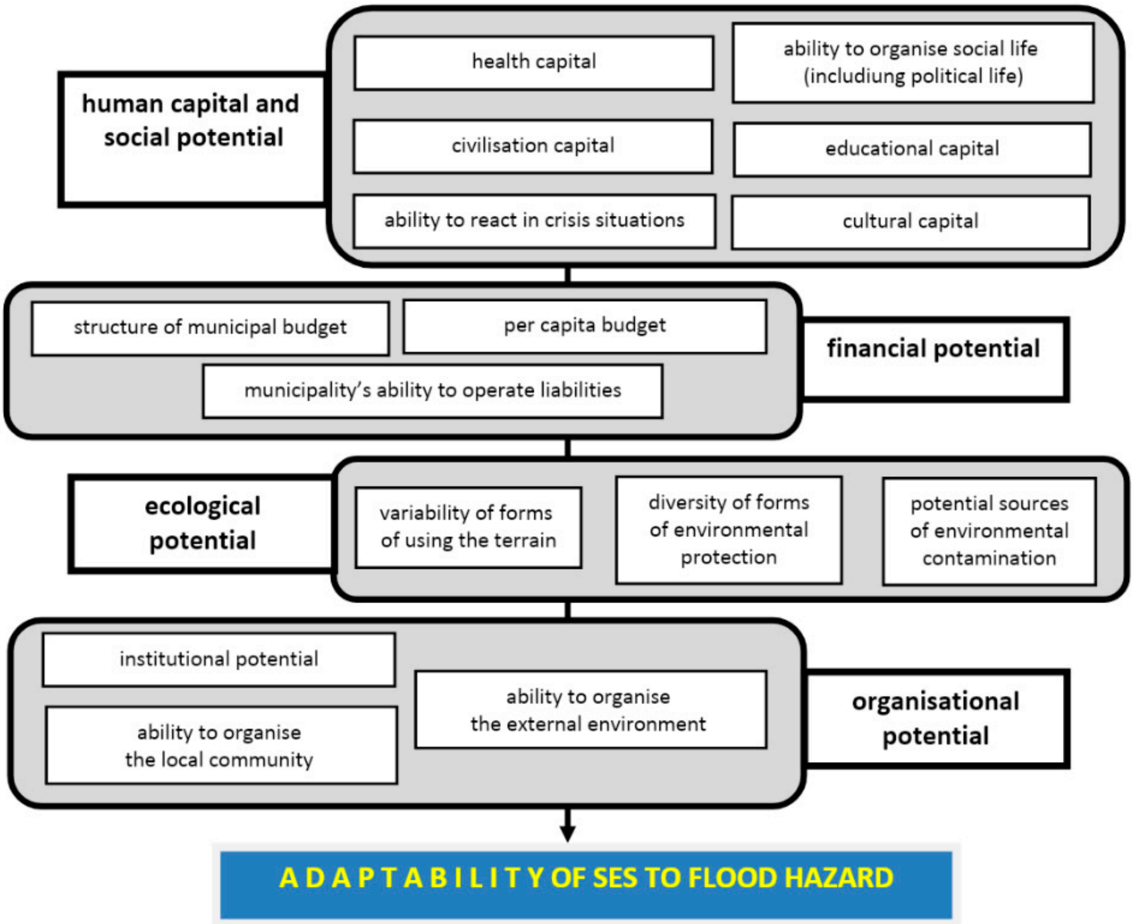


**Figure 2.** Features affecting the adaptability of a municipality as a socio-ecological system (SES) [source: own work].

Analysis with regard to the method of defining these authorial features has become the subject of papers [19,30,31].

## 3. Materials and Methods

### *3.1. Research Area*

The Flood Risk Management Plans (FRMPs) have identified problem areas in Poland that are characterized by high flood risk. They require urgent intervention and are called the "hot spots".

One such region in Poland encompasses areas located along the course of the Nysa Kłodzka river. The river has a length of over 182 km and is the left bank tributary of the central Oder river. It passes through the following geographical areas: Kłodzka Valley, Sudetic Foothills and Silesian Lowland. In the region of the Kłodzko Valley, flood risk is very high.

In the area of the conducted studies, not only were the 7 municipalities located in the abovementioned hot spots included, but altogether 18 municipalities located in the Nysa Klodzka catchment (from the spring in the Śnieżnik Massif down to its mouth in the valley of Lewin Brzeski). Within the borders of these municipalities, areas of special flood hazard were identified and Maps of Flood Risk (MRP) and Maps of Flood Hazard (MFH) were developed. The research area included 7 rural municipalities: Kłodzko, Kamieniec Ząbkowicki, Łambinowice, Skoroszyce, Popielów, Olszanka and Skarbmierz; 10 rural-urban municipalities: Międzylesie, Bystrzyca Kłodzka, Bardo, Ziębice, Paczków, Otmuchów, Nysa, Niemodlin, Grodków and Lewin Brzeski, as well as one urban municipality—Kłodzko. The abovementioned municipalities became the subject of the study. The object of the study included the adaptability of these municipalities to flood hazard and the territorial spacing of the municipalities' level of adaptability to flood hazard [29,30]. The location of the research area is presented in Figure 3. In turn, spatial distribution of the integrated level of flood risk of this research area is presented in Figure 4.

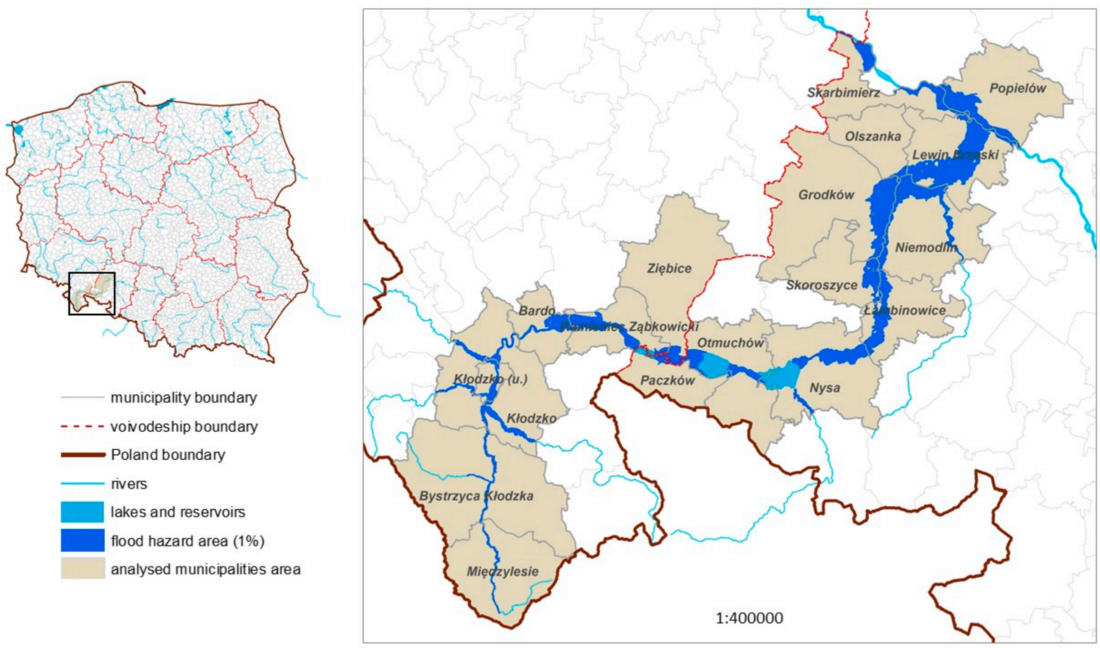


**Figure 3.** Location of the research area—municipalities along the course of the Nysa Kłodzka river [source: own work].

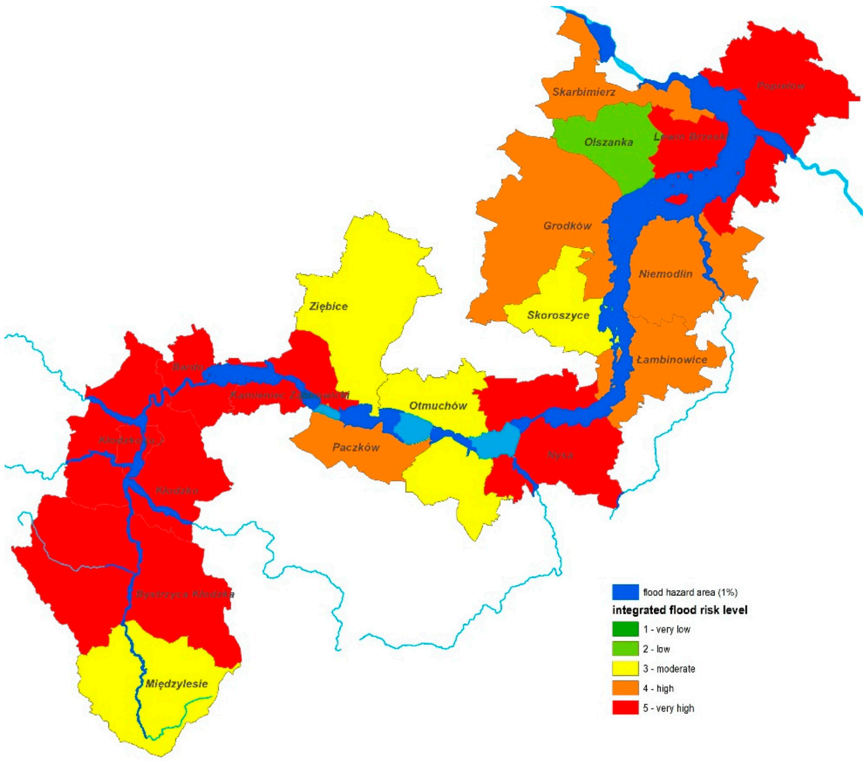


**Figure 4.** Municipalities of the sub-basin of the Nysa Kłodzka along with the assigned level of integrated flood risk set out in FRMP [source: own work].

It is worth underlining that most of the analyzed research area, i.e., Kłodzko Valley along with Kłodzko city, is a beneficiary of the currently implemented project "The Oder Flood Protection Project" within component 2: Kłodzko Valley Flood Protection. It was considered in this project that in order to build stable and sustainable social-economic development of selected areas of the Oder basin, it is necessary to strengthen flood protection [32,33].

The analysis of flood hazard and municipalities' adaptability in terms of the catchment appears to be the best solution [19,30,34]. In particular, flood protective investments implemented in Kłodzko Valley will shape flood risk of the municipalities located in the entire area of the Nysa Kłodzka catchment, and these municipalities will be able to plan their own adaptive actions towards flood hazard. Such a methodological approach also has practical justification as the results of the performed analyses and the developed research tool will support local decision-makers in setting strategic goals for adaptation to flood hazard. It will allow them to indicate these municipalities' features which influence the assessment of their adaptability to flood hazard, as such assessment deviates from the leaders' standpoint in this field and indicates areas requiring corrective actions [30].

### *3.2. Methods*

It was considered while conducting the studies dedicated to developing the method of a municipality's adaptability assessment to flood hazard in Poland [1,17,19,29,30], that the adaptability of the municipality understood as a socio-ecological system (SES) is the result of many features of this system. These features characterize both the resources of the social subsystem (its capability to activate these resources in order to reduce adverse consequences of a flood) and the resources of the ecological subsystem with the capability of reducing the adverse consequences of a flood. In total, 15 features of the municipality have been distinguished (including 12 features of the social subsystem and 3 features of the ecological subsystem) [19,30], which form non-observable measurable statistical features. Therefore, it became necessary to create research procedures allowing for the collection of empirical observations which can be used to assess the municipality's adaptability to flood hazard [29].

In order to describe these 15 theoretical non-measurable statistical features of a municipality-as-SES, which determine its adaptability to flood hazard, a public domain search was carried out in terms of finding such observable variables that would comprehensively allow the diagnosis of these features. These variables were sought in the resources of the Central Statistical Office, including the Statistical Vademecum of the Local Government, and the Local Data Bank. Data obtained from the Supreme Chamber of Nurses and Midwives, the Supreme Medical Chamber and County Sanitary and Epidemiological Stations were also used. Due to these actions, data on 83 observable variables were obtained in the first phase of empirical/quantitative data collection.

During the process of the assignment of the obtained observable variables to particular latent statistical features, the problems of shortage or lack of such variables necessary to describe all characteristics of the municipality-as-SES, which determine its adaptability to flood hazard, were highlighted. Hidden statistical features, for which unsatisfactory numbers of observable variables were collected, were: the features belonging to category K1—Human capital and social potential: D4—the ability to respond to crises and D5—civilization capital; features from the category K2—financial potential: D7—adequacy of the municipality's budget structure to the hazard and D9—adequacy of the municipality's budget per capita and features belonging to the category of features K4—organizational potential i.e.,: D14—the ability to organize local community and D15—the ability to organize the external environment. In order to supplement the list of observable variables for the abovementioned hidden statistical features (7 were defined), a questionnaire was created, adopting the thesis that quantitative research is an effective source of obtaining data with regard to the new observable variables which describe the characteristics of the municipality determining its adaptability to flood hazard [29,30].

Using statistical data from all the mentioned sources, a matrix of averaged values of diagnostic variables was created and became the base for output data for the preliminary assessment of the municipality-as-SES' adaptability to flood hazard. The results of this preliminary assessment of adaptability of municipalities in the Nysa Kłodzka sub-basin are presented in this article [25].

It is necessary to emphasize that at the previous and current stage of studies [29], the authors did not decide on the significance/importance of both non-measurable statistical features describing the SES and the measurable observable variables forming these features, in view of their influence on the assessment of the SES's current adaptability to flood hazard. The same significance was assumed for each of 15 hidden statistical features in the built-up synthetic adaptability index (SAI).

Within the conducted studies, a comparison—so-called benchmarking—was made, which took into account 18 municipalities of the Nysa Kłodzka sub-basin. The benchmark was based on the individual features that influence the adaptability of an SES to flood hazard. The method of developing partial synthetic indicators of the adaptability in relation to the preliminary analyses [25] was modified in order to make the obtained rankings play the role of a management tool. The authors wanted to create a mechanism which could be applied in the process of the assessment of adaptability to flood hazard in relation to particular non-measurable statistical features, which are determinants of adaptability at the same time. The management tool is intended to be a useful form which allows the indication that these latent statistical features (determinants) of particular municipalities-as-SES which, in comparison to other units of local government, require improvement due to "unfavorably standing out".

The research method adopted by the authors is the multidimensional comparative analysis (MCA) linear ordering method [34–37] in its classic and non-standard approach, which is based on a synthetic variable. The MCA methods form a group of statistical methods used for studying complex phenomena, which are directly non-measurable and which characterize identified objects subject to analysis [38]. These objects should form a relatively homogeneous set. During the research, the objects subject to analysis are the 18 municipalities-as-SES located in the Nysa Kłodzka sub-basin. They caught the researchers' attention due to one of their features, of complex nature—the adaptability to flood hazard. The adaptability of a municipality-as-SES cannot be measured directly. Therefore, 15 authorial non-observable statistical features were proposed, describing the municipality-as-SES' adaptability to flood hazard. For this reason, the authors' interest focused on measurable observable variables, characterizing specific non-measurable statistical features of the municipality-as-SES. The observable (diagnostic) variables were also treated as equivalent (Appendix A; Appendix B: Figures A1 and A2). In this sense, the authors of this article use the terms: the feature of the municipality describing its adaptability (non-observable statistical feature); the observable variable (measurable statistical feature, indicator) and the category (category of the municipality's features; category of non-observable statistical features) which refer to the municipality as a social-ecological system threatened by flood (Figure 5).

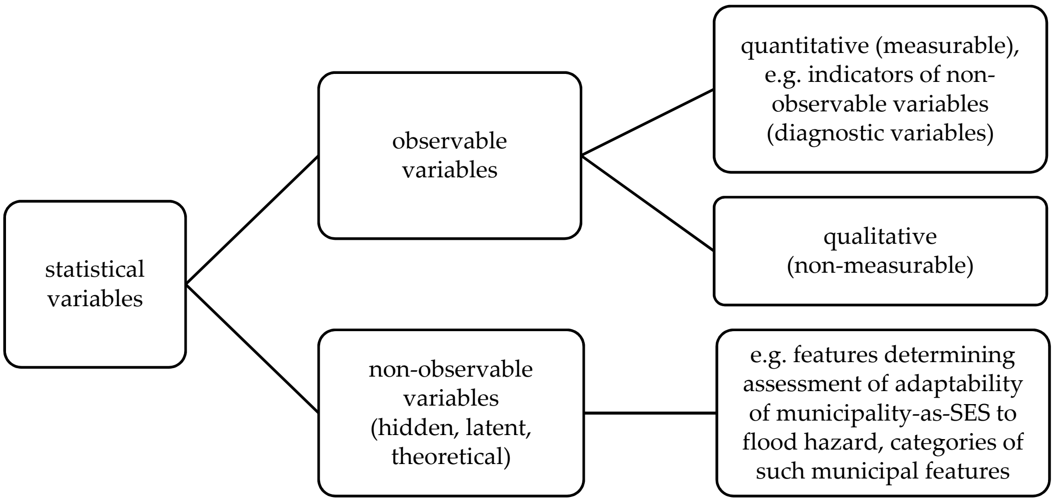


**Figure 5.** Types of statistical variables allowing the assessment of a municipality-as-SES' adaptability to flood hazard [source: own work].

The preliminary comparative assessment of municipalities' adaptability to flood hazard [29] allowed the identification of municipalities characterized by much greater adaptability to flood hazard than other municipalities. Thus, a general view of a municipality's adaptability level was obtained for the period 2010–2016. The collective classification of the considered municipalities became the source of this knowledge. It was created on the basis of the set of indicators of specially developed synthetic variable A the so-called SAI. In this way, a measurer was obtained, for which rising values reflect a higher assessment of adaptability of the given municipality. To build an SAI, the diagnostic variables (indicators) were used. The set of statistical data for the years 2010–2016 was obtained using the abovementioned sources. This is how the set of potential diagnostic variables $X_j, \quad j = 1, \ldots, 110$ containing 110 elements was created, and these variables and the values of these variables were obtained in particular years. The statistical material was preliminarily developed using the complete review method. Then, using arithmetic average, the diagnostic variables were averaged. The structure of the final set of the diagnostic variables was two-stage and was based on the selection of potential indicators. The criteria of selection are mainly of a statistical character. The diagnostic variables were researched for the variability of their observed values, as well as for the mutual linear correlation of indexes, excluding the cases of apparent correlation. As a result of these analyses, out of 110 diagnostic variables 70 were selected and these were characterized by 14 statistical features (out of 15 subject to the analysis) of the municipalities-as-SES located in the Nysa Kłodzka sub-basin, which determine municipalities' adaptability to flood hazard. The ability to react to crisis situations (D4) is the only statistical feature of the municipality-as-SES which was excluded from analyses, because it was diagnosed by variables which absorbed homogeneous results in the population of the municipality in the Nysa Kłodzka sub-basin.

Next, the observable variables (diagnostic variables) were divided into stimulants and destimulants, which results, among other things, from the specifics of the adopted research method—MCA. The authors concluded that in the case of the problem in question, the nominants do not occur. The subsequent stage of work was the normalization of the values of the diagnostic variables by the method of zeroed unitarization, which has a lot of desirable features during the ongoing research [39–43]. Performing data normalization allows the comparison of the values of variables, including the diagnostic variables. Within the normalization and transforming destimulants into stimulants, the diagnostic variables were brought down to a mutual form or mutual character. At the end, the values $a_i$ of the synthetic variables were indicated as the sum of the normalized values of the diagnostic variables. The municipality achieves a higher position in the classification as a greater value is achieved by the synthetic measure—that is, value $a_i$ corresponding to a given municipality (see Appendix B: Figures A1 and A2).

The partial classifications were used in order to benchmark 18 municipalities-as-SES of the Nysa Kłodzka sub-basin with regard to individual non-measurable statistical features determining the SES's adaptability to flood hazard. Thus, the conducted research was based on performing partial qualifications (obtaining partial classifications) of the municipalities in question, where the criterion of classification was the assessment of each theoretical statistical feature affecting the adaptability of particular municipalities to flood hazard. At the same time, the assessment of these features was performed on the basis of a set of values of the specially created synthetic variables. In order to build particular synthetic variables, diagnostic variables describing a given statistical feature were used, i.e., the determinant of the municipality-as-SES affecting its adaptability.

For each of the 14 determinants $D_k$, where $k \in \{1, 2, 3, 5, 6, \ldots, 15\}$, which are the non-measurable features of the municipalities-as-SES affecting its adaptability (the adaptability determinants), the following actions were performed:

- normalized values of the diagnostic variables characterizing $D_k$ were added, obtaining the sum of the form $d_{k,i} = \sum_j z_{ij}$, where $z_{ij}$—normalized value $j$—variable for the $i$ municipality,
- for each $k$, where $k \in \{1, 2, 3, 5, 6, \ldots, 15\}$, normalization of the data $d_{k,1}, \ldots, d_{k,18}$ was performed by the method of zeroed unitarization, obtaining the data $\widetilde{d}_{k,1}, \ldots, \widetilde{d}_{k,18}$ (see Appendix B: Figures A3 and A4).

Then, taking as a basis the partial qualifications of the studied municipalities with regard to the non-measurable statistical features, the analyzed municipalities were classified again with regard to the adaptability determinants. Thus, the obtained classification of the adaptability level of the studied municipalities turned out to be slightly different from the one described in [25], because:

- the values $a_{D,i}$ of the statistical variable $A_D$ were determined as the sum of the normalized values of the data $\widetilde{d}_{k,1}, \ldots, \widetilde{d}_{k,18}$, i.e., $a_{D,i} = \sum_k \widetilde{d}_{k,i}$, $i = 1, \ldots, 18$;
- for each $i$, where $i = 1, 2, \ldots, 18$, the normalization of the data $a_{D,1}, \ldots, a_{D,18}$ was performed by the method of zeroed unitarization, obtaining the values of the variable $\widetilde{A_D}$ (Figure 6).

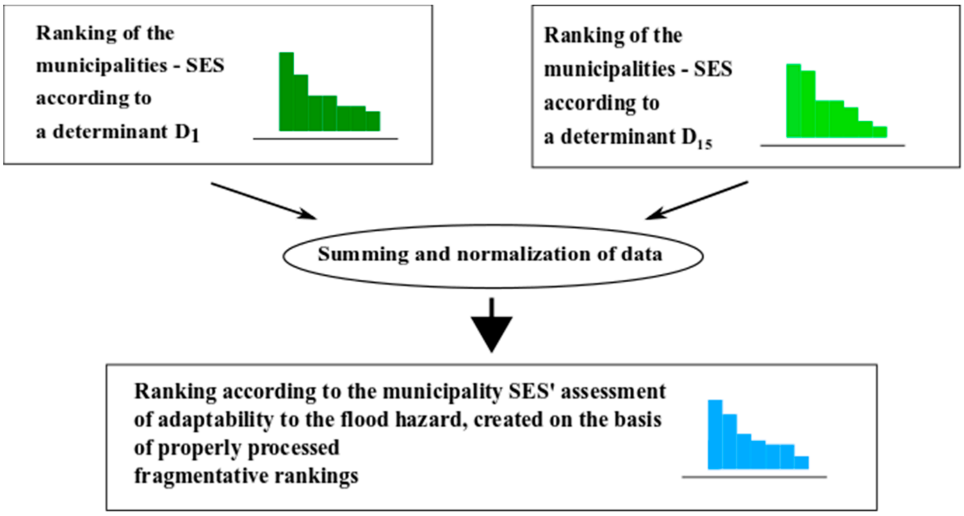


**Figure 6.** The procedure of creating a new ranking according to their adaptability to flood hazard [source: own work].

A general municipality classification of the studied area, with regard to the non-measurable statistical feature determining municipalities' adaptability to flood hazard, was created on the basis of a set of values of the variable $\widetilde{A_D}$ for each of the 14 features analyzed in the article. This classification is built with the assumption that the determinants have equal influence on the adaptability assessment. The higher a position a municipality achieves in the classification, the higher a value achieves the value of the variable $\widetilde{A_D}$ corresponding to it. These results are summarized in Figure 7.

It is necessary to emphasize that the obtained result in the form of the amount of measurable observable (diagnostic) variables, which describe the non-measurable statistical features (determinants) of a municipality-as-SES, is specific for the analyzed research area. Although the latent statistical feature (determinant) D4 (The ability to react in hazardous situations) did not maintain its form after the analyses of the representation as the observable (diagnostic) variables, it does not indicate that the feature is of marginal character.

It is highly probable that while conducting the analyses for the municipalities-as-SES located in another research area, the stake of selected variables and, in consequence, those described by these features (determinants), would be different. The features of a municipality, presented in the article, that determine the level of adaptability, can be applied within other areas of research, because they are features of universal character.

Although the observable variables as well as the non-observable features (adaptability determinants), ordered into four categories of features (determinants) of SES adaptability, may be considered universal because they result from the adopted concept of the municipality-as-SES, their usefulness in the description of an analyzed municipal population depends on the specifics of the analyzed SES and the time period of the conducted research as well as the observed values of individual statistical features.

## 4. Results

The collective results of the comparative analysis of the municipalities of the Nysa Kłodzka sub-basin are presented in Table 1. With regard to this catchment, the comparison criterion was determined by the values of the synthetic measures of 15 non-observable statistical features in relation to the characteristics of the municipalities, determining their adaptability to flood risk. Then, in Figure 8, a demonstrative drawing is presented which shows the spatial distribution of a given non-measurable statistical feature. These maps are to highlight the change of value of particular positions of the municipalities from the research area (features (F) 1–15; except for F4—insignificant statistical feature in an analyzed population of municipalities).

Finally, Figure 9 shows the spatial distribution of positions taken by the municipalities in the synthetic classification of the adaptability, based on the summary of partial classifications.

The ranking of municipalities according to the level of adaptability (synthetic adaptability index SAI form, Figure 7) is crucial for this work because it shows that each population (of municipalities) has its leader. It is also some kind of a clue for the rest of the municipalities as to how much their level of adaptability differs according to the leader's. It also suggests in which areas those municipalities need to improve. There is no adaptability threshold. Each population has its leader, thought this is not to say the leader is an ideal example.

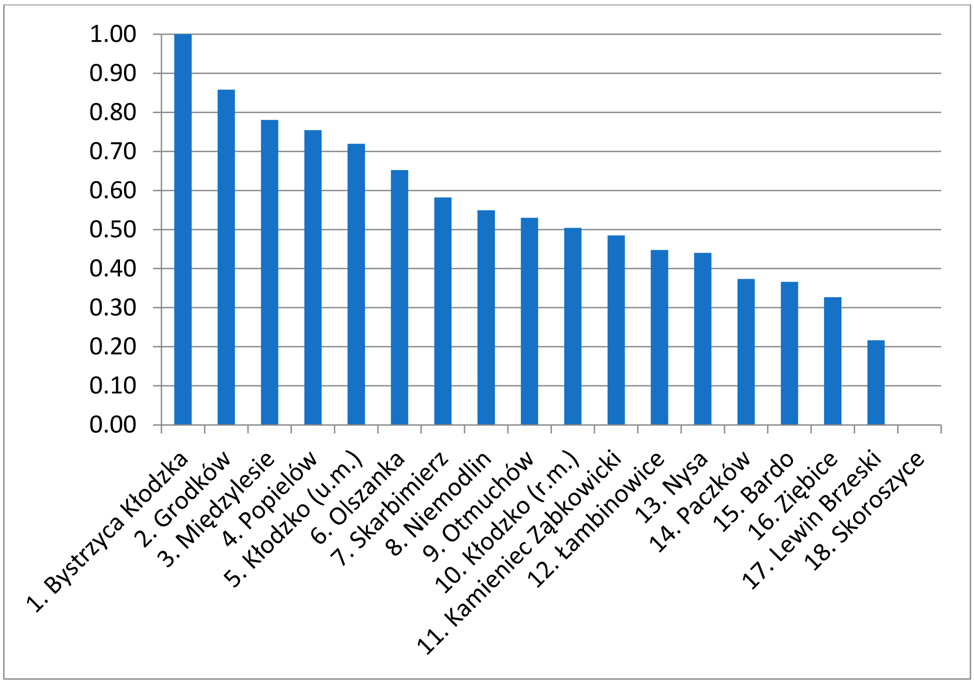


**Figure 7.** The classification of the adaptability of the municipalities-as-SES in the Nysa Kłodzka sub-basin to flood hazard, with the assumption of the homogeneous influence of non-measurable statistical features to the synthetic index of the adaptability [source: own work].

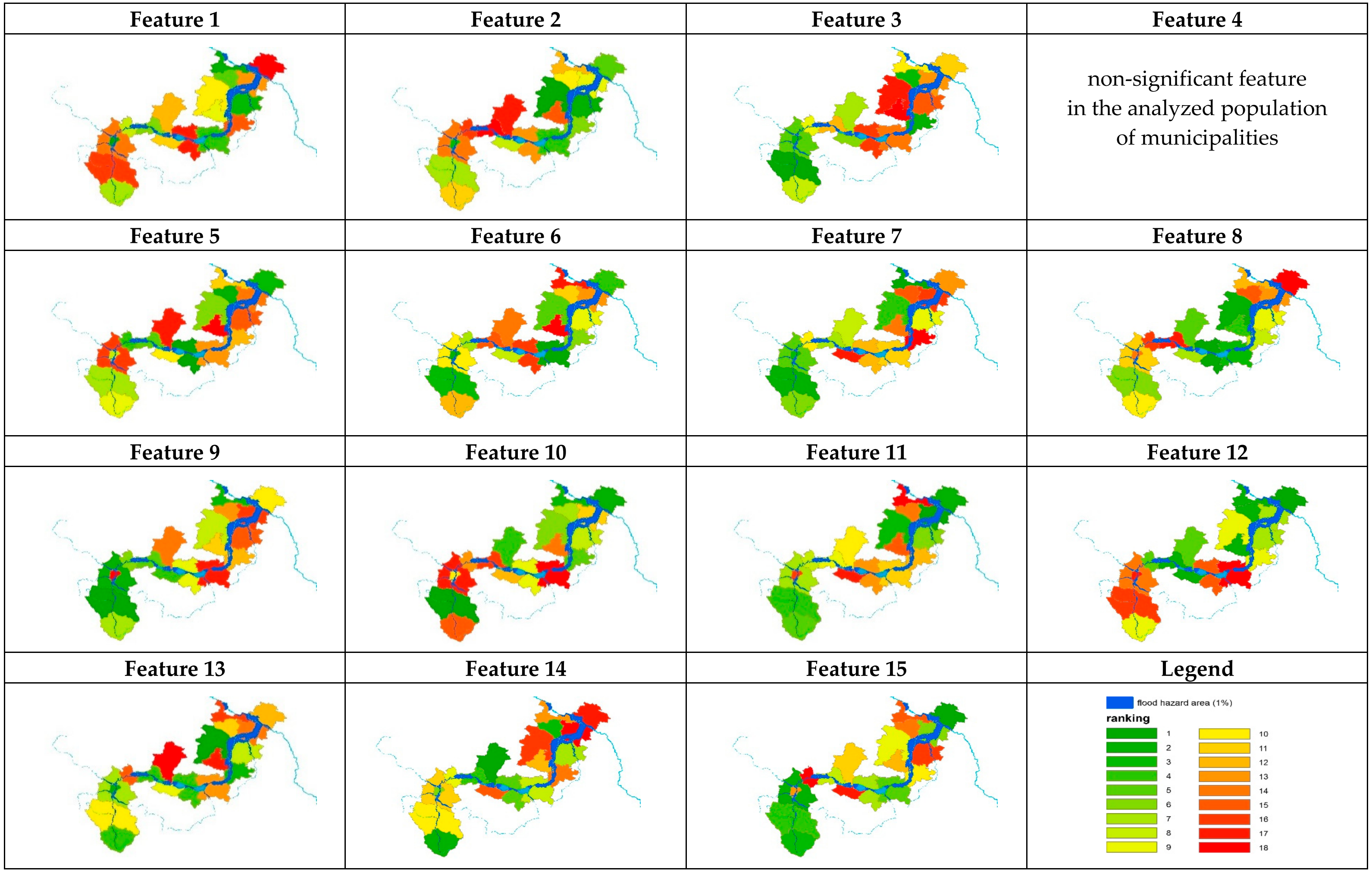


**Figure 8.** Demonstrative distribution of positions of the municipalities-as-SES according to non-measurable statistical features determining their adaptability to flood hazard [source: own work].

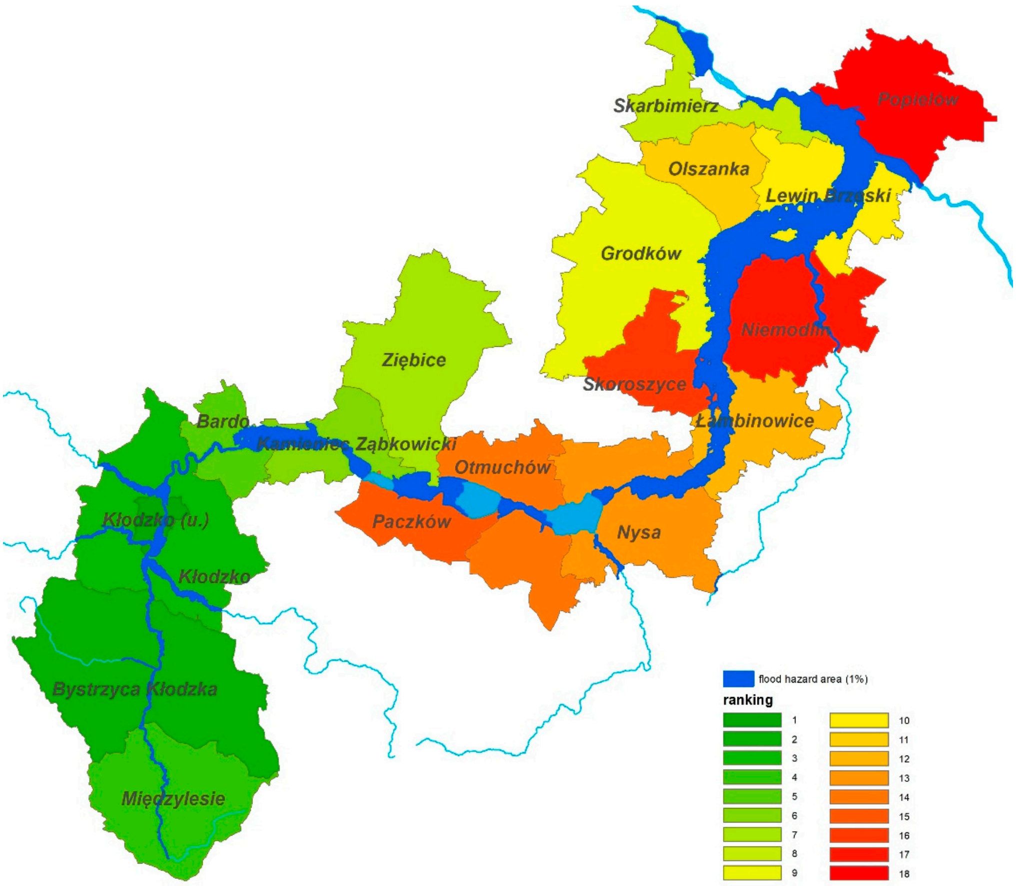


**Figure 9.** The synthetic classification of the adaptability to flood hazard in the municipalities-as-SES of the Nysa Kłodzka sub-basin [source: own work].

**Table 1.** Benchmarking of the municipalities-as-SES according to the assessment of statistical features of municipalities determining their adaptability to flood hazard.

| | **No. of Features:** | **F1** | **F2** | **F3** | **F4** | **F5** | **F6** | **F7** | **F8** | **F9** | **F10** | **F11** | **F12** | **F13** | **F14** | **F15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | name of non-measurable statistical features of a municipality-SES determining it's adaptability | Health capital | Educational capital | Civilisational capital | Ability to identify crisis situations | Ability to organize social life … | Cultural potential | Relevance of … | Municipality's ability to operate … | Municipal budget per capita | Variability of forms of development | Diversity of forms of environmental … | Risk of environmental … | Institutional potential | Ability to organize local … | Ability to organize … |
| **No.** | municipality | Position of the municipality's in the classification | | | | | | | | | | | | | | |
| **1** | Międzylesie | 7 | 11 | 8 | non-significant feature in the analyzed population of municipalities | 9 | 12 | 6 | 10 | 7 | 15 | 5 | 11 | 4 | 2 | 3 |
| **2** | Bystrzyca Kłodzka | 16 | 7 | 1 | | 7 | 3 | 2 | 6 | 1 | 1 | 4 | 16 | 10 | 10 | 4 |
| **3** | Kłodzko (r.m.) | 14 | 14 | 5 | | 16 | 10 | 5 | 11 | 2 | 17 | 7 | 14 | 7 | 11 | 2 |
| **4** | Kłodzko (u.m.) | 1 | 3 | 3 | | 8 | 2 | 3 | 14 | 18 | 10 | 16 | 17 | 2 | 6 | 13 |
| **5** | Bardo | 8 | 16 | 9 | | 4 | 7 | 10 | 16 | 6 | 13 | 8 | 7 | 15 | 9 | 18 |
| **6** | Kamieniec Ząbkowicki | 6 | 18 | 12 | | 5 | 15 | 7 | 17 | 5 | 16 | 9 | 2 | 5 | 4 | 8 |
| **7** | Ziębice | 12 | 17 | 7 | | 17 | 14 | 8 | 5 | 14 | 4 | 10 | 8 | 18 | 1 | 11 |
| **8** | Paczków | 11 | 8 | 6 | | 10 | 8 | 17 | 7 | 4 | 12 | 17 | 3 | 9 | 15 | 17 |
| **9** | Otmuchów | 17 | 13 | 16 | | 1 | 16 | 12 | 1 | 9 | 9 | 13 | 15 | 6 | 5 | 7 |
| **10** | Nysa | 4 | 4 | 14 | | 13 | 1 | 11 | 3 | 17 | 18 | 11 | 18 | 13 | 8 | 5 |
| **11** | Łambinowice | 15 | 6 | 2 | | 12 | 6 | 18 | 8 | 12 | 5 | 12 | 12 | 3 | 14 | 10 |
| **12** | Skoroszyce | 9 | 15 | 18 | | 18 | 18 | 14 | 4 | 11 | 14 | 15 | 4 | 17 | 12 | 12 |
| **13** | Niemodlin | 3 | 2 | 15 | | 15 | 9 | 9 | 9 | 15 | 8 | 6 | 9 | 8 | 7 | 16 |
| **14** | Popielów | 18 | 5 | 11 | | 3 | 4 | 13 | 18 | 10 | 2 | 2 | 1 | 12 | 17 | 1 |
| **15** | Grodków | 10 | 1 | 17 | | 6 | 5 | 4 | 2 | 8 | 6 | 3 | 13 | 1 | 16 | 9 |
| **16** | Olszanka | 5 | 10 | 4 | | 2 | 11 | 15 | 15 | 13 | 7 | 14 | 5 | 11 | 3 | 14 |
| **17** | Lewin Brzeski | 13 | 9 | 13 | | 14 | 13 | 16 | 13 | 16 | 11 | 1 | 10 | 14 | 18 | 6 |
| **18** | Skarbimierz | 2 | 12 | 10 | | 11 | 17 | 1 | 12 | 3 | 3 | 18 | 6 | 16 | 13 | 15 |

The conducted comparative analysis of the municipalities-as-SES in the Nysa Kłodzka sub-basin according to the features determining municipalities' adaptability to flood hazard has allowed the following conclusions:

- The rural-urban municipality Bystrzyca Kłodzka three times scored first place in the classification of municipalities where the municipalities were compared according to their human capital (feature D3), their budget per citizen (feature D9), as well as diverse forms of land development (feature D11). Bystrzyca Kłodzka also obtained high scores in the classifications of municipalities, according to the municipal budget structure providing financing of adaptation actions (2nd place), and in the classification of municipalities according to cultural potential (3rd place). This municipality was classified first in the classification of municipal adaptability, however, in the case of classifications according to health capital and the threat of environmental contamination, its position was 16th. Therefore, it is obvious that the leader among the municipalities in the Nysa Kłodzka sub-basin may also use the experience of partner municipalities which are ahead of Bystrzyca Kłodzka in many other classifications when it comes to the process of shaping adaptability to flood hazard.
- The rural municipality Skoroszyce was classified last three times in the classification of the municipalities, where the municipalities were compared according to their civilization capital (feature D3), the ability to organize social life, including political life (feature D5), as well as cultural potential (feature D6). This municipality was also in far-reaching positions according to institutional potential (17th place) and the diverse form of land development (15th place). Skoroszyce, in the synthetic classification of adaptability to flood hazard, took the last (18th) position among all the analyzed municipalities. However, it has to be highlighted that there were two areas in which this municipality scored 4th place—the municipality's ability to service its obligations (feature D8) and the threat of environmental contamination by objects of environmental flood risk (feature D12).
- The biggest dispersions of values for the analyzed non-measurable statistical features of the municipalities-as-SES to flood hazard were noticed for the features: D11—diverse forms of nature protection and D14—the ability to organize the external environment.
- The smallest dispersions of the values for the analyzed non-measurable statistical features of the municipalities-SES to flood hazard were noticed for the features: D7—the structure of the municipal budget and D8—the municipality's ability to service its obligations (the municipality's financial condition).
- It is worth emphasizing that the smallest changes of values for the non-measurable statistical features of the municipalities-as-SES were noticed in the areas for which the information regarding the diagnostic variables were aggregated on the county level; this is mainly reflected by feature D12—the threat of environmental contamination from the objects of environmental flood risk.

Figure 8 shows the classification of municipalities' adaptability in the Nysa Kłodzka sub-basin to flood hazard created with regard to the synthetic adaptability index (SAI). On the basis of the conducted comparative analysis of the municipal adaptability to flood hazard (Figures 8 and 9), we can conclude that due to frequent historical floods, the municipalities located in the upper run of the Nysa Kłodzka river have already developed the ability to build their resilience to floods and this is reflected by their positions in the classification of municipalities: Bystrzyca Kłodzka (1), Międzylesie (3) and the urban municipality of Kłodzko (5).

## 5. Conclusions

It is necessary to highlight that the proposed research tool in the form of a synthetic adaptability index (SAI) used to assess the municipality-as-SES's adaptability to flood hazard is the first holistic conception of such a type, aggregating many types of municipality-as-SES's activity (human, capital and social potential, financial potential, ecological potential and organizational potential). Due to the fact that the presented studies are the first of their type in Poland, which undertake the subject of the assessment of the adaptability of Polish municipalities to flood hazard, they can be considered both pioneering studies and pilot studies. The obtained results now become the basis for verifying the content of the presented research tool in the aspect of its substantive construction (an adoption of certain—and no other—features, selection of these features, their quantity, giving equivalent weight). It is necessary to emphasize that in the Polish literature on the subject there have been studies regarding selected aspects of natural hazards or floods, however, they referred to one defined component in the field of conceptual flood risk assessment (Figure 1). These studies were performed in relation to social vulnerability [10,12,44], susceptibility [18] or SESs' adaptability to weather phenomena [27].

At this stage of the study, it was recognized that each of the features used to assess the adaptability (one of 15 components building SAI) is equal, regardless of the number of indicators included in it (observable variables). In the subsequent stage of study, it will be necessary to consider giving specific weight to particular statistical features.

Authorial non-measurable statistical features, though covering the entire spectrum of an SES's functioning, may be distinctive for a specific research population in a given country. Hence, social, economic or institutional conditions in other countries may raise barriers when trying to compare one SES with another, and thus, create limitations in the development of a universal tool for assessing the adaptability of different local government units which are all, however, at risk of flooding.

A similar problem may arise when building the indicators (observable variables) and using information from the research tool in the form of a survey questionnaire. It is necessary to emphasize that the presented non-observable statistical features were built on the basis of partial indicators sourced from public domain data and also from surveys. Data from the survey questionnaire may not only be subjective because of the person who fills in the required information; these data also lack information on archive data, their fragmentation, etc., (more on the construction of the research tool in the form of a survey questionnaire performed on the population of municipalities of the Nysa Kłodzka sub-basin in Poland is discussed in [30]).

Authors from other countries indicate that there are many research approaches in resilience assessment [29,45,46] (this article considers the adaptability as part of this body), and the conclusion that comes from the analysis of this part of the literature on the subject is that it is recommended that a combination of many of research approaches is used [47].

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## Appendix A

Construction of the set of diagnostic variables was two-step and was based on the selection of potential indicators. The criteria of choice are mainly of a statistical nature. Potential diagnostic variables removed from the set include:

1. ones that are not very diverse, i.e., those for which the absolute value of the classic coefficient of variation is less than 10%, as well as those of which the vast majority of realization is the same number;

2. ones that are too strongly correlated, i.e., with similar information potential, by eliminating one variable from each pair of too closely related indicators; however, cases of apparent correlation were not taken into account.

In the correlation analysis the critical value r* of Pearson's correlation coefficient was used [29]. This value was determined with the formula:

$$r^* = \sqrt{\frac{t^2}{t^2 + n - 2}} \quad \text{(A1)}$$

where:

$n$—number of data, in this case $n = 18$,

$t$—value of statistics read from the tables of t-Student for the level of significance $\alpha$ and for $n-2$ degrees of ease, wherein it $\alpha = 0.05$ was adopted. As a result of the calculation, we get $r^* = 0.47$.

During the study, too strongly or otherwise significantly correlated variables were considered those for which the absolute value of Pearson's correlation coefficient are greater than 0.47.

The set of diagnostic variables were divided into stimulants and destimulants.

To compare the values of diagnostic variables, they should be normalized. In the subject literature, a number of methods of normalization are described [29].

The authors of this article insisted on the chosen normalization to meet the most possible of the requirements most often given to this type of methods.

These are the following postulates:

- depriving the titles in which the features are expressed;
- bringing the order of variable sizes to a state of comparability;
- the equality of the length of variability intervals of values of all normalized features (constancy of the range) and equality of the lower and upper limits of their variability interval, in particular the interval [0, 1];
- the ability to normalize the features of positive and negative values, or only the negative;
- the ability to normalize the features of the value that equals zero;
- not-negativeness of the value of the normalized features;
- the existence of simple formulas—within a given normalization formula—unifying the nature of the variables.

The normalization of the value of diagnostic variables was applied with the use of reset unitarization described with the formulas [29]:

- formula for stimulants: $z_{ij} = \frac{x_{ij} - \min\limits_i\{x_{ij}\}}{\max\limits_i\{x_{ij}\} - \min\limits_i\{x_{ij}\}}$
- formula for destimulants: $z_{ij} = \frac{\max\limits_i\{x_{ij}\} - x_{ij}}{\max\limits_i\{x_{ij}\} - \min\limits_i\{x_{ij}\}}$

where:

$z_{ij}$—normalized value $j$—variable for $i$—municipality.

## Appendix B

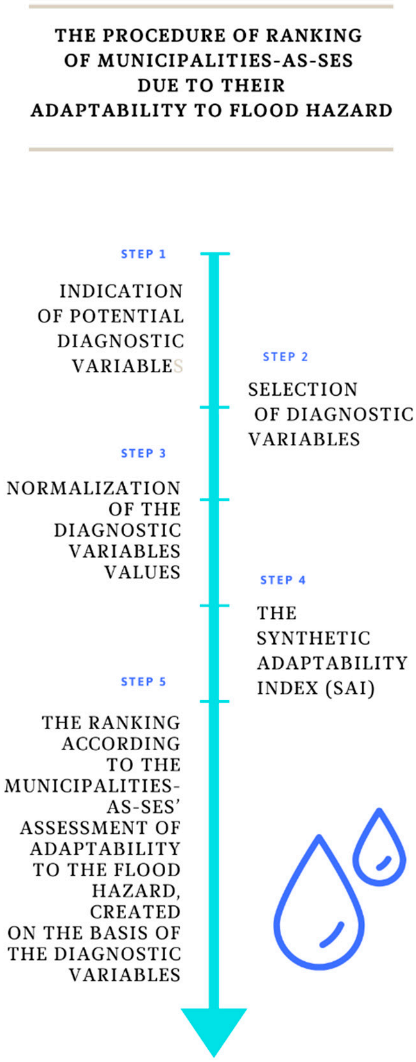


**Figure A1.** The procedure of creating a ranking of municipalities according to their adaptability to flood hazard [source: own work].

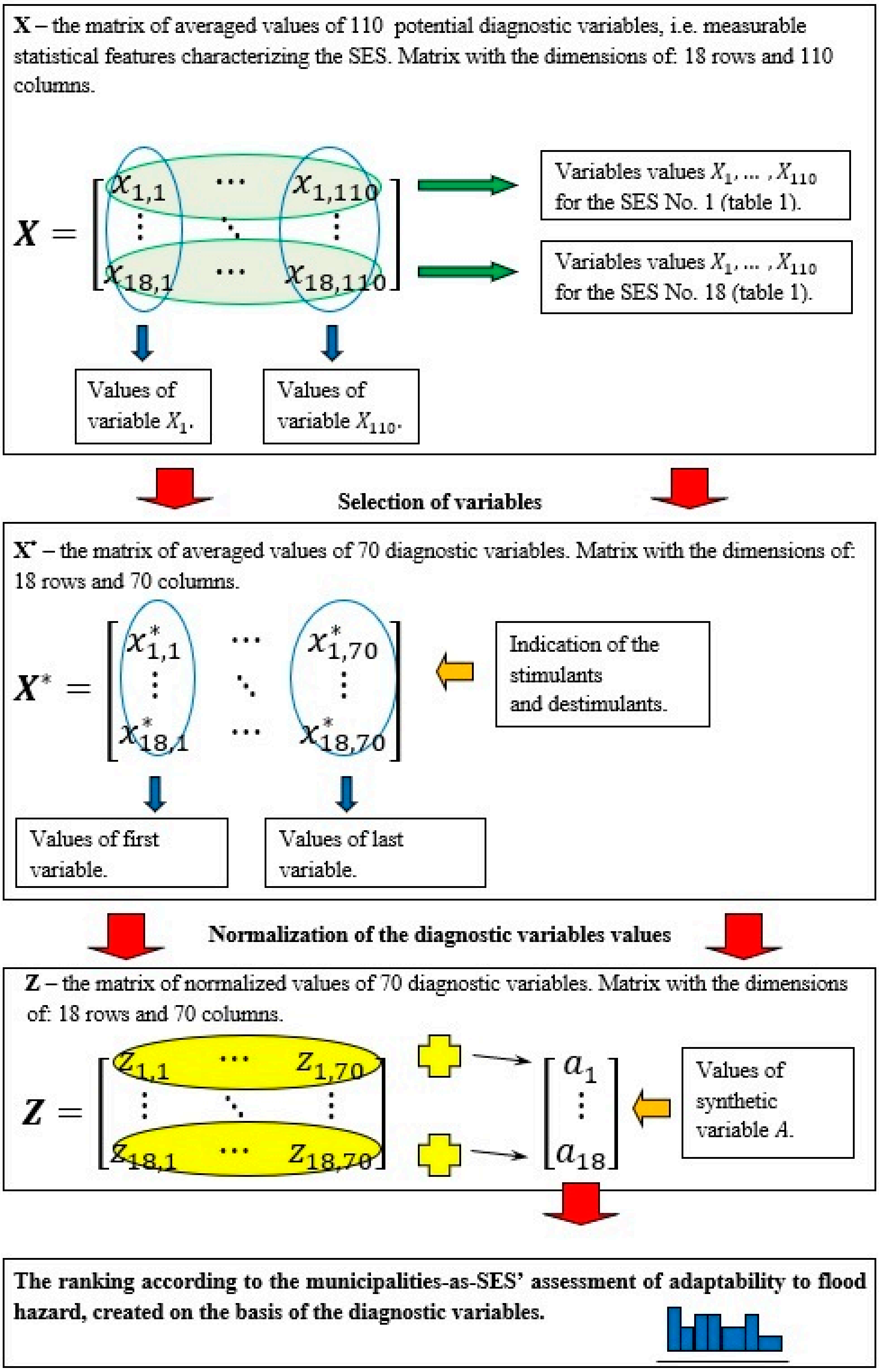


**Figure A2.** The procedure of making the ranking of municipalities due to their adaptability to flood hazard. [source: own work].

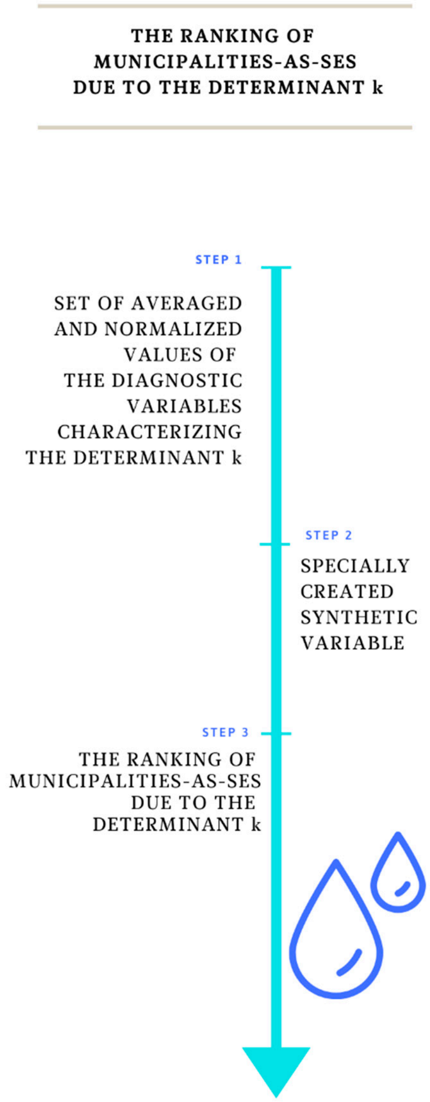


**Figure A3.** Procedure for creating a ranking of a municipality-as-SES's adaptability to flood hazard according to a random non-observable statistical feature of the municipality-as-SES determining its adaptability to flood hazard [source: own work].

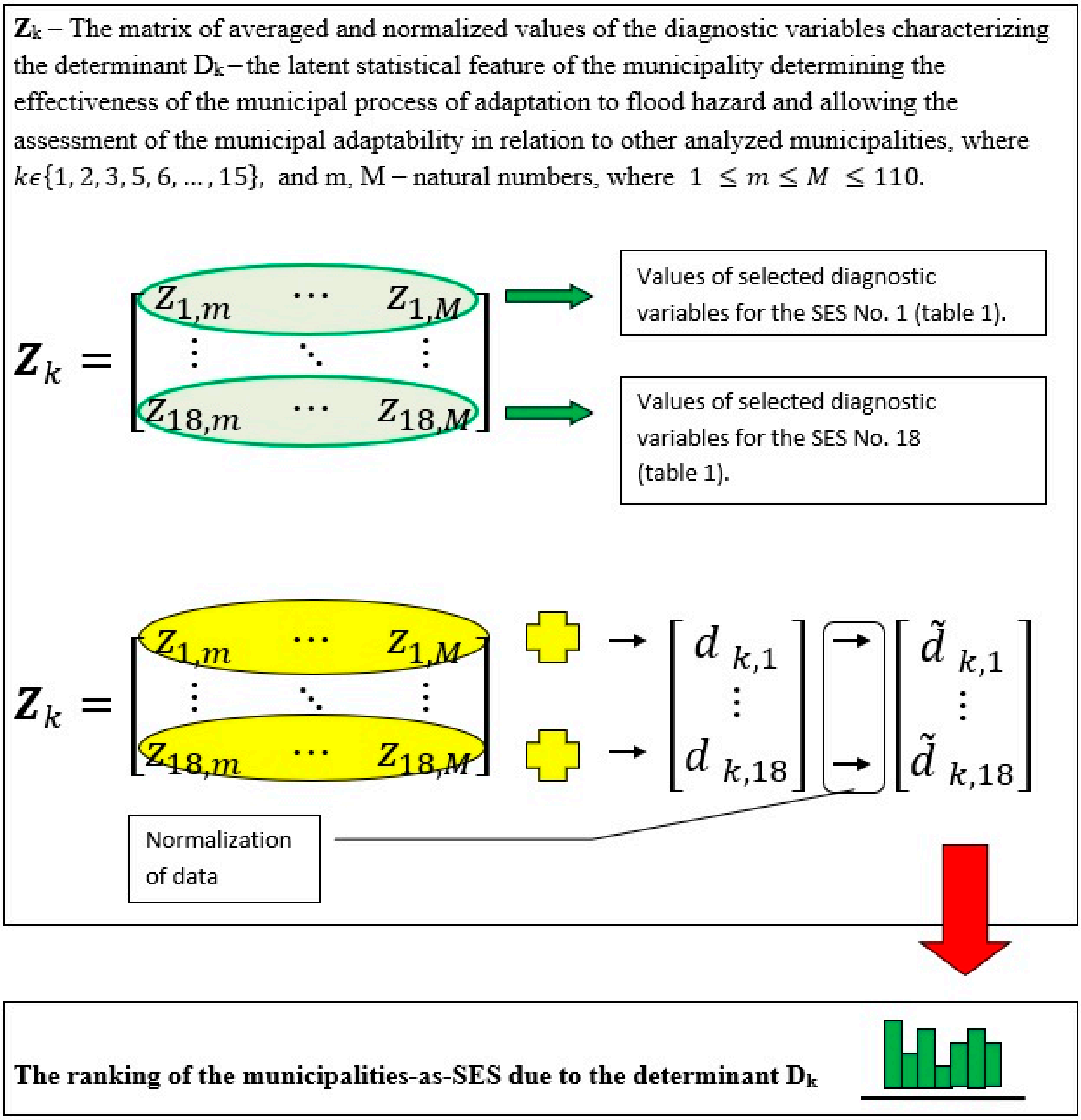


**Figure A4.** The procedure of creating the ranking of adaptability of a municipality-as-SES to flood hazard in relation to a random non-measurable statistical feature of the municipality-as-SES determining its adaptability to the flood hazard [source: own work].

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