SECURITY & DEFENCE QUARTERLY
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Flood vulnerability of the critical infrastructure in Poland

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Abstract

The purpose of this article is to examine the significance of the flood hazard for the functioning of the critical infrastructure in Poland and to suggest adequate methods and strategies for reducing the vulnerability of critical infrastructure to flooding. The main research method used is institutional and legal analysis, which shows how critical infrastructure is protected in Poland. The context of climate change is taken into account, the consequences of which may trigger increased threat, and its significance is discussed. It is also shown that river floods of a pluvial character constitute the greatest hazard in Poland, as they pose a threat to urban areas where most critical infrastructure is located. The author lists methods which can be used to protect critical infrastructure from flooding. Examples of systems are also provided. A conclusion is formed that the approach to this problem should be comprehensive and make use of methods related to flood prevention, flood defence and flood mitigation, and above all, the relocation of elements of the critical infrastructure. It is evident that the best time to reduce the susceptibility of specific systems to floods is when they are developed or modernised by taking into account the flood risk. Lastly, the biggest problem of the critical infrastructure in Poland is highlighted, namely its identification once it is already built, which means its location had not been thought through.

Keywords

critical infrastructure, floods, flood vulnerability

Article info
Received: 24 December 2021
Revised: 15 May 2022
Accepted: 26 May 2022
Available online: 22 August 2022

Citation: Morawski, M. (2022) 'Flood vulnerability of the critical infrastructure in Poland', Security and Defence Quarterly, 39(3), pp. 108–122. doi: 10.35467/sdq/150456.

Introduction

The phenomenon of flooding is commonly known and it affects a vast part of the inhabited areas around the world, being a great risk for the health and life, as well as state economies and the natural environment. It was estimated that floods constituted 43% of all natural disasters in 1994–2013 and had an impact on nearly 2.5 billion people, which is why they are the most common of natural disasters (Centre for Research on the Epidemiology of Disasters [CRED], 2015, pp. 16–19). A flood is a threat to every infrastructure element located in the floodplains. Therefore, in the context of critical infrastructure protection, it seems to be one of the most crucial threats. The author of the present article attempts to analyse this phenomenon. The main objective is to point out how to reduce the flood vulnerability of critical infrastructure. In Central Europe, floods can be regarded as one of the most significant threats. The Polish conditions determining the flood risk impact which are described are relatable to many other countries. Much of the infrastructure, as well as large urban centres, are located in areas at risk of flooding. That is why the Polish example will be a universal model in many cases.

Critical infrastructure

Although the term critical infrastructure has been used since the 1990s, development of state actions in this field happened as a result of a redefinition of the approach to infrastructure protection in the United States, which took place after the terrorist attacks of 9/11 (Moteff and Parfomak, 2004, pp. 6–10). The definition of critical infrastructure from the USA Patriot Act is that "critical infrastructure" means systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters" (US Government. 2001). This definition may be deemed quite broad, and the criterion within allows many different resources and systems to be included in the scope of critical infrastructure. The protection of critical infrastructure also became a field for cooperation among EU Member states. As a result, the Directive on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection was published in 2008. The critical infrastructure was defined there as "asset, system or part thereof located in member states which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a member state as a result of the failure to maintain those functions" (Council Directive 2008/114/EC; European Union, 2008). This definition is also broad. What is important is that although the Directive underlined the need to counteract terrorist attacks and showed it as a priority and it also took into account natural disasters as one of threats important in the context of the protection of critical infrastructure.

The term critical infrastructure was first introduced in Polish legislation along with the 2007 Act on Crisis Management (Act on crisis management, 2007), a milestone in the organisation of a modern crisis management system, which replaced earlier solutions without a systematic character and based on various loosely connected regulations. An article introduced in 2009 as an amendment to the Act was a significant change, as it established the obligation to adopt the National Critical Infrastructure Protection Programme upon a resolution of the Councils of Ministers, which was given the purpose of "creating conditions to improve the safety of critical infrastructure." It focused mainly on preventing disruptions in functioning or preparing for emergency situations negatively influencing the infrastructure

(Act on amending crisis management act, 2009). Changes in the scope of critical infrastructure protection were also introduced in 2010, by implementing the above-mentioned directive to state legislation. It was also an opportunity for corrections resulting from the desire to organise the responsibility of administrative authorities for specific departments.

The definition of critical infrastructure binding in Polish law is: "systems and their functionally related facilities, including structures, devices, installations, services key for the security of the state and its citizens, and serving to ensure smooth functioning of public administration authorities, as well as institutions and entrepreneurs." The Act also covers specific systems which the critical infrastructure is composed of, that is: "(1) energy supply, raw materials and fuels, (2) communications, (3) networks, (4) financial, (5) food supply, (6) water supply, (7) health care, (8) transportation, (9) rescue, (10) ensuring the continuity of public administration functioning, and (11) production, storage, warehousing, and use of chemical and radioactive substances, including pipelines of dangerous substances" (Act on crisis management, 2007).

The protection of critical infrastructure in Poland is based on the already mentioned Act of 2007 and the systematic solution created by it, in which public entities with specific tasks related to its protection, as well as critical infrastructure "operators" (owners and managers of its elements) participate. Ministers and heads of central offices were assigned with responsibility for specific systems of the critical infrastructure, which would enable using the potential of knowledge and ability to assess risk with regard to a given authority and the administration operating it. With the use of cross-sectional and sectoral criteria and a three-stage process, critical elements of given systems are found. The ministers and heads of central offices make the selection, the result of which is a list of elements that make up the critical infrastructure in the supervised system. The list is then sent to the Government Centre for Security, along with suggestions for protecting it and what the priorities are in case they need to be recreated. In this way, a confidential, unanimous list of facilities on a national scale is created. The owners and managers of those elements are required to prepare protection plans and keep backup systems which would enable support for the functioning of the given element if necessary. Their duty is also to inform the risk management centres about expected or occurring disruptions in functioning (Tryburska, 2018, pp. 46–48). The already mentioned National Critical Infrastructure Protection Programme is of key importance in the whole process.

Flood hazard and the issue of climate change

The phenomenon of a flood as a natural disaster should not be discussed separately from the issue of climate change. In order to outline this context, one has to step out of the security studies area and look at the findings of researchers from other scientific fields. While studying various papers, one can tell that it is difficult to determine the impact of climate change on the issue of flood occurrence, frequency or influence. As stated by Whitfield (2012, p. 359):

> Hydrological processes including floods take place on a relatively local scale and not on a global scale; making simplistic generalisations about flooding in future climates is problematic. Many processes that play a role in flood generation are unresolved in models on a global scale. On the watershed scale, land-use effects are more important than changes in the meteorological inputs of future climates. While the general view of scientists is that the warming of the atmosphere will increase the capacity of the atmosphere to hold water, and that this warming will also accelerate many of the processes involved in the redistribution of moisture in

the atmosphere and will increase excess rainfall. However, simply stating that flooding will increase with changing climate is unwise.

A noticeable increase in flooding phenomena in Europe took place at the end of the 20th century. More frequent floods with a stronger impact happened, although, as it was believed at the time that their frequency was consistent with the scope of historical occurrences, and therefore climate change was not pointed out as the main cause of the increasing damage (Barredo, 2007, p. 145). The Intergovernmental Panel on Climate Change (IPCC, 2021, pp. 9–24) report can certainly be recognised as presenting the current state of affairs. Strictly speaking, the "Summary for Policymakers," which presents findings on the present climate situation, would be enough for the purpose of the matters discussed. The following entries, most crucial for the present article, are worth citing:

- "Human influence has likely increased the chance of compound extreme events since the 1950s. This includes increases in the frequency of [...] compound flooding in some locations (medium confidence)," while "Compound extreme events" are defined as a "combination of multiple drivers and/or hazards that contribute to societal or environmental risk," and the accompanying example was "compound flooding (e.g., a storm surge in combination with extreme rainfall and/or river flow";

- "A warmer climate will intensify very wet and very dry weather and climate events and seasons, with implications for flooding or drought (high confidence), but the location and frequency of these events depend on projected changes in regional atmospheric circulation, including monsoons and mid-latitude storm tracks";

- "At 1.5°C global warming, heavy precipitation and associated flooding are projected to intensify and be more frequent in most regions in Africa and Asia (high confidence), North America (medium to high confidence) and Europe (medium confidence)";

- "At 2°C global warming and above, the level of confidence in and the magnitude of the change in droughts and heavy and mean precipitation increase compared to those at 1.5°C. Heavy precipitation and associated flooding events are projected to become more intense and frequent in the Pacific Islands and across many regions of North America and Europe (medium to high confidence).".

In the context of global climate change, forecasting and planning becomes more and more difficult. In order to adapt to the new conditions, the previously used patterns, based on data and methods from the past, should be abandoned. It enforces the use of a new approach in architecture and construction design, for instance. As pointed out by Valsson (2006, p. 28): "We should always try to seek the most secure areas and always try to make all construction as robust and resilient as possible, because all building and infra- structure will have to be able to withstand forces far greater than today's accepted standards require."

However, even though floods are most often seen as completely natural phenomena, it is not only natural conditions that decide on their effects but, predominantly, it is the development and usage of the area at risk of flooding that matters (e.g. a river valleys). The importance of the human factor is commonly known. The preamble of the European Parliament and Council Directive, significant for the risk of flooding issue, contains an important thought that flood is a natural and inevitable phenomenon, which is also susceptible to the human factor—"increasing human settlements and economic assets in floodplains and the reduction of the natural water retention by land use"

(European Parliament and Council Directive 2007/60/EC; European Union, 2007)—which does not only contribute to the increased likelihood of flooding, but also to its negative consequences. In the case of river floods, the negative influence of human intrusionincreasing the risk of flooding comprises not only ofnarrowingriverbedsin order to land developthe areas where rivers could flow. It is also connected to deforesting and widening impermeable, hard surfaces which accelerate the flow of water to the river and prevent absorption (Valsson, 2006, p. 29).

In summary, it should be stated that the risk of flooding, including for Poland, may increase and get even bigger. Thus, a flood, which has already been a threat to many areas, may become an even more significant threat to the critical infrastructure discussed.

Significance of the flood threat in Poland

Due to the multifaceted character of the phenomenon, there are many different flooding typologies. For the purpose of this study, the typology proposed for Polish conditions will be useful, as it shows the way floods arise. According to this division, we can differentiate between pluvial, melting snow, storm and winter floods (Bednarczyk *et al.*, 2006, pp. 13–39). Pluvial floods are triggered by extreme rainfall (driving and long-lasting rainfall). Pluvial and driving flooding may cover small areas and occur on little watercourses. They appear suddenly and are difficult to predict. Their violent character is mostly visible in urban areas and that is the reason why the literature describes a particular type, called "urban foods." In Poland, they occur mostly in July and August. At the same time, in the case of pluvial, frontal and long-lasting floods, the phenomenon may happen in a vast area and have disastrous results. This type of flood usually occurs in Poland between June and September. Floods due to melting snow are caused by an abrupt increase in temperature and intensified by extreme rainfall. They may occur over very big areas, yet are short-term. In Poland, they happen most often in March. Storm floods, occurring mostly in December and January, are provoked by intense windstorms. They happen only locally in Poland. Winter floods are a category that covers numerous phenomena connected with the creation of a blockage made of ice and frazil ice. They occur most often in December, January and March (Bednarczyk *et al.*, 2006, pp. 13–39). Apart from the months indicated above when floods are most common, they may appear earlier or later. It means that the nationwideflood hazard is of a permanent character.

The significance of flood risk for the security of Poland is determined not only by the possibility of flood occurrence, but most of all by the experience to date. Between 1946 and 2010, there were 16 significant floods in Poland. However, there were instances of floods with different causes, (for instance ice-jam floods in 1947 and 1982, and ones triggered by melting snow in 1979 and 2001), most of which had a pluvial character. Nowadays, for the perception of this threat and its importance in Poland, the experience of two massive pluvial floods which happened in Central Europe at the turn of the 20th and 21st centuries is crucial. These floods took on enormous dimensions and had disastrous effects in Poland. The first one took place in 1997 mostly in the Odra river basin, while the second was in 2010, mostly in the Vistula river basin. The tragic consequences of the two biggest floods included 55 casualties in 1997 and 20 in 2010. In both cases, damage reached or exceeded 1% of the Polish GDP (Kundzewicz, 2014, p. 385).

While characterising the issue of flood threat in Poland, it may be concluded that:

- river floods constitute the greatest threat. On the basis of the analysis of the flood hazard, it was estimated that as much as 29,301.7 km of Polish rivers are sections at risk of river floods (report from the review and update of the preliminary flood risk assessment; Państwowe Gospodarstwo Wodne Wody Polskie, 2018, p. 90). The floods occur in the Odra and Vistula river basinsof the two biggest Polish rivers;

- these floods are of a pluvial character–they are pluvial, frontal and long-lasting floods;
- urban areas near rivers are at risk. The biggest Polish cities, such as the capital city of Warsaw, as well as Krakow and Wroclaw, are situated by rivers which constitute a risk of flooding, for instance, the Vistula and Odra.

In order to analyse the flood hazard for critical infrastructure in Poland, one should focus on river floods triggered by the above-mentioned factors.

Different methods and approaches in the flood protection

It seems crucial to ask how to deal with a flood and what measures or tools should be used to stop it. There are numerous various methods of flood protection which can be divided into three groups:

Methods related to flood prevention

Identification of risk areas, restriction of building in these areas. Identifying areas at risk of flood, limiting their development and even relocating individuals inhabiting them (Kundzewicz, 2014, p. 392). The usage of the above methods is described in the literature as the"keeping people away from water" approach. The arguments for that approach–keeping people away from water—concern not only the efficiency of regional planning, but also to the application of methods and solutions such as education or warnings and evacuation systems.

Structural methods related to flood defence

Dykes, floodwalls, embankments, dams, reservoirs and relief channels can serve as examples. They allow a specific area to be protected from flooding, as well as hydrotechnical equipment, such as dams and reservoirs or bypass channels. The usage of the above methods is described in the literature as the "keeping water away from people" approach (Kundzewicz, 2014, p. 392). The criticism of that approach relates to its short-term efficiency, which can be measured from the time technical protection measures are established to the occurrence of such a flood, the dimensions of which they will be powerless to breach or are damaged by, for example, dykes. The conception of "the vicious circle of flood protection" can serve as an illustration here, as it refers to a false sense of security created by protective structures established in river valleys. If a given area is protected, for instance by creating dykes, it can be further developed. The developed area is then flooded during the next flood and the losses exert more intense social pressure on modernisation and development of securities (e.g. increasing the height of dykes). This cycle is then repeated and creates a vicious circle (Bobiński and Żelaziński, 1996, pp. 99–107). Criticism of the technical solutions also includes their negative impact on the natural environment, which applies not only to establishing dykes and reservoirs, but also to all regulatory processes. Moreover, economic doubts arise, especially when the dykes serve to protect arable lands and pastures instead of urban or inhabited areas.

Methods related to flood mitigation

This group contains all methods that improve the ability to retain water. A retention may be steered from outside, as in the case of artificial reservoirs, or it may be natural (Gryz and Gromadzki, 2021, pp. 161–118), as in the case ofsupporting natural processes for retaining water in the landscape, for example, in swamps, peat bogs and forests, as well as in riverbeds and valleys (Bednarczyk *et al.*, 2006, p. 103). Projects connected with moving dykes away from riverbeds and reducing the high water levels, or in the case of regulatory works, through renaturisation of rivers, can be proposed. This group also comprises some structural methods connected to through flow polders, dry reservoirs, and lateral impounding reservoirs (Żelaziński and Wawręty, 2006, pp. 45–46). All methods related to catchment area management, described as the "keeping the water where it falls" approach (Kundzewicz, 2014, p. 392), can also be included in this group.

Adequacy of methods and approaches for protecting critical infrastructure from flooding

It is vital to juxtapose the above-described methods and approaches in flood protection with the need to protect critical infrastructure. The adequacy of particular methods is shown on the basis of different elements of systems belonging to Poland's critical infrastructure.

Methods related to flood prevention

An instance worth mentioning is one of the systems most prone to flooding: the energy supply system. It has been noted that floods cause great damage to energy network resources, which results in breaks in energy supplies. The inundation of infrastructure leads to damage, especially that water and mud in the equipment may require costly and time-consuming reparations. The extent of damage, and consequently the expense and time needed to repair, increases with the depth of water and time in which the area is flooded. Damage to the power transmission grid caused by landslides and soil erosion constitutes an additional problem (Karagiannis *et al.*, 2019, p. 6). The authors of a comprehensive study on the impact of flooding on this part of the critical infrastructure also show that flooding causes breaks in energy supplies and not only in areas directly affected, due to the network structure and the locationof electrical substations (Karagiannis *et al.*, 2019, p. 2). Methods related to flood prevention seem reasonable in this case. A remedy for potential infrastructure damage is relocation of its vulnerable elements to areas above the expected flood level. However, it should be taken into consideration that this is a costly undertaking—due to the need to acquire land and investments, and also a difficult one—due to the need to rebuild a structure around a specific substation. In addition, the relocation of too many such facilities can negatively influence the power grid's reliability. Moreover, a location near a river may be necessary for technical reasons. In the case of Poland, large coal-fired power plants in river valleys may serve as examples—the Opole power plant and the Dolna Odra power plant, at risk of flooding by the Odra river, or the Kozienice power plant and the Połaniec power plant, located in the Vistula river valley. In the last one from the list, during the 2010 flood, three power units had to be disconnected due to the inundation of cable ducts (Sejm of the Republic of Poland 2010). If it's not possible to relocate, dykes and other structural methods related to floodingare the only option. Separating infrastructure from a potentially flooded area may be less expensive but also entails the need to assume a certain level which may be reached by the next flood (Karagiannis *et al.*, 2019, p. 28).

Preventive methods constitute not only relocating the critical infrastructure, but alsoabandoning the type of infrastructure that may be especially vulnerable to flooding. An example is waterways transport, part of the transportation system, asfloods have a devastating impact on it, which was emphasised in the study on potential climate change effects. Since sailing depends on the water levels, the maximum values of those levels are counted as potential obstructions in floods. The study's authors, however, claim that because of their short-term character, they are less significant in obstructing inland waterways transport than, for instance, droughts which make using a waterway impossible (Christodoulou, Christidis and Bisselink, 2020, p. 1). The situation of inland waterways transport in Poland is of a specific nature. Although the length of inland waterways amounts to 3,768 km, only 5.5% of them meet the requirements of international waterways. Polish waterways are underdeveloped, hence this type of transport does not play a significant role in the whole transport system (Główny Urząd Statystyczny, 2021b, p. 1). In 2020 in Poland, only 3,992 thousand tonnes of cargo were transported via waterways, while 2,331,758 thousand tonnes went on the roads (Główny Urząd Statystyczny, 2021a, p. 1). Notwithstanding this, the topic is worth discussing due to the demands of reinstating or creating an inland waterways transport system, establishing infrastructure and, consequently, significant regulatory activities on rivers which are recurring in Poland's publishing and political discourse. Those demands need to be understood by the present government. The government administration has been processing important documents, which are aimed at developing the most significant waterways in Poland to achieve the international class of navigability (Ministry of Infrastructure, Government of Poland, 2021). Its susceptibility to floods (and other natural phenomena) makes the sense of the advocated undertaking of its restoration questionable. Taking into account the circumstances of climate change, redirecting some transport to inland waterways transport will make the system as a whole more vulnerable. Because it constitutes a marginal part of the whole transport system in Poland at the moment, rejecting these demands will not incur significant costs, which would be inevitable if waterways were used intensively.

Surely, the critical infrastructure systems also contain those which may be situated in places free of flood hazard. For locating new facilities, the knowledge that a flood may occur in a given area is sufficient. Unfortunately, the construction of the critical infrastructure system in Poland poses some problems. Critical infrastructure protection is defined in law quite broadly as: "all actions aimed at ensuring functionality and continuity of undertakings and the integrity of the critical infrastructure in order to prevent threats, risks or weak points and limit and neutralise their consequences and quickly recreate this infrastructure if there are breakdowns, attacks or other events that make it unable to function normally" (Act on crisis management, 2007). Meanwhile, the newest version of the National Critical Infrastructure Protection Programme, adopted in 2020, contains a very narrow list of types of protection (Government of Poland, 2020). The actions listed in the current version, that is, ensuring physical safety, ensuring technical safety, ensuring personal safety, ensuring ICT safety, ensuring legal safety, along with continuity and recreation plans, seem to be wholly insufficient when juxtaposed with a flood. Although the authors of the programme wrote that the actions would result in areduction in susceptibility (National Critical Infrastructure Protection Program; Government of Poland 2013), they clearly did not take into account numerous other possibilities, which could really affect susceptibility when there are threats such as floods. It seems that narrowing actions to only ongoing, *ad hoc* and post-hazard ones is a mistake. One could have the impression that this list is fitted to a small group of threats (e.g. terrorist attacks), which is contrary to the statutory intention which setsa very broad framework of actions understood as critical infrastructure protection. At the same time, the question of critical infrastructure is present in the law regarding flood protection—the Water Law Act (2017), which takes critical infrastructure into consideration while determining actions for achieving the aims of flood risk management.

Structural methods related to flood defence

Key elements of the transportation system are apart of the critical infrastructure for which structural methods have to be used. When analysing the resilience of the transport system to flood risk, we should take into account not only all the possible damage to the road infrastructure and the cost of repairing it, but also the disruption caused, that is, the fact that the infrastructure is out of order. Bridges are most often subject to damage, since bridges or their access routes are easily destroyed. The susceptibility of the transport system to damage concerns both road transport and railway infrastructure. It can therefore be concluded that urban areas are most susceptible to the negative consequences of a flood hazard. The significant contribution of impermeable surfaces, due to which the water cannot drain off, is identified as the cause of this state of affairs (Pregnolato *et al.*, 2017, p. 67). When discussing transport infrastructure, it is worth mentioning the cascading effect which occurs when critical infrastructure is at risk of flood, as pointed out by Fekete (2019). An example of such an effect is the inability to reach and help individuals affected by a flood because of damaged roads. Here we can recall the time when a bridge abutment in Płock was destroyed during the 1982 blockage (winter) flood in the Vistula river valley. A rail disaster, in which a train went off the rails, was a direct consequence of this destruction.

Much transport infrastructure certainly cannot be "withdrawn" from areas potentially flooded. Since the relocation of all the development is impossible for many reasons, transport infrastructure will remain there. Independently from the development of floodplains, there will also be transport infrastructure crossing those areas, which is a part of transport corridors. Thus, formuch infrastructure, the only possibility will be to apply structural methods related to flood defence. Certain possibilities, taking into account the above limitations, will arise during the development of transport infrastructure and creating its new elements, which may made more resilient to flooding. Taking into consideration the cascading effect seems to be the key to protecting this part of critical infrastructure, which may cause disruptions substantially outside the transport system. This issue requires detailed analysis, consisting of selecting particularly vulnerable items, lines and nodes, relative to the requirements of this infrastructure, as well as the consequences, which may be triggered by the operational disruption or the destruction

Structural methods related to flood defence are in some cases indispensable, whereas, when possible, the methods related to flood prevention should be employed. A general observation can be put forward concerning the need to limit the scope of critical infrastructure to areas that may be flooded. It is mainly applicable to developmental activities—developing specific systems by extension or modernisation projects. When comparing the above observations with the reality of critical infrastructure protection in Poland, it should be underlined that in Poland, as pointed out by Kundzewicz (2014, p. 393), flood protection is mostly based on traditional, technical measures—dykes and impounding reservoirs on the most threatening rivers, that is, the Vistula and Odra and their tributaries. The most recent floods showed that thedykes are feeble and insufficient in many places. Notwithstanding this, he points out that the idea of using non-technical methods is gaining in popularity.

Methods related to flood mitigation

Large dams along with accompanying reservoirs and hydropower plants are an interesting example that can be discussed in the context of methods related to flood mitigation. They are built to perform various functions, including those that transform them into elements of the critical infrastructure. They constitute an important element of the water supply system—the Dobczyce reservoir can serve as an example here as it supplies water to the citizens of Cracow, just as the Zegrze reservoir supplies water to numerous Warsaw districts. They serve to generate energy that is usually recognised as 'the clean energy'. Reservoirs are also the main tool of artificial retention, which in some cases makes high water level interception possible.

At the same time, in each of those areas, problems connected with the flood hazard arise. Paradoxically, flooding constitutes the biggest threat to the infrastructure of water supply, both drinking and industrial water. During every flood, microbiological, physical and chemical parameters of water are changed. The flood water might contain wastewater or agricultural fertilizers washed out. River ecosystems are imbalanced. Reservoirs are also particularly at risk. The matter carried by a river is accumulated in the reservoir. Different types of substances, such as mineral deposits and organic sediments, or municipal waste are being introduced to it via flood water. It has particularly negative consequences for the water supply when a reservoir is the source of water supply for the population (Lipińska, 2011, pp. 38–40). The question of safety at hydropower plants should not be omitted. Even though hydro power storage dams are usually associated with preventing flooding of rivers, it should be clearly stated that they may also be at flood risk. Hauenstein (2005, p. 323) claims that hydropower plants should be considered as the most endangered facilities in the energy supply system because of their location. Despite the fact that those facilities are designed to endure large floods, he states that the examples of events in Switzerland show that, for instance, damage to the dam's foundations is possible. Vulnerability to flooding is proved by numerous incidents, including in Poland—for example, in 1979, the Dębe barrage was severely damaged by a flood (Tomoń, 2012, p. 48). One should consider if creating new artificial reservoirs, especially of a large scale, helps in flood protection, or maybe increases vulnerability due to the above-mentioned processes which can affect the critical infrastructure. The dilemma is difficult, since at the same time, some researchers voice concerns about the harmfulness of dams to the natural environment because of lowering the nature conservation value of a river ecosystem (Czerniawski, 2019).

Due to the criticism, as well as threats connected with dams, completely different solutions related to flood mitigation seem to be preferableto elements such as large reservoirs. Such solutions consist mainly of increasing the ability to retain water in the landscape, but they also cover watershed management actions that lead to retaining water. Apart from supporting the natural retention, a number of actions are described as artificial retention, which are not limited to building large reservoirs, but also include various measures, used not only at micro level, locally, (e.g. for the purposes of household use), but also at the level of the whole catchment area of a particular river. Water retention is key toflood prevention, as well as to another great threat connected withclimate change, namely drought. Sadly, the activities undertaken in this scope in Poland are regarded as insufficient (Gryz and Gromadzki, 2021, p. 84). The authors of a vast publication on the subject of drought emphasise the lack of an effective retention management system, demanding at the same time to link this issue to the crisis management system already in place (Gryz and Gromadzki, 2021, p. 161–118). They rightly underline the importance of this topic for the critical infrastructure (Gryz and Gromadzki, 2021, p. 59).

To sum up, it should be stated that critical infrastructure protection uses a number of different methods. Thus, the comprehensiveness of the state's approach towards flooding is decisive. 'The flood risk management approach' which is gaining in popularity in EU member states can serve as a positive example here. The basis of this approach constitutes the flood hazard, defined "as the 'product' of the probability of floods and their consequences, or, alternatively, as the product of flood hazard and society's vulnerability to floods" (Klijn, Samuels, Van Os, 2008, p. 309). The authors of a study on flood risk management in the EU countries identify three aspects of this approach. The first concerns mere management unrelated to the flood but not to the hazard—the threat and vulnerability of the given area. The second aspect is the comprehensive character of this approach, as it covers not only the use of traditional, technical measures, but also non-technical ones, which means that both of the previously described approaches are used, depending on requirements. The third aspect relates to the dynamic nature of this approach—it may be described as a continuous process, assuming a constant evaluation, as well as the implementation and maintenance of measures for flood risk management (Klijn, Samuels, Van Os, 2008, p. 309).

Although analysis of the Polish policy on this issue is a topic which requires a comprehensive, separate study, it is safe to claim that over the last dozen years, a number of actions were carried out to implement flood risk management. Information about the potential flood, its territorial range and the development character of the area seem to be crucial in its implementation. The lack of such knowledge was certainly one of the biggest problems of Poland's flood protection. The situation changed drastically when the implementation of the Directive of the European Parliament and of the Council No. 2007/60/EC on the assessment and management of floods, that is, the so-called Flood Directive, began (European Union, 2007). The implementation, carried out in 2011, triggered works on preliminary risk evaluation and maps of flood hazard and flood risk were drafted. Maps illustrated scenarios of destruction or damage of dykes and other protection constructions. This process ended in 2015. Two years earlier, the plans of flood management risks were outlined, which provided for both technical and non-technical actions. Plans for the basins were adopted in 2016. During the implementation of the Directive, the ISOK (IT system for protecting the country against emergencies) project was also completed, constituting a homogeneous system used mostly by government and local administration, responsible for a number of tasks related to flood protection and risk management. At the turn of 2017 and 2018, a fundamental reform of administration responsible for the water management was carried out. A distracted, underfinanced and uncoordinated structure was replaced with a new one, the core of which is the state water holding, "Polish Waters."

Conclusions

Although the above actions merit a positive evaluation and are surely steps in the right direction for implementing a comprehensive, modern approach based on flood risk management, it should also be noted that steps taken by the state are still extremely deficient. It can clearly be seen that flood protection policy is not coordinated with the natural environment protection policy. Certain remarks can be made in relation to the land management, which is still largely neglected. An obligation introduced in 2018 to coordinate the development and management of an area particularly at risk of flooding with the "Polish Waters" authority was certainly a positive undertaking. Failure to coordinate in this way may result not only from a potential breach, for instance, of arrangements for flood risk management but alsowhen the functioning of critical infrastructure is likely to be breached (Water Law Act, 2017). However, significant deficiencies are clear when flood management risk is taken into consideration. The state is not proactively looking for solutions to problems related to the existing development of areas, which, in relation to the above processes connected with implementing the directive, were identified as potentially flooded. Projects relocating these facilities that are significant on a national scale have not been carried out.

A thesis can be advanced here that the Polish approach to critical infrastructure suffers from its "departmental" or "sectorial" nature, expressed in the lack of coordination of different state fields of activities and the creation of legal and institutional solutions in restricted sectors. As Kosowski (2019, p. 138) observes: "in terms of creating new legal regulations in the discussed scope, there is no integration of security institutions and entities, and the direction of building systems protection in the sectoral system is dominant." The present study shows the multifaceted character of the problem of research on critical infrastructure protection, which requires taking into account the various consequences of threats, interdependencies between systems and cascading processes caused by disruptions in those systems. The sectorial approach is faulty in relation to hazards such as floods, or in broader terms, all natural disasters. This is because they require a coordination of threads of different public policies, including in the context of climate change.

This review of the above-mentioned systems covered by the critical infrastructure proves that their structures are very susceptible to flood risk. Questions regarding resilience to flood might be asked in relation to all the other systems as well. Surely, all infrastructure of a transmission character, including communications, networks or pipelines of dangerous substances, is at risk. Such risk is unavoidable for this part of the infrastructure. Poland's geographical conditions make it impossible to run transmission networks that omit the areas at risk. It is different in the case of other parts of the critical infrastructure. There, the location of the area potentially threatened by a flood determines the flood risk. This could concern industrial units and places where chemicals are stored. Social infrastructure such as elements of the healthcare system, rescue systems or those ensuring the continuity of public administration functioning that is located on threatened areas accounts for a significant percentage of the whole.

In order to sum up the present article, it can be stated that reducing the vulnerability of the critical infrastructure to flood hazard predominantly takes the form of various actions. Although, due to the character of the flood hazard and the risks resulting from climate change processes, the best way seems to be to relocate elements of the critical infrastructure outside the area potentially flooded, in many cases it is impossible. This mostly concerns very urbanised areas, which will probably never be relocated regardless of the flood threat. A thesis could be advanced here that in many cases, the relocation of infrastructure would technically be possible, but it is not done due to the potential costs and expenses incurred to do so. The issue of economic profitability may be decisive here, apart from practical considerations. In addition, it should be mentioned that the character of some system elements makes their validity questionable, which the example of the inland waterways transport shows. In this case, reducing the system's susceptibility would mean abandoning a risky solution.

The biggest field of improvement seems to be locating new critical infrastructure while developing present systems and carrying out great modernisation projects. The problem remains how to act towards critical infrastructure, which in Poland means the identification of its already existing elements, not at the stage of planning their execution. In the event of a flood hazard, it seems legitimate to demand analyses *ex-ante*, identifying a potential threat when decisions had not been made and significant investment expenses had not been incurred, as they would become an argument against relocation after a disaster.

The last observation concerns the discrepancy between the findings of the scientific world and the reality of political decision-makers, which is often revealed when natural disasters are discussed. Critical infrastructure and its protection are not only an interesting field of study, but also an opportunity for the observations of scientists to become the basis for constructing public policies. The author concludes this article by making a demand for greater cooperation in this area.

Funding

This research received no external funding.

Data Availability Statement

Not applicable.

The author read and agreed to the published version of the manuscript.

Disclosure statement

No potential conflict of interest was reported by the author.

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