MINIMIZING CLIMATIC FLOOD RISKS OF THE CURONIAN SPIT (BALTIC COAST)

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Abstract

The article is devoted to the application of nature-compatible solutions for minimizing climate risks and adapting to climate change. The article presents the results of a study on surface runoff in Curonian Spit area using models of the InVEST Urban Stormwater Retention software package. The modeling results identified the most vulnerable area in the Curonian Spit (Baltic Coast) in terms of potential flooding in the context of increasing climate change - specifically, the village of Rybachy. To minimize the climatic risks of flooding and to modernize the rainwater drainage and collection, nature-compatible solutions have been proposed for integration into the existing infrastructure.

Keywords: nature-compatible solutions, adaptation to climate change, risks

I. Introduction

Nowadays, significant attention is devoted to mitigating and adapting to the impacts of climate change. The 2024 Global Risks Report by the World Economic Forum identifies three key climate-related challenges as primary risks facing humanity: extreme weather events, critical changes in Earth's systems, and the loss of biodiversity and ecosystem degradation. Solutions aimed at minimizing risks and adapting to climate change are essential to reduce the effects of rising temperatures, intense storms, water pollution and eutrophication.

Anthropo-natural systems (APS), created through natural processes and human intervention, are particularly sensitive to climate change [1]. One such system is the Curonian Spit - a narrow, elongated, crescent-shaped sandspit separating the Curonian Lagoon from the Baltic Sea. The Curonian Spit has been shaped by the sea, wind, and human activity and continues to be influenced by these factors. After catastrophic human interventions that threatened its existence, the spit was restored through extensive protection and stabilization efforts beginning in the 19th century and continuing to this day. The contemporary cultural landscape of the Curonian Spit has been formed under the influence of both both human and natural forces.

The Curonian Spit is constantly affected by waves and storms, experiencing erosion and flooding, which pose threats to the population and infrastructure of the settlements within its territory. Under changing climate conditions, the frequency and intensity of such events are increasing. Additionally, the rising population and tourist numbers on the Curonian Spit, and the consequent increase in anthropogenic pressure, may lead to the loss and degradation of coastal ecosystems and their ability to protect people during storms. Thus, this topic is particularly relevant; it is crucial to understand the roles of various biological and geophysical factors that can enhance or mitigate the threat of coastal erosion and flooding to better plan future development of the territories [2].

To minimize the climate-related flood risks on in the Curonian Spit area, it is necessary to adopt technologies that can take into account climate change. In these conditions, nature-compatible solutions are most effective, using sustainable management principles and natural properties and processes to solve social and environmental problems. International experience shows that nature-compatible solutions are economically viable and sustainable, offering long-term effectiveness compared to technological investments or the construction and maintenance of infrastructure [3]. In the Russian Federation, nature-compatible solutions are rarely implemented, yet local residents of the Curonian Spit have long adapted to environmental changes, creating favorable living conditions. That is why it is particularly important to apply nature-compatible solutions for climate adaptation in the Curonian Spit area.

II. Research methods

The study employed field observations, modeling, and a monographic method. The InVEST Urban Stormwater Retention Model from the InVEST software suite was used to assess the annual volume and quality of stormwater. This model evaluates potential groundwater recharge and the amount of pollutants in surface runoff. [4]. The InVEST Urban Stormwater Retention Model primarily addresses surface runoff and is designed for implementation in urban watersheds. It calculates the annual volume and quality of retained stormwater, thus showing the prevention of pollutant transfer to water bodies. Retention, groundwater recharge, and surface runoff are evaluated on an annual scale rather than for individual adverse events. [2]. The model calculates the annual retention volume of runoff for the Curonian Spit National Park over an area of 0.1 hectares. Categorization of the results into three groups is used for clarity.

The initial data processing was carried out in two Geographic Information Systems – QGIS version 3.24.3 and ArcGIS ArcMap version 10.3. Maps and diagrams were developed in GIS ArcGIS ArcMap version 10.3.

III. Results

To identify areas on the Curonian Spit susceptible to climatic flood risks, a study on runoff retention was conducted. Runoff modeling identified critical areas for flow retention (marked in red in Figure 1). These critical areas are characterized by a low annual volume of flow retention, resulting in high flood risks. The study revealed that the village of Rybachy faces the greatest flood risk, with a retention volume of less than 220 m^3/year from an area of 0.1 hectares, while the annual runoff volume exceeds 276 m^3/year with a soil filtration coefficient of up to 44 m^3/year. The village predominantly consists of soils with high runoff potential, comprising 20-40% clay and 50% sand [5]. Based on these results, Rybachy is identified as the most flood-prone area, with a population of about 1,000 residents. The location of Rybachy is detailed in the Figure 2.

To modernize the drainage and rainwater collection system and minimize the climatic flood risks in Rybachy, nature-compatible solutions are proposed for integration into the existing infrastructure. Given the soil and climate conditions in Rybachy, bioswales and permeable parking lots are recommended for rainwater collection. Bioswales are vegetative stormwater systems that form part of a sustainable drainage system. They consist of specialized soil layers, gravel, drainage systems with perforated pipelines, and overflow mechanisms to manage substantial stormwater volumes. Bioswales will be placed in adjacent areas to collect water from roads, pedestrian surfaces, and roofs.

For flood protection, the use of wetlands is proposed. Treated water will flow through linear bioswales and drainage pipes to the wetland, which will serve as a site for wastewater accumulation and treatment. Artificial wetlands are engineered systems that enhance the physical, biological, and chemical processes of water purification. They are widely used for treating municipal wastewater, landfill leachate, urban stormwater, and industrial wastewater. Wetlands not only purify water (removing fine sediments and pesticides) but are also provide habitats for wildlife, enhance aesthetics, reduce flood risks, and facilitate water reuse. Artificial wetlands can be established in areas with high stormwater volumes.

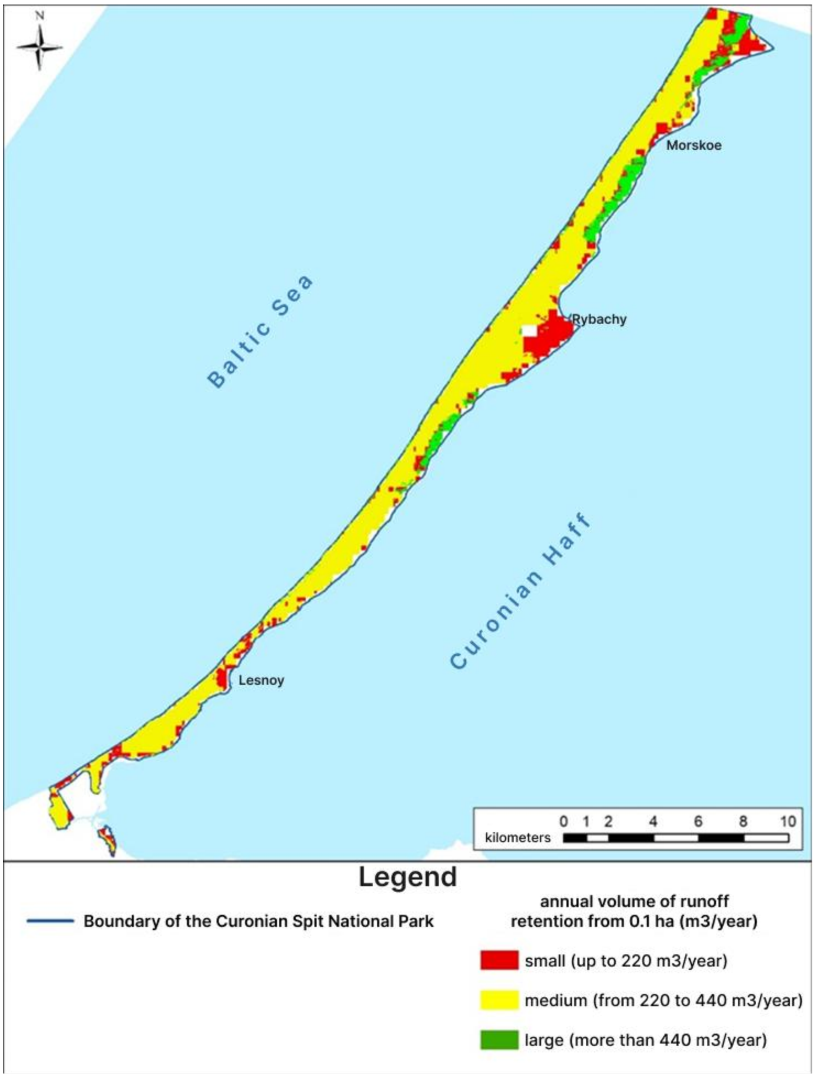

Figure 1: *Annual volume of runoff retention in the Curonian Spit territory*

Figure 2: *Area of the village of Rybachy*

Based on the studies in Rybachy, proposals were developed for the placement of bioswales, wetlands, and permeable parking lots (Figure 3).

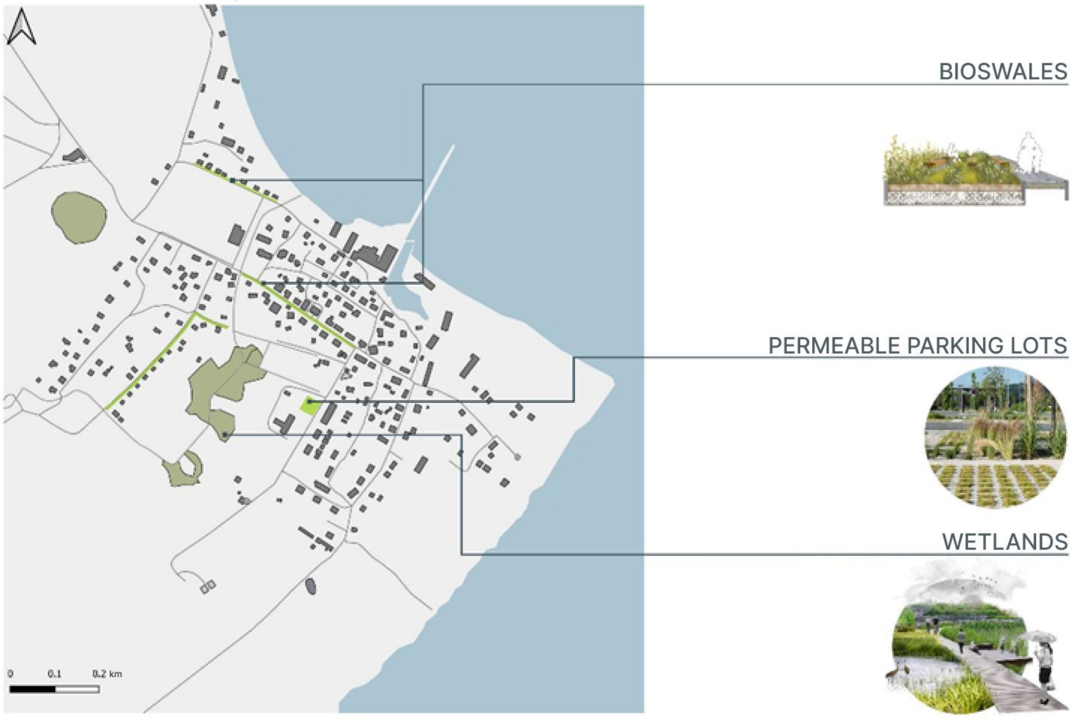

Figure 3: *Location of proposed nature-compatible technologies*

Modeling and international experience indicate that the most effective natural solution for the study site is the establishment of wetlands (Figure 4).

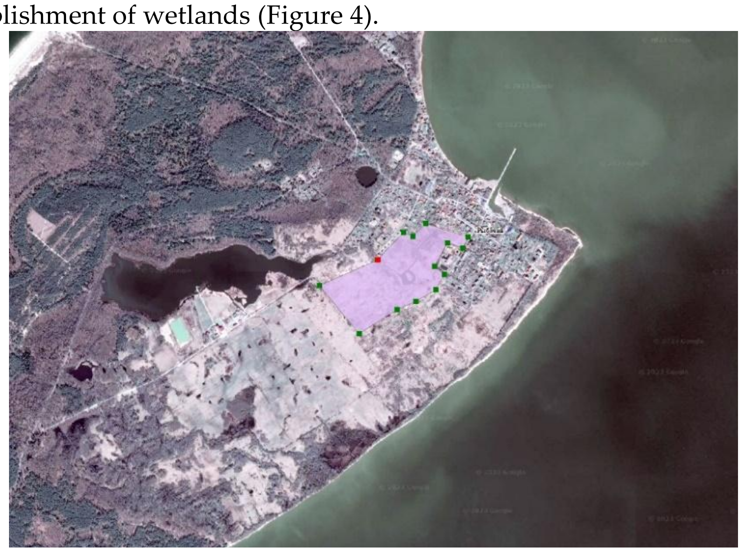

Figure 4: *Location of the proposed wetlands*

Bioswales are to be created along roads. These bioswales will be installed along the transition zone, with the covering made at an incline for natural water drainage into green islands At the same time, water entering the bioswale undergoes natural purification due to the vegetation layer, with sand acting as an absorbent and layers of gravel and geotextiles providing filtration. In other words, bioswales are multifunctional stormwater transport systems capable of retaining excess water and filtering out dirt and pollutants. The proposed locations for bioswales are shown in Figure 5.

Figure 5: *Location of the proposed bioswales*

The implementation of these nature-compatible solutions in Rybachy is expected to reduce climatic flood risks due to water retention in the wetlands. The volume of filtration directly in the wetlands and bioswales is projected to be more than 440 m^3/year, with more than 220 m^3/year retained in the village (Figure 6).

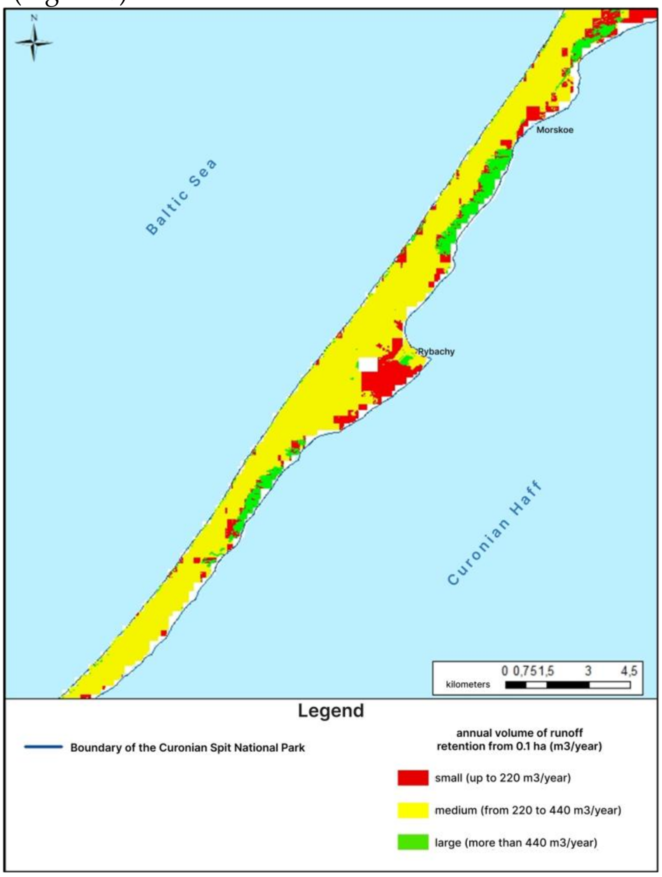

Figure 6: *Annual volume of flow retention in the Curonian Spit after the implementation of nature-compatible solutions*

IV. Discussion

The effectiveness of such solutions is well-documented internationally. In New York, there are over 5000 wetlands that provide wildlife habitats, absorb atmospheric carbon dioxide, enhance settlement resilience to climate change, reduce flood risks, and collect, retain, and filter stormwater.

V. Conclusions

Research conducted in Rybachy highlights the importance of nature-compatible solutions in minimizing climatic flood risks on the Curonian Spit. The arrangement of bioswales, permeable parking lots, ha and artificial wetlands will mitigate flood risks and modernize the rainwater drainage and collection system in Rybachy.

Modeling results show that the introduction of nature-compatible solutions reduces the flood risk by 50%, and double the volume of retained runoff. The implementation of the proposed solutions will increase the filtration volume in the wetland site from 44 m^3/year to 86 m^3/year per 0.1 hectare and raise the volume of retained stormwater to 440 m^3/year per 0.1 hectare.

In addition, the creation of artificial wetlands plays a crucial role in restoration ecology. Many wetlands are among the most productive natural ecosystems, often surpassing the best farmland and rivaling the productivity of tropical rainforests. They provide habitats for a rich diversity of native species, thereby preserving biodiversity and minimizing the risk of ecosystem destruction. Bioswales effectively treat rainwater, reducing pollutants, providing attractive wildlife habitats, and naturally replenishing groundwater reserves.

References

[1] Fomenko G.A. Ustoychivyy ekspelitel'nyy dizayn: osnovnye cherty i osobennosti: uchebno-metodicheskoe posobie [Sustainable ecosystem design: main features and features]. Yaroslavl: ANO NIPI "Cadaster", 2021. 136 p. (In Russian) (Series "Planning and Design of Spatial Development").

[2] Sustainable ecosystem design: GIS-technologies and modeling: a textbook / Scientific editor: G.A. Fomenko. Yaroslavl: ANO NIPI "Cadaster", 2023. 192 p. (In Russian)

[3] IUCN French Committee (2019) Nature-based Solutions for climate change adaptation and disaster risk reduction

[4] Beck, N. G., Conley, G., Kanner, L., & Mathias, M. (2017). An urban runoff model designed to inform stormwater management decisions. Journal of Environmental Management, 193, 257-269.

[5] State report "On the ecological situation in the Kaliningrad region in 2021" / Ministry of Natural Resources and Ecology of the Kaliningrad region. Kaliningrad, 2022. 200 p.