Cardinal Stefan Wyszyński University in Warsaw
Institute of Philosophy
Center for Ecology and Ecophilosophy

STUDIA ECOLOGIAE ET BIOETHICAE

20/3 (2022)

STUDIA ECOLOGIAE ET BIOETHICAE

2022, 20, 3: 75-90
p-ISSN 1733-1218; e-ISSN 2719-826X
DOI: http://doi.org/10.21697/seb.2022.16

Determining the Climate Risk in the City Using the Risk Matrix Method – Examples from Poland

Określanie ryzyka klimatycznego w mieście metodą macierzy ryzyka – przykłady z Polski

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Received: 16 Aug, 2022; Revised: 16 Sep, 2022; Accepted: 20 Sep, 2022

Abstract: The preparation of urban adaptation plans in Poland required application of tools, hitherto rarely used in geographical sciences. One of them is the risk matrix, the application of which originates from management science. The original application of the risk matrix is the business environment. The first prepared municipal plan for adaptation in Poland is The Climate Change adaptation strategy for the city of Warsaw by 2030 (The City of Warsaw 2019). The ongoing analytical work related to the preparation of this plan for adaptation was completed with the preparation of the draft strategy in 2017. The preparation of the draft took place during a workshop held with a group of stakeholders, called the Warsaw Climate Change Adaptation Roundtable (the so-called "WOSAK"). During this workshop, a risk matrix was used for the first time to determine climate risk in Warsaw. Subsequently, the method was used in other cities in Poland. This paper will present the basis for the application of the risk matrix method, in the assessment of a city's climate risk. The results and evaluation of the application of the method in the city's adaptation plans prepared so far by the team of the Institute for Sustainable Development Foundation, will also be presented.

Keywords: risk matrix, climate risk, Warsaw, municipal plans for adaptation

Streszczenie: Przygotowanie miejskich planów adaptacji w Polsce wymagało zastosowana narzędzi dotychczas rzadko stosowanych w naukach geograficznych. Jednym z nich jest macierz ryzyka, której zastosowanie wywodzi się z nauk o zarządzaniu. Pierwotnym zastosowaniem macierzy ryzyka jest środowisko biznesowe. Pierwszym przygotowanym miejskim planem adaptacji w Polsce jest Strategia Adaptacji do zmian klimatu Warszawy do roku 2030 (The City of Warsaw 2019). Prowadzone prace analityczne związane z przygotowaniem tego planu zakończyły się wraz z przygotowaniem projektu strategii w 2017 roku. Przygotowanie projektu odbywało się podczas warsztatów realizowanych w grupie interesariuszy zwanej Warszawskim Okrągłym Stołem Adaptacji do zmian Klimatu (WOSAK). Podczas tych warsztatów zastosowano po raz pierwszy macierz ryzyka do określenia ryzyka klimatycznego w Warszawie. Następnie wykorzystano tę metodę w innych miastach w Polsce. Referat zawiera podstawy zastosowania metody macierzy ryzyka w analizie ryzyka klimatycznego miasta. Przedstawione zostaną także wyniki oraz ewaluacja zastosowania metody w dotychczas przygotowanych planach adaptacji miast przez zespół Fundacji Instytut na rzecz Ekorozwoju.

Słowa kluczowe: macierz ryzyka, ryzyko klimatyczne, Warszawa, miejskie plany adaptacji

Introduction

International and European climate policy is paying increasing attention to climate change adaptation. This process has been observed since the mainstreaming of climate change adaptation in the synthesis reports issued by the IPCC. This took place in 2007 with the 4th synthesis report (IPCC 2007). The importance of the problem was also highlighted by subsequent climate summits. Starting with the Copenhagen summit in 2009, they failed, unable to reach an agreement on how to reduce greenhouse gas emissions from the last year of the Kyoto Protocol, 2012. In 2009, an analysis of the climate change adaptation problem for the European Union area was presented by the European Commission (2009), followed by its own adaptation strategy in 2013 (European Commission 2013a). This was followed by the emergence of national adaptation strategies, including in Poland. The national document was created in 2013 and given the name Strategic Adaptation Plan for Sectors and Areas Vulnerable to Climate Change to 2020 with an Outlook to 2030, so-called: SPA 2020 (Polish Ministry of Environment 2013). Both documents, the European and the national one, in their lines of action, firstly indicated the need to create conditions for adaptation to climate change in urban areas. These conditions were to create climate change adaptation strategies for urban areas, which in Poland were called municipal plans for adaptation. This article deals with risk analysis, which is used throughout a series of analyses related to the implementation of municipal plans for adaptation.

1. Literature review

The call for integrating climate change adaptation into development planning was made in the IPCC's 4th report in 2007 (IPCC 2007), and further developed in a special report on climate change risk management into a call for climate change adaptation management strategies (IPCC 2012). In the wake of, and even ahead of, the European Union's climate change adaptation strategy, the European Commission went several steps ahead and began to prepare documents to implement its findings. Guidelines were produced on how to adapt infrastructure investments to climate change (European Commission 2013b). Their content started to become important when the European Commission requested specific climate analyses based on the guidelines from the beneficiaries of projects financed by European funds. Later, the topic of climate change was introduced into EU legislation by including it in the Environmental Impact Assessment Directive (European Union 2014a). Guidelines for the preparation of urban climate change adaptation strategies were also produced (European Commission 2013c).

The European Commission was not the only organisation issuing its recommendations or guidance on how to analyse climate change adaptation needs in cities. The OECD (Mitchell 2013), the German Federal Ministry for Economic Cooperation and Development (Fritzsche et al. 2014), Environment Agency Austria (Prutsch et al. 2014), the Polish Ministry of the Environment (2014), the European Environment Agency (2016), and the Stockholm Environmental Institute (2017) also issued their manuals and guidance materials. These guidelines mostly confirmed that one of the key methods to capture climate change adaptation needs is risk assessment. However, only a few focused on a more detailed treatment of the topic with a proposal to use a so-called: risk matrix to implement the assessment, including the OECD (Mitchell 2013) and the Polish Ministry of the Environment (2014).

The first examples worldwide of the use of risk matrices in climate change analyses in the context of cities were described in Cho et al. (2019, 11-24), among other publications. The studies for these cities were mainly based on the guidelines proposed by ICLEI in 2007 (ICLEI et al. 2007, 87-91). This manual explains the concept of risk in

simple terms and suggests what questions to ask when conducting a risk analysis. It is worth noting at the outset that all the examples in Cho's et al. (2019) publication focus on the technical aspects of performing a risk assessment and do not show the links of this analysis to other processes involved in preparing for climate change adaptation, including the social process and in particular stakeholder participation. It can be presumed that these analyses were carried out only among experts and not through a social process.

The first example described is the US city of Atlanta. The analysis made there used a qualitative description of the possible impacts of individual climate change risks presented for this region of the world in the climatological literature. The description of impacts consisted of three criteria: the size of the city's exposed population, the scale of the threat to human life, and the scale of material damage. The fourth evaluation criterion was the likelihood of the hazard occurring. Each criterion could be scored by 1 to 3 points, and the sum of the points in the total score allowed for three ranges of risk: low, medium, and high.

In the example of the city of Melbourne, Australia, the risk assessment was slightly different, but was also based on qualitative descriptions, which were assigned a corresponding number of points. The description of climate change impacts was scored independently from 1 to 5 for the two types of impacts identified according to the PESTEL analysis: economic-environmental-social and technical-political-legal. Risk was also scored on a scale of 1 to 5, but the most likely events had high scores and the unlikely events had the lowest scores. Overlaying the scores given to consequence and probability resulted in a scoring matrix that divided each event into ranges of intensity of action to be taken by the city to adapt to climate change. These ranges were four: no need to counteract, periodic monitoring of actions, maintaining continuous control of actions, active continuous management of actions.

The third example was the city of Vancouver, Canada. It rated on one scale the likelihood of an event occurring on in range of 1 to 5, where 5 represented the most likely event. On a second scale, the consequences of an event were scored across five scopes of activity in the city: public safety, local economy and development, society and lifestyle, environment and sustainability, and public administration. Points on this scale were awarded from 1 – negligible consequences, to 5 – catastrophic consequences. All points on this scale were added together and then multiplied by the probability score. This operation resulted in 8 risk ranges, from very low, to extreme.

The fourth city shown in the manual analysed was Copenhagen. Copenhagen also used a simple risk matrix combining the assessment of probability and impact of climate change events. The focus was on quantifying both the probability and impacts of events. Impacts were expressed in terms of the amount of resources needed to repair the damage of a single event. Risks were assessed by calculating the amount of resources needed to deal with the consequences of events that will occur over the next 100 years. As a result, depending on the amount of resources needed, the risk was assessed as low, medium or high, with a high level of risk considered as one that required adaptive action.

The other two examples in Cho's et al. (2019) handbook were for entire countries: Kenya and South Korea. Kenya also assessed the likelihood and consequences of climate change on five-point scales. The probability of an event could receive a rating from A – very unlikely; to E – very likely. The consequences of an event could receive a rating from 1 – least significant, to 5 – most significant. Whereby impacts were assessed in several different scopes (sectors) categorised as follows: agriculture and fisheries; manufacturing, trade, and tourism; environment and water management; health and human environment; economically important infrastructure; security. For each of these,

a descriptive range of possible damage specific to the scope is given, e.g., an assessment of the possibility of repairing/rebuilding infrastructure after an incident. The assigned ratings at the intersection of the probability and impact assessment were followed by a risk assessment, which separated 4 groups: serious risk, high risk, medium risk, and low risk. Severe and high risk were considered as signals for adaptive action.

In Korea, the risk assessment was more complicated and did not rely on the construction of a simple risk matrix. However, this deepened approach was probably possible since the assessment only looked at one type of hazard – heat waves – for only one type of impact – the number of potential deaths or people affected. In effect, risk was calculated as the relationship between exposure to heat waves, sensitivity to them and adaptive capacity. This was a more sophisticated method of risk assessment than the one also used in the LIFE_ADAPTCITY_PL project, for assessing past impacts of heat waves (Rabczenko et al. 2016). The assessment of the result obtained was directly related to the benchmarks included in the IPCC's 4th report (IPCC 2007).

Risk assessment methods for countries were and still are more widespread and developed than risk assessment methods for cities. This is since countries started to develop documents analysing the issue of adaptation, including adaptation strategies, earlier than cities, of which Poland is also an example. This statement is also supported by the entire March 2018 issue of the Royal Society of Science's journal Philosophical Transactions A (Adeger et al. 2018). It discusses risk assessment methods applied to entire countries: the UK (Surminski et al. 2018), Italy (Mysiak et al. 2018) or Mexico (Hear et al. 2018), as well as detailed risk assessment methods for individual sectors (Dawson 2018). Throughout the issue we find only one risk matrix, which in essence only identifies the potential scale of the impacts of various climate risks in the UK to 2020, 2050 and 2080 on business. It does not include a consideration of the likelihood of specific impacts occurring (Surminski et al. 2018).

The literature review suggests that further-reaching city-level risk assessments using risk matrices have also been carried out in later years, but probably after the LIFE_ADAPTCITY_PL project risk workshop in Warsaw described later in this article. This supposition seems to be confirmed by the team of researchers Tung, Tsao, Tien, Lin and Jhong (2019) writing "a specific qualitative method for interdisciplinary assessment of climate risk has rarely been developed and provided as a fundamental principle for climate adaptation strategies based on a crucial concept of climate risk defined by the IPCC." Therefore, in their article, they propose a risk matrix as the final element of a structured algorithm for analysing climate change adaptation. This matrix ties together the scale of impacts and the scale of climate vulnerability (which is the result of sensitivity and exposure analysis) yielding a risk assessment that is recorded at the intersection of the two scales.

This type of risk assessment is also slowly penetrating corporate applications. McMahan and Gerlak (2020) developed a risk matrix, guided by a qualitative description, for the Tucson Electric Company in the US state of Arizona. Climate risk is becoming an important element of corporate operations, as highlighted by recent changes to European Union law on non-financial reporting (European Union 2014b) and emerging guidelines (Latino et al. 2022).

2. Climate adaptation analysis and risk assessment

The described cases of performed analyses prove that risk assessment is not yet a very common method of proceeding in case of adaptation analysis at the municipal level. Above all, there was no record of this type of assessment being performed for local government units in Poland prior to the LIFE_ADAPTCITY_PL project in Warsaw. The project was led by Institute for Sustainable

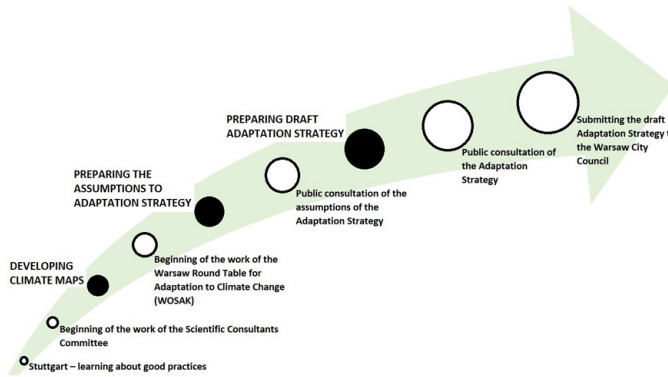

Figure 1: Process of preparation of Climate Change Adaptation Strategy for the city of Warsaw (The City of Warsaw 2019)

Development Foundation with partnership of Warsaw City, Union of Polish Metropolises and Verband Region Stuttgart.

It was not until the LIFE_ADAPTCITY_PL project, starting in 2014, that the preparation of a Climate Change Adaptation Strategy for the City of Warsaw was addressed. The project was an extensive process involving several stages, which are summarised in Figure 1. The first milestone of the process was the preparation of climate maps of the city, which was tantamount to collecting, analysing and organising data on the current climate of the city and its changes in the future. This milestone consisted of a series of analyses, culminating in a climate risk assessment. The layout of these analyses is shown in Figure 2. These were, in turn:

1. Hazards analysis or climate exposure analysis;
2. sensitivity analysis;
3. adaptive capacity analysis;
4. resilience assessment;
5. vulnerability assessment;

Exposure analysis resulted in identification of the most dangerous climate phenomena that can occur in Warsaw due to climate change. Sensitivity analysis found weak points of a city, that allow for the losses to spread. Adaptive capacity analysis identified strong points of the city, that helps minimizing the losses. Resilience assessment resulted in a list of sectors or territories where sensitivity is much higher than adaptive capacity. Vulnerability assessment reduced the number of sectors or territories to those, where dangerous climate phenomena are likely to bring losses.

The course and results of these analyses are presented in detail in the strategy document (The City of Warsaw 2019). It is worth mentioning at this point that these analyses determined for which climate hazards in which sectors it is important to assess the scale of the climate risks involved due to their high vulnerability to climate change. This was a starting point for risk analysis as described in part 3 of the article.

The second milestone in the process of preparing the adaptation strategy was the preparation of the assumptions of the Adaptation Strategy. This took place in a participatory process, with the participation of representatives of city hall offices, businesses and NGOs interested in the topic in the form of a round table, called the Warsaw Climate Change Adaptation Roundtable (WOSAK). It was at this stage that a proper climate risk assessment using a risk matrix took place, which was the starting point for the formulation of the strategic vision, goals, principles and especially directions for action on climate change adaptation in the city. The next milestone was the preparation of the draft Adaptation Strategy, which was

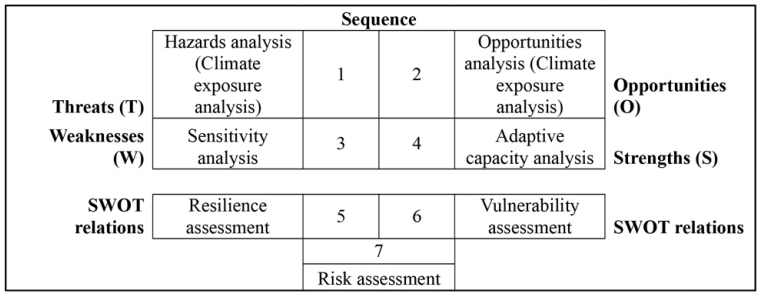

Figure 2. Layout of analyses pursued in preparation in Warsaw Adaptation Strategy (The City of Warsaw 2019)

supplemented by comments and opinions expressed by the city's residents in a public consultation process that considered the broad voice of people gathered during meetings in the city's various neighbourhoods. Finally, the draft document was subjected to consultation during meetings open to the public from all over Warsaw and voted on by the City Council. The entire process was attempted to be kept in line with the Polish Ministry of the Environment's Adaptation of the City to Climate Change Handbook (2014). The handbook describes a risk analysis as part of the preparation of an adaptation plan, but the project team felt that the theoretical approach proposed there was insufficient for the first implementation of this analysis in Poland.

The LIFE_ADAPTCITY_PL project was also rich in other activities not previously implemented in practice in Poland. These are documented, among others, by scientific articles on hydrological and meteorological risks for Warsaw (Żmudzka et al. 2019) and the assessment of heat wave mortality in Warsaw (Rabczenko et al. 2016). The advancement of the project is also confirmed by a relatively new publication (Gallina et al. 2019) describing a summary analysis of several risks on an area basis, which was realised very similarly to the study for Warsaw (Żmudzka et al. 2016). Also, in the case of risk assessment, the project team faced the challenge of developing a practical approach to the concept of climate risk assessment described in various guidelines. This necessity arose from the fact that the process of preparing the adaptation strategy for Warsaw took place with the participation of social partners. The risk assessment is an element that makes it possible to involve these partners in an important way in the diagnostic work. At the same time, it is an analysis that requires a more practical knowledge of the risks present in the city, and it is this knowledge that the social partners should have in the process of developing the strategy. Therefore, after studying the theoretical literature available at the time and examples from other countries, a method of risk analysis with simultaneous stakeholder participation was proposed using various elements of existing implementation and theoretical guidance.

3. Risk assessment method for Warsaw, its further use, and modifications

Risk assessment seeks to determine the probability of specific losses from a specific hazard according to the general risk formula:

$$R = P*S$$

R – risk,
P – probability of loss occurrence,
S – size of loss.

Usually, e.g., in banking and management, this type of assessment aims at a strict mathematical representation of the variables contained in the formula (Melnick and Everitt 2008). However, guidelines for climate-related risk analysis allow for a qualitative

Consequences (losses)				
	High	2	3	3
	Medium	1	2	3
	Low	1	1	2
		Low	Medium	High
	Probability			

Degree of reaction legend:
1. Low reaction, 2. Medium reaction, 3. High reaction

Figure 3. Risk matrix. Derived from Fijak and Shamych 2020

approach to determine these variables using what is known as: a risk matrix (ICLEI et al. 2007; European Commission 2013c; Mitchell 2013; Polish Ministry of the Environment 2013). The risk matrix is used in the management sciences, where it helps to determine the possible consequences of different events and their probability obtaining a risk scale as a result (Fijak and Shamych 2020), as shown on Figure 3.

It has the same function in climate change risk analysis, as the matrix is used to determine the possible consequences of climate change and the probability of their occurrence in the analysed location obtaining an assessment of the so-called: climate risk. However, it is usually not possible to quantify these consequences or probabilities, so they are described qualitatively. In particular, the magnitude of losses can be determined qualitatively, as can be seen in all examples of this type of method described before its implementation in Warsaw (Cho et al. 2019, 11-24). Sometimes the probability of loss occurrence is also qualitatively determined, which is referred to as "likelihood".

In Warsaw, a qualitative approach to determining the magnitude of losses was also proposed, and the way it was described was adapted to the audience that was to attend the risk workshop. The scope of the analysis in terms of the number of city sectors analysed was also adapted to local possibilities, above all the time available for the meeting. The team preparing the strategies also defined the period and scope of the risks.

Based on previous analyses, it was possible to determine that it would be relevant for the city to analyse the risks for all 10 sectors considered in the analysis from the outset with the exclusion of specific risks for some sectors. Still, the combination of the number of sectors and risks analysed would have resulted in the need to analyse at least 27 separate units. This would have meant discussion in at least 27 sections, which would have required a very long time, while one day was available for the workshop. Analysing risks by hazard was out of the question, as such an arrangement of analyses would have dominated the studies carried out previously and the available stakeholders would have made better use of their knowledge to speak from a sectoral point of view. Therefore, it was decided to reduce the number of sectors analysed from 10 to four, grouping them into larger categories.

An analysis was proposed in a system of four impact categories:

a. Human health and life,
b. Technical infrastructure,
c. Green and blue infrastructure,
d. Supply of utilities (water, energy, public transport, sewage, wastes) and food to the city.

This provided the opportunity to work with stakeholders in four groups in parallel. To determine losses, sample loss scales were

Table 1. Template of risk matrix prepared for the risk assessment workshop in Warsaw City with empty cells to be filled in during the workshop. Own study

Degree of loss ↓ Climate hazard →	Flash floods	River floods	Heat	Drought	Strong wind
Human health and life					
Immediate death of many people, many casualties					
Increased mortality, damage to the health of many people					
Single deaths, injured persons					
Few casualties					
No casualties					
Technical infrastructure					
Complete paralysis of infrastructure functioning					
Area paralysis of urban infrastructure					
Minor infrastructure disruption					
Minor technical infrastructure disruption					
No disruption					
Green and blue infrastructure					
Complete loss of ecological functions of trees, shrubs, rivers					
Loss of green infrastructure in some areas of the city					
Local damage to green infrastructure or minor damage to a whole area of the city					
Minor point damage					
No disturbance					
Supply of utilities and food to the city					
Long-term disruption of supply of all utilities to the entire city					
Short-term disruption of supply of utilities to the entire city or long-term but area-wide					
Short-term disruption of media supply, area-wide					
Spot disruption of utility supply					
No interruption					

developed for each impact category. These scales emphasised the area and time range of loss occurrence in a descriptive manner – this was a qualitative input to the risk matrix that represented the size of loss in the risk general formula (S). These scales are presented in Table 1. The project team also defined an analysis horizon of 30 years and used a question directed to the workshop participants: With what probability will the identified losses for each hazard occur in the next 30 years? The hazards were those identified as relevant to the city through the exposure analysis: flash floods, river floods, heat, drought, and strong wind.

Probability has been proposed to be determined on the scale used by the Intergovernmental Panel on Climate Change (IPCC 2010) – this was a qualitative input to the risk matrix that represented the probability of loss occurrence in the risk general formula (P). The exception is that the lowest probability grade (0-1%) was not used in the Warsaw exercise. This scale used was:

- almost certain – corresponds to a probability of occurrence in the range of 99-100%,
- very likely – corresponds to a probability of occurrence in the range 90-100%,
- likely – corresponds to a probability ranging from 66% to 100%,
- moderately likely – corresponds to a probability ranging from 33% to 66%,
- unlikely – corresponds to a probability of occurrence of between 0 and 33%,

- highly unlikely – corresponds to a probability of between 0-10%.

Based on this framework, the workshop participants were asked to fill table presented as table 1.

The workshop was attended by representatives of:

- Warsaw City Office for Safety Management,
- Warsaw City Office for Infrastructure,
- Warsaw City Office for Spatial Planning and Architecture,
- Warsaw Municipal Water and Sewage Company,
- Warsaw City Office for Environmental Protection,
- Polish Association of Development Companies,
- National Headquarters of the State Fire Service of Poland,
- Association of Architects of Poland,
- Association Green Mazovia,
- Gazeta Wyborcza daily newspaper.

Representatives of the Warsaw City Office were usually directors or chiefs of departments. Other organisations were represented with specialists of environmental protection, prevention of hazards or spatial planning.

The work during the meeting took place using the WORLD CAFÉ Method (The World Café 2022). The workshop participants were divided into 4 groups, whose work took place in 4 rounds. In each round, a different group worked on assigning probabilities for specific impact categories. The group had to decide what is the probability of occurrence for the losses described by each climate hazard on their climate category. Each group had a part of a table as shown in table 1, which allowed for work only on one impact category. Between rounds, the groups changed tables where the discussion took place. These changes allowed each group to work on each impact category, but in subsequent rounds. The first change of tables occurred after 45 minutes, the second and third after 30 minutes, the fourth after 15 minutes. Since the second round the results of the previous group's work at a given table were modified by the work of the next group. At the table, the work went on with an external facilitator. After the all the rounds were completed, the facilitators reported the results of each group's discussion and there was an acceptance of the results by all workshop participants.

This is how the first risk workshop was implemented on 20 October 2016 in Warsaw. The immediate results of the workshop were summarized in tables similar to Table 1, but with cells filled in with the probability of loss occurrence values. There was a separate table for each impact category. After the meeting the results of the work were summarized in the report. The report underlined the most probable losses that may occur for each of the climate hazards and summarized the most probable losses overall, what is further described in part 4 of the article.

The results of the workshop were promising, so it was decided to follow a similar method when implementing other urban adaptation plans by Institute for Sustainable Development Foundation. However, during the Warsaw workshop it became clear that certain things should be modified or supplemented for further work. Firstly, in Mińsk Mazowiecki and Wołomin it was decided to define the nature of the risk more precisely for the purposes of the workshop. The analyses preceding the risk workshops allow for a more qualitatively precise description of the threat that may occur in the city under consideration in the next 30 years than simply stating its name. An example of such a term is for Wołomin, e.g., "occurrence of a single rainfall episode of 90mm/sq.m." for the threat of flash flood. Such an element was missing from the workshop held in Warsaw, although some groups tried to imagine the risks in question in this way.

In Mińsk Mazowiecki and Wołomin, the workshop was also not implemented in full. For these cities, it was the project team that initially determined the probability of loss occurrence, and then the workshop only served to verify the probability assessments

made in this way. This made it possible to assess the probability in all analysed sectors without having to group them into categories. New loss scales were therefore developed for all sectors. The expert determination of probabilities also made it possible to move away from determining each sector's probability of loss for all hazards. Although there were usually more than 20 units of analysis to be discussed during the workshop, in the smaller stakeholder groups found in these cities, the implementation of the workshop did not prove to be particularly time-consuming. In practice this means that in Mińsk Mazowiecki and Wołomin only the last part of the workshop conducted in Warsaw, i.e., the discussion and acceptance of the results by the participants, was carried out in the workshop format. Nevertheless, the outcome of the analysis remained valuable, although the workshop participants had less input into it.

4. Results of risk assessments

The result of the analyses carried out in all three cities are risk matrices. From these matrices, it is possible to read out what probability is assigned to a particular scale of loss for a particular hazard occurring in a particular city. It is also possible to try to summarise the risk of a specific scale of losses for several different hazards or the risk caused by a specific hazard. Examples of the results determined for each of the three cities analysed are described below.

Warsaw was identified as having the highest probability of high losses, defined as "Increased mortality, damage to the health of many people" for human health and life in the case of heat. These were the highest losses of all those analysed, which were assigned a probability with a value of 'almost certain'.

When assessing the risks from multiple hazards, it was found that the following could primarily occur (by the degree of risk) (The City of Warsaw 2019):

a. Spot destruction or damage to green and blue infrastructure or minor damage throughout the city because of any climate hazard.
b. Minor malfunctions or spot disruptions to technical infrastructure because of flash floods, heat, or wind.
c. Short-term disruption of utility and food supplies limited in area mostly because of river floods or heat.
d. Individual compliant and affected persons (not their property, but their health) because of river flood or strong wind.
e. Area-wide paralysis of the functioning of urban infrastructure because of river flood.

Although qualitative, such statements are detailed enough to decide in which direction the city should take priority action. Sample of a risk matrix with results from Warsaw is shown as table 2.

In Mińsk Mazowiecki (The City of Mińsk Mazowiecki 2018), losses were not specified as high as in Warsaw, but the heat also proved to be the greatest threat to people's health and lives. "Almost certain" proved to be "single deaths, injured persons" in the case of heat. The average magnitude of losses in the energy sector was also determined at the same level of probability, viz: "Damage to low voltage networks and lack of supply of energy utilities to individual properties, facilities for several hours". The other effects of the hazards assessed with a high degree of probability were less severe. If one were to assess the risks from multiple hazards then the most likely effect related to crisis management was: "Crisis services handle all interventions, but single one's cause problems". Sample of a risk matrix with results from Mińsk Mazowiecki is shown as table 3.

In Wołomin (The City of Wołomin 2020), the high probability of high losses in the assessment accepted by the adaptation team was present in more sectors and for more hazards. For the energy sector, the almost certain losses were "Disruptions to low voltage lines with few hours energy cuts to some buildings" during strong wind. For the city's natural system almost certain was "Local

Table 2. Sample of risk matrix with results for green and blue infrastructure in Warsaw City. Derived from The City of Warsaw 2019

Green and blue infrastructure	*Flash floods*	*River floods*	*Heat*	*Drought*	*Strong wind*
Complete loss of ecological functions of trees, shrubs, rivers	highly unlikely	highly unlikely	highly unlikely	highly unlikely	highly unlikely
Loss of green infrastructure in some areas of the city	highly unlikely	likely	unlikely	very likely	moderately likely
Local damage to green infrastructure or minor damage to a whole area of the city	moderately likely	almost certain	likely	almost certain	almost certain
Minor point damage	almost certain	unlikely	very likely	almost certain	almost certain
No disturbance	highly unlikely	highly unlikely	highly unlikely	highly unlikely	highly unlikely

Table 3. Sample of risk matrix with results for crisis management in Mińsk Mazowiecki. Derived from The City of Mińsk Mazowiecki 2018

Crisis management	*Fast floods*	*Heat*	*Strong wind*
No possibility to react on the hazard	moderately likely	likely	unlikely
Reaction struggle with problems in most parts of the city	unlikely	moderately likely	unlikely
Crisis services handle interventions, but many are delayed	very likely	very likely	very likely
Crisis services handle all interventions, but single one's cause problems	almost certain	almost certain	almost certain
Crisis services react without problems	almost certain	almost certain	almost certain

Table 4. Sample of risk matrix with results for green and blue infrastructure in Wołomin. Derived from The City of Wołomin 2020

Green and blue infrastructure	*Flash floods*	*Heat*	*Drought*	*Strong wind*
Complete loss of ecological functions of trees, shrubs, rivers	moderately likely	likely	likely	likely
Loss of green infrastructure in some areas of the city	likely	likely	very likely	very likely
Local damage to green infrastructure or minor damage to a whole area of the city	likely	very likely	almost certain	almost certain
Minor point damage	very likely	almost certain	almost certain	almost certain
No disturbance	unlikely	unlikely	unlikely	unlikely

damage to green infrastructure or minor damage to a whole area of the city" during strong wind and drought. Concerning citizen's awareness almost certain was that "Part of citizens is not ready to react properly for the hazard" during heat. Summarising the probabilities from several hazards, it was assessed that the most likely to occur were: "Local damage to the city's natural system". Sample of a risk matrix with results from Wołomin is shown as table 4.

5. Evaluation of the risk assessment exercises

The risk assessment is the culmination of a series of analyses related to adaptation to urban climate change. In the approach worked out in LIFE_ADAPTCITY_PL project, used further by the Institute for Sustainable Development Foundation team, the results of the risk assessment are a very good starting point for planning adaptation measures. This opinion is primarily related to the fact that the results of the analysis provide

a risk-ranked description of the potential impacts of climate change risks. The impacts with the highest risk should be addressed by adaptation action first. This outcome of the analysis provides a firm basis for prioritising adaptation actions related to addressing the impacts with the highest risk of occurrence. This addresses an important weakness of many strategic documents in Polish municipalities, which is the lack of prioritisation of actions (Sekuła 2007), which is sometimes noted even in public consultation processes (The Municipality of Izabelin 2015). From an international perspective, McDermott and Surminski's (2018) analysis of the example of the city of Cork in the UK provides an insight into how such risk analysis can be translated into policy decisions.

The risk analysis method prepared for the stakeholder work proved to be a very good tool for filling knowledge gaps on climate change adaptation in individual cities. Stakeholders worked on a scheme that allowed them to use their own knowledge to make an assessment guided by the relatively precise criteria expressed in the matrix. This provided the opportunity to develop a good score, the advantages of which were described in the previous paragraph. At the same time, in cities where stakeholders merely accepted the results of the analysis performed by the Foundation's experts, there were also changes at the risk workshop stage, either by increasing or decreasing the risk assessment. This shows the maintenance of a significant influence of stakeholders on the outcome of the analysis, despite a reduction in the scope of their involvement.

The risk assessment method proposed and used by the Foundation does not differ in quality from methods previously used in other cities around the world. Most of these also used a 5-degree scale of damage associated with climate risks (Cho et al. 2019). What is new in the method used for the first time in Warsaw, is the application of the probability scale used by the IPCC to assess the impacts of climate change in their reports. As it seems, this is a step towards refining the qualitative probability assessment that each of the cities described in this article has used. The applied description of loss scales for individual sectors may need to be refined and improved in subsequent applications.

Conclusion

The application of the risk matrix in climate change adaptation planning in Warsaw was the first exercise of its kind at the city level in Poland. At the same time, it was probably the first application of risk assessment in a workshop format with the participation of a wide range of stakeholders in urban adaptation issues. The simplifications applied to carry out the assessment in Warsaw do not seem too far-reaching compared to other such analyses in cities around the world. Further implementations of the described method in Mińsk Mazowiecki (2018) and Wołomin (2020) proved that it is applicable to different cities and different scales of stakeholder involvement in the process. It is a method worth recommending in the preparation of further urban adaptation plans in Poland.

The authors of the implemented method see further opportunities to make the method more precise, without loss to its utility and audience comprehensibility. As described earlier, some such improvements were made as further assessments were implemented, e.g., refinement of the hazard description. The most hopeful improvements can be made to the refinement of loss descriptions. It seems possible to use already existing or describe new loss scales related to specific hazards and sectors of the city. One known scale of this type is the Fujita scale (NOAA 2009), which is applicable for assessing wind strength based on the damage it causes. It is possible that similar scales may have already been developed and fit for use as part of risk-related assessments of the activities of individual economic sectors.

What is worrying about the work done in connection with the preparation of

municipal plans for adaptation is the still perceived low correlation of the risk assessment results with the planned measures. Even though the risk assessment carried out using the method described produces concrete, well-founded results, city authorities still do not seem to be sufficiently interested in developing and implementing appropriate measures based on these results. There is also the possibility that cities are not sufficiently prepared for the results of such assessments. Today, cities are still more focused on the priorities they have already adopted, but the authors hope that the necessary changes based on the results obtained from the climate risk assessments will come with time and, above all, that this will take place in good time, and certainly not too late.

Authorship: Conceptualization, W.Sz., A.K.; Formal Analysis, W.Sz.; Investigation, W.Sz., A.K.; Methodology, W.Sz., A.K.; Supervsion, W.Sz.; Validation, W.Sz., A.K.; Visualization, W.Sz.; Original Draft Preparation, W.Sz.; Writing – Review & Editing, W.Sz., A.K. Both authors have read and agreed to the published version of the manuscript.

Financing: This publication is a result of a grant LIFE13 INF/PL/000039 co-financed by European Commission financial instrument LIFE and the National Fund for Environmental Protection and Water Management.

Statement by the competent ethics committee: not applicable

Conflict of interest: The authors declare that there are no conflicts of interest related to the publication of this research. The sponsors of the present study had no role in the planning of the study; in the collection, analysis, or interpretation of the data; in the preparation of the manuscript; and in the decision to publish the results of the study.

Acknowledgments: Both authors would like to thank the City of Warsaw, especially the Warsaw City Office for Infrastructure and its director Leszek Drogosz, for fruitful cooperation in the project ADAPTCITY.

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