UNIVERSITÀ DEGLI STUDI DI TORINO

Research Programme
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Multi-hazard Risk Analysis under Climate Change: West Africa Case Studies

Synthesis

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Introduction

Developing countries are increasingly challenged to respond to harmful effects of natural disasters under climate change (desertification, floods, climate related hazards, etc.). However, the response to these threats is complex and requires many economic and technical resources, while, in developing countries, responsive local governance for climate adaptation is constrained by weak technical capacity, poor interactions with other institutions, weak observation networks and data quality, weak communication capabilities, and unclear mandates and conflicting priorities between levels and agencies of government. These weaknesses generate serious implications for the poorest and most vulnerable communities that are frequently the most adversely impacted by climate stress.

The research activity during my PhD career has focused on the investigation of multi-hazard risk assessment in Sub-Saharan Africa, one of the places on Earth most vulnerable to climate change, with the aim to support decision makers in increasing the effectiveness of their interventions. The study takes its cue from two works published during my PhD career [1-2].

The thesis contributes to the exploration of new and innovative methodologies by supporting the adaptation process to climate change and disaster risk prevention in least developed countries through the assessment of multi-hazard risk under future climate scenarios.

The work gathers, with a holistic and interdisciplinary approach, a review of concepts of multi-hazard risk assessment and notions about climate modeling and downscaling techniques, then, starting from the two above mentioned papers, it produces the bias-corrected climatic projection datasets and develops the future multi-hazard risk assessment for the two case studies. The future scenarios are compared with the current assessment thus intercepting the most significant trends in risk evolution. The study follows on with a discussion on the obtained results. The last chapter draws conclusions on the sustainability and replicability of the method in similar contexts and its ability to support the medium-long term planning process through the identification of intervention priorities.

The investigated case studies are:

- Hodh El Chargui Region, Mauritania
- Dosso Region, Niger

Objectives

The main goal is to develop a multi-hazard risk assessment at regional scale, which considers future climate scenarios, that will be useful for the decision-making process.

The realization of this goal must be conceived trough (i) the characterization of hydroclimatic threats at sub-national level, (ii) the characterization of the risk level according to administrative jurisdictions and (iii) the setting up of a sustainable assessment process.

The analysis of each hazard, their combination and the evolution of climate extremes ultimately lead to a comparison of results (current vs. future) which allows the identification of priority intervention areas considering the dynamic of the risk. This feature is the most innovative one in addressing regional and local planning, because the comparison of current and future risk scenarios allows to intercept the risks' trends and their level of confidence.

The research approach is operational and the results could be directly applied in the case study regions. Nevertheless, this research should guide the replication of the risk analysis in other countries featuring similar characteristics (lack of observation data, low economic resources, high number of causalities and damages by natural disaster).

Organization of the research

The study is organized into the following chapters:

1. Introduction; which gives the context of the climate risk in developing countries and the need of a multi-hazard risk approach.
2. Climate change and risk assessment; this chapter make a brief introduction to climate projections and the climate future scenarios.
3. The following chapter deploys the case study in the Hodh El Chargui Region, its multi-hazard risk analysis with the definition of the current and future multi-risk zones in the Region.
4. Case study analysis in the Dosso Region, with the multi-risk approach able to identify the current and future multi-risk index in the Dosso Region.
5. The discussion chapter explores the identification of priority areas in the two case studies highlighting the advantages and the limits of the present methodology and the possible application to others realities.
6. Conclusions of the study.

Characterization of multi-hazard risks

Multi-hazard may refer to:

- different hazardous events threatening the same exposed elements (with or without temporal coincidence);
- hazardous events occurring at the same time or shortly following each other (cascade effects).
- the totality of relevant hazards in a defined administrative area.

Using this definition, the first step is the characterization of the existing natural hazard in the study area through a diagnosis of the recurrent disasters in the study area. To assess the risk, a complete vision of the information available about the configuration of the territory (orography, hydraulic network, population distribution, etc.), the weather and hydro observation network, the ancillary databases (climate, agricultural and pastoral statistics, registered damages and losses) and, if present, the mapping of damages distribution (areas affected by floods, loss of agricultural production, spread of diseases, etc.), would be useful to correctly detect and describe the risk. Unfortunately, in many cases, this material is not available in the required detail or its quality is weak.

The preliminary assessment should be followed by the production of a characterization of the territory and its environmental threats. Once the threats are identified it is possible to proceed with the integration of every single hazard, that might affect the area, in a multi-hazard risk analysis.

There are several methodologies in literature to assess multi-hazard risk [i.e. 1-2, 6-9] and as always the choices largely depends on the specificity of the territory and its threats, the data available, the scale and the aim of the study. So the selection of the methodology to reach a MHRI assessment is site-specific and its application is dependent on the material available. In this work, two case studies are proposed, thus allowing to apply these methodologies to similar contexts, quite common in Sub-Saharan Africa and other countries worldwide.

Hodh El Chargui region – Mauritania

The risk equation (R), used in this context proposed by Tiepolo et al. [2], combines hazard (H), exposure (E), vulnerability (V) and adaptive capacity (AC) namely "the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" [10]:

$$R = H * (E + V - AC)$$

The equation is an adaptation of that proposed by Crichton [10]. Each risk determinant is expressed by indicators, identified after participatory meetings with the communities and visits to the exposed items. In this case the option to reach every single community in the region is possible due to the low density of the population. So, it is convenient to spend some time in retrieving direct information about risk determinants through field surveys.

Dosso region - Niger

The risk equation (R) chosen by the authors [1] combines hazard (H), and potential loss and damages (L&D):

$$R = H * L\&D$$

The decision to use this equation instead of one that includes vulnerability and exposure is due to the impossibility of accurately ascertaining the level of vulnerability and exposure for each municipality while a dataset of L&D, at the municipality level, is available. In this case, it is simpler to use such database instead of conducting a field survey in each municipality to retrieve information to set up a list of indicators.

Case study analysis in Hodh El Chargui Region

Multi-hazard risk analysis in Hodh El Chargui Region

The Hodh El Chargui is a landlocked region 1,100 km from the Atlantic coast (*Fig. 1*) in Mauritania in a semi-arid environment.

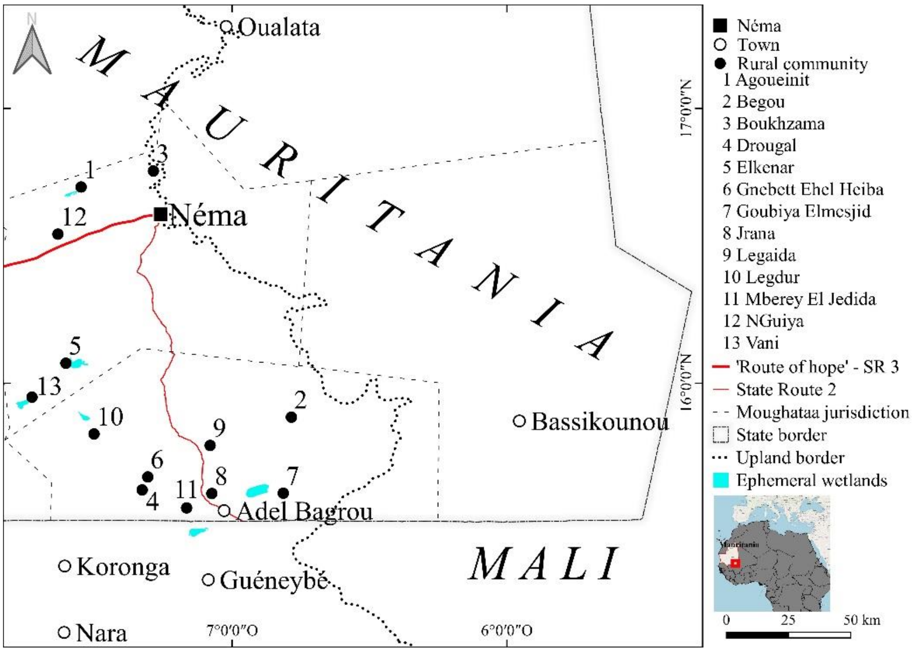


Fig. 1 The 13 rural communities of Hodh El Chargui where the multi-hazard risk assessment was developed. Map from Tiepolo et al. [2]

In the Hodh El Chargui a multi-hazard risk assessment is carried out in 13 rural communities of the 4 municipalities of Adel Bagrou, Agoueinit, Bougadoum, Oum Avnadech. These communities have between 400 and 2,600 inhabitants and they are strongly affected by hydro-climatic risks [2].

Multi-hazard risk level

The risk level in each community is defined by the following formula:

$$R = H * (E + V - AC)$$

Replacing the values in the formula for the four hazard risks it is possible to calculate the MHRI. Combining all the 4 components it is possible to produce the MHRI table (Table 1).

Table 1 Multi-hazard risk index for 13 communities of Hodh El Chargui, Mauritania.

Community	Meteorological drought	Hydrological drought	Agricultural drought	Heavy rain	MHRI Score
Begou	0.05	0.04	0.60	0.35	**1.04**
Agoueinit	0.04	-0.02	0.64	0.33	**0.99**
Legdur	0.02	0.04	0.59	0.29	**0.95**
NGuyia	-0.07	0.03	0.73	0.13	**0.82**
Boukhzama 1	-0.02	-0.01	0.00	0.77	**0.75**
Legaida	0.10	0.09	0.27	0.21	**0.67**
Gnebett Ehel Heiba	0.00	0.06	0.30	0.23	**0.60**
Elkenar	-0.05	0.12	0.29	0.04	**0.40**
Jrana	0.01	0.08	0.31	0.00	**0.40**
Drougal	0.00	0.04	0.26	0.08	**0.38**
Vani	-0.02	0.13	0.20	0.06	**0.37**
Goubya Elmesjid	0.00	0.14	0.09	0.08	**0.30**
Mborey El Jedid	-0.01	0.02	0.15	0.12	**0.28**

The interval between the maximum and minimum value of the multi-hazard risk index (MHRI) represent the severe (above 0.90), high (0.60-0.89), moderate (0.35-0.59) and low risk (below 0.35) conditions. The most northern communities tend to have the highest risk levels and the 5 southernmost communities tend to have a low to moderate risk level. The value of the risk index is substantially determined by that of agricultural drought and heavy rains (Table 1).

The next map (Fig. 2) shows the distribution of the municipalities at high and severe risk in the region.

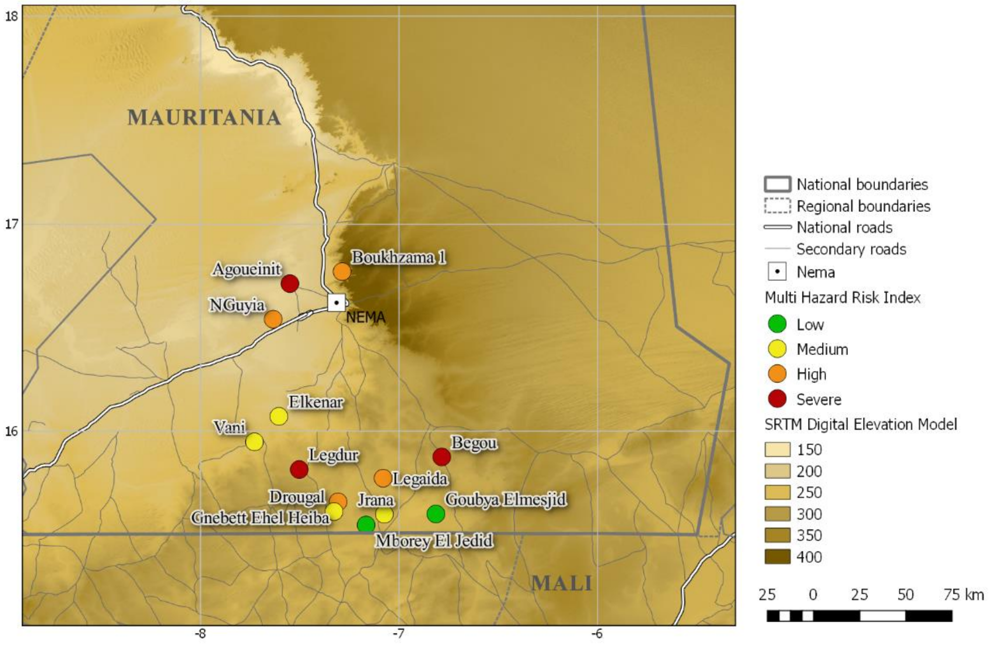


Fig. 2 The 13 rural communities at multi-hazard risk in the Hodh El Chargui, Mauritania

Application of future projections to the current multi-hazard risk characterization in Hodh El Chargui Region

The combination of the four components of the MHRI, the meteorological hazard, the hydrological hazard, the agricultural hazard and the heavy rainfall, allows to produce the final index. Using the outputs from the models, it is possible to produce 3 scenarios for the future evolution of climate: the 25th, the 50th and the 75th centile, which represent the optimistic, the average and the pessimistic scenarios respectively. The use of models by different sources and different parameterization, allows to produce a more robust analysis for the future progress of natural risks covering several possible future configurations of the climate.

Looking at the Table 2 it is possible to make a comparison between the current conditions and the future ones.

Table 2 Multi Hazard Risk Index in Hodh El Chargui communities, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th)

	Meteorological drought				***Hydrological drought***				***Agricultural drought***				***Heavy precipitations***				***MHRI***			
Community	Present	25	50	75	Present	25	50	75	Present	25	50	75	Present	25	50	75	Present	25	50	75
Agoueinit	0.04	0.01	0.03	0.06	-0.02	-0.01	-0.02	-0.03	0.64	0.46	0.71	0.84	0.33	0.14	0.20	0.32	0.99	0.60	0.91	1.19
Begou	0.05	0.00	0.03	0.06	0.04	0.03	0.07	0.14	0.60	0.34	0.72	0.92	0.35	0.29	0.40	0.58	1.04	0.66	1.22	1.70
Boukhzama 1	-0.02	-0.01	-0.01	-0.02	-0.01	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	0.77	0.16	0.22	0.33	0.75	0.15	0.20	0.30
Drougal	0.00	0.00	0.01	0.06	0.04	0.03	0.09	0.15	0.26	0.20	0.48	0.61	0.08	0.09	0.12	0.15	0.38	0.32	0.70	0.97
Elkenar	-0.05	-0.02	-0.05	-0.20	0.12	0.12	0.26	0.43	0.29	0.23	0.49	0.60	0.04	0.04	0.05	0.08	0.40	0.37	0.75	0.91
Gnebett Ehel Heiba	0.00	0.00	0.00	0.02	0.06	0.03	0.08	0.14	0.30	0.24	0.56	0.71	0.23	0.26	0.37	0.44	0.60	0.53	1.00	1.31
Goubya Elmesjid	0.00	0.00	0.00	0.00	0.14	0.08	0.17	0.31	0.09	0.07	0.14	0.18	0.08	0.05	0.07	0.12	0.30	0.20	0.38	0.60
Jrana	0.01	0.00	0.00	0.01	0.08	0.04	0.10	0.18	0.31	0.17	0.46	0.61	0.00	0.00	0.00	0.00	0.40	0.21	0.56	0.80
Legaida	0.10	0.00	0.09	0.16	0.09	0.07	0.16	0.29	0.27	0.15	0.29	0.38	0.21	0.17	0.24	0.40	0.67	0.39	0.78	1.24
Legdur	0.02	0.00	0.04	0.09	0.04	0.00	0.01	0.04	0.59	0.48	1.01	1.19	0.29	0.29	0.43	0.60	0.95	0.76	1.49	1.91
Mborey El Jedid	-0.01	0.00	0.00	-0.01	0.02	0.01	0.04	0.07	0.15	0.08	0.22	0.29	0.12	0.30	0.36	0.48	0.28	0.40	0.61	0.83
NGuyia	-0.07	-0.02	-0.05	-0.11	0.03	0.13	0.25	0.32	0.73	0.52	0.81	0.96	0.13	0.06	0.08	0.13	0.82	0.69	1.08	1.30
Vani	-0.02	0.00	-0.04	-0.09	0.13	0.04	0.14	0.25	0.20	0.16	0.34	0.40	0.06	0.06	0.10	0.13	0.37	0.27	0.54	0.70

The uncertainty of the future evolution of precipitation is intercepted by the models, placing the actual risk between the future optimistic and pessimistic scenarios except for Mborey El Jedid which has all the three future risk scenarios higher than the current one. Boukhzama 1 represents an exception, in fact, all the three future scenarios MHRI values are below the current one. In this case we must consider the predominant effect of the heavy precipitation component with respect to the other ones. More investigations are needed to understand such behaviour but, essentially, it seems that the critical threshold defined by the methodology proposed in this work heavily underestimates the heavy precipitation risk in this site. But again, this is the only exception because in the other communities the method seems to fit the expected result of future risk distribution very well.

Comparison of results (present vs. future) and identification of priority intervention areas in Hodh El Chargui Region

The differences in the level of agricultural drought and heavy rain risks among the 13 communities drives to a differentiated multi-hazard index. Using the projected climate scenarios it is possible to map the comparison among the present and the three future scenarios (Fig. 3).

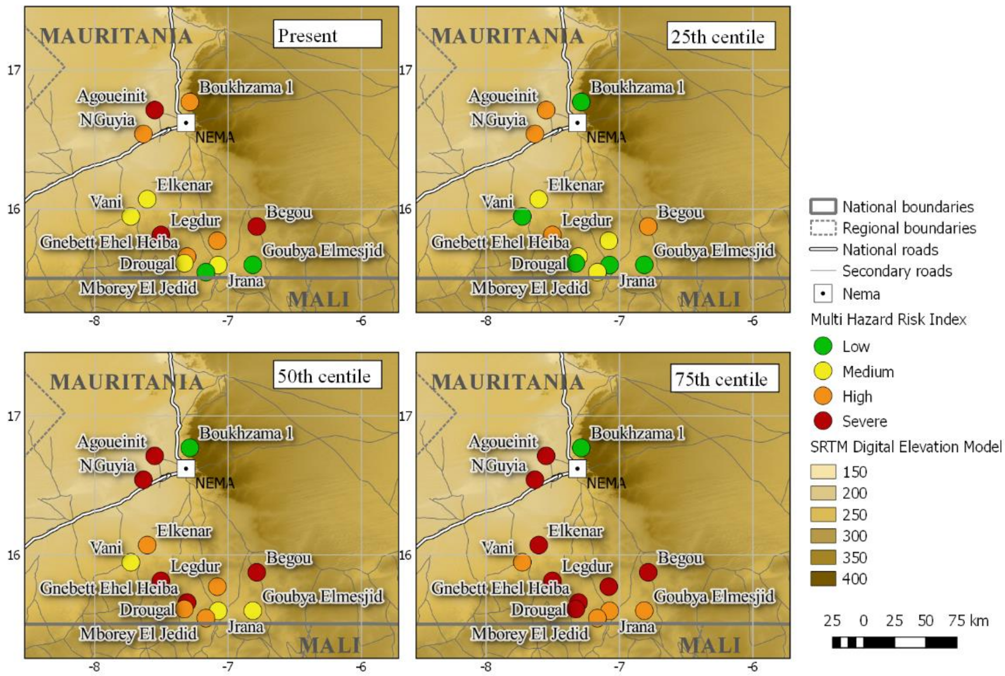


Fig. 3 Multi Hazard Risk Index in Hodh El Chargui communities, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th)

Future climate has a strong impact on Hodh El Chargui communities and, as showed in the Fig. 3, the impact of climate change could drastically reduce or increase the risk. For this reason, it is particularly important to perform a constant monitoring of the climate evolution to early prevent and reduce the impacts of future natural risks. The following figure (Fig. 4) shows the possible evolution of the MHRI in the three future scenarios compared to the current climate. If the difference between the future and the current MHRI is below -0.1 the community is flagged as with a decreasing trend, while if the difference is above +0.1 it is flagged as with an increasing trend, otherwise the risk is stable.

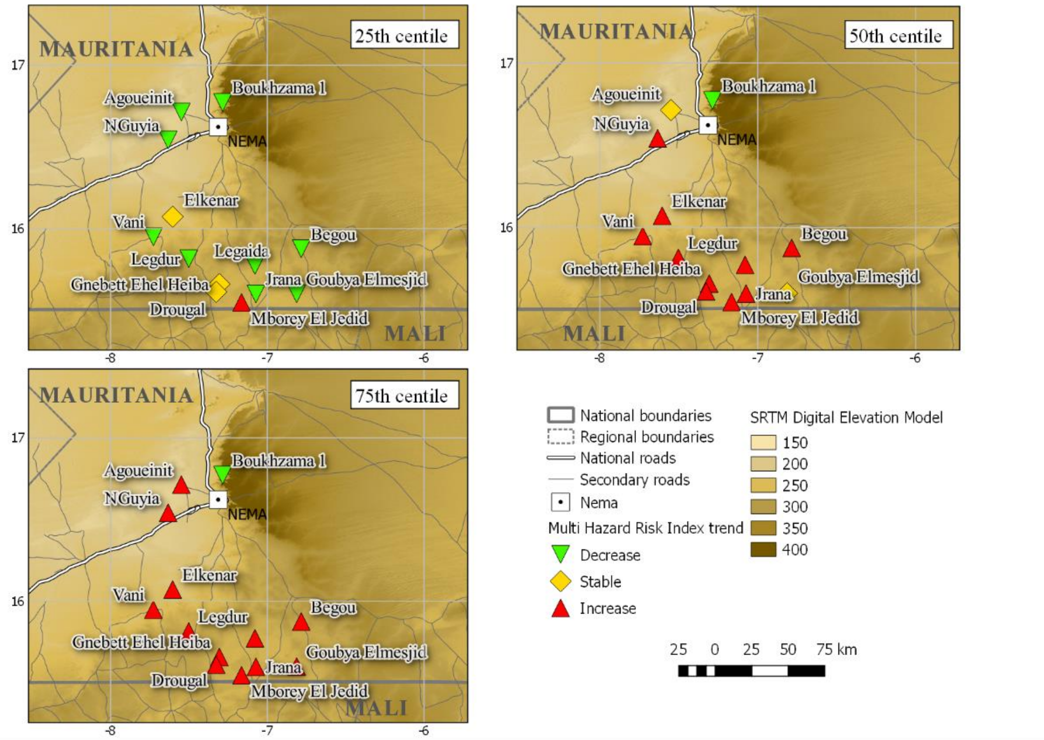


Fig. 4 Trends in MHRI index for the 3 future scenarios.

The best case scenario (25th centile) clearly shows an overall decrease of future MHRI with the exception of Mborey El Jedid which shows a positive trend and the communities of Elkenar, Gnebett Ehel Heiba and Drougal which are stable. Inversely in the median scenario the communities already show a general increase of risk reaching, in the worst case scenario, an increase of risk in all the communities with the exception of Boukhzama 1. This behaviour is quite alarming because if in the future we might expect an increase of risk with a high probability, then the adaptation process becomes urgent especially in the communities already at a severe risk.

To rank the priorities of intervention, the next output with the overlapping of present level of risk with the intercepted trend for the 3 scenarios allows us to define the priorities of interventions in the region, as per the following Table 3.

Table 3 Contingency table to assign the priorities of intervention

MHRI \ MHRI Trend	*Increase (>0.1)*	*Stationary*	*Reduction (<-0.1)*
Severe (>0.8)	Highest priority	High priority	Medium priority
High	High priority	Medium priority	Low priority
Medium or Low (<0.6)	Medium priority	Low priority	Lowest priority

By applying this classification to MHRI values and trends in Hodh El Chargui region it is possible to produce the following maps (Fig. 5) for the 3 scenarios.

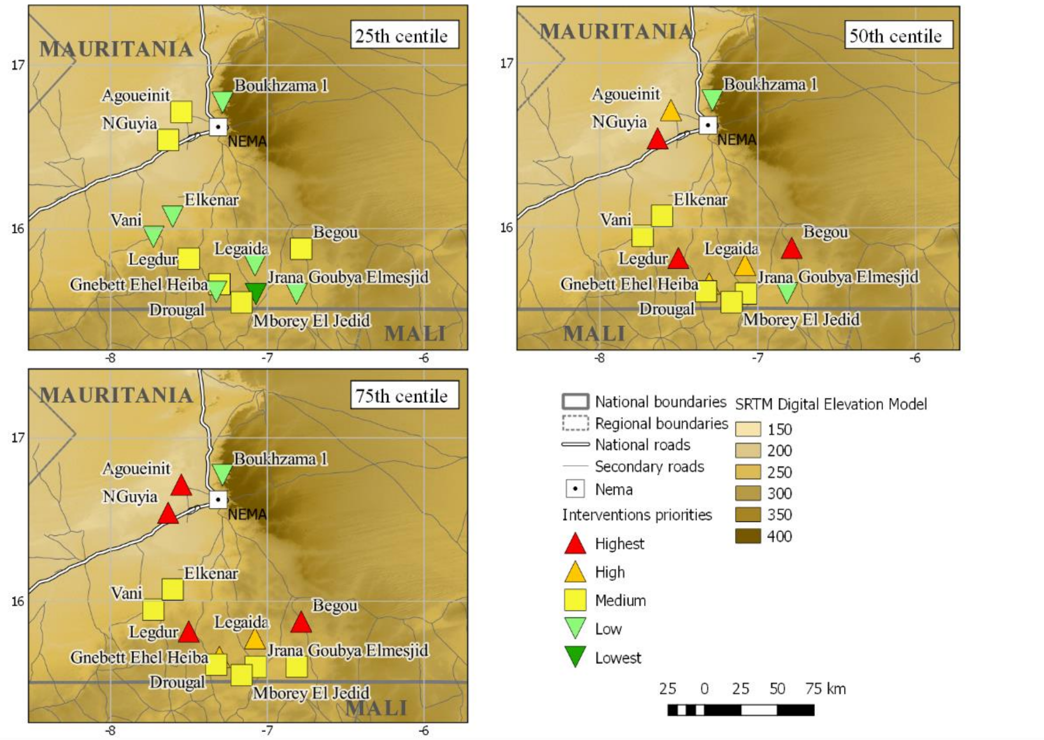


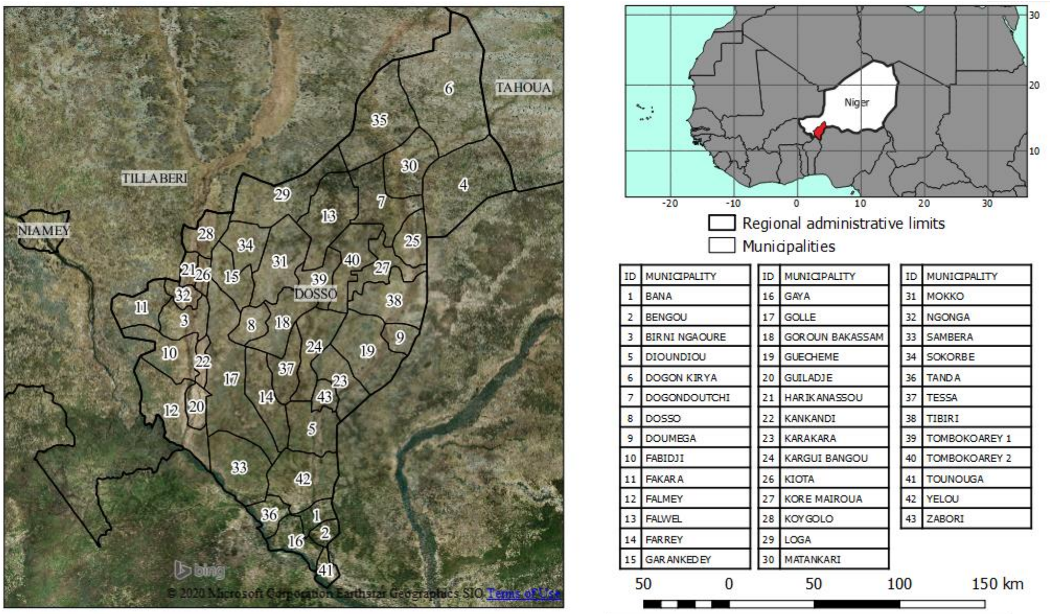
Fig. 5 Intervention priorities in Hodh El Chargui for the 3 future scenarios

The maps show that Nguyia, Legdur and Begou are the communities with the highest priority of intervention also in the median scenario. In the worst case scenario also Agoueinit calls for a highest priority of intervention. These must be the communities where the deployment of interventions is most urgent. In a second instance, Legaida is characterized by a high priority of intervention, while Boukhzama 1 remains the only community with a low priority of intervention even in the worst case scenario. As already previously noted in this chapter, this community must be deeply investigated to confirm its level of risk. The southern communities present the lower priority of intervention.

Case study analysis in Dosso Region

The multi-risk approach in Dosso Region

The Dosso region (31,000 km^{2}) in Niger has a population about of two million (*Fig. 6*), and, within its country, it is one of the most affected regions by floods. Moreover, Niger has the highest hydro-climatic risk in West Africa [12].



ID	MUNICIPALITY	ID	MUNICIPALITY	ID	MUNICIPALITY
1	BANA	16	GAYA	31	MOKKO
2	BENGOU	17	GOLLE	32	NGONGA
3	BIRNI NGAOURE	18	GOROUN BAKASSAM	33	SAMBERA
5	DIOUNDIOU	19	GUECHEME	34	SOKORBE
6	DOGON KIRYA	20	GUILADJE	36	TANDA
7	DOGONDOUTCHI	21	HARIKANASSOU	37	TESSA
8	DOSSO	22	KANKANDI	38	TIBIRI
9	DOUMEGA	23	KARAKARA	39	TOMBOKOAREY 1
10	FABIDJI	24	KARGUI BANGOU	40	TOMBOKOAREY 2
11	FAKARA	26	KIOTA	41	TOUNOUGA
12	FALMEY	27	KORE MAIROUA	42	YELOU
13	FALWEL	28	KOYGOLO	43	ZABORI
14	FARREY	29	LOGA		
15	GARANKEDEY	30	MATANKARI		

Fig. 6 The 43 municipalities of the Dosso Region, Niger.

Similarly to the previous case study in Mauritania, the study involves the characterization of the climate regarding each of the region's municipalities. Here the basic unit of analysis is the municipality and the National Directorate of Meteorology of Niger (DMN) has several meteorological station placed in the region that have been recording rainfall for decades. This represents a better condition compared to the previous case study and it leads to a different approach.

Regarding the risk identification, the Dosso region has more information collected on the ground and it is possible to find out which settlements have been hit by different hydro-climatic events and how often floods and drought events turn into disasters.

Considering all these features, in the Dosso Region Multi-hazard risk assessment, Tiepolo et al. [1] use the Loss and Damage (L&D) approach using the recorded data over the past seven years to evaluate the vulnerability component in the risk formula.

From Single to Multi-Hazard Risk Levels

The combination of the individual hazard (pluvial flooding, fluvial flooding, drought) components creates the MHRI by summing the pluvial flood (PFRI), fluvial flood (FFRI) and drought (DHRI) risk indices. The municipalities with a risk level higher than 1 determine a risk higher than their demographic weight in the region.

Table 4 Multi-hazard risk index (MHRI) level in the Dosso region at municipal level, 2011-2017

Municipality	PFRI	FFRI	DHRI	MHRI
1 Bana	0.91	-	0.91	1.82
2 Bengou	45.17	-	0.00	45.17
3 Birni N'Gaoure	1.41	-	0.17	1.58
4 Dan Kassari	0.64	-	0.56	1.2
5 Dioudiou	0.97	-	0.08	1.05
6 Dogon Kiria	0.03	-	0.37	0.4
7 Dogondoutchi	3.37	-	0.25	3.62
8 Dosso	0	-	0.09	0.09
9 Doumega	4.05	-	3.73	7.78
10 Fabidji	0.48	-	0.87	1.35
11 Fakara	0	-	0.64	0.64
12 Falmey	2.14	0.9	0.13	3.17
13 Falwel	0.78	-	0.61	1.39
14 Farrey	0	-	0.20	0.2
15 Garankedey	1.04	-	0.69	1.73
16 Gaya	3.03	6.1	0.03	9.16
17 Golle	0.14	-	0.17	0.31
18 Gorouban Kassam	0	-	0.36	0.36
19 Guéchémé	5.07	-	0.53	5.6
20 Guilladjé	8.98	-	0.17	9.15
21 Harikanassou	0.02	-	0.72	0.74
22 Kankandi	0.41	-	0.14	0.55
23 Kara Kara	0.83	-	0.74	1.57
24 Kargui Bangou	6.84	-	0.39	7.23
25 Kieché	2.8	-	0.32	3.12
26 Kiota	1.59	-	0.64	2.23
27 Kore Mairoua	1.43	-	0.74	2.17
28 Koygolo	0.48	-	0.38	0.86
29 Loga	0	-	0.35	0.35
30 Matankari	2.98	-	0.35	3.33
31 Mokko	0	-	0.45	0.45
32 N'Gonga	0.92	-	0.17	1.09
33 Sambera	1.55	3.8	0.03	5.38
34 Sokorbé	0	-	0.00	0
35 Soucoucoutane	1.33	-	0.44	1.77
36 Tanda	4.97	22.9	0.09	27.96
37 Tessa	1.96	-	0.45	2.41
38 Tibiri	1.01	-	0.30	1.31
39 Tombo Koarey I	1.03	-	0.61	1.64
40 TK II-Sakadamna	0	-	0.28	0.28
41 Tounouga	21.51	13.7	0.20	35.41
42 Yelou	4.36	-	0.22	4.58
43 Zabori	0	-	0.53	0.53

The level of risk ranges from severe in the municipalities of Bengou (Dallol) and Tounouga (River Niger), high at Tanda (River Niger), elevated in another 12 municipalities, located in the dallols (Guilladjé 9.3, Doumega 8.6, Kargui Bangou 7.5) and along the river (Gaya 9.2). The risk is low in 27 municipalities and negligible or absent in one of them (Table 4).

Using the mapping tools, it is possible to plot the distribution of the different hazard risks (Fig. 7).

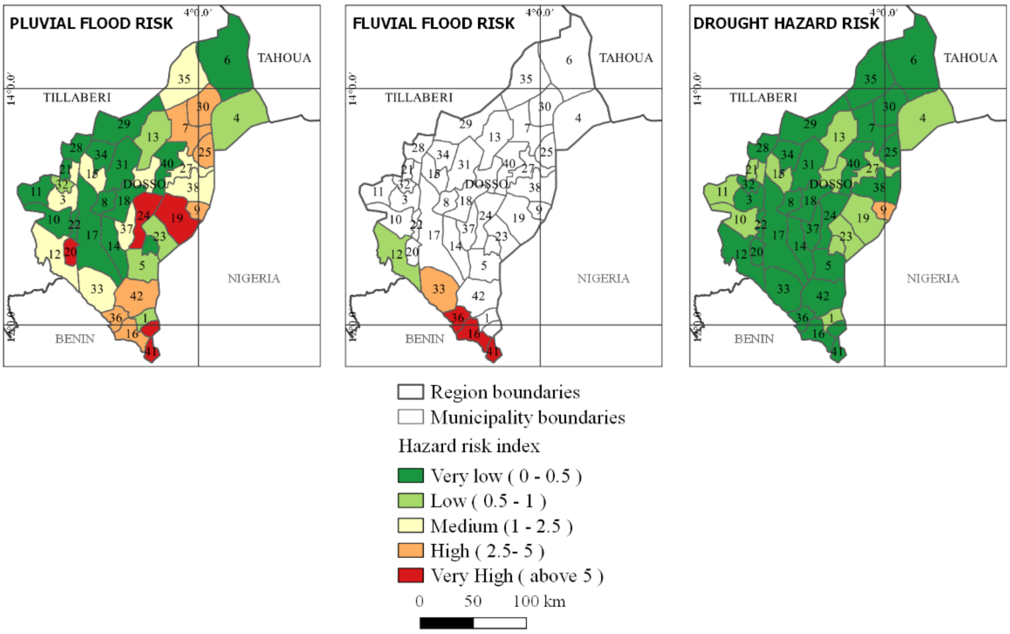


Fig. 7 Pluvial flood (left), fluvial flood (center) and drought (right) risk index levels in the Dosso region

The spatial combination of the different hazard risk levels provides the final MHRI results (Fig. 8).

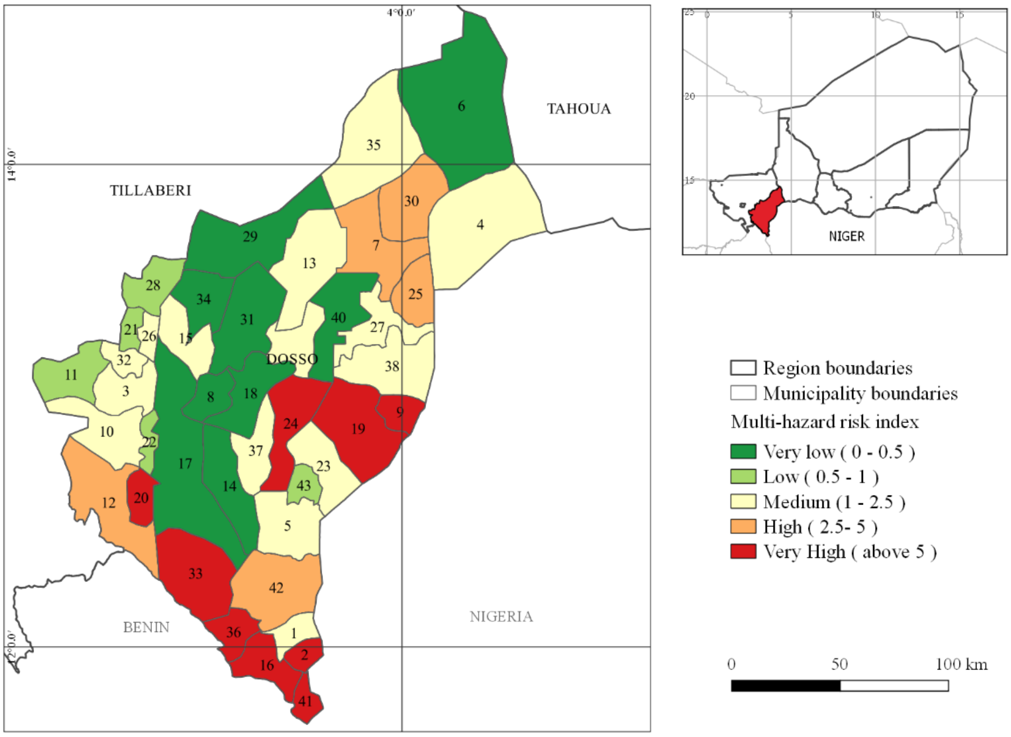


Fig. 8 Multi-hazard risk index at municipal level in the Dosso region.

The municipalities located along the Niger river are at higher risk because of the combined effects of the three risk components. Moreover, it is possible to intercept two groups of municipalities, the first one in the center with Kargui Bangou, Guéchémé and Doumega and the second one in the north-eastern part with Dogondoutchi, Matankari and Kieché, relatively at risk while in Sokorbe, in the western part of the region, the risk is negligible.

Application of future projections to the current multi-risk characterization in Dosso Region

The combination of the three risk components, notably the Pluvial Flood Hazard, the Fluvial Flood Hazard and the Drought Hazard, allows to produce the final MHRI index. Using the models' outputs, it is possible to produce the 3 future climate scenarios: the 25th, the 50th and the 75th centile.
Looking at the following Table 5 it is possible to make a comparison between the present conditions and the future ones.

Table 5 Multi hazard risk components in the three scenarios

	PFRI				FFRI	DHRI			
Municipality	**Present**	**Centile 25**	**Centile 50**	**Centile 75**	**All**	**Present**	**Centile 25**	**Centile 50**	**Centile 75**
1 Bana	0.91	0.00	0.00	0.23		0.91	0.53	0.98	1.42
2 Bengou	45.17	22.59	38.39	45.17		0.00	0.00	0.00	0.00
3 Birni N'Gaoure	1.41	0.23	0.35	0.52		0.17	0.08	0.12	0.18
4 Dan Kassari	0.64	0.10	0.21	0.32		0.56	0.22	0.40	0.47
5 Dioudiou	0.97	0.97	0.97	0.97		0.08	0.06	0.09	0.11
6 Dogon Kiria	0.03	0.00	0.01	0.01		0.37	0.10	0.24	0.36
7 Dogondoutchi	3.37	1.58	2.56	3.24		0.25	0.14	0.20	0.33
8 Dosso	0.00	0.00	0.00	0.00		0.09	0.04	0.07	0.10
9 Doumega	4.05	1.13	1.82	2.55		3.73	2.21	3.50	5.06
10 Fabidji	0.48	0.05	0.19	0.29		0.87	0.34	0.57	0.93
11 Fakara	0.00	0.00	0.00	0.00		0.64	0.22	0.51	0.75
12 Falmey	2.14	2.14	2.14	2.14	0.9	0.13	0.06	0.11	0.16
13 Falwel	0.78	0.56	0.78	0.78		0.61	0.40	0.61	0.77
14 Farrey	0.00	0.00	0.00	0.00		0.20	0.09	0.13	0.25
15 Garankedey	1.04	0.06	0.12	0.28		0.69	0.36	0.56	0.78
16 Gaya	3.03	2.39	3.03	3.03	6.1	0.03	0.02	0.03	0.05
17 Golle	0.14	0.14	0.14	0.14		0.17	0.09	0.12	0.22
18 Gorouban Kassam	0.00	0.00	0.00	0.00		0.36	0.18	0.28	0.47
19 Guéchémé	5.07	0.15	0.46	0.66		0.53	0.26	0.40	0.68
20 Guilladjé	8.98	4.67	5.66	6.47		0.17	0.06	0.12	0.20
21 Harikanassou	0.02	0.01	0.01	0.02		0.72	0.42	0.70	0.93
22 Kankandi	0.41	0.04	0.12	0.19		0.14	0.05	0.09	0.15
23 Kara Kara	0.83	0.13	0.27	0.37		0.74	0.49	0.73	0.97
24 Kargui Bangou	6.84	2.12	3.56	4.72		0.39	0.25	0.35	0.52
25 Kieché	2.80	0.73	1.29	1.62		0.32	0.13	0.21	0.32
26 Kiota	1.59	0.80	0.94	1.42		0.64	0.36	0.61	0.82
27 Kore Mairoua	1.43	0.43	0.74	0.93		0.74	0.38	0.59	0.78
28 Koygolo	0.48	0.06	0.12	0.20		0.38	0.26	0.39	0.53
29 Loga	0.00	0.00	0.00	0.00		0.35	0.14	0.24	0.42
30 Matankari	2.98	1.01	1.55	2.06		0.35	0.18	0.30	0.42
31 Mokko	0.00	0.00	0.00	0.00		0.45	0.25	0.41	0.69
32 N'Gonga	0.92	0.15	0.23	0.34		0.17	0.07	0.11	0.18
33 Sambera	1.55	1.07	1.35	1.55	3.8	0.03	0.01	0.03	0.05
34 Sokorbé	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00
35 Soucoucoutane	1.33	0.27	0.65	0.70		0.44	0.22	0.34	0.50
36 Tanda	4.97	3.63	4.97	4.97	22.9	0.09	0.04	0.08	0.11
37 Tessa	1.96	0.22	0.45	0.57		0.45	0.31	0.39	0.63
38 Tibiri	1.01	0.32	0.49	0.63		0.30	0.14	0.22	0.37
39 Tombo Koarey I	1.03	0.82	1.01	1.03		0.61	0.36	0.57	0.78
40 TK II-Sakadamna	0.00	0.00	0.00	0.00		0.28	0.15	0.23	0.36
41 Tounouga	21.51	11.40	18.71	21.51	13.7	0.20	0.17	0.26	0.32
42 Yelou	4.36	2.35	3.53	4.36		0.22	0.10	0.18	0.25
43 Zabori	0.00	0.00	0.00	0.00		0.53	0.33	0.43	0.72

Combining the different hazards, it is possible to calculate the MHRI for all the municipalities in the Dosso Region with the future scenarios.

Table 6 Multi hazard risk index (MHRI) in the Dosso region at municipal level 2021-2080 – 3 future scenarios and the present

		MHRI		
Municipality	*Present*	*Centile 25*	*Centile 50*	*Centile 75*
1 Bana	1.82	0.53	0.98	1.64
2 Bengou	45.17	22.59	38.39	45.17
3 Birni N'Gaoure	1.58	0.31	0.47	0.70
4 Dan Kassari	1.20	0.32	0.61	0.79
5 Dioudiou	1.05	1.03	1.06	1.08
6 Dogon Kiria	0.40	0.10	0.25	0.37
7 Dogondoutchi	3.62	1.72	2.76	3.56
8 Dosso	0.09	0.04	0.07	0.10
9 Doumega	7.78	3.34	5.32	7.61
10 Fabidji	1.35	0.39	0.76	1.22
11 Fakara	0.64	0.22	0.51	0.75
12 Falmey	3.17	3.10	3.15	3.20
13 Falwel	1.39	0.96	1.39	1.55
14 Farrey	0.20	0.09	0.13	0.25
15 Garankedey	1.73	0.41	0.69	1.06
16 Gaya	9.16	8.51	9.16	9.18
17 Golle	0.31	0.23	0.26	0.36
18 Gorouban Kassam	0.36	0.18	0.28	0.47
19 Guéchémé	5.60	0.41	0.86	1.34
20 Guilladjé	9.15	4.73	5.78	6.66
21 Harikanassou	0.74	0.43	0.72	0.95
22 Kankandi	0.55	0.09	0.21	0.33
23 Kara Kara	1.57	0.63	1.00	1.34
24 Kargui Bangou	7.23	2.37	3.91	5.24
25 Kieché	3.12	0.86	1.50	1.94
26 Kiota	2.23	1.15	1.55	2.23
27 Kore Mairoua	2.17	0.81	1.34	1.71
28 Koygolo	0.86	0.32	0.51	0.73
29 Loga	0.35	0.14	0.24	0.42
30 Matankari	3.33	1.19	1.85	2.47
31 Mokko	0.45	0.25	0.41	0.69
32 N'Gonga	1.09	0.22	0.34	0.52
33 Sambera	5.38	4.88	5.17	5.40
34 Sokorbé	0.00	0.00	0.00	0.00
35 Soucoucoutane	1.77	0.48	0.99	1.20
36 Tanda	27.96	26.57	27.95	27.98
37 Tessa	2.41	0.52	0.84	1.20
38 Tibiri	1.31	0.46	0.72	1.00
39 Tombo Koarey I	1.64	1.18	1.58	1.81
40 TK II-Sakadamna	0.28	0.15	0.23	0.36

41 Tounouga	35.41	25.27	32.67	35.53
42 Yelou	4.58	2.45	3.71	4.61
43 Zabori	0.53	0.33	0.43	0.72

In the outputs is possible to observe that in the future multi hazard risk index spread around the present values with only few exceptions where the present risk is higher than the predicted one (also using the pessimistic scenario). The variability of the rainfall distribution cannot allow to retrieve clear signals but, analyzing each municipality, it is possible to observe different behaviors.

The mapping tool helps in the comparison of the distribution of the risk in the region intercepting the differences among the 3 scenarios (Fig. 9).

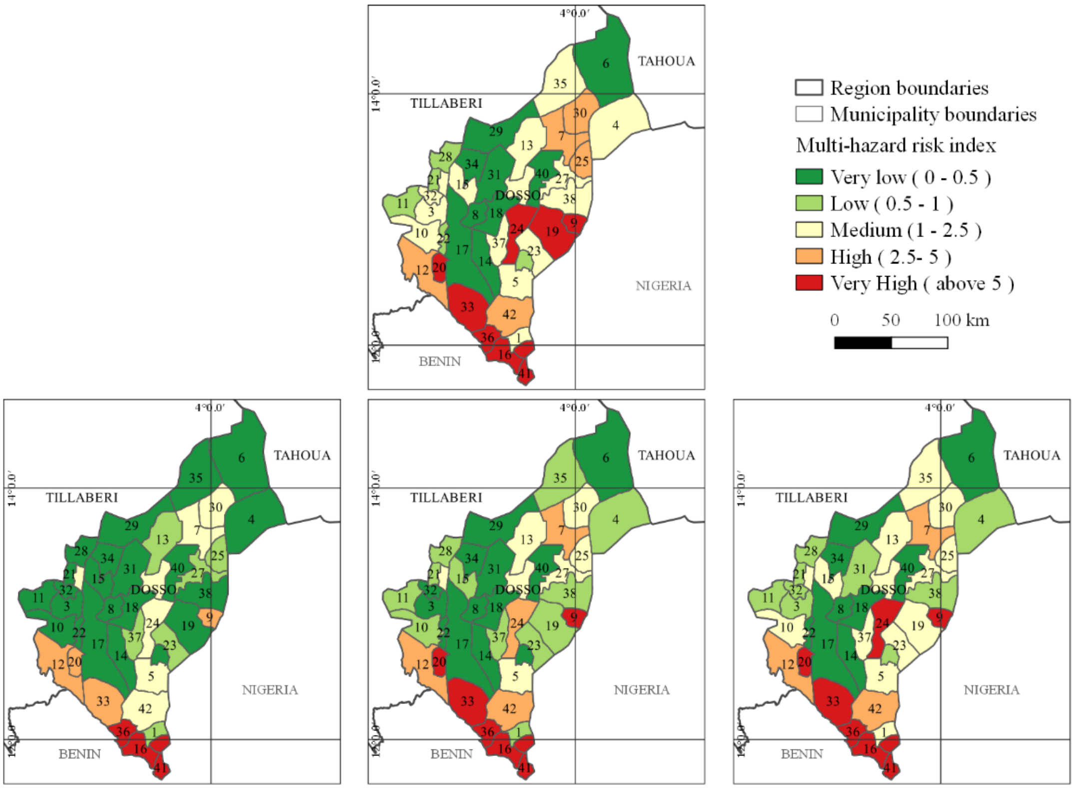


Fig. 9 MHRI comparison Present and 3 futures scenarios (in the bottom line, from left to right the 25th, 50th and 75th centile scenarios)

The future scenarios comparison analysis offers the chance to immediately catch the most important signals. The municipalities along the Niger river will present a consistent higher risk in all the scenarios while in the eastern part of the region the results of the three different scenarios give three very different evolutions of MHRI. The northern and western parts of the region seem less at risk with few municipalities at medium risk in the pessimistic scenario.

Comparison of results (present vs. future) and identification of priority intervention areas in Dosso Region

The comparison of the different levels of risk, from the present climate to the future one, aims to insert a dynamic analysis of the evolution of the risk in order to prevent it in the most efficient way. For this reason the following maps (Fig. 10) will add more information for decision makers.

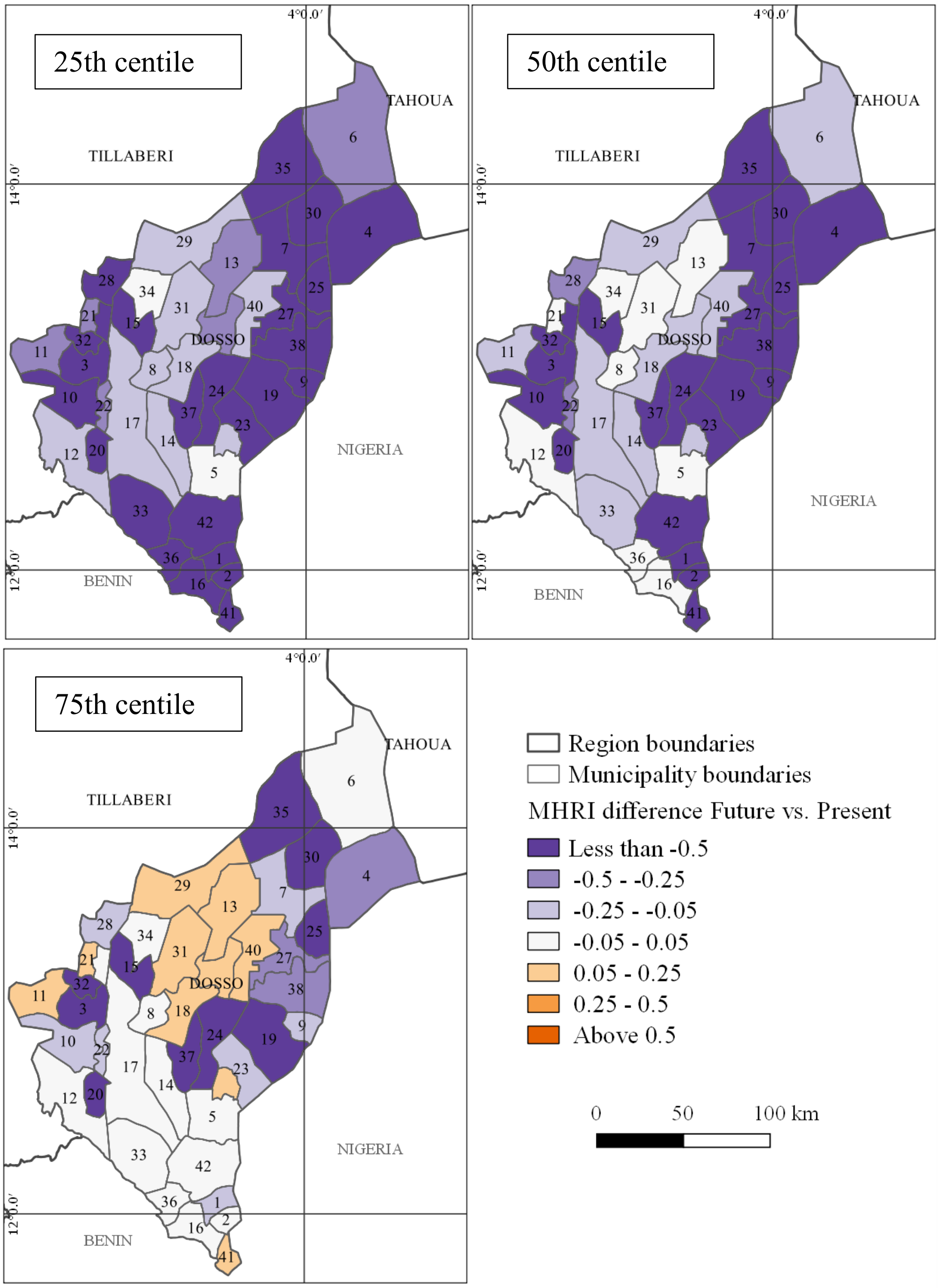


Fig. 10 MHRI trends in Dosso region, comparison of the MHRI in the 3 scenarios in respect to present conditions

The figure illustrates the three MHRI differences with respect to present MHRI following the three future quartiles. The results show that in the optimistic and median scenario the global MHRI level is stable or better. While in the worst case scenario some municipalities will present a higher MHRI with respect to the present status. The municipalities with a higher increase of risk are concentrated in the western and central part of the region.

Trying to summarise all this material in one single map to perform the priority intervention ranking is not easy. Here, the choice was to overlay the information of the MHRI with the MHRI trend for the 3 scenarios.

The aim is to detect the municipalities which need the highest priorities of intervention, hence the following contingency table was created (Table 7) to try to combine these two components.

Table 7 Contingency table to assign the priorities of intervention

MHRI \ MHRI Trend	*Increase (>0.05)*	*Stationary*	*Reduction (<-0.05)*
High (>2.5)	Highest priority	High priority	Medium priority
Medium	High priority	Medium priority	Low priority
Low (<1)	Medium priority	Low priority	Lowest priority

By applying this classification to the previous outputs it is possible to produce the following maps following the three scenarios approach (Fig. 11) .

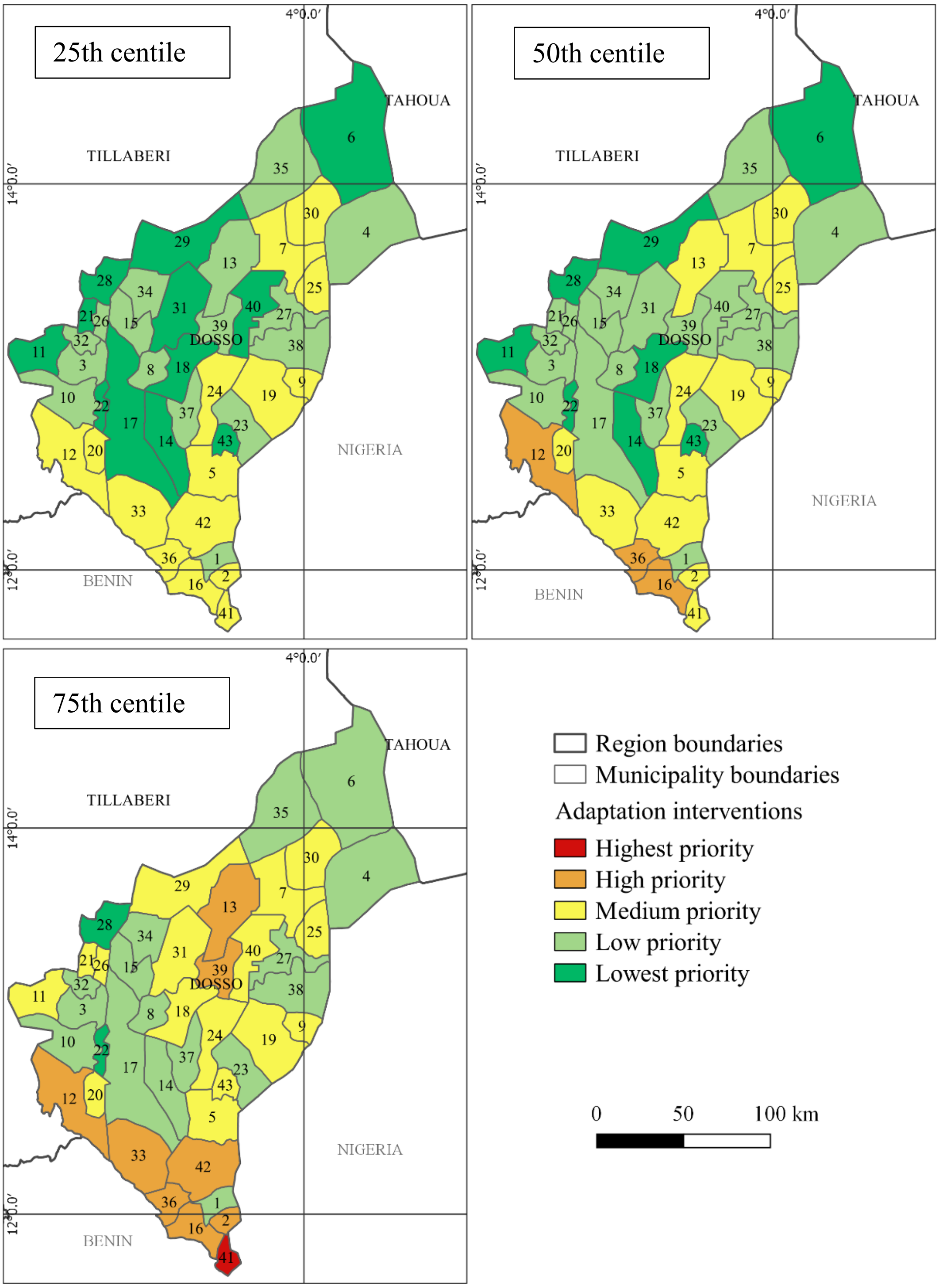


Fig. 11 Priorities of adaptation interventions in the Dosso municipalities in the 3 future scenarios

The highest priorities are placed in the southern part of the region alongside the Niger river while in the northern municipalities of the Dosso region the priority of intervention is lower.

In the western part of the region there are several municipalities whose results are in medium and high priority in the worst case scenario while in the best and the average case scenarios they result a low priority.

Discussion: Identification of priority areas

The use of the multi-hazard risk index for the identification of risk treatment actions

The risk assessment at a regional scale aims to support the development aid active in the region and the national and regional administrations. Nevertheless, the method may also be applied in other contexts exposed to similar hazards. The main advantage of this process is that it gives a complete framework of the current risk level of the communities and it proposes 3 different risk scenarios for the future climate helping the ranking of priority interventions and raise the awareness of the communities in taking the necessary actions for the adaptation process to these threats. The urgency of intervention must represent a priority especially in communities identified as having a severe and high risk. The future scenarios are build using 18 configurations available within the CMIP5 initiative and they represent a wide spectrum of possible evolutions of the future climate. This means that the study is quite confident about the coverage of the possible future evolution of climate.

Local authorities and central government can take their options to best respond to these threats. There are several possibilities, at a local scale, the communities could act on the water supply actions, protect crops and cattle from inundations and reduce the impact of heavy rains, at a national level, central government could invest more on the improvement of species resistant to drought or on early warning systems able to intercept floods and drought conditions.

At the national level the adaptation measures could be more challenging because one must consider a longer time horizon for the coordination and implementation of the strategic choices able to reduce the impact of natural disasters.

The design of resilient communities and the rural development should ideally be based on the actual data and knowledge regarding multi-hazard risks, the potential impacts of related economic losses, and potential threats to human life and safety [14]. Therefore, the multi hazard risk assessment is necessary for a rational decision making in the adaptation and spatial planning processes [15]. A knowledge-based approach should aid the improvement of land configuration and the reconfiguration of urban areas, the production systems, the planning of infrastructures, the material of buildings and water management, which play a crucial role in flow accumulation and inundation [16]. The so-called best management practices (BMPs) and low impact development practices (LID) are examples of adaptation measures [17].

The clear identification of significant changes in the risk distribution provides the key to understanding the evolution of natural disasters and guide regional and urban development, providing an identification of the intervention priorities allowing a more efficient use of the resources. Currently, one of the key challenges faced by decision makers is to choose the best option for the adaptation to climate change. But these options vary over space and time. So it is important to combine spatial planning on different time horizons to successfully implement adaptation plans. It is recommended to choose target solutions enabling the assessment and comparison of the results for each adaptation mechanism. One must acknowledge that the proper assessment of existing hazards always needs to come prior to the implementation of a specific preventive action.

The usefulness of this assessment arises if a comparison between its results with the current intervention areas is made. 14 Projects for climate adaptation and resilience are currently deployed in the Dosso region. Using the outcomes of this work and the adaptation actions envisaged by the projects and by six local development plans (LDPs) (Tounouga, Tanda, Doumega, Dogondoutchi, Falmey and Guéchémé) [18-23] it is possible to produce the comparison between a preliminary assessment and the implemented actions to highlight the coherence between the two.

Some discrepancies were found in the implemented actions. Placing the number of Projects above of the current MHRI assessment it is possible to obtain the following map (*Fig. 12*).

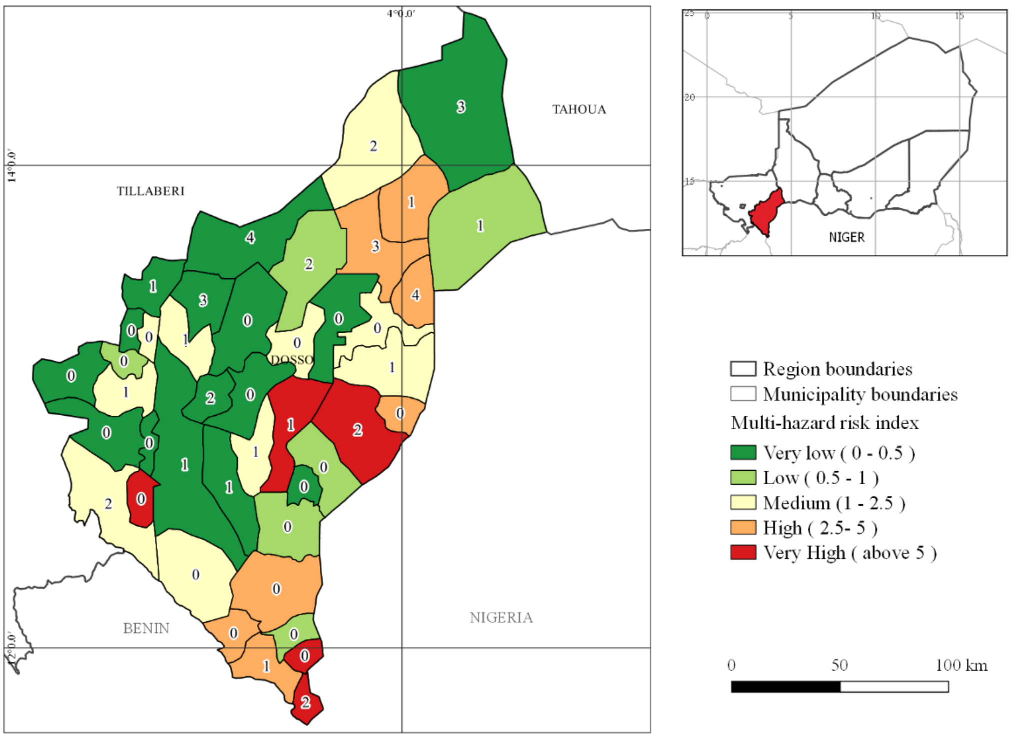


Fig. 12 Present Multi-Hazard Risk Index in Dosso Region and number of interventions per each municipality

On the map it is clear how the projects per municipality do not follow the MHRI ranking. Once more, a preliminary assessment of the MHRI ranking is recommended to properly invest the resources. As side note, if the presence of a high number of projects in low risk municipalities contributes in reducing the risk level then the current assessment could measure the effectiveness of the interventions. The production of the assessment on a routinely basis could assure an ex-post assessment of the effectiveness of the initiatives and their outcomes for local populations.

Therefore, the final exercice is to compare the risk ranking following the worst case scenario and the number of projects (Fig. 13) with the aim to verify if the current distribution of the interventions is coherent with the priorities derived by the MHRI assessment for future climate scenarios.

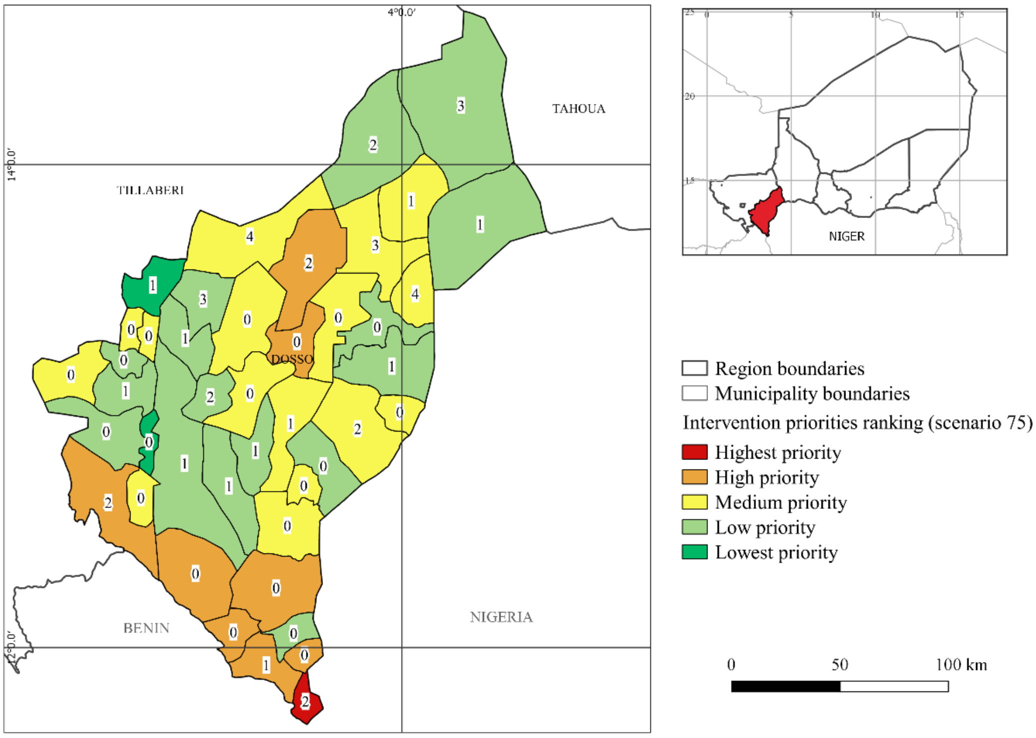


Fig. 13 Intervention priorities for the worst case scenario and number of Projects

The maps show that many municipalities with low priority have a higher number of projects which are intervening. Where the projects are placed in the municipalities with high priority, they must provide the useful actions to prevent future risk. In such case, the intervention could be planned with a longer temporal horizon, in fact this could represent an effective measure to prevent risks. In municipalities with higher priority where there are no projects, it could be useful to support the installation of new projects.

Uncertainties

The weak spatial coverage of weather stations available for climatic analysis, the number of settlements whose population and location is unknown and those disasters that have an unquantified L&D (e.g. a degree of cereal deficit), the lack of studies on the hydrological network and ephemeral watershed are some of the sources of uncertainties in the analysis. Especially the lack of observations with a high temporal resolution for the definition of the rainfall critical thresholds is one the most delicate constraints in the process. Especially, with the data available through of the 3-hours rainfall estimation dataset (TRMM), it is not possible to discriminate exactly the threshold that could trigger a flood in a municipality. The evidence is that in many municipalities there has been up to 4 record floods in a year with the consequence that episodes could easily reoccur in future. This means that the hazard probability is almost certain, which implies that every year, in many municipalities, there are the potential conditions to trigger a flood. This does not allow a real differentiation of the pluvial risk among the municipalities hence flattening the pluvial flood risk index. On the other hand, with more data available, especially from ground observation networks and a clear understanding of the driving phenomena, the result could be much closer to reality and more accurate. For this reason, the author strongly encourages the scientific community and the local authorities to invest more in reinforcing the observation network.

Dealing with future climate projections, the analysis introduces another element of uncertainty. The methodology here presented tries to expose this uncertainty by giving the probability of each signal in the forthcoming years by basing it on the results of the 18 climate models outputs. Meanwhile, in supporting decision makers, it has been adopted a scenario approach, choosing the 3 centiles (25^{th} 50^{th} and 75^{th}) out of the 18 model configurations which give the range of the possible future hazard evolutions.

Regarding the communication issue, i.e. how to properly communicate the uncertainty regarding climate risk, this is quite challenging. In fact, despite the evidence that uncertainties are present in all our important decisions, and that we still make them without a perfect knowledge, in climate analysis these are synonymous to inaccuracy. It is clear that we cannot reproduce a perfect evolution of the daily climate from now up to 2080, but the main features of the climate can be represented by the models.

For citizens, climate projection uncertainty is a significant barrier to the trust they have in the climate change projection outcomes while for policy-makers, the uncertainty concept can be a distraction from the underlying important messages.

When the general public hears politicians having different points of view on climate change, or when the media attribute the same weight to the scientific community as they do to skeptical voices, people are doubtful of what they are hearing. Different people reading the same conflicting information may reach different conclusions [24]. And this behaviour is quite dangerous in disaster risk prevention.

Sustainability of the method

The study aims to draw some conclusions on the sustainability of the method. First of all, it is a method tailored for tropical regions characterized by a systematic lack of field data and few resources. Situations with a more consistent observation network, with a higher capability to retrieve socio-economic data about population and with a consistent disaster database could choose to execute their analysis with other more sophisticated tools. The methodology presented proposes an analysis path able to find the best option to estimate a risk level through proxy indicators and remote sensing data. Moreover, the method is conceived to be applicable by authorities with few resources and basic analytical skills.

All things considered, this methodology should help in the objective identification of the intervention priorities, hence allowing a more efficient use of the resources and supporting the production of a medium-long term planning of interventions.

The method bases its analysis on simple field surveys and on the production of a climatic index able to characterize the main extreme event features. The most difficult task is the management of remote sensing images, such as the rainfall estimation by satellite, which requires more advanced skills. Normally these skills are commonly available in the national technical services such as the national directorate of meteorology or in the agricultural services.

The mapping of the results requires competencies in GIS tools. Which is nowadays are quite a common skill in all governmental institutions worldwide.

More advanced skills are required for the bias correction of the climate projection. Fortunately, this task may be carried out by experts or, as in the case of discussion, all the West Africa domain has already been elaborated for the purposes of this study. It could therefore be possible to easily extract the future time-series for another location and perform its index elaboration.

Last but not least, the entire process is made using open-source software and a notebook. The process does not require complex and advanced machines and this could assure the easy replicability in the majority of institutions.

The improvement of the analysis with new events recorded each year could assure the refining of the results or the highlighting of new dangerous conditions in the territory for a specific land use change (i.e. building of a dam or an intense deforestation process) which could change the ranking of the basic units most at risk. Moreover, the possibility to retrieve data from specific field surveys could update the exposure and vulnerability components of the risk formula, hence producing new results. The method is not conceived as rigid and static but rather as easily customizable to follow the peculiarities of the study area.

Finally, the scientific community, especially the with CMIP6 initiative, will produce new climatic datasets with a higher resolution and more sophisticated physics. This represents a huge advantage for the prediction of the future evolution of climate. When it will become available it might be useful to reiterate the analysis using the last up to date climatic dataset available.

Weakness

A systematic lack of information cannot produce a robust analysis in any system. The exact measure of the risk components in a large region equates to wishful thinking, so some simplifications are required. The right level of simplification in the process is quite challenging because it is possible to oversimplify the analysis hence obtaining outliers or systematic errors. In many cases the option is to find a balance between the need for useful information for decision makers and the cost to reach the desired data quality for the purposes of the analysis itself.

Nowadays many climatic datasets from satellite observation are freely available and climate projections could partially fill the gap for a climatic analysis, however, it is important to consider that in a territory characterized by a weak observation network these data are not fully validated and corrected on the ground. This means that the remote sensing images could present bias errors or they could be unable to intercept the most intense phenomena.

Moreover, the exposure and vulnerability components of the risk formula require a lot of resource to be investigated. It is not always possible to retrieve the needed information to correctly estimate these parameters. Plus, the future projection of these components is quite unknown in many regions. This is due to the impossibility to correctly model the possible evolution of human society and its impacts on such territories.

Especially because of these components, decision makers could influence the urban and regional planning to reduce or remove some vulnerabilities. For instance, the construction of a dam is a facility that could assure water for several villages or towns, for irrigated farm fields or to prevent flood events. Such a change could reduce the vulnerability to zero and consequently the risk.

The urbanization process, quite a common phenomenon in West Africa countries, could increase the exposure component in urban areas and reduce it in the rural ones. Also in this case, the demographic trends could be applied to adapt the result into a more likely future scenario. Unfortunately, these data not always are available at municipal or community scale, such as in the case of Niger and Mauritania.

Conclusions

The study explores the possibility to improve the risk assessment in Sub-Saharan territoritories with the aim to reinforce the process of adaptation to Climate Change for local communities and the strategic planning for Disaster Risk Reduction. Through a reproducible approach, the research applies a methodology that is able to characterize multi hazard natural risks at a sub-national scale. The main innovation is the ability to estimate the future impact of natural threats proposing a multi-scenario multi-hazard risk assessment at a municipal scale.

The results of the study are promising. They show that future climate condition could exacerbate the effects of global warming in a different way in the single analysis unit. This means that the method has enough sensitivity to catch differences even on a limited territory. Moreover, the results seem to be coherent with the global trends of climate extremes.

In the Mauritania case study, the uncertainty of the future evolution of the precipitation is intercepted by the models, placing the actual risk between the future optimistic and the pessimistic scenarios with few exceptions which requires further investigations. More specifically, the method highlights that the critical threshold for heavy precipitation defined in the methodology seems to underestimate the risk in some cases.

The main findings of the multi-hazard index for the Hodh El Chargui region are that some risk dynamics are intercepted by the method. The agricultural risk will become higher in the northernmost communities compared to the five southern communities. However, the presence of the large market of Nema (22,000 inhabitants in 2013) could represent a valid option to reduce the effects of climate change allowing the convenient trade of horticultural products in a region in which they are scarce. Therefore, they have greater opportunities to diversify their livelihood with commercial cultivation if they are able to improve the access to water. The communities at the foot of the uplands (Boukhzama 1 and Begou) are more exposed to the risk of heavy rains and therefore to flash floods.

In the Dosso region, the greatest uncertainties concern field data availability or quality (the lack of a distributed weather observation network, the absence of the location and population of settlements that were hit by disaster, the measure of the level of cereal deficit). This imposes the attribution of climate risk using the rainfall measurement in the nearby weather station and the difficulty in the assessment of flooding risk when a disaster is registered without a clear temporal or spatial reference.

The main finding is the production of a detailed list of the municipalities at risk and their specific risk level. The study highlights that in the municipalities of Birni N'Gaoure, Dan Kassari, Dogon Kiria, Loga, Matankari, N'Gonga and Soucoucoutane an increased frequency of extreme rainfall events is expected. While, for the river flooding assessment, the presence of higher river flooding and the predominance of red floods require as a priority intervention the protection of rain-fed crops during the rainy season and the development of early warning systems which allow the local population to safety store equipment and livestock before floods events.

The predicted drier conditions in the municipalities of Birni N'Gaoure, Dosso, Fakara, Farrey, Garankedey, Golle, Gorouban Kassam, Harikanassou, Kiota, Koyogolo, N'Gonga, Sokorbe, Soucoucoutane and Tessa require greater attention in rainfall monitoring and particularly the adoption of adaptation strategies such as the introduction of drought-resistant cultivars, crop diversification, changes in cropping patterns and sowing dates and a more efficient early warning system.

In the Dosso region, during the recent years, local rainfall monitoring, warning products and green infrastructures have been rarely used in adaptation and resilience projects. Projects often operate at a national level and extend the same actions to all areas of intervention, which explains their inconsistencies of results and sustainability as described in this work by showing the differences between risk assessment and intervention projects. Also at a regional scale, the need of tailored intervention to reduce the effects of climate threats is mandatory to reach an effective adaptation to global warming.

Since the beginning, the study was focused on the replicability of the analysis to guarantee its sustainability. This is the other pivotal aspect in all the process.

To perform a very sophisticated analysis with very advanced tools means, in this context, to preclude the possibility for local actors to reproduce the analysis in the forthcoming years. This, in the author's opinion, represents a key aspect in the conception of the analysis process.

The results of the overlapping of present and future MHRI with the running dynamics in the hazard risk characterization allow the production of a thematic mapping, apt to redesign the intervention projects in the region, and providing the priorities of intervention for each municipality. The allocation of the funds in the region, through projects and interventions, currently seems to not follow an objective criterion whilst more coordination is needed to maximize the use of the resources available. Moreover, the presented methodology could support the accountability of the intervention projects through the comparison of the changes in the risk index before and after the intervention.

A fruitful communication of the results of the study represents the successive step to effectively implement the interventions on the territory. This work partially explores the topic of the communication but it clearly represents a key aspect in the disaster risk reduction process, especially considering the correct communication of the uncertainties linked to climate risk studies and their perception by final users.

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