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D3.2 - Vulnerability and risk assessment (current conditions)

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Short summary	Assessment and mapping of urban flash flood risk (current conditions) at the sub-city scale in Monastir integrating flash flood hazard data for a 100-year return period, downscaled population data and information on social vulnerability patterns. Further, the report presents the outcomes of the coastal erosion hazard assessment.	
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1 Introduction

Urban disaster risk is a growing problem driven by two megatrends of global change: urbanization and the increasing frequency and intensity of climate-related extreme events. Coastal cities are additionally confronted with sea level rise, land subsidence and coastal erosion. Combined with high levels of societal vulnerability, these trends increase disaster risk and associated loss of life and economic damage. Tunisia faces major risks among the EU neighbourhood countries, given its rapid population growth and almost 80% of its urban areas concentrated along the Mediterranean Sea.

Against this background, the Tunisian "Ministère de l'Equipement de l'Habitat et de l'Aménagement du Territoire" plans to develop a national urban Risk Information and Analysing System (RIAS) to assess the impact of these hazards and reduce their effects. Its implementation, however, faces several major challenges including the lack of relevant geospatial data for urban risk analyses as well as an insufficient understanding of the underlying drivers, current hotspots and possible future scenarios of urban disaster risk. To support this process, the UD-RASP project uses the city of Monastir as a pilot case, representative of Tunisian coastal urban areas faced with similar environmental hazards.

Following up on the identification of drivers of disaster risk (Deliverable 3.1), a risk assessment was conducted at the sub-city scale focusing on present-day conditions. The assessments integrates the spatial analysis and modelling of (1) hazards (i.e. flash floods, coastal erosion), (2) exposure to flash floods, and (3) social vulnerability in the context of flash floods.

2 Conceptual framework

According to IPCC's Fifth Assessment Report (AR5), disaster risk is defined as the likelihood over a specified time period of severe alterations in the normal functioning of a community or a society leading to widespread adverse effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery (IPCC 2014).

As shown in Figure 1, it results from the interaction of one or multiple *hazards* (a natural or human-induced physical event), *exposure* (the physical overlap between the hazard extent and the elements that could be adversely affected by it), and *vulnerability* (the predisposition of an element to be adversely affected). Vulnerability is oftentimes further divided in three sub-components, namely *susceptibility*, short-term *coping capacity*, and long-term *adaptive capacity*.

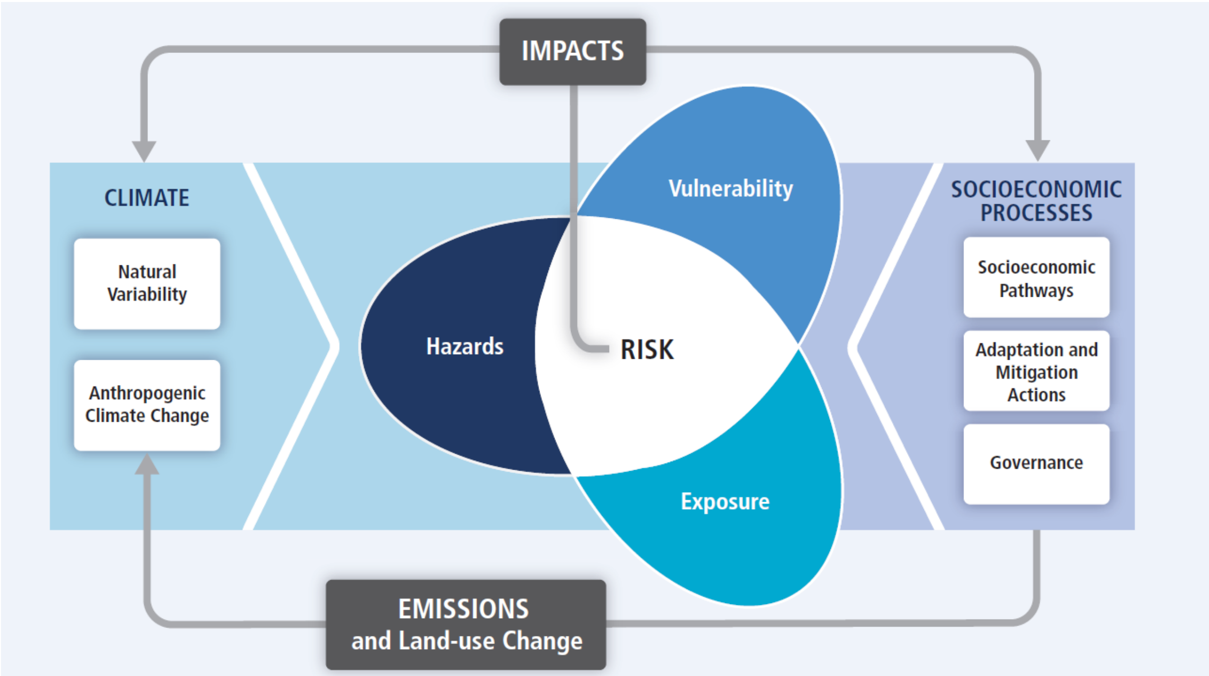

Figure 1: Conceptual framework for the risk analysis (IPCC 2014)

3 Methods to assess vulnerability and risk at the sub-city scale

A multi-step, mixed-methods approach that integrates participatory qualitative analysis with empirical data collection and quantitative modelling and spatial analysis was pursued to assess flash flood risk at the sub-city scale. The subsequent chapters are structured along the three components of risk (hazard, exposure, vulnerability) and describe the respective analyses that were conducted.

3.1 Assessment and simulation of hazard-prone areas

3.1.1 Flash floods

To analyze flash flood hazard, a software-based modelling of surface runoff and flow paths was conducted using the physical process-based modeling suite MIKE FLOOD[1]. Based on high-resolution optical satellite imagery (World View 3), a DTM with 1 meter spatial resolution was derived and for modeling purposes rescaled to 5 meters resolution. Height information about the buildings and roads was added to generate a base for the runoff modelling. Different roughness values are assigned to main elements like road networks or natural areas depending on their drainage characteristics to account for differences in surface runoff velocities (Engman 1986). Additionally, parameters like infiltration values of the soil, porosity, ground water floor distance and saturation are considered in the model.

[1] MIKE FLOOD – Modelling Software *MIKE21* (source: DHI – Wasy)

In a next step, precipitation data from 1982 to 2016 was integrated into the model. Hazard-prone areas of a past and present extreme event were modelled using data from high intensity rainfall events in 1982 and 2016. Furthermore, past extreme events were extracted and prioritized according to their precipitation values to extrapolate a 100-year flooding event. To simulate the HQ100 scenario in Monastir a 12-hour rainfall according to EULER II distribution was applied over the study area.

In a next step, a flash flood hazard classification was calculated considering a depth-velocity-related debris coefficient by DEFRA (2006) , which combines **water depth, flow velocity** and a **debris factor.** The generated hazard layer was classified into categories that correspond to increasing hazard levels (Table 1).

Table 1: Flash Flood Hazard Classification

Hazard Class	Range
Moderate	0.75 - 1.5
Significant	1.6 - 2.5
Extreme	>2.5

3.1.2 Coastal Erosion

Coastal erosion was analysed based on World View 3 satellite imagery and the digital terrain model. The extension of the hazard area was defined depending on slope and maximum flow velocities that were modelled in the course of the flash flood analysis (HQ100). The land use within the hazard area was classified into five main categories of land use (see Fig. 2) to provide information concerning the exposure of the area. Each object was also assigned to a coastal sector, which differed in terms of the investigation phase where as part of the national coastal protection program, multiple coastlines are examined each year by APAL, and the extension of the coastal protection. This value is expressed as development status (derived from APAL reports and interviews with APAL and the municipality):

- Fully developed: all coastal protection activities are completed.
- Partly developed: coastal protection structures available, but not finished
- Examined but not developed: initial examination by APAL is completed, protection structures not started
- Not inspected: no examination by APAL or protection activities

3.2 Exposure analysis

3.2.1 Flash floods

The HQ100 model for flash flood hazard was used to identify and quantify exposed residential urban areas, population as well as transport areas. Census data, provided by the Institute National de la Statistique (INS) was downscaled from the unit to the building block level to get detailed information about the distribution of the population and, in a next step identify the total exposed population per building block. The total population was calculated for each building block, depending on the Urban Fabric class (see Deliverable 1.2) as well as the size of the building block. A class factor was assigned to each “Urban Fabric” class to account for the different population densities (Table 2).

Table 2: Class factor, depending on population density as defined by the Urban Atlas

Urban Fabric Class	Class Factor
Continuous urban fabric	1
Discontinuous dense urban fabric	0.8
Discontinuous medium density urban fabric	0.5
Discontinuous low density urban fabric	0.3
Discontinuous very low density urban fabric	0.1

To assess exposure to flash floods in Monastir, the building blocks and the transport areas were intersected with the hazard layer of the HQ100 rainfall event scenario. As a result, the absolute exposed population as well as the exposed transport areas were calculated. For a detailed description of the workflow for hazard and exposure assessment of flash flood, see Deliverable 1.1 and 2.2.

3.2.2 Coastal Erosion

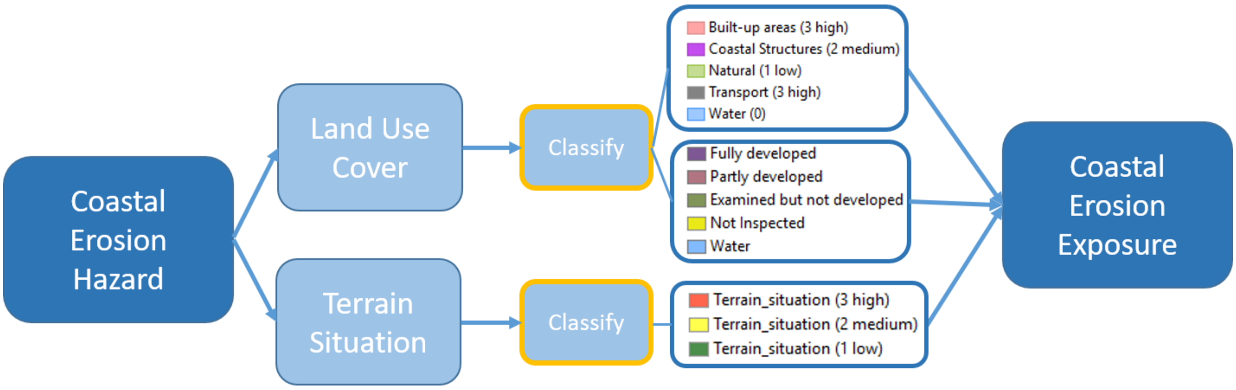

Figure 2: Workflow Exposure Analysis (coastal erosion)

The exposure of the coastal area was examined and described considering the terrain conditions, land use cover and development status (Figure 2). Terrain conditions are classified in 3 categories:

- high (slope > 15°),
- medium (slope 5°- 15°)
- low (slope < 5°)

The results of the GIS analyses are subsequently combined with results of reports by local authorities. Furthermore, findings from a field survey are interpreted to gain further understanding of the coastal erosion processes in the study area. For a detailed description of the workflow for hazard and exposure assessment of coastal erosion, see the reports of Deliverable 1.1 and 2.2.

3.3 Social vulnerability and risk to flash floods

For the assessment of social vulnerability and risk an iterative modelling framework, pursuing a traditional index-based approach (OECD 2008; Hagenlocher et al. 2018) was applied. Relevant modelling phases include: (1) definition of the conceptual risk framework (Fig. 1), (2) identification of potential drivers of risk and associated indicators based on a systematic review of literature, expert consultation (see Deliverable 3.1); (3) data acquisition and pre-processing; (4) analysis and imputation of missing data; (5) outlier detection and treatment; (6) assessment and reduction of existing multicollinearities; (7) normalization; (8) expert-based weighting; and (9) weighted aggregation. In the following sections, the most recent steps for vulnerability and risk assessment are outlined.

3.3.1 Vulnerability indicators

Indicators for the vulnerability index were derived from a systematic literature review, expert interviews and online survey of local stakeholders (see Deliverable 3.1). The 24 indicators thus identified were then sorted into vulnerability's sub-components, as described in the 5th IPCC report (IPCC, 2014): susceptibility, lack of short-term coping capacity, and lack of long-term adaptive capacity. The 2014 Tunisian national census of households (HH) was originally planned as the principal data source for the indicators. However, data for only three indicators (education, unemployment, dependency ratio) were eventually made available at the sub-city scale. In order to cope with that challenge, the project team decided to conduct a household survey in order to collect primary data relevant for the proposed vulnerability assessment[2]. One indicator for susceptibility - *Illegally built residential houses (%)* – was derived from the analysis of remote sensing data and the available urban planning regulation. Five non-spatial indicators (*availability of an EWS*; *number of trucks/pumps/ambulances per 1000 inhabitants*; *number of doctors per 1000 inhabitants*; *recovery budget per capita*; *availability of an adaptation plan for Monastir*; *risk-informed urban planning*) were discarded since data from reliable official sources could not be obtained; two spatial indicators (*household with access to radio/TV/internet*; *households accessible in case of flooding*) were discarded because of uncertainties in the data collection and treatment. The final list of 17 indicators was structured as follows: 6 *susceptibility* indicators, 9 *lack of coping capacity* indicators, 2 *lack of long-term adaptive capacity* indicators.

3.3.2 Household survey

To collect relevant socioeconomic data for the vulnerability assessment, a household survey was conducted in Monastir between May 8th and May 12th 2018. In order to obtain a balanced sampling, a consultation meeting with local experts was organized prior to the beginning of the survey with the goal of identifying areas representative of the spectrum of residents' socio-economic conditions. Participants of the consultation (who included members of the local project team and members of different civil society organisations) were asked to classify each of the city's 78 census sub-units (data for which was available for the 2014 census) into four different categories: 1) *Low income*, 2) *Medium income*, 3) *High income* and 4) *Very high income*. Additional information was also provided on the rate of recent immigration and the period of urbanisation of each sub-unit. The outcome of the

[2] Note: this activity was not initially foreseen in the proposal.

consultation informed the choice of 15 census sub-units that were targeted by the survey and which were considered to be representative for the remaining sub-units of the city (see Figure 3).

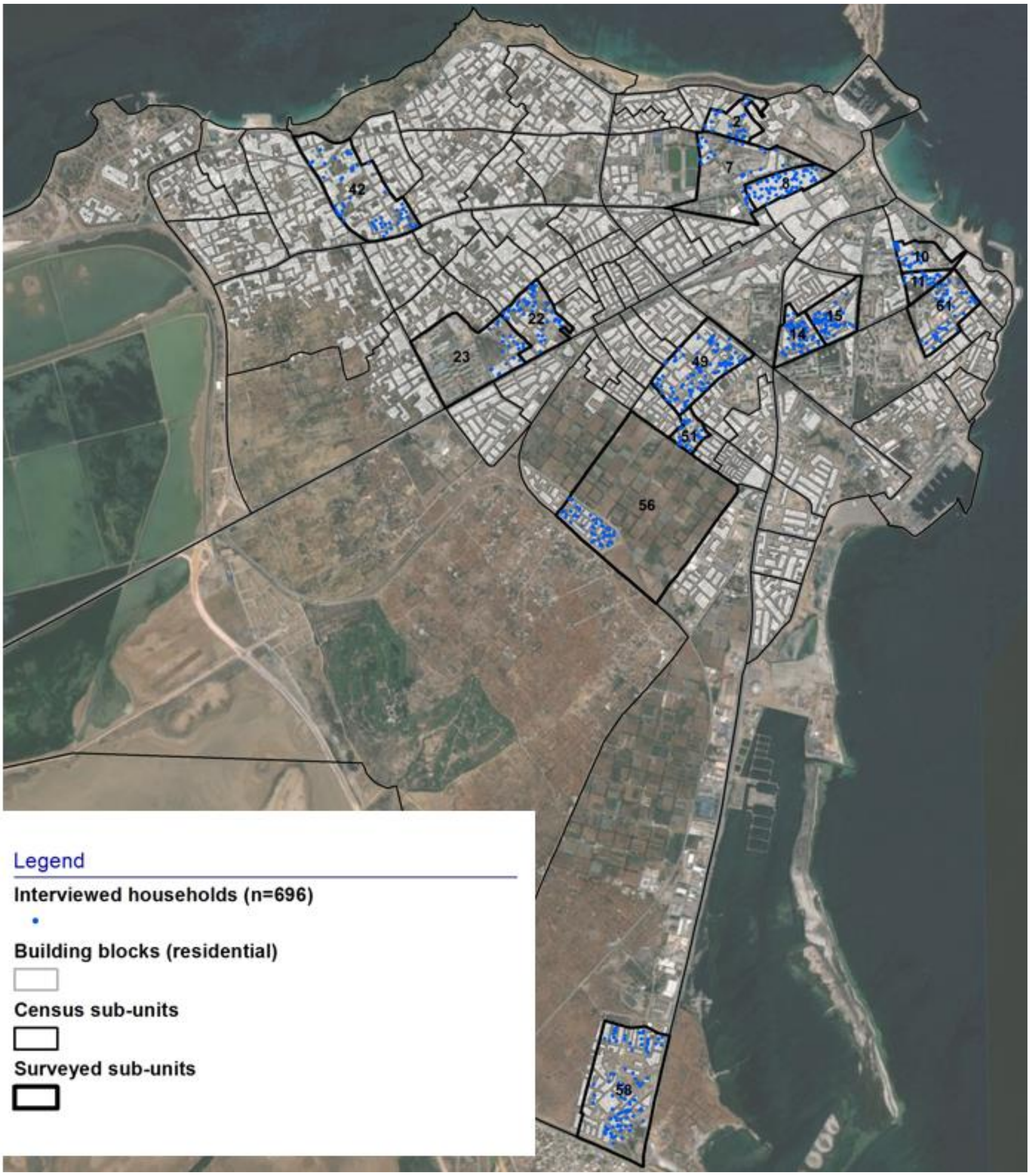

Figure 3: Location of interviewed households

Given the focus on flash floods, a choice was made to survey only households located at the ground floor. 15 locally recruited enumerators underwent a training to familiarize themselves with the scope of the project, the questionnaire and generic survey techniques. The questionnaire was divided into four different parts:

a) Knowledge of hazard settings (11 questions)

b) Prevention & preparedness (21 questions)

c) Housing characteristics (13 questions)

d) Household composition and needs (46 questions)

Each enumerator was then assigned to individual residential buildings selected in the 15 targeted census sub-units. During the survey, 727 interviews were completed (Table 2).

Table 3: Distribution of interviews across the 15 sub-units

Census sub-unit	Number of completed interviews	Percentage of households surveyed (estimate)
2	29	17 %
7	31	19 %
8	56	15 %
10	22	14 %
11	21	18 %
14	56	17 %
15	53	18 %
22	51	20 %
23	25	18 %
42	55	26 %
49	117	14 %
51	24	11 %
56	47	12 %
58	94	13 %
61	46	11 %
TOTAL	**727**	**15** %

The estimate of the number of households in each unit was obtained by dividing the total population (available through the census data) for an average household size of 4.5 people (derived from analysis of the first 150 interviews). A selected group of enumerators then digitised the questionnaires. After data cleaning, 696 questionnaires were retained, based on the percentage of missing data.

Figure 4 shows how the interviews are distributed across gender and different age groups, household sizes, as well as education and income levels.

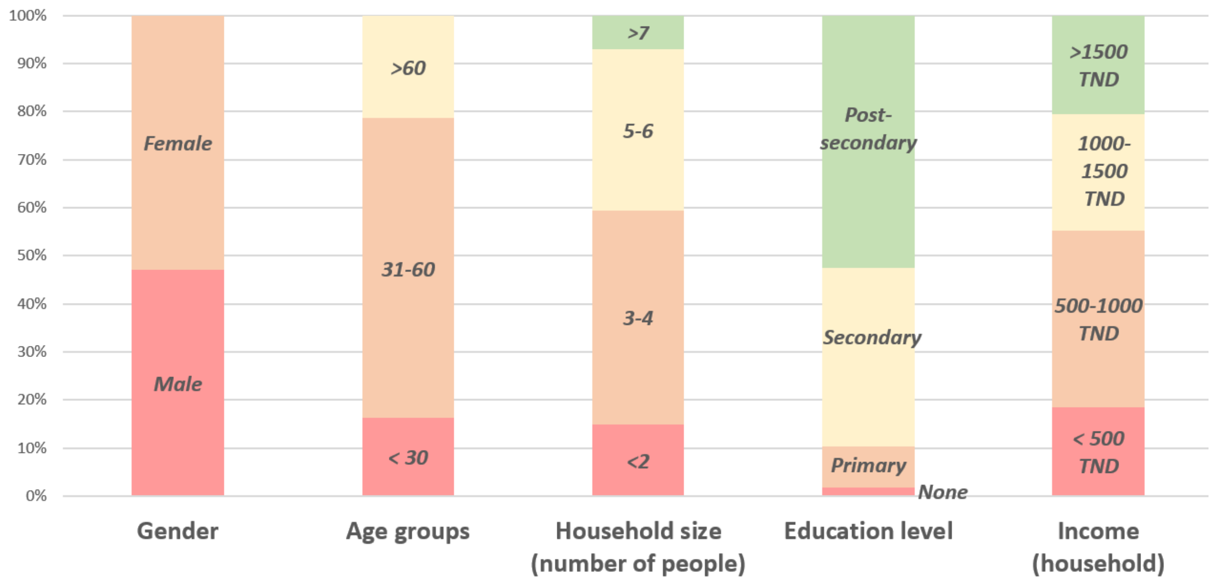

Figure 4: Distribution of interviews across gender, age groups, and household size, education and income levels following data treatment (*n* = 696)

3.3.3 Vulnerability index

Since all vulnerability indicators represent percentages (e.g. percentage of households below the national poverty line, etc.), data for these indicators did not have to be normalized. However, for some indicators (e.g. percentage of households with savings, percentage of households receiving remittances, etc.) the direction of the indicator had to be changed to ensure that high indicator scores always contribute to an increase in vulnerability. Before aggregating the individual vulnerability indicators into an index, an online survey was sent out to selected local stakeholders between 15th and 31th August 2018 in order to evaluate the relevance of each indicator for social vulnerability to flash floods. In the online survey, participants were asked to indicate the relative weights (in a scale from 0 to 4) that each indicator should have in the final index, according to their perception and knowledge of the local context. Seven local experts participated in the survey. For each indicator, the average weights expressed by the stakeholders was considered when constructing the index. Further, the standard deviation was analysed in order to evaluate the level of agreement/disagreement on indicator weights by the experts. The weighted indicators were then aggregated into an index of social vulnerability for each of the 15 sampled sub-units using weighted arithmetic aggregation:

$$Social\ vulnerability = \sum_{i=1}^{n} w_i x_i$$

Where n equals the number of vulnerability indicators, w_i are the weights for each normalized dataset x_i. A final risk score for each of the 15 sub-units was then derived based on the following equation:

$$Risk = flash\ flood\ exposure * social\ vulnerability$$

4 Results

4.1 Hazards

Figure 5 shows the outcomes of the flash flood model for the HQ100 scenario, where light blue represents a moderate, medium blue a significant, and dark blue an extreme flash flood hazard. In the event of a flash flood, the surface runoff is channeled along the main roads, which follow their path until the water accumulates at hotspots around the city. During a 100-year rainfall event, the eastern part of the city is especially influenced by flash floods.

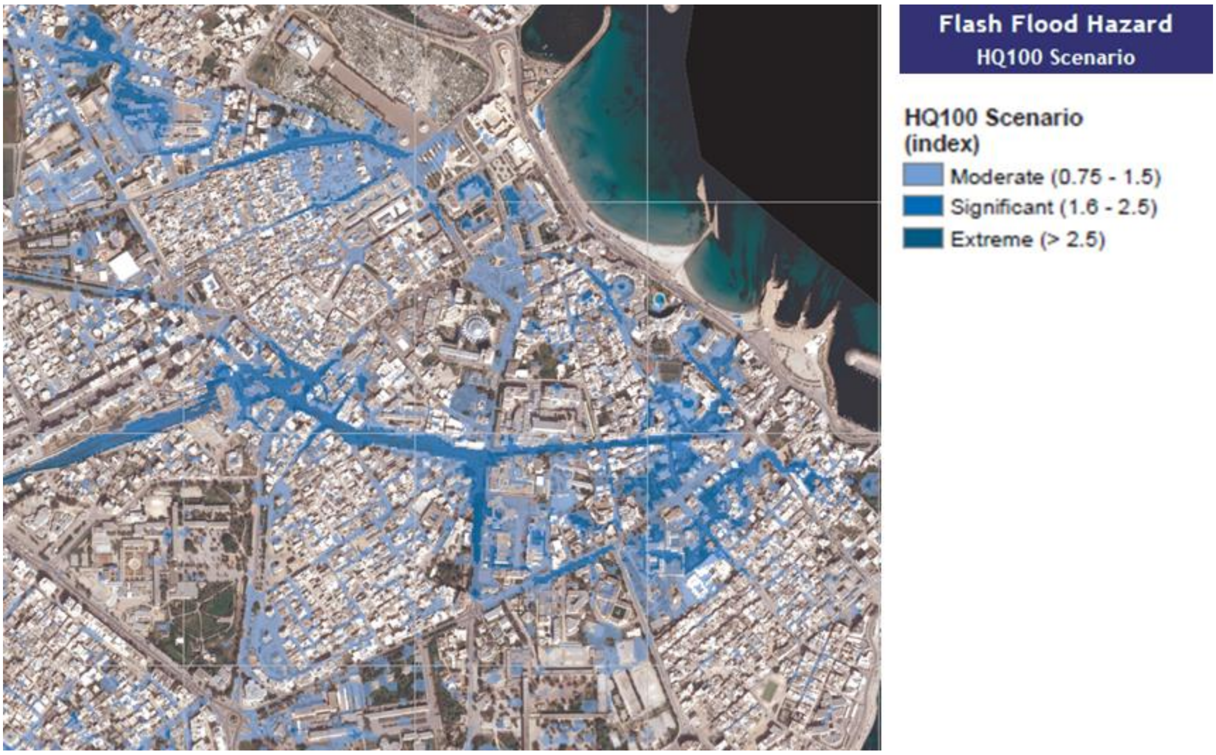

Figure 5: Flash flood hazard in Monastir (100-year return period)

For the analysis of coastal erosion, the coastline of Monastir was divided into 6 coastal segments that were consequently analysed. Figure 6 shows the coastal erosion analysis which was conducted for Part 2 of the Monastir coast. The area is dominated by steep terrain with gentler slopes in the east. The whole section has been fully developed in terms of protective measures.

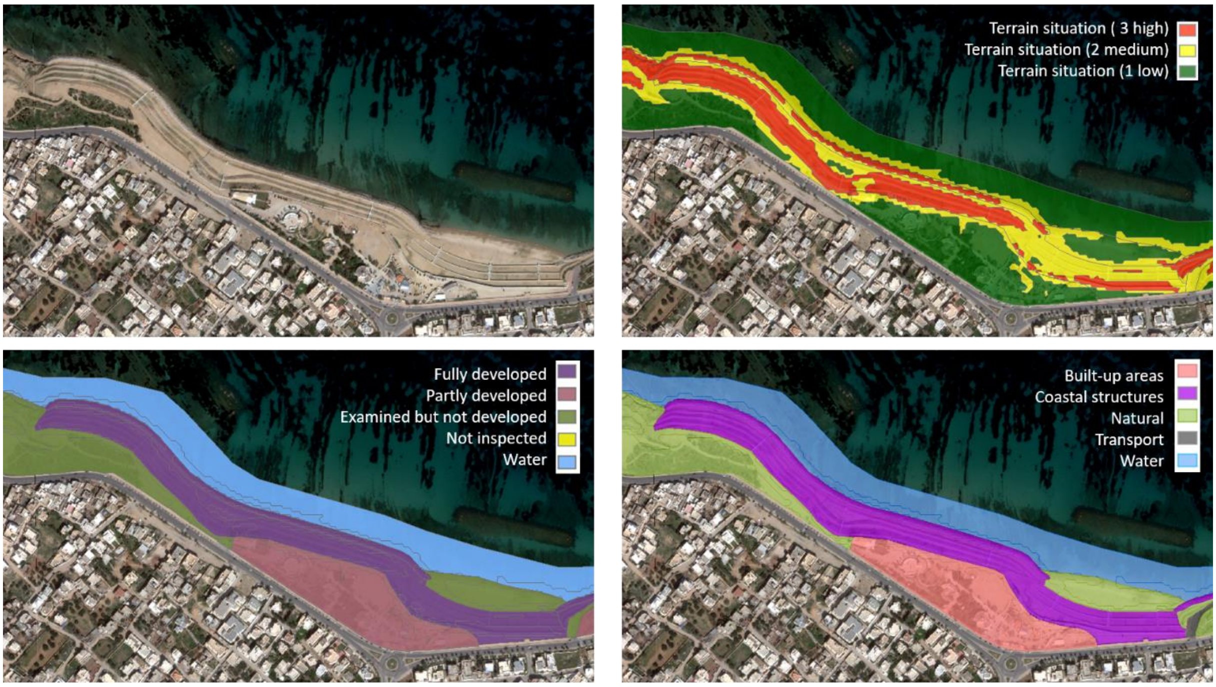

Figure 6: Coastal Erosion Analysis in Part 2

In the eastern part, sea walls with drainage channels as well as headland breakwaters have been installed (Figure 7.1). In the western part, ripraps in combination with vertical as well as horizontal drainage channels been constructed (Figure 7.2, Figure 7.3). According to experts in the municipality, the previous erosion has been reduced in the area as a consequence of the implemented measures.

Figure 7: Part 2 - 1) Sea Walls 2) Rip Raps 3) Drainage Channels

For description of the other sections of the Monastir coast and a more detailed illustration of the workflow for the coastal erosion analysis, see the reports of Deliverable 1.1 and 2.2.

4.2 Exposure

The exposure of the population to a 100-year return period flash flood event is represented as percentages of the total population in each census sub-unit. Overall, 8,871 people (9.53% of the total population) could be affected by such a large-scale event. The analysis was conducted both at the sub-city scale (Figure 8) and on the building block level (Figure 9).

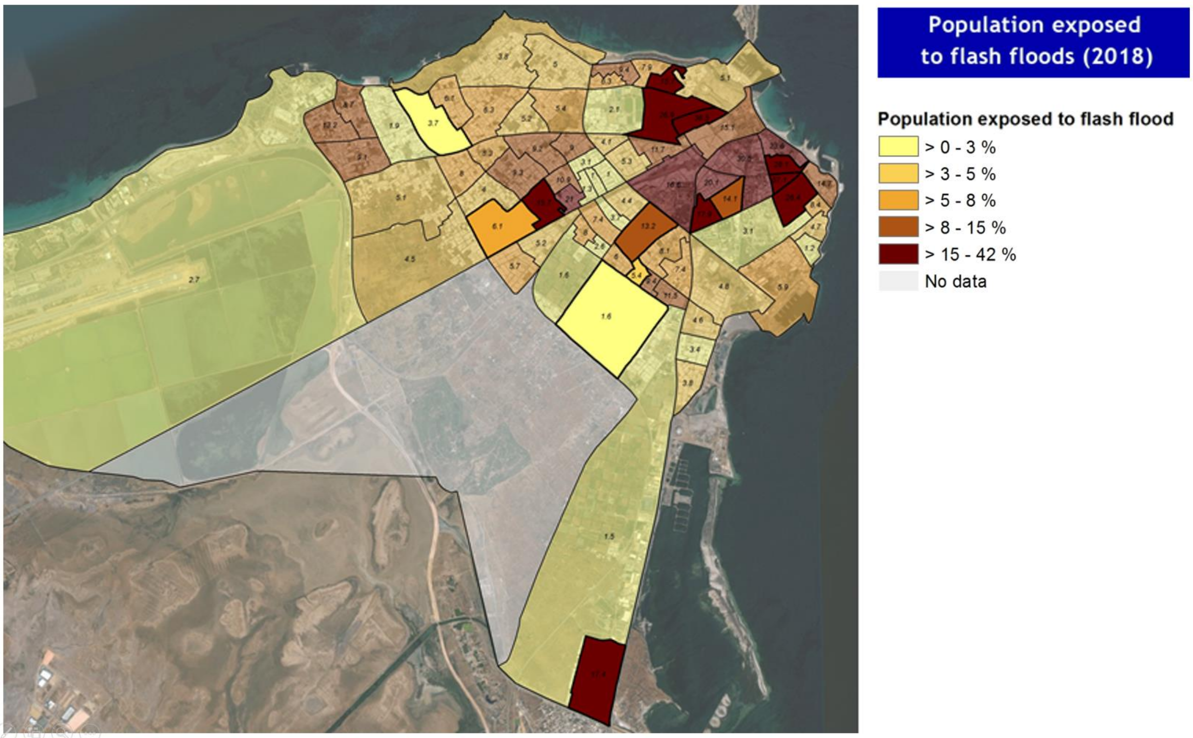

Figure 8: Exposure of the population to flash floods (100-year return period, building block level)

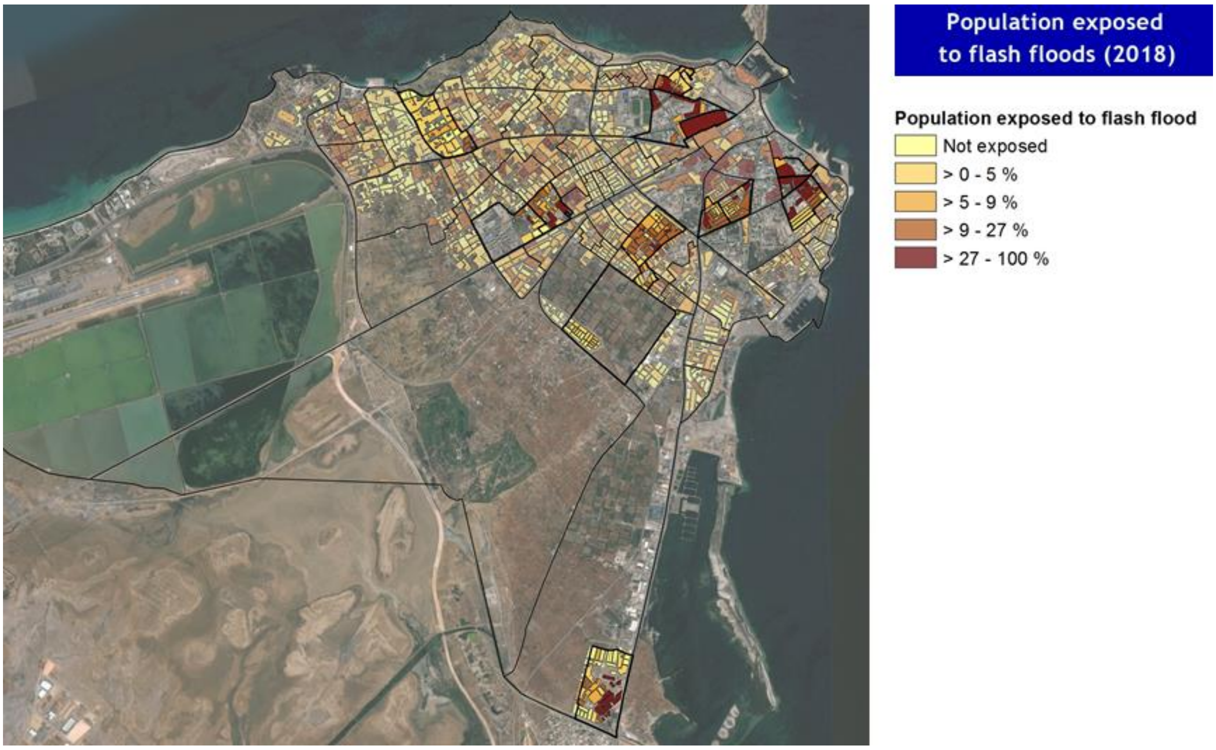

Figure 9: Exposure of the population to flash floods (100-year return period, building block level)

The analysis shows that exposure of the population is generally higher in the oldest areas of the city (the *Madinat*), scoring 36.5 % of people exposed, and in the eastern part of the city centre, of more recent construction, where it ranges from 16.6 to 57.1 % across different contiguous sub-units. These results are consistent with the dense residential pattern of these areas, which at the same time are heavily affected by the flood hazard, aggravated by the poor conditions of the water network system.

4.3 Social vulnerability to flash floods

4.3.1 Indicators

Table 4 presents an overview of key social vulnerability indicators relevant in the context of flash floods, split by its key components: susceptibility, lack of short-term coping capacity, and lack of long-term adaptive capacity. It lists the final indicators, their data source, the weighting assigned by local experts, their geographic coverage and the positive or negative impact they have on social vulnerability to flash floods ("direction").

Table 4: Vulnerability indicators

VULNERABILITY INDICATORS (FLASH FLOOD)

Category		Indicators (expert consultation & lit. review)	Code	Available datasets/proxies	Direction*	Weight (0-1)**	Data source	Coverage
Susceptibility	Poverty & income	Households below national poverty line (%)	SUS_POV	People with less than 120 TND/month (%)	+	0.79	HH survey	15 sub-units
		Unemployment rate (%)	SUS_UNE	Individuals over 15 years old (who are not currently in school) unemployed (%)	+	0.54	HH survey *Census*	15 sub-units *Entire city*
		Dependency ratio (%)	SUS_DEP	Population <15 & > 60 years divided by the working-age population (15-60 years)	+	0.39	HH survey *Census*	15 sub-units *Entire city*
	Health status	Disabled people (%)	SUS_DIS	People with reduced mobility and need for special assistance (%)	+	0.61	HH survey	15 sub-units
	Anarchic urban development	Illegally built residential houses (%)	SUS_LEG	Illegally built residential houses (%)	+	0.82	Remote sensing	Entire city
	Risk perception	Risk perception of local population (categorical)	SUS_PER	HHs who are located in flood-prone areas but who do not think that they are (%)	+	0.75	HH survey	15 sub-units
Lack of coping capacity	Early warning system (EWS)	Availability of an EWS (yes/no)	n/a	n/a	-	n/a	n/a	n/a
		Household with access to radio/TV/internet (%)	n/a	n/a	-	n/a	n/a	n/a
	Accessibility (evacuation & emergency response)	Households accessible in case of flooding (%)	n/a	n/a	-	n/a	n/a	n/a
		Number of people trained in crises management per 1,000	CC_CRI	People trained in first aid (%)	-	0.46	HH survey	15 sub-units
		Number of trucks/pumps/ambulances per 1,000	n/a	n/a	-	n/a	n/a	n/a
		Number of doctors per 1,000	n/a	n/a	-	n/a	n/a	n/a
	Building condition	Houses with more than one floor (%)	CC_STO	Households (HHs) with access to upper floor (%)	-	0.46	HH survey	15 sub-units
	Financial capital	Households with savings (%)	CC_FIN	HHs with savings worth a month's income (%)	-	0.50	HH survey	15 sub-units
		Households with access to credits / loans (%)	CC_CRE	HHs who can lend enough money from a private person OR get credit from a bank to sustain the household and get over an emergency (%)	-	0.46	HH survey	15 sub-units
		Households receiving remittances (%)	CC_REM	HHs receiving remittances (%)	-	0.17	HH survey	15 sub-units
	Insurance	Households with flood insurance (%)	CC_INS	HHs without flood insurance (%)	+	0.50	HH survey	15 sub-units
	Contingency funds	Recovery budget per capita (TND)	n/a	n/a	-	n/a	n/a	n/a
	Social capital	Households with a social network/external help (%)	CC_SOC	HHs that can rely on external help (%)	-	0.46	HH survey	15 sub-units
	Government assistance	Households subscribed to government assistance (%)	CC_AS1 / CC_AS2	HHs subscribed to government assistance (%)	+	0.61	HH survey	15 sub-units
Lack of adaptive capacity	Education	Population with post-secondary education (%)	AC_EDU	Population with post-secondary education (%)	-	0.32	HH survey *Census*	15 sub-units *Entire city*
	House ownership	Renters (%)	AC_OWN	Renters (%)	-	0.54	HH survey	15 sub-units
	Plans & strategies	Availability of an Adaptation Plan for Monastir	n/a	n/a	-	n/a	n/a	n/a
		Risk-informed urban planning (integrating risk information into Plan d'Amenagement)	n/a	n/a	-	n/a	n/a	n/a

** high indicator scores increase [+] or decrease [-] vulnerability;. ** according to local expert judgement (n = 7) - for index construction weights are re-scaled to sum up to 1*

4.3.2 Social vulnerability index (flash floods)

Figure 10 shows the spatial variation of the vulnerability index across the surveyed sub-units (scores are labelled in percentages to facilitate comparison). Index scores of zero indicate no vulnerability, while index scores of 100 represent extremely high vulnerability. The results show that social vulnerability is medium to high throughout all 15 sub-units with very little variability (minimum score: 38; maximum score: 53).

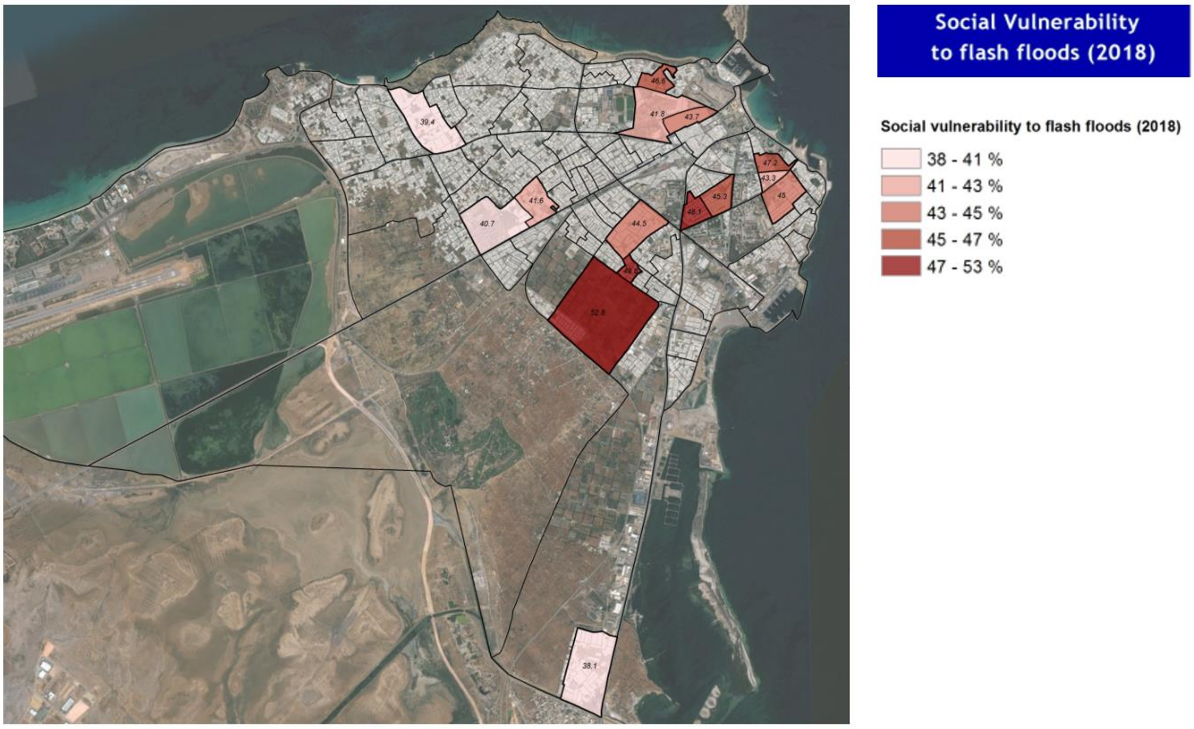

Figure 10: Social vulnerability to flash floods in Monastir

Figure 11 shows the contribution of each indicator to the final index value for each of the 15 sampled sub-units and hence provides entry points for reducing vulnerability. The graph clearly shows that while some indicators are contributing almost equally to social vulnerability throughout all 15 sub-units (e.g. lack of flood insurance), other indicators are more spatially varied (e.g. % of households below the poverty line), hence warranting targeted, place-based solutions.

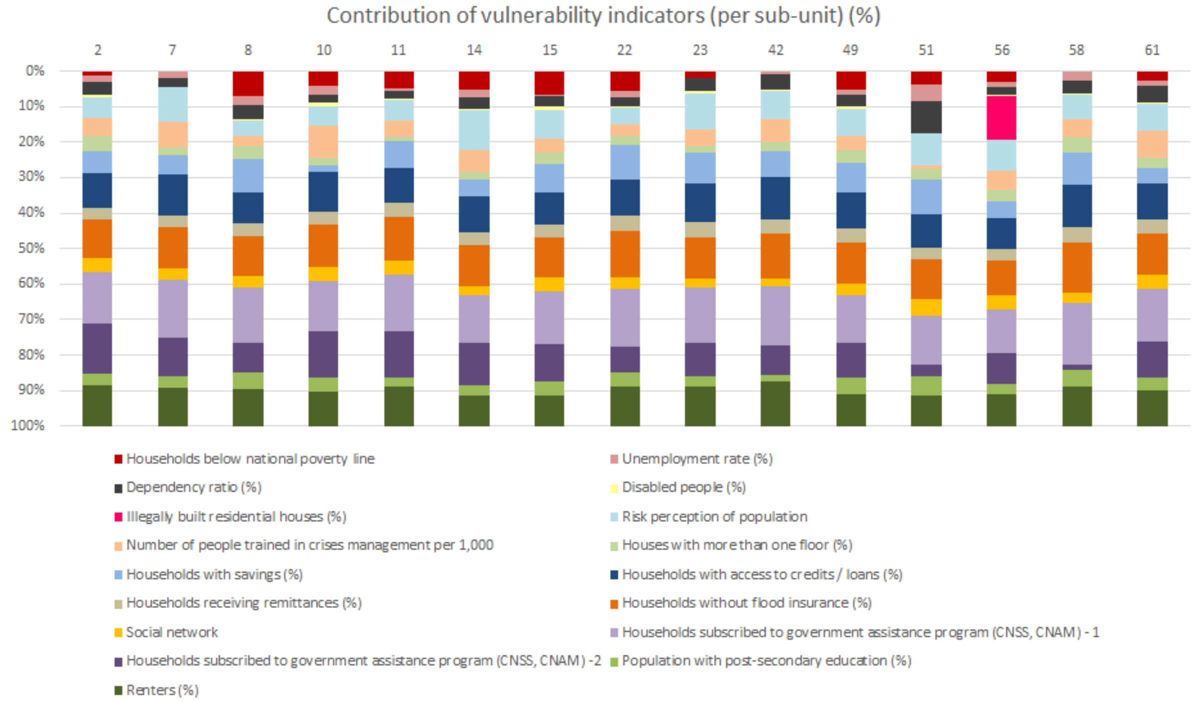

Figure 11: Vulnerability profiles for the 15 sampled sub-units

4.3.3 Flash flood risk

Figure 12 shows flash flood risk in Monastir based on the above-described hazard, exposure and vulnerability data. As for the social vulnerability index, index scores of zero indicate no risk, while index scores of 100 represent very high risk. The results show that flash flood risk is low to medium depending on the specific neighbourhood (minimum score: 0; maximum score: 24). However, given that social vulnerability to flash floods is medium to high throughout the city, risk could drastically increase if flash floods become more frequent in the future as a result of climate change and surface sealing.

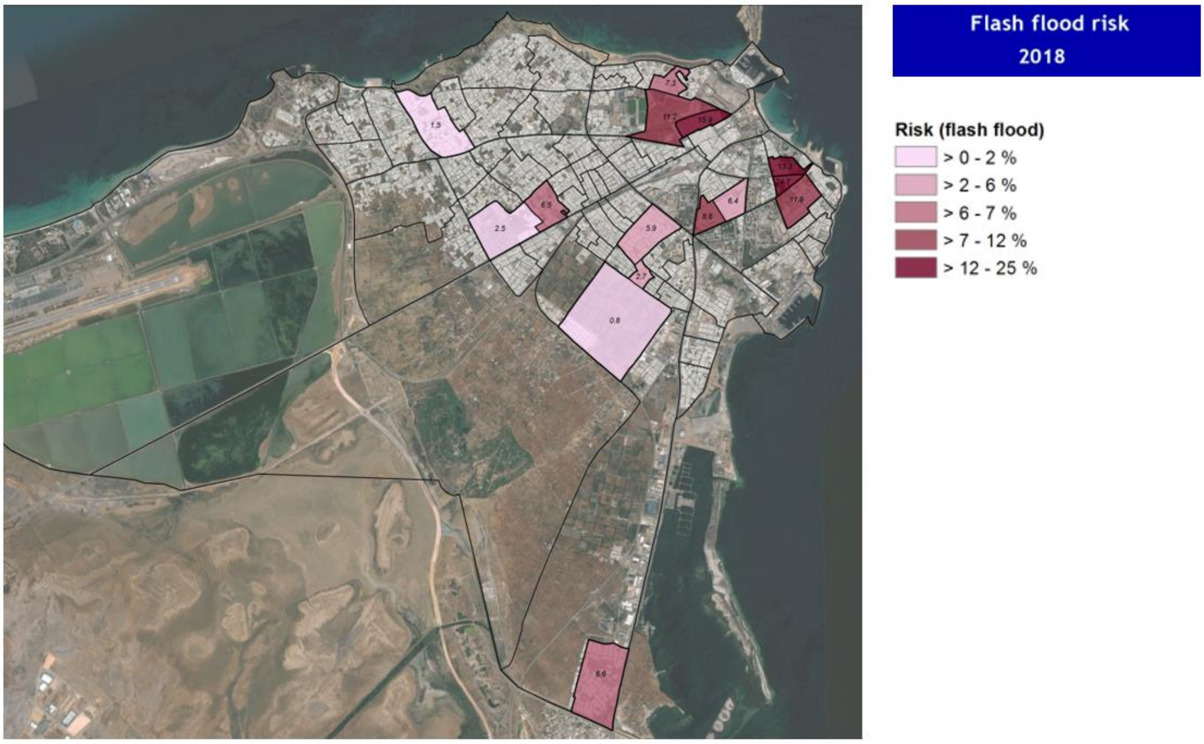

Figure 12: Flash flood risk in Monastir

Table 5 summarizes the final scores for hazard (in terms of area affected), exposure (in terms of population), social vulnerability and overall flash flood risk for all the 15 sub-units targeted by the survey.

Table 5: Flash flood risk scores for the 15 sub-units

Census sub-unit	Flash flood hazard	Exposure of the population	Social Vulnerability	Flash flood risk
2	0.27	0.16	0.47	0.07
7	0.42	0.27	0.42	0.11
8	0.47	0.36	0.44	0.16
10	0.43	0.28	0.47	0.13
11	0.68	0.57	0.43	0.25
14	0.35	0.18	0.48	0.09
15	0.31	0.14	0.45	0.06
22	0.26	0.16	0.42	0.07
23	0.10	0.06	0.41	0.02
42	0.08	0.04	0.39	0.01
49	0.20	0.13	0.44	0.06
51	0.16	0.05	0.50	0.03
56	0.05	0.02	0.53	0.01
58	0.30	0.17	0.38	0.07
61	0.47	0.26	0.45	0.12

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