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Development of flood prone areas in Wielkopolska region

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Abstract

The aim of the study was to analyse the state of flood-prone areas development in 10 towns on the Warta River in the Wielkopolska region in terms of the possibility of adapting existing and planned buildings to flood risks. A significant percentage of the areas exposed to floods was the basic criterion for selecting three towns for the second stage of the research. The analysis of the content of 22 local spatial development plans (LSDP) in three selected towns has revealed that the plans for special flood hazard areas (SFH) and embanked areas lack precise requirements for flood adaptation. The research proved that small riverside towns in Wielkopolska region insufficiently use planning tools to create appealing and resilient waterfronts and reduce their vulnerability. New buildings not adapted to changing water levels are still being built in the flood-prone areas, because LSPD plans do not impose such requirements. The authors proposed the graphical analysis method (based on overlay maps), which allows to indicate the areas requiring special flood-adaptation guidelines. The building and site recommendations in LSDP should refer to BFE level and may include various types of amphibious architecture and their location conditions, which has been identified in the study.

Key words: *amphibious architecture, flood adaptation, flood-resilient development, spatial planning documents, Warta River, Wielkopolska region*

INTRODUCTION

Coastal areas and river valleys are particularly attractive for residential and service buildings due to landscape and recreational values therefore they are under constant investment pressure (e.g. BREEN, RIGBY [1996]; BRUTTOMESSO [2001]). However, the spontaneous urbanization may deprive them of ecological capital and retention capacity [JANUCHTA-SZOSTAK 2018], increase the risk of flooding [KUNDZEWICZ *et al.* 2018] and generate series of conflicts [AVNI, TESCHNER 2019; KOWALCZAK, KUNDZEWICZ 2011], which must be carefully recognised in the spatial planning process.

According to the Spatial Planning and Development Act of 27 March 2003 [Ustawa… 2003] and the Act of 20th July 2017 on Water Law [Ustawa… 2017], the flood prone areas are not excluded from building development in Poland. However, they require consideration of special flood hazard (SFH) areas in all planning documents and relevant arrangements with the State Water Holding – Polish Waters (Pl. Państwowe Gospodarstwo Wodne Wody Polskie) – the authority responsible for water management in Poland. The problem is that spatial planning in Polish cities is not sufficiently associated with water management and flexible flood risk governance [MATCZAK *et al.* 2015]. The reports on the flood in the Poznań poviat and Wielkopolska region in 2010 [KOWALCZAK *et al.* 2010] indicate the extent and effects of this phenomenon, but many problems could be avoided if flood hazards were taken into account in local spatial development plans (LSDP) of riverside areas. The aim of the presented study was to analyse the current state of flood-prone areas and development plans on example of selected towns in the Wielkopolska region in terms of the possibility of adapting existing and planned buildings to flood hazards. Spatial development of flood-prone areas needs holistic approach and precise regulations of local plans (LSDP) as well as the availability of information on flood-resilient solutions and amphibious architecture models [BERMAN 2010].

MATERIAL AND METHODS

On the basis of literature review and study of good practices, the authors analysed flood risk management strategies and types of amphibious architecture that allow adaptation to changing water levels, which can be applied in local documents on spatial planning in Poland.

The scope of the local research included analysis of the spatial development of riverside areas in 10 towns located by the Warta River in the Wielkopolska region (Poland). A significant percentage of the areas exposed to floods was the basic criterion for selecting three towns for the second stage of the research, which was aimed at checking adaptation and retention solutions used in flood risk zones and analysing the content of local planning documents in terms of architectural guidelines (especially in residential and service buildings) enabling reduction of flood risk. The starting material for the analyses included flood hazard and risk maps (available at: Hydroportal, http://mapy.isok.gov.pl/imap/), local studies of conditions and directions of spatial development of communes (SCDSD) and local spatial development plans (LSDP) as well as GIS data and tools (available at: https://www.geoportal.gov.pl/, websites of the towns studied). Forms of building and land use were verified using the Street Viewer tool and site queries.

FLOOD RISK REDUCTION STRATEGIES AND COEXISTENCE WITH WATER

According to Floods Directive [Directive 2007/60/EC] "flood risk means the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event". "As the flood risk is a function of the flood hazard, the exposed values and their vulnerability" [KRON 2002], the reduction in flood losses can be achieved by implementing appropriate strategies [KZGW 2013]:

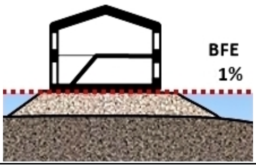
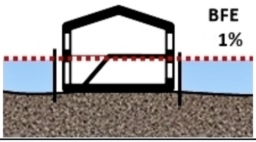
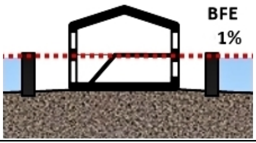
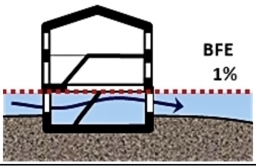
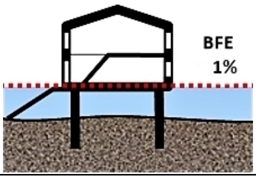
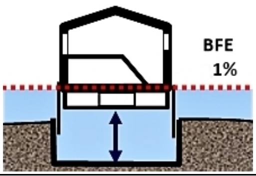
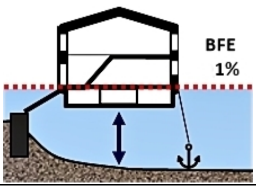
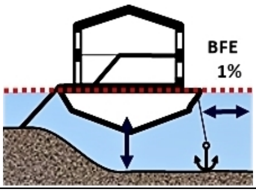
- flood hazard can be reduced by using measures increasing retention, both natural and artificial (retention reservoirs) and structures limiting the extent of floods, i.e. embankments, relief channels, river channel regulations etc.; that is, mainly with the help of technical flood protection infrastructure as well as increasing and protecting natural retention; this strategy is called "move the flood away from people";
- exposure (understood as buildings, objects and communities located in hazardous areas), which can be minimized by reducing investment in floodplains, mainly through bans or restrictions on building development, or setting special conditions for the construction of objects and by purchasing land and providing compensation; this strategy is associated with "moving people away from the water" and adapting possible development to eco-hydrological conditions;
- vulnerability (defined by the preparation of objects and people for floods), which can be reduced by using structural methods (e.g. protection of building and land development against floods) and non-structural, such as: flood insurance, early warning systems and response to floods, awareness of residents and education about prevention and dealing with floods; the "living with a flood" strategy, focused on reducing vulnerability to floods, is a key element of the broader "coexistence with water" strategy.

In practice, "we manage neither to keep destructive waters away from people at all times nor keep the people away from destructive waters" [KUNDZEWICZ *et al*. 2018], so the most effective strategy seems to be "coexistence with water", which combines actions aimed to limit the exposure and vulnerability and reduce sources of flood hazard. Comparative studies of flood risk management carried out as part of the STAR-FLOOD project[1)] prove that it is necessary to create appropriate combinations of structural and non-structured mechanisms in different locations. In order to increase the cities' resilience, it is crucial to strengthen the three pillars of the system: the ability to resist (e.g. through defence mechanisms), flexibility in absorbing floods and regaining efficiency (e.g. through spatial planning, disaster management and insurance), as well as seizing opportunities in the process of adaptation and transformation [KUNDZEWICZ *et al*. 2018].

In the face of climate crisis, amphibious architecture is becoming an increasingly attractive alternative to costly flood-control infrastructure. The presented research focuses on spatial and technical aspects related to reducing vulnerability of various types of buildings and land development in areas exposed to fluvial floods. Reports on flood loss and damage in Poland as well as flood risk assessment methodology for the purposes of flood insurance [NRC 2015] and analysis of flood resilience technologies (FRe T) were a valuable sources of information in this regard. American and British guidelines (e.g. RIBA [2018]) for the development of flood prone areas emphasize the importance of adapting the forms, functions and structure of buildings to the peculiarity of flood hazard (including flow speeds and water depth at the 1% flood event) and the use of waterproof materials and installation systems resistant to water penetration. As a result of the analysis of numerous examples of amphibious architecture, five basic types of buildings adapted to changeable water levels were identified (Tab. 1).

[1)] The STAR-FLOOD project (2012–2016), available at: www.starflood.eu/, carried out in six EU countries (Belgium, England in the United Kingdom, France, The Netherlands, Poland, and Sweden), focused on the analysis, assessment and planning policies aimed at reducing flood risks in urban agglomerations throughout Europe. The results are important for policy and law at European, national and regional level and for the development of public-private partnerships [STAR-FLOOD undated].

Table 1. Basic types of buildings adapted to changeable water levels

Type No	Schema	Type characteristics	Location and application	Location preferences**		
				flood-plains a	flash floods b	water environment c
1		**buildings on artificial hills or embankments**	forms of development in extensive flood plains, where there is no danger of narrowing the valley cross-section and restricting the flow of flood waters	+	+	–
2A		**buildings with individual flood barriers: 2a**	protection of existing compact development in flood-prone areas (also embanked) – e.g. temporary flood guards (boards) for doors	+	+	–
2B		**real estates with individual flood barriers: 2B** surrounding the plot	protection of existing dispersed buildings (settlement, single-family) in flood-prone areas (also embanked) – e.g. permanent site embankments or watertight fences	+	+	–
3A		**water-penetrable buildings: 3A** penetrable ground floor	buildings permanently connected with the ground in areas exposed to flash floods - buildings with openwork walls that reduce water pressure	+	++	–
3B		**water-penetrable buildings: 3B** open ground floor on stilts/posts	buildings permanently connected with the ground located in water-retention areas exposed to flash floods - buildings on stilts, allowing free flow of water	+	++	+
4		**floating buildings: 4** placed in foundation docks, which can rise up and float during floods	forms of buildings not permanently connected with the ground, located on flooding terraces (slow flow speed)	+	++	+
5A		**floating buildings: 5A** anchored in ports and at the quays	buildings floating on pontoon platforms, permanently moored in ports and at the quays	–	++	++
5B		**residential barges: 5b**	residential vessels capable of navigating on waterways and mooring at quays	–	++	++

Explanations: BFE = base flood elevation is the computed elevation to which flood waters are anticipated to rise during the base (1% annual chance) flood event; location preferences: – unsuitable; + appropriate, ++ preferred.
Source: own study.

The most suitable types of amphibious architecture for different flood risk zones should be specified in building manuals attached to the planning documents, e.g.:

– types 1 and 2B – in flood-prone areas where there is no danger of narrowing the valley cross-section and restricting the flow of flood waters;
– type 2 – on floodplains or embanked areas already invested to protect existing buildings in compact (2A) or dispersed (2B) urban structures;
– type 3 – in areas at risk of flash floods and water – retention areas (3B);
– type 4 – in areas where rising flood waters are not accompanied by high flow speeds;
– type 5 – on waterbodies (applicable only in the aquatic environment).

One of the most important guidelines is to raise the floor level of the building's ground floor above the BFE level[2)]. The floor level can be fixed (types: 1, 2, 3) or changeable due to the use of floating structures (types: 4 and 5). In the case of buildings exposed to high flow speed and water pressure, it is necessary to create openwork water-penetrable streamlined structures. The location of various land and buildings functions should be adequate to their vulnerability to flood hazards. It is also important to adapt the forms of flood-resilient building to architectural and landscape context, and to ensure convenience in everyday use. The amphibious building type 4 retains a close proximity to the ground and relationship with the neighbourhood in the dry periods, while providing protection in an extreme flood events.

DEVELOPMENT OF SPECIAL FLOOD HAZARD ZONES IN THE WIELKOPOLSKA REGION

OBJECTIVES, STAGES AND METHODS

The first stage of research on the development of urban riverside areas (URA) in Wielkopolska region covered 10 small towns on the Warta River (Tab. 2). The analysis revealed that the percentage of special flood hazard (SFH) areas in relation to the area of these towns ranges from 6% (Luboń, Oborniki) to 28% (Sieraków). Four out of ten towns are protected against flooding by levees, with the percentage share of embanked areas exposed to flooding in the event of levees damage being the highest in Śrem (27%) and Koło (24% of the total urban area).

In the second stage, three towns of similar size were selected for the study: Śrem (12 km^2), Koło (14 km^2) and Sieraków (14 km^2) in order to thoroughly analyse contents of the LSDP plans for the flood-prone areas. The basic criteria for choosing the towns were: a significant percentage of SFH areas (Sieraków) or embanked terrains exposed to flooding in the event of damage of levees (Koło and Śrem)[3)]. In the selected municipalities, a total of 22 local plans were analysed, including 8 in SFH areas and 14 in embanked areas, focusing on records regarding the design of residential and commercial buildings and elements of land development which allow adaptation to flood hazards[4)]. It was also examined whether the buildings in SFH areas in the Wielkopolska region have been adapted to coexist with water and protected against flooding. The graphic method of spatial development analysis in the context of flood hazards was developed, and used for 3 selected towns (Fig. 1).

RESULTS AND DISCUSSION

The analysis of the local planning documents (SCDSD and LSDP) as well as the flood hazard and flood risk maps revealed that LSDP coverage (Tab. 2) in flood-prone areas in the majority of towns is fragmentary (only in Międzychód it is 100%), or even negligible (0% in Koło and Wronki).

The SFH areas are generally extensively used (Tab. 3). Land functions with low vulnerability to flood hazards prevail, e.g. green areas, communal forests, meadows and arable land, but there are also areas that serve residential (e.g. Oborniki 4.5%, Międzychód 3%) and industrial functions (Oborniki 8.5%, Luboń 7.5%). Areas for recreational functions can be found only in Wronki (11.0%). Investments in embanked areas is much higher (e.g. in Koło 13.0% of these areas are covered by housing Tab. 4).

Flood protection strategies in Wielkopolska are primarily based on defensive solutions (levees, Jeziorsko flood reservoir) and reducing flood exposure through legal restrictions. Existing buildings, especially in embanked areas, are highly vulnerable and not adapted to the possibility of penetration by flood waters. The only form of architectural adaptation is raising the ground floor level by 10–30 cm in relation to the ordinate of the area (without reference to BFE level). In all the towns there are small marinas or wharfs for mooring, but there are no floating buildings or residential barges. Apart from sections of riverside boulevards in Śrem (2 km) and Sieraków (240 m), areas along the Warta do not constitute attractive public spaces, and the banks of the river are generally poorly accessible, which limits the possibilities of recreational use. However, the advantage of the low level of investment lies in the high ecological potential of the Warta valley in small towns.

The analysis of the content of 22 local plans (LSDP) in flood-prone areas in the three selected towns revealed that:

[2)] Base Flood Elevation (BFE) is the computed elevation to which flood waters are anticipated to rise during the base (1% annual chance) flood event [FEMA undated].

[3)] Areas cut off by embankments make up 80% of flood-prone areas in Śrem and 70% in Koło.

[4)] The study highlighted the presence of prohibitions, orders and approvals, as well as indicators and parameters of building and site development including the ground level of the building relative to the surrounding area, allowing underground floors, walls and external embankments, stabilization of stream channels and strengthening of river banks, the percentage of biologically active areas or rainwater management.

Table 2. The percentage of the areas at risk of flooding as well as local spatial development plans (LSDP) coverage in the analysed towns in Wielkopolska region

Town	Town area (km^2)	Length of the Warta River section within the town borders (km)	Percentage of SFH areas in proportion to the town area	Percentage of embanked[1)] areas in proportion to the town area	Percentage of the urban area covered by LSDP	Percentage of SFH areas covered by LSDP	Percentage of embanked[1)] areas covered by LSDP
Koło	14	2.75	11	**24**	46	0	28
Pyzdry	12	2.50	7	21	15	44	0.5
Śrem	12	4.00	7	**27**	43	9	34
Puszczykowo	16	6.50	13	0	35	58	not applicable
Luboń	14	3.25	6	0	86	55	not applicable
Oborniki	14	4.25	6	0	9	12	not applicable
Obrzycko	4	2.50	10	0	3	4	not applicable
Wronki	6	1.50	9	0	16	0	not applicable
Sieraków	14	7.00	**28**	0	15	7	not applicable
Międzychód	7	2.00	14	2	100	100	100

[1)] Embanked areas exposed to flooding in the event of levees damage.
Explanations: SFH = special flood hazard areas; LSDP = local spatial development plans.
Bold values indicate the highest percentage of SFH and embanked areas among the towns surveyed.
Source: JANUCHTA-SZOSTAK, FLORKOWSKA [2017], modified.

Table 3. Functions of special flood hazard areas (SFH) areas in the analysed towns in Wielkopolska region

Town	Functions of SFH areas (%)								
	residential areas	industrial areas	transportation area	forests	recreational areas	arable lands	grasslands	surface waters	other
Koło	0	0	0	0	0	<0.5	87	11	1
Pyzdry	2.5	0	<0.5	8	0	<0.5	54	18	1
Śrem	1.5	0	0	1	0	5	56	26.5	0
Puszczykowo	1	<0.5	<0.1	47	0	5	32.5	13	<0.5
Luboń	1	7.5	<0.5	37.5	0	1	26	26.5	0
Oborniki	4.5	8.5	1	7.5	0	6	34	36	2.5
Obrzycko	2	0	0	18	0	11	28	37	5
Wronki	2	0.5	< 1	6	11	5.5	37	34	3
Sieraków	<0.5	<0.1	0	12	0	40	28	19.5	0.5
Międzychód	3	<1	< 1	< 1	0	40	41	11.5	2

Source: own calculation, based on flood hazard and flood risk maps, available at: http://mapy.isok.gov.pl/imap/

Table 4. Functions of embanked areas in the analysed towns in Wielkopolska region

Town	Functions of embanked areas (%)								
	residential areas	industrial areas	transportation area	forests	recreational areas	arable lands	grasslands	surface waters	other
Koło	**13**	1	<1	8	5	6.5	62.5	2.5	<1
Pyzdry	0	0	0	1.5	0	31	58	4.5	5
Śrem	2	1.5	18.5	4	21	11	34	2	0.5
Międzychód	<0.2	0	0	0	0	17	69	0	5

Source: own calculation, based on flood hazard and flood risk maps, available at: http://mapy.isok.gov.pl/imap/

– LSDP take into account and respect the location in flood hazard zones, but the provisions of the plans are mainly limited to bans and restrictions on investment, resulting from the provisions of the Polish Water Law;
– there are no alternative solutions facilitating vulnerability minimisation of existing or planned buildings;
– the provisions specifying the building conditions marginally refer to flood hazards; only in 8 out of 22 examined plans, the level of the buildings' ground floor was mentioned (1 in Koło, 7 in Śrem), including 3 plans with references to the level of embankments or the ordinate of the flood occurring with a 1% probability (BFE); there are no guidelines for waterproof construction and material solutions;
– underground floors are allowed in almost all of the plans;
– local plans do not provide for retention and management of rainwater on site, but on the contrary, they require its discharge to the rainwater drainage system. rainwater management on the plot is allowed only in situations where there is no access to the technical infrastructure network;
– requirements for biologically active areas (natural land cover) range from 5% to 70% (for most areas only about 30% is required) are not related to the flood hazard zones, the ecological value of river valleys nor their retention needs;
– land development plans do not take into account the direction, depth and speed of flood flows.

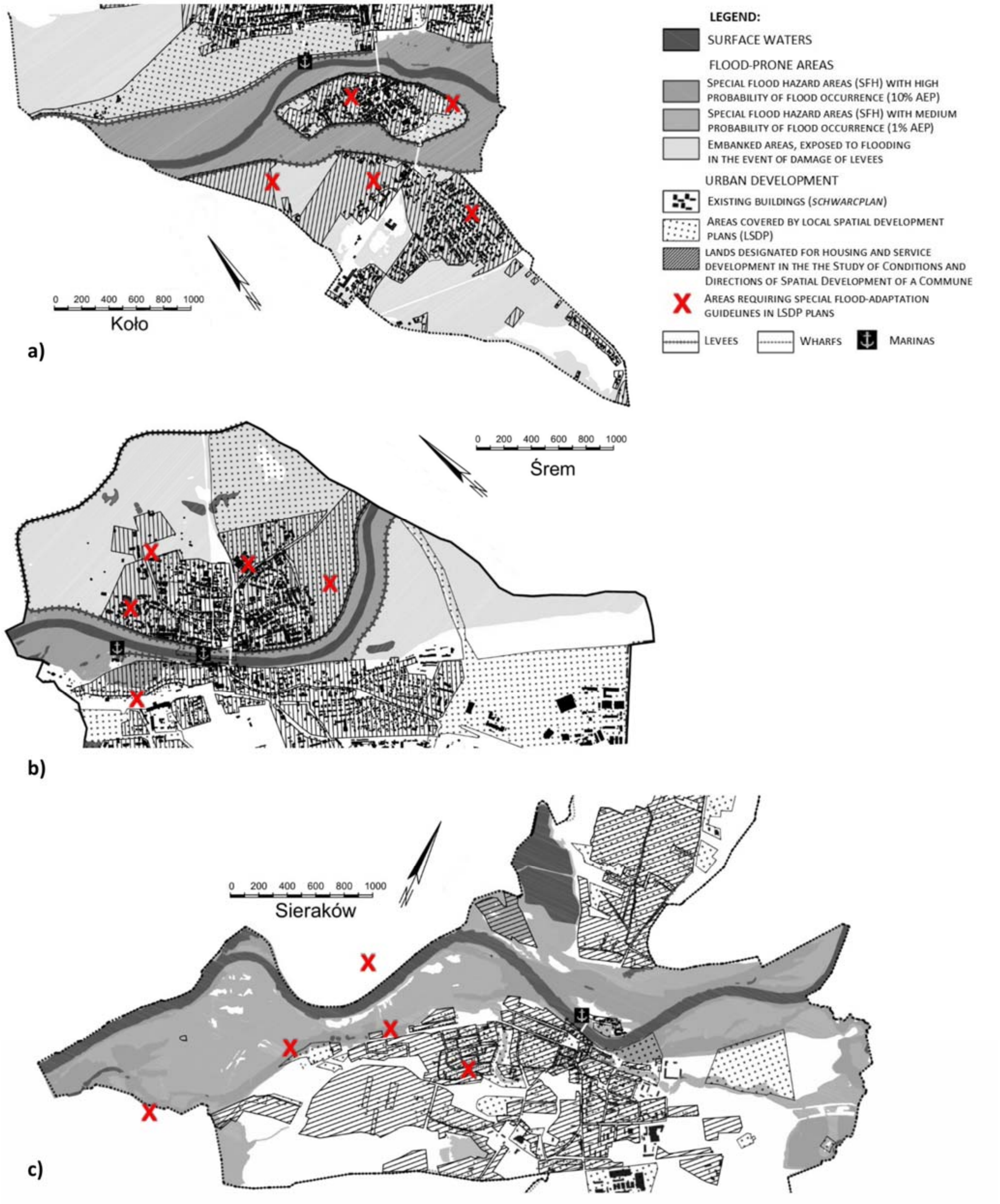


Fig. 1. The analysis of spatial development in flood-prone areas: a) Koło, b) Śrem, c) Sieraków; source: own study

The records of LSDP plans in flood-prone areas are conservative and do not encourage municipalities to turn their towns towards the river with respect for eco-hydrological conditions. The advantage of this approach is the reduction of exposure to the flood hazards and the ability to preserve natural values, but at the cost of accessibility, recreational values and the quality of riverside public spaces.

THE GRAPHIC METHOD OF SPATIAL DEVELOPMENT ANALYSIS

Spatial development studies in the context of flood hazards, carried out by the graphic overlay method, included the following data presented on individual layers.

- existing urban development (so-called schwarcplan) in the context of the hydrographic structure (own study based on data from GIS portals: https://www.geoportal.gov.pl/);
- special flood hazard (SFH) areas, where the probability of flood occurrence is high – once every 10 years (Q10%) and medium – once every 100 years (Q1%) based on flood hazard maps (source: Hydroportal, http://mapy.isok.gov.pl/imap/);
- layout, course and length of levees on the basis of flood hazard maps (source: as above);
- embanked areas, exposed to flooding in the event of damage of levees on the basis of flood hazard maps (source: as above);
- coverage of local plans LSDP (based on publicly available GIS data);
- location of lands designated for housing and service development based on the local documents of SCDSD in selected towns.

As a result of the graphical analysis, maps of three selected towns were prepared (Figs. 1–3). They show the existing buildings and areas of planned residential and service functions, which are partly located in SFH areas (in Sieraków 7%) or in embanked areas prone to flooding in the case of levees breaks (in Koło 28%, in Śrem 34%).

These maps can be helpful in the process of preparing local SCDSD documents and LSDP, as well as taking administrative decisions on determining the development conditions for public and private investments. They can also be the basis for designating zones for the location of amphibious architecture (see Tab. 1) and formulating specific guidelines for flood-prone areas development.

CONCLUSIONS

The research proved that small riverside towns in Wielkopolska region insufficiently use planning tools to create appealing and resilient waterfronts and reduce their vulnerability. The defensive approach to the development of river valleys still dominates. The SFH areas are usually poorly accessible and neglected, and most of the LSDP plans in embanked areas do not take into account the hazards associated with levees damage or pluvial flooding. The lesson from the recent floods are visible in the improvement of technical flood protection measures (levees and bank reinforcements), but the flood hazard maps are not sufficiently used in formulating LSDP plans. New buildings that are not adapted to changing water levels are still being built in the flood-prone areas of the towns studied, because local plans do not impose such requirements. This, unfortunately, proves the lack of coordination between flood risk management and spatial planning. General legal restrictions are not enough to prevent an increase in flood risk. LSDP plans must contain more precise conditions for the development of flood-prone areas, as well as guidelines for innovative and resilient building structures.

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