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Research Article

Estimation of Road's Exposure to Floods in the Province of Larache, Morocco

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ABSTRACT

Generally, the road infrastructure suffers from significant damage caused by natural disasters (flood, earthquake, etc.). In particular, the Kingdom of Morocco experienced several interruptions of the road network during previous floods. In this sense, paper presents a new method for estimating the exposure's degree of the road infrastructure to the risk of flooding. This method has been applied to the province of Larache. Based on the flood history, a model is developed to define areas exposed to flood hazard and deduce the exposure's degree of each road to floods. Several results are obtained allowing a detailed mapping of flood risk in the province of Larache.

Keywords: Flood hazard; Road network; Exposure; Larache; Mapping

INTRODUCTION

Flooding is a natural phenomenon that affects a portion of the territory and creates risk for installations and humans [1]. Understanding flood's risk is based on the study of previous flood's history [2] and the basic parameters are frequency and intensity of floods [3]. Indeed, the intensity of a flood corresponds to the estimated water's depth in a flood zone, whereas the frequency defines the time interval between two flood occurrences a given intensity [4]. The identified parameters therefore serve as a basis for the development of flood risk mapping: This map represents the exposure's degree of the areas in which floods are likely to occur following the natural overflow of a watercourse.

In fact, the flood risk map, often referred to as a flood hazard map, reflects the severity of past floods. In practice, the flood risk map is often confused with the flood zone map [5], but this latter only provides an approximate area of flood for each analysed period [6]. On the other hand, some organizations consider the counting of points exposed to floods as a flood risk map [7].

In Morocco, several hydraulic and hydrological modelling were carried out for the delimitation of the flood zones [8], or for the estimation of the flood scale [9], or for the simulation of the hazard flood [10]. But rare are the studies which carried out the flood hazard mapping [11].

According to [12], the flood risk map is deduced from the old flood maps through GIS operations which determinate two levels of exposure: high or moderate. While [13] derives the flood risk map from the geographical representation of the estimated water depth, and defines three levels of flood exposure: low, moderate and strong. Nowadays, flood risk mapping models are based on crossing the intensity and frequency of a flood [4,11].

In this perspective, these articles propose a new method of flood risk mapping. The model is based on past flood history and infers the degree of exposure of each road. The area chosen to evaluate the relevance of our research's methodology and prototype is the province of Larache. The reason behind this choice is that this province regularly suffers from interruptions of the road infrastructure during the winter season. The main objective of the presented work is to deliver decision-makers a better knowledge of the areas most exposed to floods. In terms of urban planning, this approach will help put in place appropriate and targeted risk reduction measures for the Larache region.

Study area

The province of Larache is located in the north of the country, exactly in the Tangier-Tetouan-Al Hoceima Region (Figure 1); it extends between the parallels 34° 55' 36.594" and 35° 28' 18.223" North and the latitudes 5° 27' 52.972" and 6° 6' 18.064" West on an area of 2783 Km^2. The study area is limited to the east by Marly hills and to the west by the Atlantic Ocean. The average annual rainfall varies between 800 and 1000 mm, concentrated for almost all between October 15th and April 15th. This has the direct effect

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of causing regular road interruptions in the province of Larache during this period [14].

Among the characteristics of the study area: The existence of the Loukkous River which is the main river in the region (Figure 1). On this stretch, the river crosses wide plains with flat relief making this area, where agricultural activity is the main wealth of the Province, a floodable area.

MATERIALS AND METHODS

The cindynic's theorists (science of risk study) define the flood risk as the combination of the possibility of a hazard occurrence (heavy rains, flood, and dam failure) and the vulnerability of the exposed environmental issues (Figure 2). They summarize it by the following formula: "Risk=hazard × Vulnerability of stakes" [15].

The regular approach of the flood risk focus on the vulnerability of the issues exposed to the floods but it does not make it possible to identify vulnerabilities independent of the exposure [16]. Indeed, the classic flood risk modeling procedure consists first of all in defining the space exposed to the hazard, then in identifying the issues that lie on this space, and finally in analyzing their vulnerabilities [17].

Our proposal provides effective flood risk prevention since the manager can take place to reduce the vulnerabilities of the issues before the occurrence of the hazard [18]. Our conception places the challenges of a territory and their vulnerabilities at the center of the definition of risk. Thus, exposure to floods is considered a form of vulnerability whereas usually it was estimated as a full component of flood risk.

In order to calculate the level of flood exposure, we first carried out a mapping of the flood zones (§a) of the province of Larache. Then, we modeled the flood hazard (§b) to finally deduce the degree of exposure of the road infrastructure of the study area (§c).

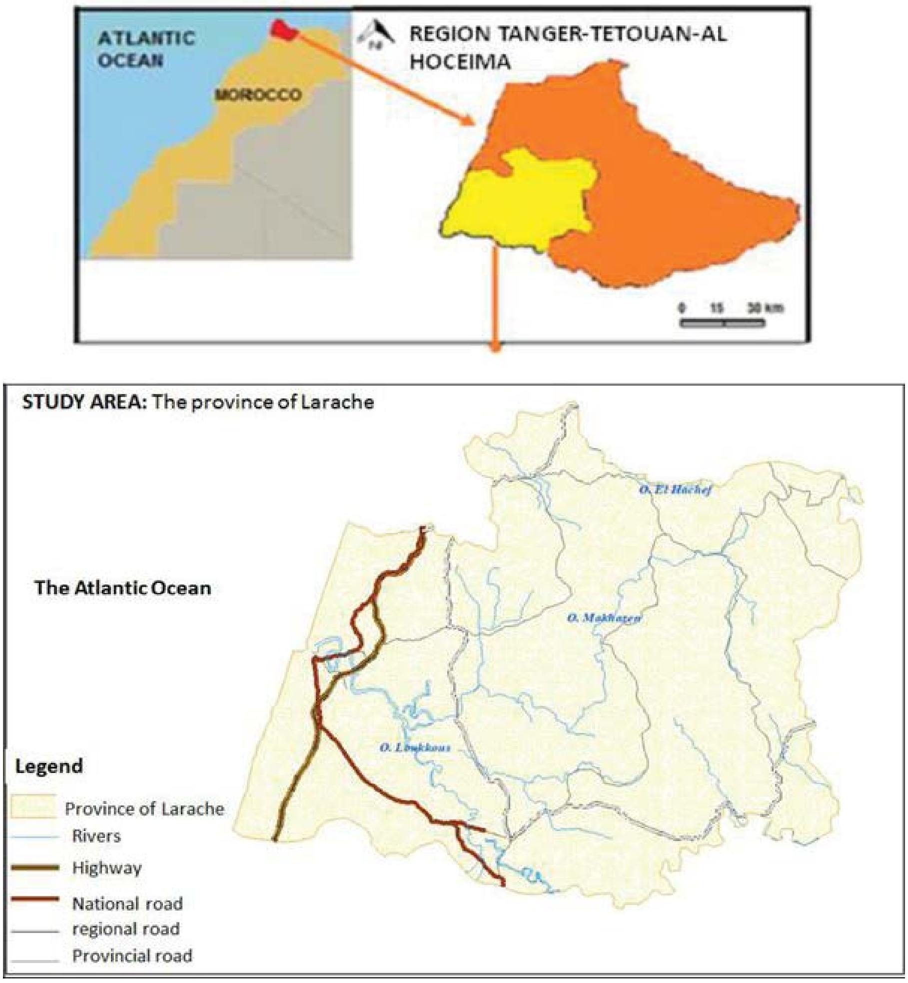

Figure 1: Study area: The province of Larache.

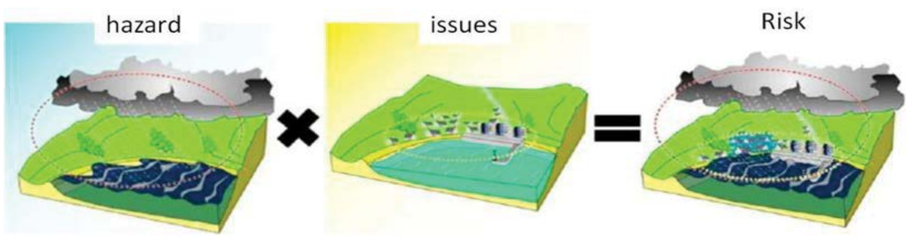

Figure 2: Risk definition (IMDC and Alp'Géorisques, 2014).

Mapping of flood zones

The mapping of flood zones requires the determination of two basic parameters:

The frequency of a flood: The frequency of a flood is the period of return. It indicates the time necessary for the occurrence of a historical flood of a certain importance. Thus, a 100-year flood (100-year return period) could occur on average once every 100 years and has a probability of occurrence of 0.01 [19]. In general, the design of flood protection works is based on return periods of 20 years, 50 years and 100 years [11]. The longer the return period, the rarer the flood and the modelling is more accurate since it supports the largest historically known flood.

The intensity of a flood: The water's depths observed during a flood assess the severity of a flood. Hydraulic simulation of the behavior of a river can be used to calculate the water depths of historical floods of some importance.

We chose for hydraulic simulation the final stretch of the wadi Loukkos between the Oued El Makhazine reservoir and the mouth of the wadi at Larache. On this stretch, the river crosses vast plains and valleys giving rise to a constant flow of water that does not depend on time. So the modelling of the flow of the wadi is carried out in steady state thanks to the HEC-RAS software. The latter makes it possible to simulate free surface flows and to generate homogeneous water distribution models [20]. The results of the calculations carried out with the HEC-RAS software are transferred to the HEC-GEORAS extension dedicated to work under Arc GIS for the development of the flood zone maps of the Province of Larache based on the Peak flows from historical floods (Figure 3).

Flood hazard modelling

The flood hazard map is then deduced by adding the flood zone maps according to the impact of the estimated water depth (Intensity) on each return period (Frequency). In fact, an area where the estimated water depth is 0.5 m with a 0.01 probability of occurrence (return period of 100 years) will not have the same impact if the return period is 25 years (occurrence's probability is 0.04), the last case will have a greater impact on Larache's road infrastructure (Figure 4).

The difficulty of flood risk modeling lies in the translation of the magnitude of past floods into numerical variables. Indeed, the model adopted for estimating flood exposure is based on three indicators grouped according to the formula in Figure 5 and Figure 6. To obtain the degree of exposure to the floods, the three indicators are assigned numerical values of 10, 20 and 30 according to the weight of the water height and the return period (Matrix of Figure 4). These ratings are assigned to designate a low (10), moderate (20) or high (30) hazard level.

Thus, the exposure of the road infrastructure of the Province of Larache to the flood risks is indicated by a value belonging to the interval [0,4] indicating the degree of exposure of each road; the principle of assigning values is as follows:

- If the road is located in an area where there is no flood →0
- If the road (all or part) is located in an area where the hazard is low →1
- If the road (all or part) is located in an area where the hazard is moderate →2
- If the road (all or part) is located in an area where the hazard is strong →3

The data used in this work to map the degree of exposure of the Larache road network to the risk of flooding are summarized in Table 1. The various data processing operations is performed using ArcGIS software with the extension Hec-GeoRAS and Hec-RAS software. They are presented in chronological order in Table 1.

RESULTS AND DISCUSSION

The major challenge for calculating the degree of exposure to floods is to quantify a qualitative

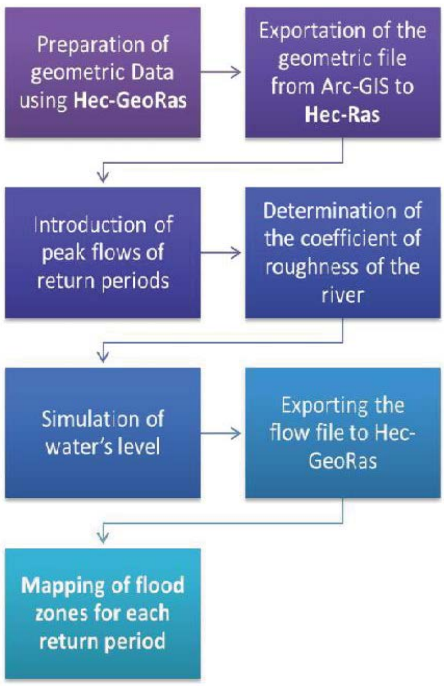

Figure 3: Flood zone mapping method.

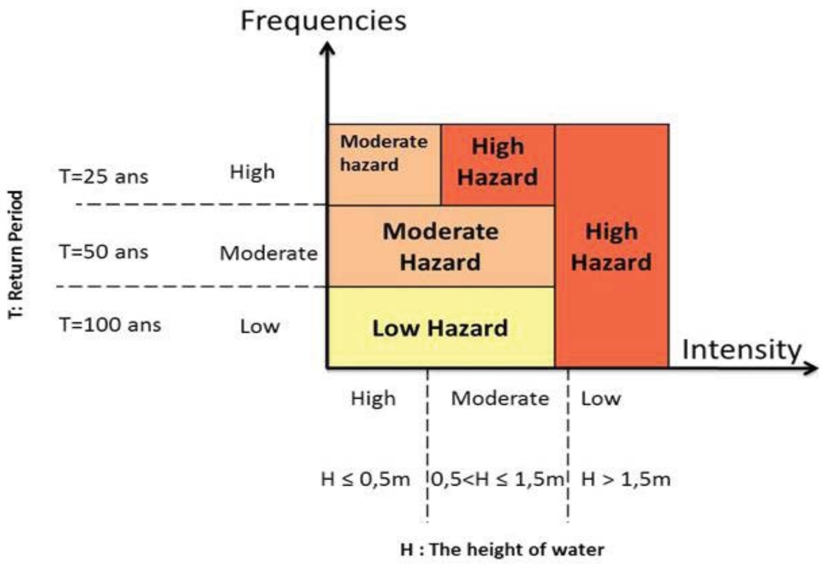

Figure 4: Matrix for determining the flood hazard.

$$\text{Hazard}_{\text{Flood}} = \text{Hazard}_{25} + \text{Hazard}_{50} + \text{Hazard}_{100}$$

Figure 5: Indicators for estimating flood exposure.

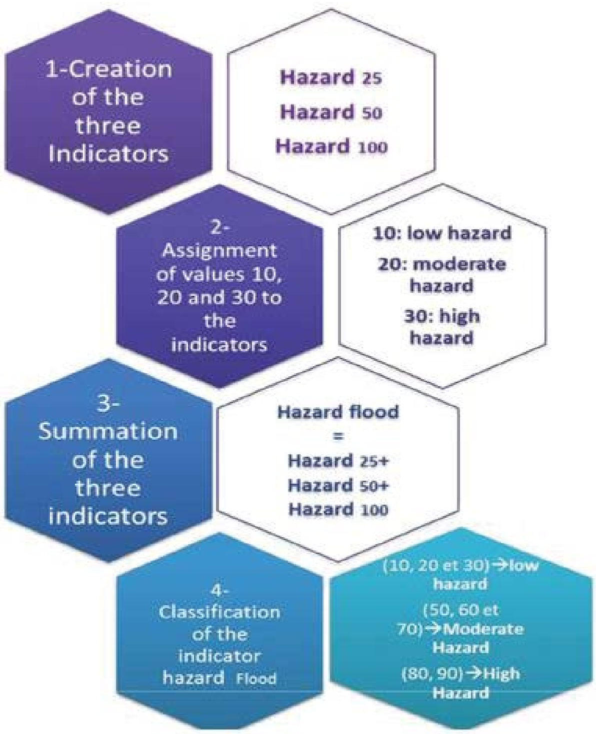

Figure 6: Model for estimating the degree of exposure to floods.

phenomenon by quantitative values (§3). In this context, the Hazard 25, Hazard 50 and Hazard 100 indicators provide information on the degree of exposure of the Province of Larache to previous floods with a return period of 25 years, 50 years and 100 years, respectively.

25-year flood hazard indicator (Hazard 25)

Indicator Hazard 25 provides information on the degree of exposure of the Province of Larache to flood risks with a probability of occurrence of 0.04 (Figure 7). Indeed, when flooding occurs frequently during the last 25 years, the hazard is either moderate or strong [4], no area is exposed to a low degree of hazard. The hazard is rated as high or moderate depending on its intensity, so the degree of flood exposure depends on the water depth. Thus, for exposed areas whose water depth does not exceed 0.5 m; the hazard is considered moderate (according to the matrix of Figure 4).

In addition, 14% of the exposed areas have a moderate level of hazard (in blue). In this case, the flood will be quantified by the value 20, thus denoting a moderate degree of exposure according to the estimation model of Figure 5. While the rest, 86% of the exposed areas, are surfaces with a high level of hazard (in red).

Table 1: Data sources and treatments performed.

Data Sources	Treatments	Results
MNT (ASTER GDEM, produced in 2009 with a resolution of 30 m)	Ras geometry-hydraulic works	Geometry file regrouping: - Bank lines, Flow lines, Cross profiles, Hydraulic works
Geometry file/Peak flows of return periods	Simulation (Under Hec-RAS software)	Flow file containing simulated water levels.
Flow file	Ras mapping function (under the Hec GeoRas extension)	Mapping the flood zones of the three return periods (25, 50 and 100 years)
Flood zone shape files	Editor function (Under ArcGIS software)	Create three fields and assign values to Hazard 25, Hazard 50 and Hazard 100
Union of three flood zone shape files	Field calculator function (Under ArcGIS software)	Calculation of the degree of exposure to flood hazard
Larache road network/Flood hazard map of Larache	Intersect function (Under ArcGIS software)	Estimation of road infrastructure exposure to flood risks

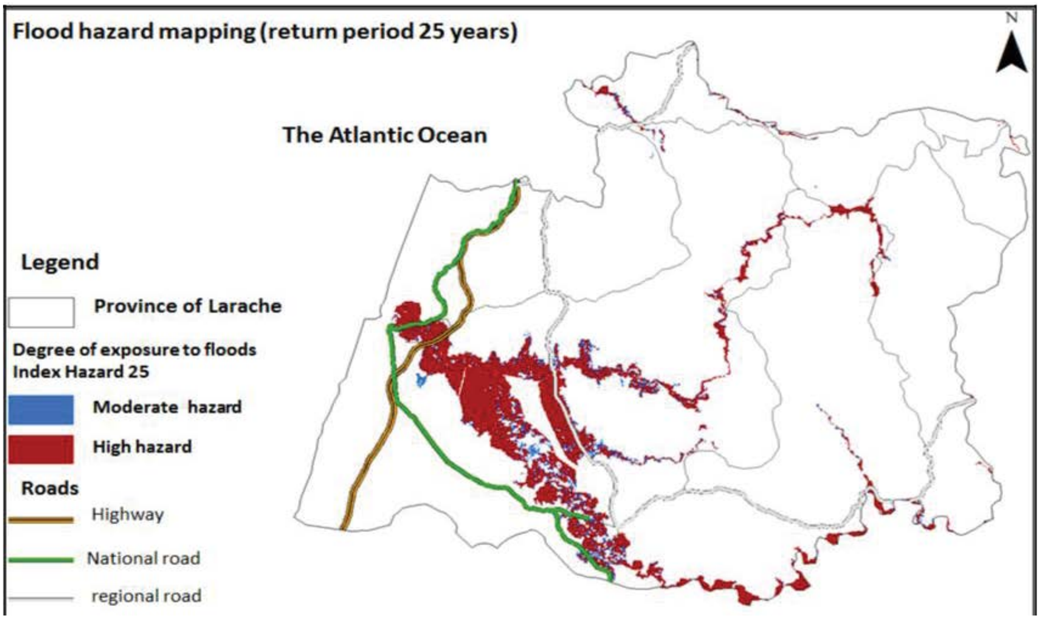

Figure 7: Flood hazard map (25 years).

Flood hazard indicator 50 years (Hazard 50)

Indicator Hazard 50 estimates the Province's exposure to flood risk with a probability of occurrence of 0.02 (return period of 50 years) (Figure 8). Indeed, for a return period of 50 years, the hazard is either strong or moderate. Its determination depends on the intensity of the flood (water level).

Thus, the Hazard 50 indicator shows that 55% of the exposed zones have a high level of hazard since the height of the water is greater than 1.5 m; In this case, the flood is quantified by the value 30 indicating a high degree of exposure following the estimation model of Figure 5. While 45% of flood areas have a moderate level of hazard as the water depth does not exceed 1.5 m (Figure 4).

Flood hazard indicator 100 years (Hazard 100)

The Hazard 100 indicator calculates the degree of exposure of the Province to flood risks with a probability of occurrence of 0.01 (Figure 9). For a return period of 100 years, and with a water depth not exceeding 1.5 m, the hazard is quantified as low (according to the matrix of Figure 4). Thus, 42% of the exposed areas have a low hazard level (in green); while the rest, 58% of the flood zones, shows a high level of hazard (in red).

Degree of flood hazard of the province of Larache

The flood hazard mapping of the province of Larache (Figure 10) is computed using both the model of Figure 5 and the maps of the indicators already obtained. It shows three levels of exposure to flood hazard: weak, moderate and strong. 59% of the areas likely to be flooded present a level of strong hazard. This is because they are historically located in areas where the hazard is strong (Hazard 25=Hazard 50=Hazard 100=Hazard 30). 6% of areas at risk of flooding in Larache Province have low hazard levels, while 35% of the area of floodable areas has a moderate level of hazard.

Exhibition of the road infrastructure of the province of Larache

The exposure of roads in the province of Larache to the risk of flooding (Figure 11) results from GIS spatial intersection requests: Crossing the road layer and flood-prone areas (map of Figure 10) to deduce the degree of exposure of each road to the risk of flooding. The result obtained shows the existence of four levels of risk exposure:

- **Zero exposure:** Provincial roads P4704 and P4402 are not exposed to flooding since they are located in areas where there is no flooding.
- **Light exposure:** Regional Road R410 and Provincial Road P4403 are slightly exposed to flooding

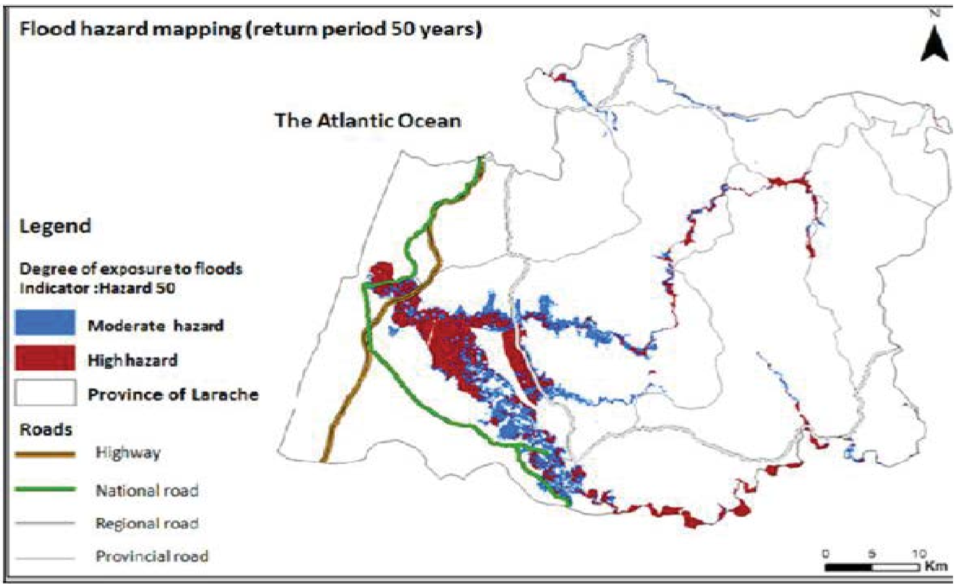

Figure 8: Flood hazard map (50 years).

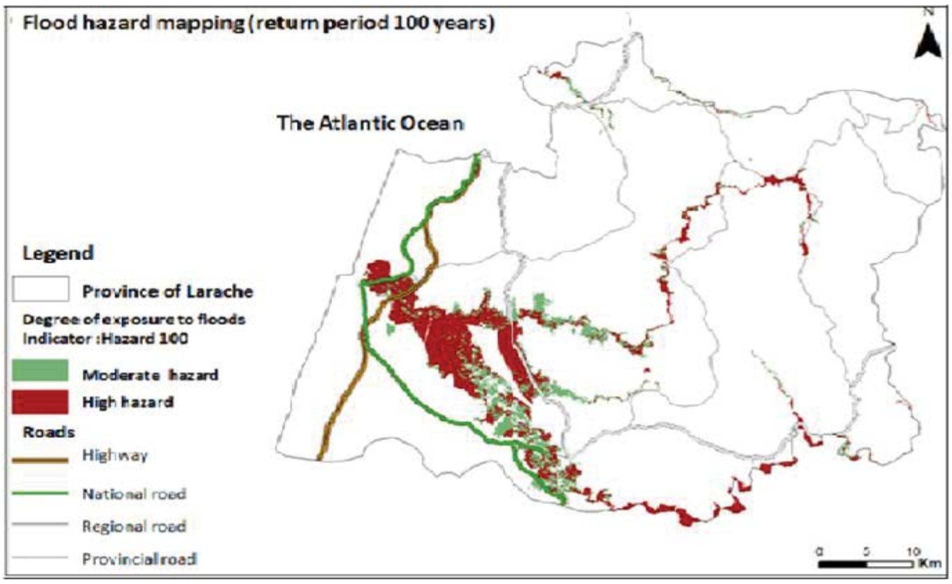

Figure 9: Flood hazard map (100 years).

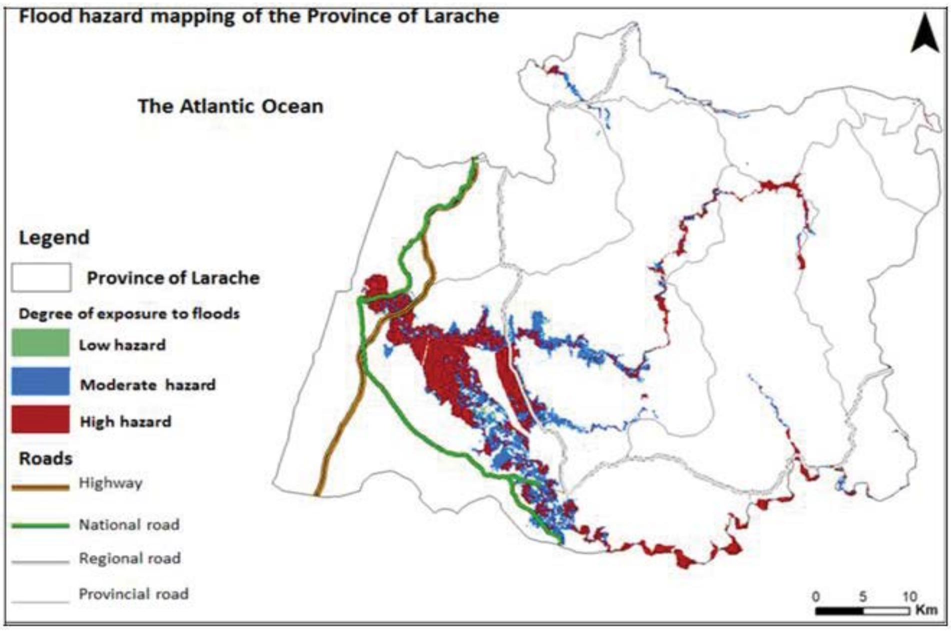

Figure 10: Floods hazard map of the province of Larache.

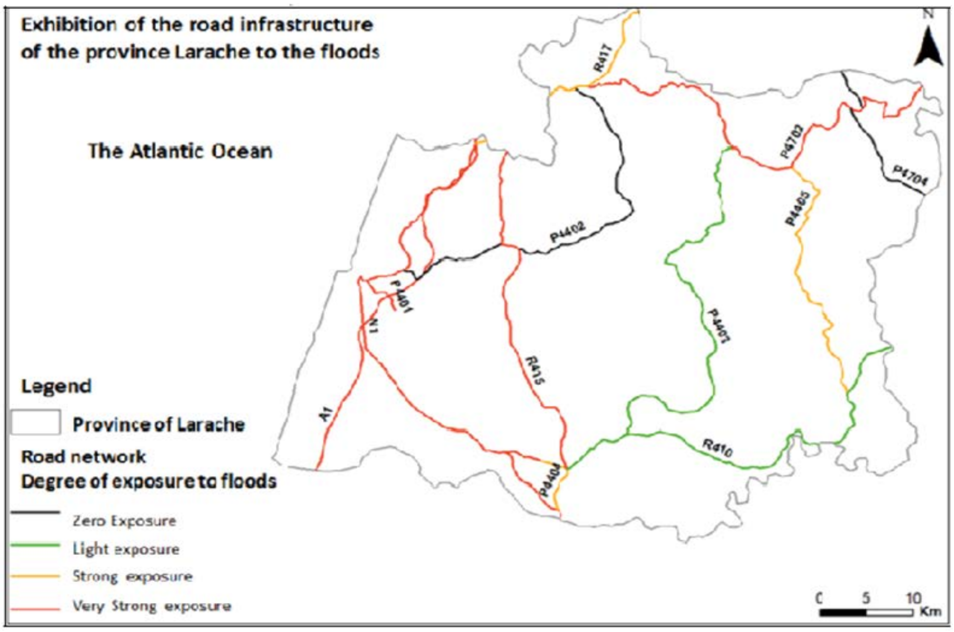

Figure 11: Map of road infrastructure exposure to flood hazards.

- **Strong exposure:** The provincial road P4405 has a fairly strong exposure.
- **Very strong exposure:** The national highway N1, the A1 motorway and the provincial road P4401 are highly exposed to floods, they cross areas of strong hazard.

CONCLUSION

The new method of calculating the degree of exposure to flood risk adopted in this work has yielded several results in map format. Each map presents an indicator of the degree of flood hazard for a given return period (25, 50 and 100 years). The method used also made it possible to measure the degree of exposure of each road in the province of Larache to the risk of flooding.

The indicators used in the new method as well as the values assigned to each index are based on criteria that are particularly relevant to the risk of flooding a road. However, for a better estimate of exposure to flood hazards, the approach used must cover each section of road.

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