Vulnérabilité et coûts des mesures d'adaptation de logements exposés aux risques de submersion marine

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RÉSUMÉ. *Le retour d'expérience suite à la tempête Xynthia en 2010 a mis en évidence la localisation et la configuration du logement résidentiel en tant que facteurs de vulnérabilité cruciales pour les habitants. Après cet événement, le gouvernement français a décidé de détruire leslogements le plus dangereux; cependant, cette stratégie a été critiquée, notamment pour son coût élevé et le manque d'étude de solutions alternatives. L'objectif de cette communication est de comparer différentes stratégies d'adaptation en termes de coût et d'efficacité (réduction de la vulnérabilité des habitants). Les stratégies sont: (i) la protection, (ii) la réinstallation, (iii) l'adaptation architecturale du logement et (iv) l'avertissement préventif et l'évacuation. Ce travail est appliqué sur La Guérinière, une ville côtière de l'Atlantique exposée aux inondations côtières. Les résultats indiquent que la stratégie la plus efficace pour réduire la vulnérabilité humaine est aussi la plus coûteuse (relocalisation). En revanche, l'avertissement préventif et l'évacuation sont la stratégie la moins coûteuse, mais son efficacité est faible parce que son évaluation dépend de la connaissance actuelle du comportement humain en cas d'un événement de submersion. Des travaux futurs devraient aborder cet aspect pour améliorer l'évaluation de l'efficacité de cette stratégie.*

ABSTRACT. *The feedback of the Storm Xynthia in 2010 highlighted the localization and configuration of residential housing as factors increasing human vulnerability. After this event, French government decided the destruction of the most dangerous building;however, this strategy was criticized, especially for its high cost and the lack of study of alternative solutions. The goal of this paper is to compare different adaptation strategies in terms of cost and efficiency (reduction of human vulnerability). The strategies are: (i) protection, (ii) relocation, (iii) housing architectural adaptation and (iv) preventive warning and evacuation. This work is applied on La Guérinière, which is an Atlantic costal town exposed to coastal flood. The results indicate that the most efficient strategy to reduce human vulnerability is also the most expensive (relocation). In contrast, preventive warning and evacuation is the less expensive strategy but its efficiency is low because its assessment depends on current knowledge of human behaviour in case of a submersion event.Further work should address this aspect to improve the assessment of the efficiency of this strategy.*

MOTS-CLÉS : *Xynthia, submersion marine, vulnérabilité des habitants, maisons résidentielles, changement climatique, stratégies d'adaptation.*

KEY WORDS: *Xynthia, coastal flood, human vulnerability, residential houses, climate change, adaptation strategies.*

1. Introduction

Storm Xynthia hit the French Atlantic coast from the Loire until the Gironde estuaries in February 2010. The Xynthia feedback highlighted the importance of the location and configuration of residential buildings with respect to human life vulnerability [ViBD11]. Indeed: (i) 100% of deaths occurred in buildings where the water level was greater than 1 meter; (ii) 90% of deaths took place in buildings located at less than 400 meters of

dikes; and (iii) 78% of deaths were reported in single-story buildings. It was then found that the location and configuration of residential buildings may expose their occupants to an ‘extreme’ vulnerability (including death) in case of marine flooding events [CPGM15].After the Xynthia storm, the French government decided to identify, acquire and destroy housing located in flood areas characterized with higher deadly risk to occupants through the so-called ‘black areas policy’. This measure was criticized for its hasty implementation, the criteria used to delineate the black areas [MeCh12], and its high cost. This black areas policy is a measure of ‘relocation’ that is expensive in short-term but effective to protect human life against coastal flooding risks. Nevertheless, several questions concerning the potential implementation and effectiveness of alternative measures remain still open. For instance, it would be possible to raise the dikes to protect the more exposed housing instead of their systematic destruction? or it would be possible to build a shelter floor (allowing people to take refuge in case of a flooding event) for single-story buildings?Within this context, the main objective of this paper is to evaluate the vulnerability and costs of different adaptation measures to protect occupied housing located in higher flooding risk areas in the French Atlantic coast.

2. Materials and Methods

2.1. Study site: La Guérinière town on the Noirmoutier Island

Noirmoutier Island is a 49km² French Atlantic island, located in the Vendée department. It is a low-lying area where 68% of the island could be under the sea-level reached during storm Xynthia [CCMP15]. Consequently, it is protected from sea by 24km of dikes on the east coast, and an important sandy barrier on the west coast.Noirmoutierisland was few impacted by Storm Xynthia in 2010 with only 3% of the territory flooded. Any major event has been reported since the 50’s; but the 2/3 of the territory were flooded in 1937 without larger consequences for the less developed urbanized areas built at that time. Taking into account the natural risk of flooding of this island, the additional risk related to sea-level rise and the present urbanization of the island, it is paramount to evaluate the potential consequences if such an event occurred nowadays. This study focuses on one the most vulnerable towns of the island called La Guérinière.

2.2. Coastal flood scenarios

This work analyses the vulnerability of houses for people and costs of adaptation strategies for four scenarios of coastal flood: frequent, medium, medium including sea level rise in 2100 and extreme. These scenarios have been defined on the basis of studies made by the French administration to implement the European Directive on the assessment and management of flood risks [Euro07]. This work uses the values proposed on a study carried out in Fromentine that is a place close to La Guérinière [Drea14]. Table 1 describes the characteristics for each scenario. Based on sea water levels presented in Table 1, the potentially flooded areas were determined using a “static” flood modelling [BCBG13] that uses high resolution topographic datasets Lidar Litto-3D [IgSh12] and considers that inland areas located below the sea water level are floodable if they have a point at less than 100 m from the seashore. The difference between this sea water level and the ground level of the house allows us to assess the potential water level in case of flood.

Table 1:*description of the considered coastal flood scenarios (based on [Drea14])*

Name of the scenario	Return period	Sea water level at Fromentine (in front of Noirmoutier Island)
Frequent	10 years	3.6 m NGF
Medium	Between 100 and 300 years	4.2 m NGF
Medium + SLR*	Same as above + 0.6 m	4.8 m NGF
Extreme	1,000 years or more	5.2 m NGF

*SLR means Sea Level Rise

2.3. Extreme Inherent Vulnerability (VIE) index

The VIE index is a method developed by Creachet al[CPGM15] to assess the vulnerability of houses for people buildings subjected to coastal flooding risks. It is a micro-scale index that aims to identify and locate houses in which people can be trapped inside (and die) in case of flood due to building location and characteristics. This method allows classifying the buildings into four classes:

- Green class (VIE equal to zero) includes buildings where no vulnerability is identified (there are not exposed to coastal flood). It is important to note that if the result of the first criterion (potential water level inside) is 0 (no water inside), the result of the VIE index is null.

- Yellow class (VIE index between 1 and 5) concerns buildings that are exposed to flood but their location or characteristics do not generate to a high vulnerability for people.
- Red class (VIE index between 5 and 8) encompasses buildings in which vulnerability for people is important but not expected to lead to death unless non-adapted behaviour.
- Black class (VIE index between 8 and 12) concerns buildings in which death may occurs in case of flood due to the location and the configuration of the building.

2.4. Adaptation strategies

Various adaptation strategies could be implemented to reduce vulnerability of houses for people and then protect human life from coastal flooding risk. This study considers protection, retreat and two accommodation strategies. The first accommodation strategy encompasses housing architectural adaptation that aims to protect population. The second one includes those actions that facilitate preventive warning and evacuation in case of an imminent flooding event. The description and costs of each adaptation strategy is detailed in [CBPM17].

3. Results

Cost and efficiency results separately do not provide sufficient information for policy makers. The European Commission [Euro07] recommends therefore performing an economic analysis in flood management projects to ensure transparency and to provide strong choices in a context of SLR. Different methods are used for economic analysis: cost-benefit analysis, cost-effectiveness analysis, multicriteria analysis, etc. In this study, we propose to relate (i) the adaptation cost with (ii) the reduction of risk related to the implementation of an adaptation strategy, Δrisk. Δrisk (in percentage) is estimated as a function of the number houses in the black class with and without the implementation of the adaptation strategy by using the following equation:

$$\Delta\text{risk} = \frac{nb_{with\,adap} - nb_{without\,adap}}{nb_{without\,adap}} \times 100 \qquad [1]$$

where $nb_{with\ adap}$ and $nb_{without\ adap}$ are respectively the number of houses in the black class with and without considering the adaptation strategy. $nb_{with\ adap}$ and $nb_{without\ adap}$ are estimated on the basis of the methods presented in Section 2.

Figure 1 shows the adaptation costs and Δrisk of the considered adaptation strategies. This analysis also indicates that the reduction of risk is most important for the more expensive adaptation strategies. The ranking from the most efficient and expensive to the less efficient and expensive is: retreat, housing architectural adaptation, protection and warning and evacuation. These results indicate that the choice of the adaptation strategy depends on the goal: maximize efficiency or minimize costs. Nevertheless, these results (and therefore this ranking) could have some limitations, especially for efficiency assessments for which there are many uncertainties. The main uncertainty is related to human behaviour. Indeed, to assess the efficiency of strategies to protect human life we used an index based on the vulnerability of houses for people. But, human behaviour can increase or decrease vulnerability. During Storm Xynthia, 5 deaths were located inside houses with a rescue level or a story in which people were trapped on the ground floor. As a consequence it can be concluded that architectural adaptation is not sufficient to prevent death in case of flood because human behaviours are a key factor [ViBD11].

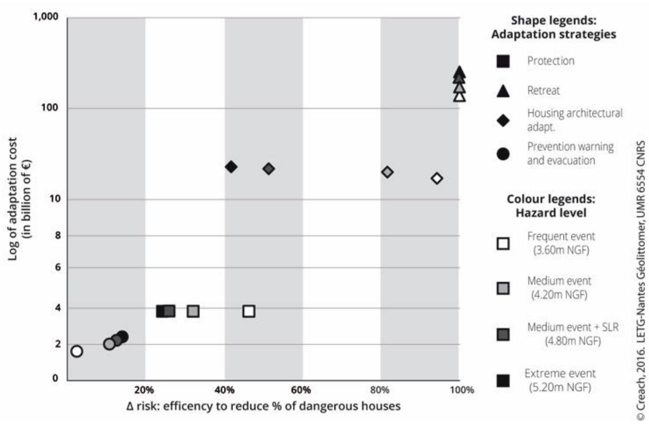

Figure 1: *Summary of the cost/efficiency evaluation*

In this work we identified four strategies to reduce vulnerability of houses for people in a context of SLR: protection with the reinforcement and rising of existing dikes, retreat of the most dangerous buildings, housing architectural adaptation and preventive warning and evacuation. These four strategies were virtually applied on La Guérinière town which is exposed to coastal flood, in order to compare the costs and the efficiency of their implementation for four coastal flood events: frequent, medium, medium + SLR and extreme. We can observe that the most expensive strategies are also the most efficient. From the most to the less expensive and efficient, we can find: retreat (more than 138 billion of euros), housing architectural adaptation (more than 17 billion of euros), protection (more than 3.8 billion of euros) and prevention (more than 1,6 billion of euros). Costs are increasing and efficiency decreasing for larger coastal flood intensity.At this stage, it could be said that, despite its cost retreat is a necessary strategy for the most exposed houses. Housing architectural adaptation is a less expensive strategy which can be adopted for the less exposed houses. Protection and preventive warning and evacuation are the less efficient. However, it is important to highlight that the way to measure efficiency of the strategies has some limitations. Although we measure it in terms of the reduction proportion of dangerous houses (black class of the VIE Index), the preventive warning and evacuation strategy is more focused on the improvement of human behaviour than on the reduction of the level of vulnerability of houses for people. The best way would be to assess the efficiency in number of lives saved with the strategies. This could be done using methods of estimation of flood fatalities and introducing a parameter of vulnerability of houses for people which can increase or decrease the risk of death. It will be a better way to assess the cost-efficiency of adaptation strategies to coastal flood within a context of SLR.

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