Doctoral Dissertation
Doctoral Program in Urban and Regional Development

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

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January, 2021

I hereby declare that, the contents and organisation of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

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Turin, January 20, 2021

Summary

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 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 thesis takes its cue from two papers published during the three years of doctorate which are: i) *Multihazard risk assessment for planning with climate in the Dosso Region, Niger*, by Tiepolo, Maurizio; Bacci, Maurizio; Braccio, Sarah [1], and ii) *Multi-Hazard Risk Assessment at Community Level Integrating Local and Scientific Knowledge in the Hodh Chargui, Mauritania*, by Tiepolo, Maurizio; Bacci, Maurizio; Braccio, Sarah; Bechis, Stefano [2]. Both papers deal with the current multi-hazard risk assessment, at a regional scale basis, in these two territories. A part of the chapters 3.1, 3.2, 3.6, 4.1, 4.2, 4.6 and 5 are wrote considering the previous and cited papers.

This thesis 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, produce the bias-corrected climatic projections datasets and develop 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

Acknowledgement

I'm extremely grateful to Prof. Maurizio Tiepolo and Prof. Alessandro Pezzoli for their support in my PhD career and their help in guiding me in the redaction of this thesis.

I would like to extend my sincere thanks to my colleague Vieri Tarchiani, my Directors Giampiero Maracchi, Antonio Raschi, Federica Rossi and Giorgio Matteucci, my CNR-IBIMET and CNR-IBE colleagues, the Italian honorary consul in Niamey Paolo Giglio and all the staff of the National Meteorological Direction of Niger, in particular Katiellou Gaptia Lawan, Aissa Sitta, Ousman Baoua, Labo Moussa, Moussa Mouhaïmouni, Binta Adamou, Aissa Liman for their support in all my activities in Niger.

I very much appreciate the support and the kindness of Daniela Belloni during my PhD career and I'd like to acknowledge Sarah Braccio and all the PhD students of Urban and Regional Development and the Sottopalco group.

Last but not least, I'd like to thank all my family, Claudia and the three little and terrible ladies: Matilde, Giulia and Teresa.

A mamma e babbo

Contents

1. Introduction...14

1.1 Context 14
1.2 Towards a multi-hazard risk approach 15
1.3 Objectives 16
1.4 The case studies 19
1.5 Organization of the research 21

2. Climate change and risk assessment 22

2.1 Climate projections 22
2.2 Climate future scenarios 25
2.3 Application of Bias correction methodology 28
2.4 Risk mapping 31
2.5 Priorities in the interventions 32
2.6 Characterization of multi-hazard risks 33

3. Case study analysis in the Hodh El Chargui Region 38

3.1 Multi-hazard risk analysis in the Hodh El Chargui Region 38
3.2 Definition of the current multi-risk zones in the Hodh El Chargui Region 41
3.3 Local climatic projections in the Hodh El Chargui Region 66
3.4 Application of future projections to the current multi-hazard risk characterization in the Hodh El Chargui Region 77
3.5 Comparison of results (present vs. future) and identification of priority intervention areas in the Hodh El Chargui Region 79
3.6 Discussion about the Hodh El Chargui Region case study 82

4. Case study analysis in the Dosso Region 86

4.1 The multi-risk approach in the Dosso Region 86
4.2 Definition of the current multi-risk index in the Dosso Region 92
4.3 Local climatic projections in the Dosso Region 117
4.4 Application of future projections to the current multi-risk characterization in the Dosso Region 127
4.5 Comparison of results (present vs. future) and identification of priority intervention areas in the Dosso Region 131

4.6 Discussion about the case study in the Dosso Region.........................134

5. Discussion: Identification of priority areas..138
6. Conclusions...152
7. References...156

List of Tables

Table 1: Climate models and Institution 27
Table 2 Correlation precipitation-ephemeral wetland surface....................... 45
Table 3 Meteorological number of drought years and drought probability for the 13 communities of the Hodh El Chargui... 48
Table 4 Average of the August-Sept. rainfall during the 3 years with lowest water accumulation in the mares (mm) 50
Table 5 Hydrological drought probability for the 6 ephemeral wetlands in the Hodh El Chargui.. 51
Table 6 Agricultural drought probability expressed by dry spells frequency in 13 communities of Hodh El Chargui, 1981-2018. 52
Table 7 Heavy precipitations (> 20 mm in 3 hours) probability according TRMM dataset, 1991-2014. 53
Table 8 The exposure component for meteorological drought in each community 54
Table 9 The exposure component for hydrological drought in each community 54
Table 10 The exposure component for agricultural drought in each community 55
Table 11 The exposure component for heavy rains in each community 55
Table 12 The vulnerability component for meteorological drought in each community 56
Table 13 The vulnerability component for hydrological drought in each community 56
Table 14 The vulnerability component for agricultural drought in each community 57
Table 15 The vulnerability components for heavy rains in each community .. 58
Table 16 The adaptive capacity components for meteorological drought in each community 58
Table 17 The adaptive capacity components for hydrological drought in each community 59
Table 18 The adaptive capacity components for agricultural drought in each community 60
Table 19 The adaptive capacity components for heavy rains in each community 60
Table 20 Meteorological risk components for each community in the Hodh El Chargui 61

Table 21 Hydrological risk components for each community in the Hodh El Chargui *63*
Table 22 Agricultural drought risk components for each community in the Hodh El Chargui *63*
Table 23 Heavy rain risk components for each community in the Hodh El Chargui *64*
Table 24 Multi-hazard risk index for 13 communities of Hodh El Chargui, Mauritania. *64*
Table 25 Percentage of models showing future higher or lower meteorological hazard probability *67*
Table 26 Hazard component of the meteorological drought risk in the Hodh El Chargui villages, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th) *67*
Table 27 Average August-September rainfall in the 3 years with lowest water accumulation in the ephemeral wetlands *68*
Table 28 Percentage of models showing future higher or lower hydrological hazard probability *68*
Table 29 Hazard component of the hydrological drought risk in each ephemeral wetland, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th) *69*
Table 30 Hazard component of the hydrological drought risk in the Hodh El Chargui villages, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th) *69*
Table 31 Percentage of models showing future higher or lower agricultural drought hazard probability *70*
Table 32 Hazard component of the agricultural drought risk in the Hodh El Chargui villages, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th) *72*
Table 33 Reconstructed daily critical threshold in the Hodh El Chargui villages *73*
Table 34 Percentage of models predicting future higher or lower heavy rains probability *75*
Table 35 Hazard component of the heavy precipitation risk in the Hodh El Chargui villages, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th) *75*
Table 36 Multi Hazard Risk Index in the Hodh El Chargui communities, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th) *78*
Table 37 Contingency table to assign the priorities of intervention *81*
Table 38 Human settlements in the Dosso region flooded and affected by agricultural drought from 2011 to 2017 by Tiepolo et al. [1] *98*
Table 39 Factors contributing to disastrous flooding as ascertained in five settlements representing the various different regional environments (Tiepolo et al. [1]) *99*
Table 40 The weather station assignments for each municipality *105*

Table 41 Critical rainfall threshold (mm) characterizing each municipality 106
Table 42 Pluvial flood risk (PFRI) level in the Dosso region at municipal level 108
Table 43 Fluvial flood risk (FFRI) level in the Dosso region at municipal level, 2011-17 110
Table 44 Probability of 2 months with SPI lower or equal to -0.5 in three different period 113
Table 45 Drought risk index (DHRI) level in the Dosso region at municipal level 114
Table 46 Multi-hazard risk index (MHRI) level in the Dosso region at municipal level, 2011-2017 115
Table 47 Percentage of models predicting future higher or lower critical rainfall probability 118
Table 48 Hazard component in pluvial flood risk index (PFRI) in the Dosso region at municipal level 2021-2080 – 3 scenarios 120
Table 49 Pluvial flood risk (PFRI) level in the Dosso region at municipal level 2021-2080 – 3 scenarios and present 121
Table 50 Fluvial flood risk (FFRI) level in the Dosso region at municipal level, 2011-17 123
Table 51 Percentage of models predicting future higher or lower drought probability 124
Table 52 Hazard component in Drought hazard risk index (DHRI) in the Dosso region at municipal level 2021-2080 – 3 scenarios 125
Table 53 Drought hazard risk index (DHRI) in the Dosso region at municipal level 2021-2080 – 3 scenarios and present 126
Table 54 Multi hazard risk components in the three scenarios 128
Table 55 Multi hazard risk index (MHRI) in the Dosso region at municipal level 2021-2080 – 3 future scenarios and the present 129
Table 56 Contingency table to assign the priorities of intervention 132
Table 57 Risk treatment for the 5 communities at severe and high risk of the Hodh El Chargui, Mauritania 139
Table 58 Actions scheduled by LDPs for municipalities at hydro-climatic risk (values expressed in thousands of US$) adapted by Tiepolo et al. [1] 141
Table 59 Municipalities benefitting from adaptation, resilience and MHRI projects 143
Table 60 Categories of adaptation actions according to the level of multi-hazard risk 147

List of Figures

Fig. 1 Integration of 3 natural disaster assessment in a multi-risk analysis, Dosso Region – Niger in Tiepolo et al. [1] *18*

Fig. 2 Well usually flooded during the wet season in Legdur (Photo by M. Tiepolo 2018) *19*

Fig. 3 Niger, a photo of the landscape of Dosso Region (Photo by M. Bacci 2018) *20*

Fig. 4 Projected radiative forcing (RF, $W\ m^{-2}$) over the 21st century using the Special Report on Emissions Scenarios (SRES) and Representative Concentration Pathway (RCP) scenarios defined by the 5th AR of IPCC [66] *23*

Fig. 5 Maps of CMIP5 multi-model mean results for the scenarios RCP2.6 and RCP8.5 in 2081–2100 of (a) annual mean surface temperature change, (b) average percent change in annual mean precipitation. The number of CMIP5 models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Hatching indicates regions where the multi-model mean is small compared to natural internal variability (i.e., less than one standard deviation of natural internal variability in 20-year means). Stippling indicates regions where the multi-model mean is large compared to natural internal variability (i.e., greater than two standard deviations of natural internal variability in 20-year means) and where at least 90% of models agree on the sign of change [65] *24*

Fig. 6 Annual rainfall average in a) ensemble of unbiased CEMS simulations, c) CHIRPS and e) ensemble of bias corrected CEMS simulations and their relative standard deviation respectively in b) ensemble of unbiased CEMS simulations, d) CHIRPS and f) ensemble of bias corrected CEMS simulations *29*

Fig. 7 Difference between unbiased and biased ensemble CEMS members in the two temporal horizons: 2021-2050 and 2051-2080, evaluating their ensemble average and standard deviation *30*

Fig. 8 The 13 rural communities of Hodh El Chargui where the multi-hazard risk assessment was developed. Map from Tiepolo et al. [2] *38*

Fig. 9 Main hazards and their impacts on livelihoods in the Hodh El Chargui, Mauritania from Tiepolo et al. [2] *40*

Fig. 10 Hodh El Chargui multi-hazard risk assessment flowchart *40*

Fig. 11 Indicators used in the multi-hazard risk index for 13 communities in the Hodh El Chargui, Mauritania from Tiepolo et al. [2] *42*

Fig. 12 Interpolated profile of ephemeral wetlands area in 2014 and 2015 and average growth curve *44*

Fig. 13 Normalized growth curves of the 6 ephemeral wetlands *44*

Fig. 14 Yearly precipitation 1981-2018 in the Southern Hodh El Chargui region by CHIRPS dataset and 150 mm limit *48*

Fig. 15 Minimal (left) and maximal (right) surface of six ephemeral wetlands with date and surface of the waterbody in the Hodh El Chargui, Mauritania, 2001-2018 by Tiepolo et al. [2] 50
Fig. 16 Maximum dry spell length in July, August and September in the Hodh El Chargui using CHIRPS dataset....................51
Fig. 17 The 13 rural communities at multi-hazard risk in the Hodh El Chargui, Mauritania 65
Fig. 18 Multi Hazard Risk Index in the Hodh El Chargui communities, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th) 80
Fig. 19 Trends in MHRI index for the 3 future scenarios. 81
Fig. 20 Intervention priorities in the Hodh El Chargui for the 3 future scenarios 82
Fig. 21 The 43 municipalities of the Dosso Region, Niger. 86
Fig. 22 Evolution curve of the average annual rainfall from 1961 to 2005 compared to normal (Source PANA-Niger[133]) 87
Fig. 23 The average difference in accumulated yearly rainfall during 2011-2017 and 1981-2010 (rainfall data source from CHIRPS). 88
Fig. 24 The difference in the average number of rainy days with over 20 mm in the 2011-2017 and 1981-2010 periods (rainfall data source from CHIRPS) 88
Fig. 25 The difference in the maximum number of consecutive dry days between 2011-2017 and 1981-2010 (top); the difference in the number of spells of at least five dry days between 2011-2017 and 1981-2010 (below) (rainfall data source from CHIRPS). 90
Fig. 26 Peaks of river Niger at Malanville (Benin), during Red floods (orange bars) and Guinean floods (white bars) with highest levels respectively in 2013 and 2006, period of observation: 1981-2017 [1] 93
Fig. 27 Municipality of Tanda, 2016. Village of Albakayzé flooded by Niger river in 2013 and 2015....................94
Fig. 28 Municipality of Tounouga. The administrative village of Gondorou (1,696 inhabitants) twice flooded 95
Fig. 29 Falwel location on the edge of Dallol Fogha (blue outline) 96
Fig. 30 Tombokoirey I and the Dallol Fogha (blue outline)....................96
Fig. 31 Settlements of the Dosso region affected more than one year (dots) by pluvial flooding, fluvial flooding and drought from 2011 to 2017 (Tiepolo et al. [1]). 98
Fig. 32 Weather stations (black dots) with 30 years of daily registrations in the Dosso region. 100
Fig. 33 Risk determinants and indicators from Tiepolo et al. [1] 102
Fig. 34 Pluvial flood (left), fluvial flood (center) and drought (right) risk index levels in the Dosso region 116
Fig. 35 Multi-hazard risk index at municipal level in the Dosso region. 117
Fig. 36 MHRI comparison Present and 3 futures scenarios (in the bottom line, from left to right the 25th, 50th and 75th centile scenarios) 130

Fig. 37 MHRI trends in the Dosso region, comparison of the MHRI in the 3 scenarios in respect to present conditions 131
Fig. 38 Priorities of adaptation interventions in the Dosso municipalities in the 3 future scenarios 133
Fig. 39 Current Multi-Hazard Risk Index in the Dosso Region and number of interventions per each municipality 144
Fig. 40 Intervention priorities for the worst case scenario and number of Projects 145

Section 1

Introduction

1.1 Context

“The implementation of the mitigation and adaptation policies necessary to successfully address the climate change challenge will only be achieved, and sustained, through involvement and commitment at all levels of decision-making. In particular, sub-national authorities (regions, provinces, states or municipalities) have a key role to play in actively incorporating climate change considerations in day-to-day business and in introducing climate-friendly policies, regulations and investment decisions at their level, as a direct outreach to the public. Adaptation to climate change is very site-dependent, and local planning decisions will be critical to tailor almost every single adaptation action to the conditions in which it will take place. Similarly, 50% to 80% of GHG emissions are influenced by local behaviour and investment choices.” [3]

Climate change is one of major challenges of our time. Scientific community underline that if immediate action is not taken to slow the growth of greenhouse gas emissions, changes in our climate could have catastrophic consequences for the environment [4]. Moreover the negative effects of global warming would hit many of the poorest people in the world, the most vulnerable, and will impact more deeply in developing countries [5].

Mitigation and adaptation to climate change are entirely compatible with pursuing development [6]. The knowledge of this process and its effects could support policies, skills, and incentives to reduce the harmful effects of climate change and support initiatives to mitigate such phenomenon.

Global warming will have strong impacts on the global terrestrial biosphere, but the magnitude of these impacts are difficult to estimate. This is due to several factors such as large gaps in ecophysiological process understanding, lack of insight into the principles of generalization from case studies, lack of sufficient past precedence or analogues for future climate states, and a rather large uncertainty regarding the magnitude and spatial pattern of potential future climate change in climate model projections due to the uncertainties in the future evolution of anthropic forcing [7].

Few studies on climate change impacts produce the analysis with a holistic approach. However, given the many potential responses of a production system to external pressure and its resilience to absorb shocks through compensatory mechanisms, a comprehensive risk assessment of climate impacts on human activities should comprise several aspects and interactions of the system functioning [8].

A multi-hazard risk analysis should support the conception and implementation of initiatives and projects towards communities that are the most at risk and it should help the monitoring, the evaluation, the communication and the awareness-raising activities. The multi-hazard approach is increasingly included in recent risk reduction plans and in publications addressing risk on a local [9-15] and regional [16-20] scale. But some difficulties still emerged in the cases in which this approach has been used up to now revealing the difficulties by applying this method in areas where a lack of field data and information exists [21-25].

For instance, in West Africa, during the last decades, it has been recorded an increased number of extreme heat waves, and heavy precipitation events [26-31] combined with an increase in the number of hydroclimatic disasters [32]. The impact was catastrophic, considering the main economic system of the Region that is based on food crops and pastoralism [33].

Tiepolo et al. [1] estimate that only in the period 2010-2016 international aid earmarked $7.3 billion for creating 715 climate change (CC) adaptation projects in West Africa’s 17 countries. Most part of the projects operate on a local scale (districts and municipalities) or at national scale and typically they lack of coordination with the initiatives that each individual country is already implementing with its own resources. In this vast scenario of initiatives, the terms “climate adaptation” and “resilience” often appear in these projects, but the definition and location of actions is not linked to climate analysis, risk mapping [34], or disaster databases on a regional scale [35]. In some cases, subnational risk mapping lacks detail [36-39] and is mainly limited to floods. It happens that risk is calculated using indicators that do not properly represent risk factors or the techniques involved are too complex to be sustainable in such environment and replicable over time and space [40-54]. At national level, multi-hazard risk and future evolution of climate are rarely taken into consideration while at a sub-national scale these two are not taken into account.

1.2 Towards a multi-hazard risk approach

Developing countries are increasingly challenged to respond to increased risk to natural disasters (desertification, floods, climate related hazards, etc.) [55-56]. However, responsive local governance for climate adaptation is constrained by weak technical and managerial capacity, poor coordination with other institutions at different levels, weak systems for gathering and disseminating information, and unclear mandates and conflicting priorities between levels and agencies of government [57]. This generates serious consequences for the poorest and most vulnerable groups that are the most adversely impacted by climate threats.

More efforts should be made to carry out risk analysis with a holistic vision as recommended by the Sendai Framework for disaster risk reduction and the Sustainable Development Goals [58]. This should orient the creation of plans and projects towards communities that are the most at risk helping the monitoring, evaluation, communication and awareness-raising activities.

For these reasons, a more sophisticated approaches in defining the priority interventions are needed. This research contributes in defining methodologies able to reach this goal despite the chronical lack of field data. In fact, in developing countries it is difficult to use standard approach in defining risk areas.

The literature shows many case studies related to the risk assessment of a single natural disaster [i.e. 59-62], but unfortunately in poor countries, the sum of the effect of natural disasters often drives the population in a famine condition. Thus, it is crucial to pursuit a holistic approach in defining the level of risk of the territory and the population.

Climate change is acerbating this level of risk and this work applies some methods able to produce scenarios for the future evolution of hazards and, consequently, the evolution of risk. The management of climate projections uncertanties is also challenging because many datasets are available by the international scientific community and each one produce different evolution of climate in time. The use of an ensemble approach gives a more comprehensive vision of future evolution of climate. The ensemble approach refers to a methodology widely used by *Intergovernmental Panel on Climate Change* (IPCC) assessments, throughout a comprehensive collection of climate models available through the *Coupled Model Intercomparison Project* (CMIP). Members of a multi-model ensemble are developed by different organisations involved in climate change research using a common standard and can differ substantially in their software design, programming approach and in the parametrization of physical, chemical and biological processes that cannot be described at the spatial resolution of these Global and Regional model. The benefits of using a multi-model ensemble are seen in "*the consistently better performance of the multi-model when considering all aspects of the predictions*" [63].

The study aims to define procedures in multi-hazard risk assessment in developing countries characterized by a high vulnerability to natural disasters considering current and future climate scenarios. The application of the identified methodology to specific case studies allows the detection of the zones the most prone to natural disasters (i.e. Flood, Drought) and the combination of these threats.

1.3 Objectives

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

The realization of this goal must be conceived through (i) the characterization of hydroclimatic threats at a 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 produces an integration of different hazards assessment into a multi-hazard risk approach. The methodology has to be simple and realistic in order to let institutions from different countries to reproduce it in their own situation and make it sustainable.

Moreover, this work aims to support local communities towards the adaptation process to climate threats, arguing that the full engagement of sub-national authorities is a priority to move the climate change and development agendas forward. Taking the necessary action to address local interventions to tackle climate change for the prevention of natural disasters and the increase of food security will meet stronger public consensus and it could be more effective.

Furthermore, the outcomes of this work benefit local authorities with a deeper comprehension of natural hazard risk, addressing some options of prevention which, when tailored to specific conditions, could help balance the pursuit of both climate change adaptation and disaster risk reduction.

The work would contribute to the ongoing process of risk prevention, and helps sub-national authorities with new approach and guidance as they seek to take steps to mitigate and adapt to climate change.

This study defines a methodology for the integration of different components of natural hazards, that affect the study area, using the data available at local scale with the integration of global or regional dataset. The process follows the next phases:

- Hazard assessment, retrieving information about the most dangerous hazards that hits the study area;
- Integration of data not available or available at loose resolution with remote sensed data and models outputs;
- Satellite/models estimations data validation using ground data;
- Measuring the gap between observations and estimations and produce a bias correction of estimations;
- Exposure analysis through a methodology able to produce a unique index of exposure to natural disasters;
- Vulnerability assessment, through the determination of the elements to be considered for the definition of the vulnerability;
- Produce the integration of components of risk into a single index able to characterize the basic unit of the analysis.

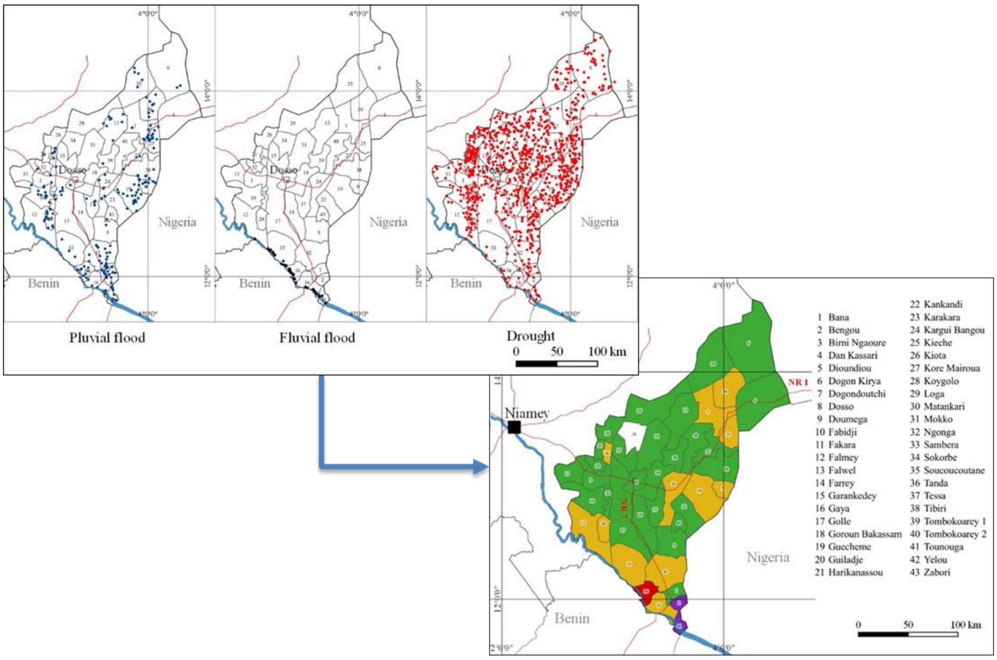

Fig. 1 Integration of 3 natural disaster assessment in a multi-risk analysis, Dosso Region – Niger in Tiepolo et al. [1]

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.

Thus, the study helps in the identification of the intervention priorities supporting the strategic choices for the adaptation process in natural disasters prevention.

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). In particular, the research should orient further studies in the definition of the analysis of climate related risks by using technologies and approaches that could overcome the difficulties generated by a systematic lack of data and information. Finally, the study contributes in the multi-hazard risk investigations in regions between 10000 and 200000 Km²: the sub-national scale.

1.4 The case studies

For the aim of this research, the proposed case studies are:

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

These territories are both characterized by a systematic lack of economic resources and unavailability of field data. Here, the effects of natural disaster are increasing and it becomes urgent to define methodologies able to catch the level of risk allowing a more efficient deployment of the interventions.

Initially there has been also the option of the investigation in Huila region in Angola, but unfortunately, due to some limitation for security factors and the impossibility to move abroad in 2020 for covid19 pandemic, it has not been possible to complete the assessment for this region.

These regions differ by the environmental and climatic characteristics, but at the same time, they are placed in some of the poorest countries in the world and they are hit by different natural disaster such floods and droughts.

Hodh El Chargui Region, Mauritania

The Hodh El Chargui Region in Mauritania is located 1,100 km from the coast, and it extends in the transition zone between the semi-arid and the arid climate for 183,000 km². The Hodh El Chargui is in strong demographic growth and it has always been a melting pot of nomadic and semi-nomadic communities, who follow the southernmost pastures in the dry season and the more northern ones in the wet period.

The Hodh El Chargui is located at the limits of the arid zone, it is characterized by weak precipitations, the annual amount is about 300 mm, with recurrent drought and heavy precipitations events. This is a typical context of the coexistence of subsistence agricultural activities (flood recession agriculture, vegetable gardening) and pastoral activities.

Fig. 2 Well usually flooded during the wet season in Legdur (Photo by M. Tiepolo 2018)

Dosso Region, Niger.

The Dosso region in Niger is a region located in the south-western part of the country with an extension of 33,844 km², with a population of 2,037,713 inhabitants in the last census of 2012 [70]. Most people live in rural areas, with only 18.6% of the population residing in urban areas.

The Dosso Region is located in the Soudano-Sahelian climatic zone, characterized by annual precipitations around 600-800 mm with a one single rainy season which lasts from May to October. Climate variability mainly affect the area with droughts and heavy precipitations.

Considering the agriculture production of the region, the main staple crops cultivated are the Pearl Millet and the Sorghum and pastoral activities are mostly dedicated to the transhumant breeding with the prevalence of goats and sheep.

The institutions involved in the activities are the *Direction de la Météorologie Nationale au Niger* (DMN), the *Cellule de Coordination du Système d'Alerte Précoce et de Prévention des Catastrophes* (CC/SAP/PC) and the extension services of the ministry of Agriculture and the Governorate in the two regions. The collaboration with these institutions allows the accessibility to meteorological and disaster database to perform the analysis in Dosso Region and support the territorial planning for disaster prevention. The collaboration is framed in the *Climate change adaptation, Disaster reduction and agriculture development for food security* (ANADIA 2) Project by POLITO and CNR *Institute of BioEconomy* (IBE), formerly CNR- *Institute of Biometeorology* (IBIMET), financed by *Agenzia Italiana per la Cooperazione e Sviluppo* (AICS) to promote the resilience to climate change in Niger.

Fig. 3 Niger, a photo of the landscape of Dosso Region (Photo by M. Bacci 2018)

1.5 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. The chapter defines the objectives and the case studies investigated.
2. Climate change and risk assessment; this chapters makes a brief introduction to climate projections and the future climate scenarios. Also it gives a brief introduction to bias correction methodologies and its application to produce the future climatic dataset for this study. Finally, it explores some concepts of risk mapping and the definition of the priorities in the interventions through the characterization of multi-hazard risks.
3. The following chapter deploy the case study in the Hodh El Chargui Region and its multi-hazard risk assessment with the identification of the current and the future multi-risk zones in the Hodh El Chargui Region. Hence the identification of the priority intervention areas in the Hodh El Chargui Region through the comparison of the results (current climate vs. future). A discussion about the Hodh El Chargui Region case study concludes the chapter.
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. Hence the identification of priority intervention areas in the Dosso Region through the comparison of results (current climate vs. future) allows. The chapter ends with a discussion about the case study.
5. The discussion chapter explores the identification of priority areas in the two case studies highlighting the advantages and the limits of the methodology and the possible application to other situations.
6. Conclusions of the study.

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Section 2

Climate change and risk assessment

2.1 Climate projections

The global climate projections predict the future evolution of climate, but any projection is characterized by uncertainty which drives to different evolution of climate. The *Coupled Model Intercomparison Project* (CMIP), organized under the auspices of the *World Climate Research Programme's* (WCRP) *Working Group on Coupled Modelling* (WGCM), is an initiative where the climate researchers community, from institutions all over the world, share, compare and analyze the outcomes of global climate models [64].

The CMIP initiative began in 1995 as a comparison of few early global coupled climate models. The increasing need to systematically analyze coupled ocean and atmosphere model outputs from multiple climate modeling centers, makes this initiative every year more demanding then nowadays it becomes the large program to advance model development and scientific understanding of the Earth system. To meet these goals, CMIP has developed well-defined climate model experiment protocols, formats, standards, and distribution mechanisms to ensure model output availability to a wide research community. The IPCC Fifth Assessment Report [26] openly acknowledged a heavy reliance on CMIP Phase 5.

The outputs of this initiative are largely applied in climate studies allowing to investigate the climate system in all its components and iterative feedbacks. Nevertheless, it is important to remind, that these outputs are simulations of what will really happen in future.

The large scientific community in climate research are continuously improving the complexity and the reliability of these models but the chaotic nature of the atmospheric process could lead to very different results only changing a small parametrization in the model. For this reason, normally scientific community use an ensemble approach able to define the uncertainty of the models' outputs [65].

Apart the difficulty to represent correctly all the process in the atmosphere, there is another variable: the anthropic emissions. These emissions are the main forcing factor in the global warming process. Considering this, if we want to move ahead with climate projections, it is important to estimate also this emissions trajectories. This evolution is strongly dependent by the choices of the human community worldwide, for instance, with their use of fossil fuels or renewable energy, the policies regarding the industrial pollution or the use of clean transports, etc. A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory adopted by the climate scientific community to produce climate projections [66] with the aim of simulating different scenarios of the possible future anthropic emissions.

In the last assessment report, four pathways have been selected for climate modeling and research, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come.

The four RCPs, namely RCP2.6, RCP4.5, RCP6, and RCP8.5, are labelled after a possible range of radiative forcing values in the year 2100 (2.6, 4.5, 6.0, and 8.5 W/m^2, respectively) (Fig. 4).

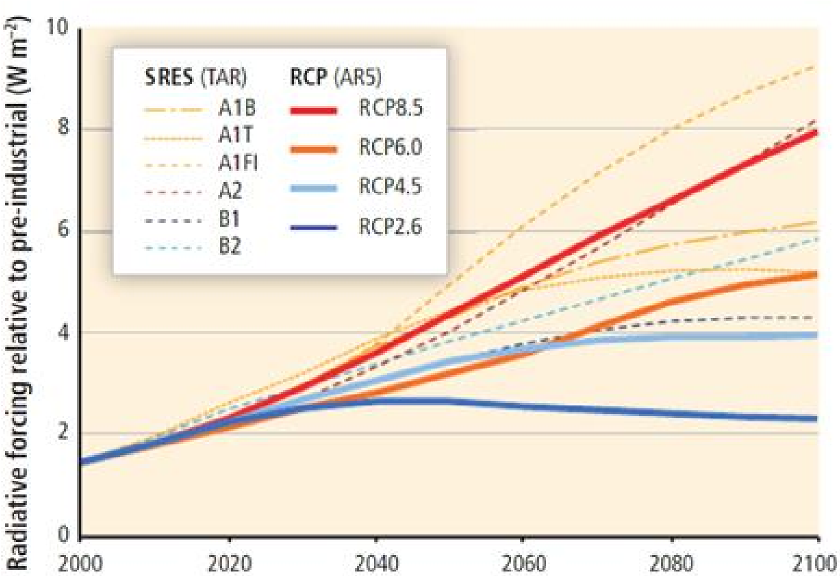


Fig. 4 Projected radiative forcing (RF, $W\ m^{-2}$) over the 21st century using the Special Report on Emissions Scenarios (SRES) and Representative Concentration Pathway (RCP) scenarios defined by the 5th AR of IPCC [66]

The use of several models outputs with different RCPs means to manage a huge quantity of data and results. Normally, these results of climate projections must be organized and analyzed to produce useful synthesis for the aim of the study.

Moreover, the output of these models are normally not sufficient and accurate to describe the climatic variability of the small portion of territory such as the regions involved in the study because of the native spatial resolution of the GCM and RCM. The ability to capture local-scale or regional-scale patterns, that are directly relevant to end users for decision making and mitigation strategy planning at a sub-national scale, is less promising, especially for precipitation [67]. This limit could be reduced by the application of some bias correction techniques able to reduce the systematic errors of the models, using data available on the ground [68]. This is the most challenging task of the study and the most expensive in term of hours of machine elaborations.

With this large bias correct dataset available it is feasible to estimate the hazard component in future risk. Using different models, it is possible to produce a risk index in the study area by three scenarios: the optimistic, the average and the pessimistic one. This differentiation could integrate the information available for the decision making process with the range of the incertitude in the projections.

The methodology adopted for the creation of a daily precipitation dataset in the period 2021-2080 for the purposes of the thesis follows the next phases:

- Selection and download of Climate projections dataset;
- Application of the bias correction method using a rainfall estimation dataset;
- Creation of bias-correct datasets;
- Evaluation of intra-model signals.

The use of several models configurations permits to create a wide range of scenarios of possible climate evolution. In fact, the uncertainties in the parametrization of the models and the future evolution of human's societies could impact positively or negatively on this energetic forcing of the system then in the final results. Some signals are more evident because the sign and the magnitude of the changes are robust, which means an overall consistency among models. For instance, the global warming will hit the earth in the next decades with a high degree of confidence as sentenced by the IPCC [69]. Inversely the precipitation shows different possible evolutions with different RCPs and models. The IPCC fifth assessment report [65] shows this difference among temperature and precipitation projections at the end of this century (*Fig. 5*).

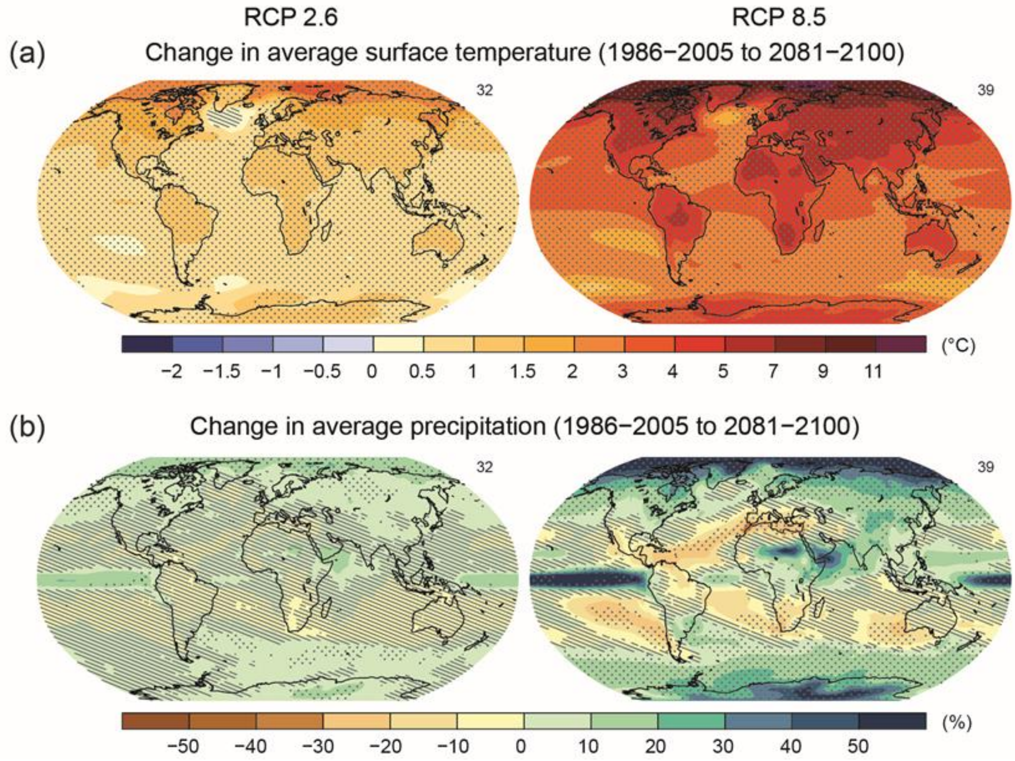


Fig. 5 Maps of CMIP5 multi-model mean results for the scenarios RCP2.6 and RCP8.5 in 2081–2100 of (a) annual mean surface temperature change, (b) average percent change in annual mean precipitation. The number of CMIP5 models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Hatching indicates regions where the multi-model mean is small compared to natural internal variability (i.e., less than one standard deviation of natural internal variability in 20-year means). Stippling indicates regions where the multi-

model mean is large compared to natural internal variability (i.e., greater than two standard deviations of natural internal variability in 20-year means) and where at least 90% of models agree on the sign of change [65]

Different datasets from CMIP5 climate projections are applied to create a series of scenarios for possible future evolution of hazard component.

Despite such effort in defining the evolution of the hazard component, the multi hazard risk analysis still presents some gaps due to the future evolution of exposure and vulnerability components in the risk formula. Basically the main issues are:

- How do we have to consider the exposure component of the risk? Is it only dependent on population growth rate or we must include other factors? Land use dynamics, which are not studied in deep in these regions, can modify the exposure of the population to natural hazards? How new phenomena, which are intensely impacting the rural areas of sub-Saharan Africa, such as the migrations, will impact? In the end, are we able to intercept and project the future evolution of exposure component?
- How is it possible to integrate adaptation process in the vulnerability component? The simple knowledge of the future risks allows the population to take some actions to reduce the impact of natural disasters. Information and education are the main drivers in the prevention of natural disaster. How can we simulate the future evolution of awareness to climate disaster in the local population?

More investigations are needed in these topics and within this study it has been possible to suggest only some toughs and recommendations about these issues in the discussion section.

2.2 Climate future scenarios

A Climate Model is a numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes. The climate system can be represented by models of varying complexity. A Coupled Atmosphere-Ocean General Circulation Models (AOGCMs) provide a comprehensive representation of the climate system interactions. During the time there has been an evolution of the models, from the simplest one during the '80 towards more complex models with interactive chemistry, biology and human interactions. It is possible to use climate models as a research tool, to study and simulate the climate, and for operational purposes, including monthly, seasonal, and interannual climate predictions.

Numerical models, General Circulation Models (GCMs), if they refer to the entire globe, and Regional Circulation Models (RCMs), if they concern only a portion of the globe, typically a continent, represent physical processes in the atmosphere, ocean and land surface by explicit physics rules. They are the tools most commonly used for simulating the response of the global climate system to increasing greenhouse gas concentrations and provide spatially and physically consistent estimates of climate change which are required in impact analysis.

GCMs represent the climate using a three dimensional grid over the globe. Their spatial resolution is not able to represent extreme phenomena to the scale of exposure units in most impact assessments. Moreover, many physical processes, such as those related to convective precipitations, also occur at smaller scales and cannot be correctly modelled. Instead, their known properties must be averaged over the larger scale in a technique known as parameterization. Parametrization process and the estimations of natural and anthropic feedback interactions mechanisms in the models are the main sources of uncertainties in GCM-based simulations of the future climate. This simplification of the reality drives GCMs to simulate different responses to the same forcing, simply because of the way certain processes and feedbacks are parameterized.

Both GCMs and RCMs are characterized by a spatial resolution not sufficient to discriminate the climate evolution at very local scale (<100000 km^2). So, in this study, it is necessary to push the description of the phenomena at higher resolution. The application of bias correction to models outputs can help in this downscaling process. Bias corrections are an ensemble of techniques widely used able to obtain datasets statistically closer to the real distribution of climatic parameters, because the climate signal is modulated by the observation at higher resolution.

The scientific community, through the Intergovernmental Panel on Climate Change (IPCC) [71] and the data sharing projects relates to this initiatives, i.e. Coupled Model Intercomparison Project 5 (CMIP5) [72], made available an huge amount of data about the future evolution of climate. Considering the large amount of existing datasets with different parametrization and scenarios, in the study it has been chosen a selection of a certain number of outputs, enough to evaluate the intra-model and inter-model signals with the ensemble approach.

In order to evaluate the intra-model signal, it has been selected the CESM Large Ensemble Project. This dataset of climate model simulations is publically available with the aim of advancing in the understanding of internal climate variability and climate change. The simulations are performed with the nominal 1-degree latitude/longitude version of the Community Earth System Model version 1 (CESM1) with Community Atmosphere Model version 5.2 (CAM5.2) as its atmospheric component. The Large Ensemble Project includes a 40-member ensemble of fully-coupled CESM1 simulations for the period 1920-2100. Each member is subject to the same radiative forcing scenario (historical up to 2005 and RCP8.5 thereafter), but begins from a slightly different initial atmospheric state (created by randomly perturbing temperatures at the level of round-off error) [73].

The inter-model signals are evaluated using a large dataset of CMIP5 outputs coming from different sources. The following table list the models and their relative institution.

Table 1: Climate models and Institution

Model ID	*Institution*	*Source*
BCC-CSM1-1	Beijing Climate Center Climate System Model	http://forecast.bcccsm.ncc-cma.net/web/channel-43.htm
CCSM4	Community Climate System Model (CCSM) by National Center For Atmospheric Research (NCAR) University Corporation for Atmospheric Research (UCAR)	http://www.cesm.ucar.edu/models/ccsm4.0/
CMCC-CM	Centro Euro-Mediterraneo sui Cambiamenti Climatici	https://www.cmcc.it/models/cmcc-cm
CMCC-EMS	Centro Euro-Mediterraneo sui Cambiamenti Climatici	https://www.cmcc.it/models/cmcc-esm-earth-system-model
CNRM-CM5	Centre National de Recherches Météorologiques	http://www.umr-cnrm.fr/spip.php?article126&lang=en
CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organisation	https://confluence.csiro.au/public/CSIROMk360
GFDL-CM3	Geophysical Fluid Dynamics Laboratory	https://www.gfdl.noaa.gov/coupled-physical-model-cm3/
GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory	https://www.gfdl.noaa.gov/earth-system-model/
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory	https://www.gfdl.noaa.gov/earth-system-model/
HadGEM2-CC	Met Office	https://www.metoffice.gov.uk/research/approach/modelling-systems/unified-model/climate-models/hadgem2
IPSL-CM5A-LR	Institut Pierre Simon Laplace	http://cmc.ipsl.fr/international-projects/cmip5/
IPSL-CM5A-MR	Institut Pierre Simon Laplace	http://cmc.ipsl.fr/international-projects/cmip5/
IPSL-CM5B-LR	Institut Pierre Simon Laplace	http://cmc.ipsl.fr/international-projects/cmip5/
MIROC5	Center for Climate System Research (CCSR), University of Tokyo	https://ccsr.aori.u-tokyo.ac.jp/~hiro/img/miroc5_desc.rev.v3.pdf
MPI-ESM-LR	Max Planck Institut	https://www.mpimet.mpg.de/en/science/models/mpi-esm/
MPI-ESM-MR	Max Planck Institut	https://www.mpimet.mpg.de/en/science/models/mpi-esm/
MRI-CGCM3	Meteorological Research Institute of the Korea Meteorological Administration	https://catalogue.ceda.ac.uk/uuid/08520fcbae6e43c9bfeb786b4c73c4a1
NorESM1-M	Norwegian Climate Center's	https://folk.uib.no/ngfhd/EarthClim/Data/data.html

The models outputs are freely available and distributed by some data portal (i.e. CMIP5 data portal). The data are distributed in the network Common Data Form (netCDF) format, which is a format widely used among the scientific community for storing multidimensional data such as temperature, humidity, pressure, precipitation, etc. over a specific domain organized by a temporal timestep.

For the purposes of this study the precipitation dataset has been downloaded at daily resolution for the period 2006-2080. The period 2006-2016 has been used for the models' bias correction process while the 2021-2080 is the selected forecast period.

The combined use of the ensemble members' simulations of the models from CMIP5 allow to obtain a wide vision of the possible changes in the statistics of the extremes in rainfall distribution.

2.3 Application of Bias correction methodology

For risk assessment, in a changing climate, the understanding, quantifying and attributing the impacts of extreme weather and climate events in the terrestrial biosphere is crucial.

Despite considerable progress in recent years, global and regional climate models typically exhibit biases in various statistical moments of their simulated variables [74-75], which often impedes direct assessments of climate extremes [76] or simulating impacts [77-78]. These biases are often due to an imperfect representation of physical processes in the models, parametrizations of sub-grid scale processes, and an over- or underestimation of the land–atmosphere or ocean-atmosphere feedbacks [74, 79].

For the purposes of this study, a downscale and de-bias daily precipitation values are made using Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) observations (2006-2016) dataset [80]. CHIRPS is a quasi-global rainfall data set, spanning 50°S-50°N (and all longitudes) and ranging from 1981 to near-present.

The CHIRPS dataset has a spatial resolution of 0.25' so by applying this estimation dataset for the bias correction in each grid point of the domain, it is consequently possible to have also a downscaling of the models output.

The overlapping period 2006-2016 of the two dataset (CHIRPS and models) has been used to sort daily rainfall by increasing accumulation and map the model data to observations via a parametric fit to the transfer function [81-82]. Then, for each grid point of the domain, the Quantile Mapping Using Parametric Transformations (*fitQmapPTF*) by *R software package* [83] has been used because it gives good results in reproducing the real distribution of the extremes [84]. The function fits a parametric transformation to the quantile-quantile relation of observed and modelled values. In particular, in this process, it has been selected the "*expasympt*" (exponential tendency to an asymptote) transformation:

$$Po = (a + b * Pm) * \left(1 - e^{\frac{-Pm}{\tau}}\right)$$

Where: Po refers to observed and Pm to modelled Cumulative Distribution Functions (CDFs) and τ determines the rate at which the asymptote is approached.

Moreover, in this transformation we set the criterion for optimization as "RSS" which minimizes the Residual Sum of Squares and produces a least square fit setting the sample size as 0.01 (*qstep* argument). Finally, we set the function argument *wet.day* as 0.1 as threshold below which all values are set to zero.

Furthermore, the function *doQmapPTF* [83] uses the transformation to adjust the distribution of the modelled data to match the distribution of the observations for each grid point of the domain.

Considering the uneven rainfall distribution during the rainy season it has been chosen to apply such transformation dividing the rainy season in 7 months, starting from April to October, and we apply the transformation for each month in order to have 7 monthly transfer functions to produce 7 monthly fitted distributions in every grid point of the domain. The combination of these allows to rebuild the whole rainfall distribution over the years. Thus, it is possible to have an unbiased projection on the entire domain, at daily resolution, from 2021 to 2080, for each single model output (ensemble of CEMS and CMIP5).

To figure out the effects of the bias correction in the model outputs it is possible to plot the average of the CEMS biased and unbiased models in the 2006-2016 period allowing a comparison able to intercept differences in rainfall patterns and distribution (*Fig. 6*).

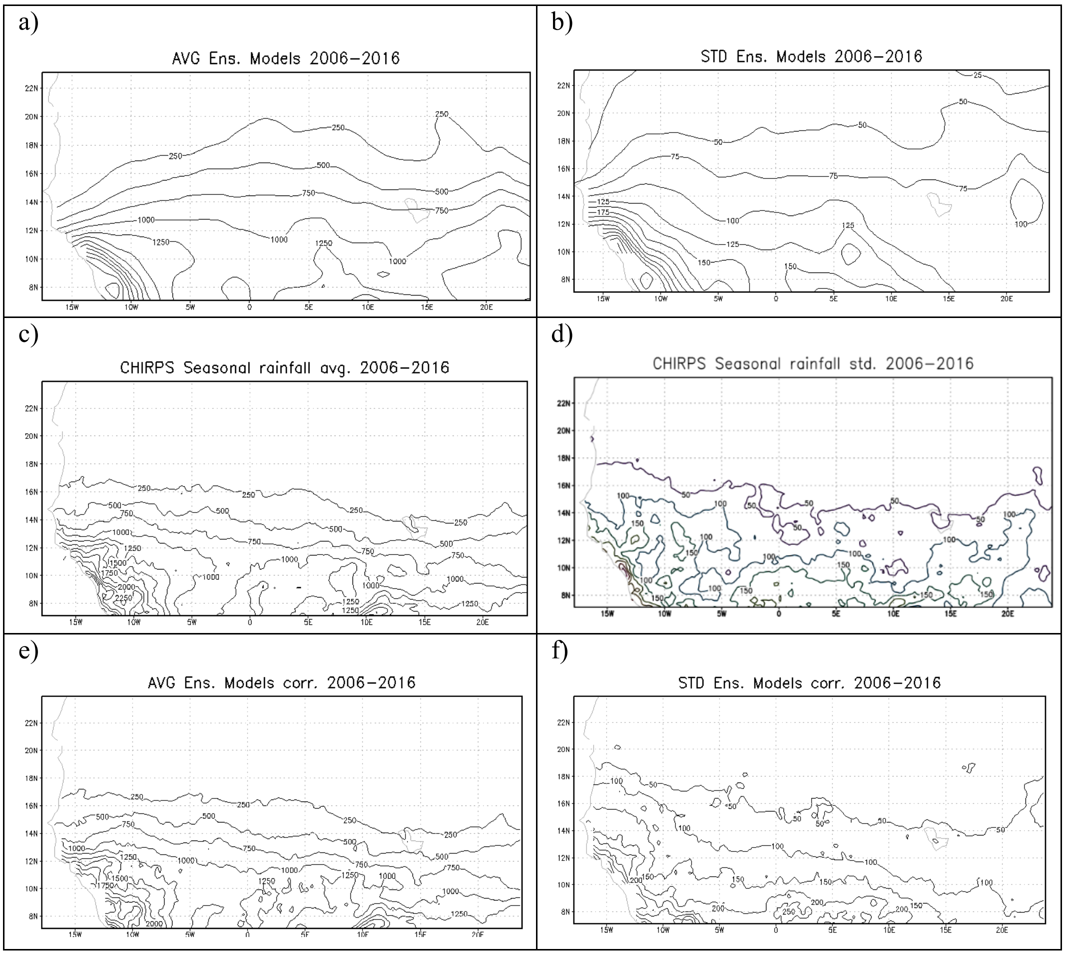
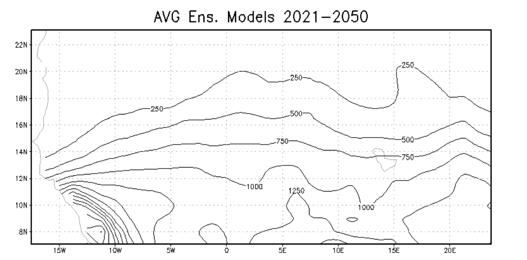
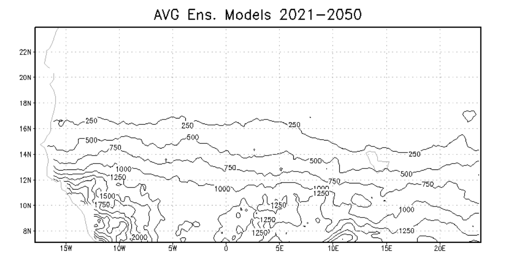


Fig. 6 Annual rainfall average in a) ensemble of unbiased CEMS simulations, c) CHIRPS and e) ensemble of bias corrected CEMS simulations and their relative standard deviation respectively in b) ensemble of unbiased CEMS simulations, d) CHIRPS and f) ensemble of bias corrected CEMS simulations

Downscaling process drastically reduces the bias in total seasonal rainfall in the whole domain (left column) and it reduces the bias in inter-annual variability in the Sahel region (right column).

When comparing bias adjusted results to the unbiased model outputs, it is possible to observe that the precipitation change is largely affected by bias adjustment over most areas, in some cases the difference can be substantial. Especially in the northern zone the unbiased models drastically overestimate the rainfall amount. While the configuration of the precipitation distribution in the biased outputs are quite similar to the estimated one by CHIRPS.

The application of the transfer function to the future projections, split in two periods: 2021-2050 and 2051-2080, allows to evaluate the difference between unbiased and biased models (*Fig. 7*).

<table>
<tr><th>Unbiased</th><th>Biased</th></tr>
<tr><td colspan="2">2021-2050</td></tr>
<tr><td>
</td><td>
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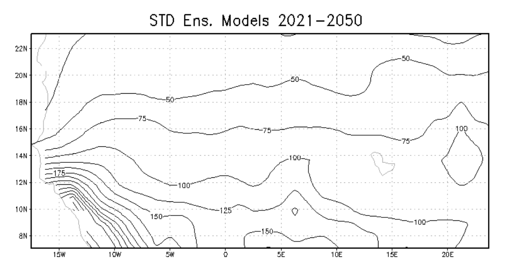
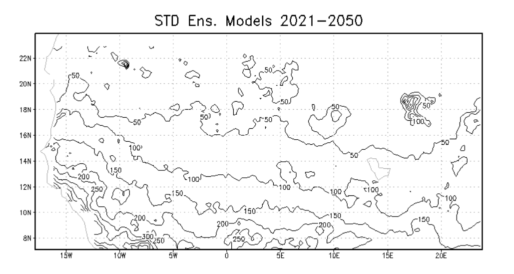
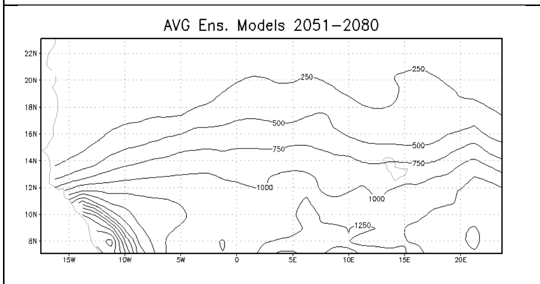
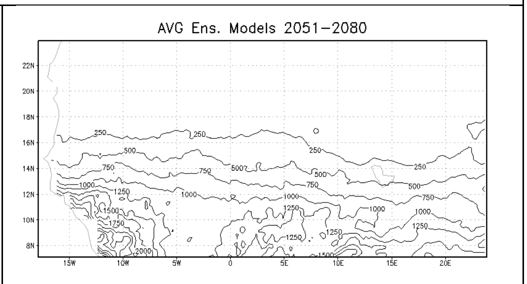
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">2051-2080</td></tr>
<tr><td>
</td><td>
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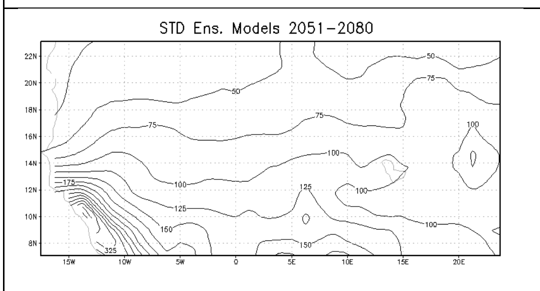
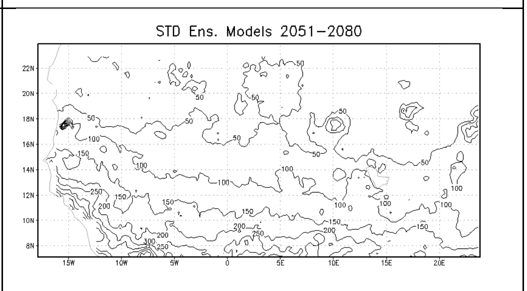
<tr><td>
</td><td>
</td></tr>
</table>

Fig. 7 Difference between unbiased and biased ensemble CEMS members in the two temporal horizons: 2021-2050 and 2051-2080, evaluating their ensemble average and standard deviation

Looking at the statistics of the ensemble of future projections it becomes clear how the unbiased models cannot be applied for future evaluation of the extreme distributions because the smooth effect of models resolution in the description of the precipitation in West Africa. While the effects of the bias correction are clear and they drive the rainfall distribution, its average and standard deviation, closer to the observed one in current climate. Consequently, the process allows to represents future extremes events distributions in a similar way of the reality which is crucial for the needs of hazard risk assessment.

The availability of a gridded dataset at high resolution (0.25') allows to use the products of these projections at the scale of analysis of this study. In fact, for every grid point of the domain it is possible to extract the time series of rainfall distribution and use it as input for the recurrence of extreme events.

The bias corrected datasets are produced over the west Africa window and they could be available for further studies in the region.

2.4 Risk mapping

Natural risks are complex and they have a multi-sectoral nature, then it is critical to communicate the results of the prospective exercise and the possible risk prevention strategies in an accessible way to decision makers or general public.

Nowadays, many tools are available to support decision-making for adaptation at low cost. Of these, maps showing the probability to climate-related risks are often used to raise the awareness and support planning and budgetary allocations for interventions. Cartography is widely used and it represents one of the oldest and most effective mechanisms for analysis and communication of spatial information. Nevertheless, in many risk assessments the spatial allocation and distribution of risks are barely considered. While, the evaluation and selection of appropriate mitigation measures cannot be made properly without a precise indication of the areas the most at risk. Therefore, it is frequently not considered which areas benefit the most from a specific adaptation measure and which areas do not. This may lead to spatial disparities of disaster risk which are not desirable or acceptable [85].

Maps are a very useful tool for the analysis of the distribution of any spatial event. In this case, each area is characterized by a set of natural risks and producing the integration of different risks into a multi-hazard approach in current and future conditions. Geographical Information Systems (GIS), with their ability to handle spatial data, are an appropriate tool for processing spatial data of risk.

Moreover, considering the aim of this study, it is important to evaluate the dynamic of these risks over time. Tools and software, such as *Climate Data Operators* (CDO) [86] and *Grid Analysis and Display System* (GrADS) [87], are able to produce complex multidimensional elaborations and outputs from the climatic dataset analysis. Such tools produce geographically referenced products which could be easily integrated in GIS systems.

In addition, climate change may contribute in the emergence of "new" types of hazards, that were previously absent or rare, or changes in risk factors (i.e. the probability of harmful consequences). Hence, adaptation efforts will need to be closely linked with strategies for Disaster Risk Management (DRM).

The integration of climate change risk assessments into planning processes for disaster risk reduction must be a priority, thus, the outputs of the hazard characterization has to be provided in a comprehensive and useful format for local decision makers. For this purpose, the study uses the municipality as basic unit of analysis allowing an easy application of the findings in prevention actions at local scale.

2.5 Priorities in the interventions

Decision-makers everyday have to deal with the uncertainty regarding the future changing conditions and their associated impacts. This is quite challenging because they need to produce medium- to long-term decisions today under conditions of imperfect information.

Climate change adaptation requires long-term, orientated planning approaches from national to local level. Reacting to changes, without considering the dynamics of risk, could drive to poor investment decisions. The exercise made with the comparison of resulting hazard risks (current and future scenarios) helps the identification of priority intervention areas trying to anticipate the risk distribution. Thus, the study supports the definition of significant changes in risk distribution and it provides a key to understand local natural disaster evolution. The general aim is to guide regional and urban development in these zones and secondarily it produces a baseline for the setting up of adaptation strategies to climate change.

It is important to underline that the objective of this exercise will not be to predict exactly the future but, instead, trying to support development strategies, policies and measures able to cope with a range of possible future climatic scenarios. The key objective is to help decision makers and planners in identifying the appropriate set of responses that could manage current and expected climate-induced challenges and opportunities.

It has been recognized that it is important to promote “bottom-up” effective adaptation [88] in order to strength the existing systems of governance. The maximization of the efficiency of public goods and services requires that the ministries responsible for the provision and management of public goods, food production and water management, are fully accountable for their interventions and they have to produce actions oriented to reduce the fiscal burden in case of climate threats. The nature of climate change requires a behavioural shift and the mainstreaming of adaptation into development and investment decision-making processes at all levels of society in the coming years and decades.

As stated by Tiepolo et al. [1], still, most local development planning tools has a traditional structure and they have not been designed to incorporate climate information. Typically, they focus on short-term threats in two or three key sectors, with less emphasis on the resilience of long term investment in a context of climate uncertainty. It might be useful to suggest to decision-makers, at the sub-national level, to reconsider their planning tools and processes and incorporate climate change considerations.

Decision makers must be aware about the difficulties in communicating about climate change. Uncertainties management is quite challenging because there is a delicate balance in this process between being too precise [89], which can lead to overconfidence in perceived accuracy of the information, or making obviously vague statements, which contain less information than evinced by scientific consensus.

Decision makers need to be sensitive to the fact the uncertainty is often interpreted by the audience differently than intended by the communicators [90], especially in rural areas. As general approach it is suggested to convey such complexities and lack of predictability in the climate system through an appropriate scientific communication strategy [91].

In any case, the identification of interventions priorities and implementation of the right policies with an appropriate communication campaign could reduce the costs associated to the effects of a changing and uncertain climate future, and protect vulnerable groups from extreme natural events.

The development of comprehensive climate change strategies, reflecting local development priorities combined with the national development strategies, should represent the starting point to empower national and local actors to efficiently manage climate threats [92].

2.6 Characterization of multi-hazard risks

In literature, the terms multi-hazard risk refers to *the risk arising from multiple hazards* [93-95].

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.), could be useful to correctly detect and describe the risk. Unfortunately, in many cases, this material is not available at the required detail or their 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.

The process must produce a clear and shared definition of hazard risk defining a methodology able to integrate any single risk component in one final index through a homogenous path founded on data available. Moreover, it is important to produce an analysis as simple as possible to guarantee the sustainability and the reproducibility of similar initiatives.

Hazard

Hazard is defined by the United Nations Office for Disaster Risk Reduction (UNDRR) [96] as: "*A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Hazards may be natural, anthropogenic or socionatural in origin. Natural hazards are predominantly associated with natural processes and phenomena. Anthropogenic hazards, or human-induced hazards, are induced entirely or predominantly by human activities and choices. This term does not include the occurrence or risk of armed conflicts and other situations of social instability or tension which are subject to international humanitarian law and national legislation. Several hazards are socionatural, in that they are associated with a combination of natural and anthropogenic factors, including environmental degradation and climate change.*"

Changes in hazard may arise from natural variability or anthropic forcings. The latter are particularly important for changes driven by climate change such as hydrometeorological hazards. As global warming change influences the distribution and seasonal patterns of precipitation and monsoon events, regional changes occur in flood, drought, and heat wave hazards.

The process to characterize the natural hazard component in the risk analysis pass thought the integration procedures for all data not available or available at loose resolution. The most fundamental data about the disaster are the historical statistics, in particular the temporal reference, the geographical location and extension and the magnitude of the event.

Moreover, every natural hazard, such as drought, storms or flooding, has different indicators and time of evolution. While flash floods depend on very intense phenomena from few minutes to few hours, agricultural drought could have a slow onset which last weeks or months. The integration of such different phenomena in one single analysis is challenging especially in countries where the observation network is insufficient to describe the conditions at high spatial and temporal resolution.

A useful support in this process come from the estimation datasets by satellite and/or models that nowadays are freely available for the most part of the world. Sometimes, it could be convenient to conduct an evaluation of the gap between observations and estimations to produce the necessary choices and adjustments.

The interaction between meteorological hazards and climate change highlights the possibility that these hazards will respond differently to future changes in climate. It is difficult to specify accurately how hazard occurrence and intensity will change by region, and this represent the main scientific focus of this research.

Exposure

Exposure is defined by the UNDRR [96] as: "*the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas*" and, as noted in the terminology, "*measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability and capacity of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest*".

The exposure characterization is made by a specific methodology able to catch the peculiarities of the zone defining several components of exposure for the multi-risk analysis. Exposure modelling techniques are different at different scales. Global-scale and local-scale use different methodologies: the former works with information and data carried out by governments or large institutions, whereas the latter works by methods such in situ surveys. Regional scale must work with the integration of the previous two methods. At the global scale, efforts to generate globally consistent exposure data sets in terms of quality and resolution have increased in time while at national level the availability of data is inhomogeneous. In some national institutions, especially in least developed countries, the lack of resources and skills to produce and maintain large dataset of such information drive to the unavailability of data, especially at a sub-national scale. This represent the main limiting factor when an exposure analysis is made.

The information available to develop exposure data sets could result from various sources and methods. At local level, the main data sources are surveys, decentralized government agencies, aerial photos, local projects or initiatives lasted for many years on the territory. While we move towards regional level and above, national institutions, census data, national statistics and existing thematic GIS data (i.e. Shuttle Radar Topography Mission (SRTM) [97], Harmonized World Soil Database by FAO [98]) are common sources of exposure information for developing exposure data.

The experience in risk assessment produced in least developed countries has shown that a tailored approach for describing, collecting, validating, and communicating data about exposure component could produce a better and accurate results. Nevertheless, the main limit still remains the difficulty in accounting how the exposure evolves over time as a result of demographic growth, market demands, conflicts and migrations, and other factors.

The approach adopted in this study aims to characterize each single basic unit of the study area using the data available about the socio-economic context and the specific environmental conditions for the specific hazard. If a hazard occurs in an area of no exposure, then there is no risk [99].

In semi-arid environment, such as in Mauritania, exposure to drought is more related to the accessibility to water reservoirs or wells while in sub-humid ecosystems, such in the Dosso region, the exposure depends on the rainfall distribution. Regarding the natural threats, the exposure to flooding is given by the facilities in flood prone areas while for flash floods the micromorphology of the terrain plays a key role.

The measure of exposure component could be difficult in some context because the absence of any institutional and quality controlled dataset drives only to a rough estimation of this component in the risk formula.

Vulnerability

Vulnerability is defined by the UNDRR [96] as: *"the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards."*

Vulnerability is quite complex to estimate and typically it is described in terms of damage and/or loss, which are the measure of the impacts of a natural disaster in a specific context. The statistics of damages and losses from previous disasters provides useful information to understand the physical, social, and economic interactions of the systems and its vulnerability to a specific threat.

Damage and loss are typically assessed using functions that relate hazard intensity to damage. For a global- or regional-scale model, the losses typically refers only to total direct loss, whereas at local scale some detailed site specific models may estimate loss in very accurate way.

The vulnerability characterization deals with the determination of all the elements to be considered for the definition of the vulnerability to different risks.

Multi-hazard risk index (MHRI)

Multi-hazard risk index means the analysis, through a synthetic index, of multiple major hazards that the country, region or village, faces, and the specific contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects. Severe hazardous events can lead to a disaster as a result of the combination of hazard occurrence and other risk factors, so it becomes useful for a decision maker to assess how each single basic unit of a territory is at risk. [58]

There are several methodologies in literature to assess multi-hazard risk [i.e. 1-2, 100-103] 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. Some methods are not applicable to some context, simply because there is no data available for such investigation or it becomes too expensive. Moreover, as previously mentioned in the introduction, the methodology has to be simple and realistic in order to let institutions from different countries to reproduce it in their own situation and make it sustainable.

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 context, 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” [104]:

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

The equation is an adaptation of that proposed by Crichton [104]. 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.

Section 3

Case study analysis in the Hodh El Chargui Region

3.1 Multi-hazard risk analysis in the Hodh El Chargui Region

The Hodh El Chargui is a landlocked region 1,100 km from the Atlantic coast (*Fig. 8*) in Mauritania in a semi-arid environment.

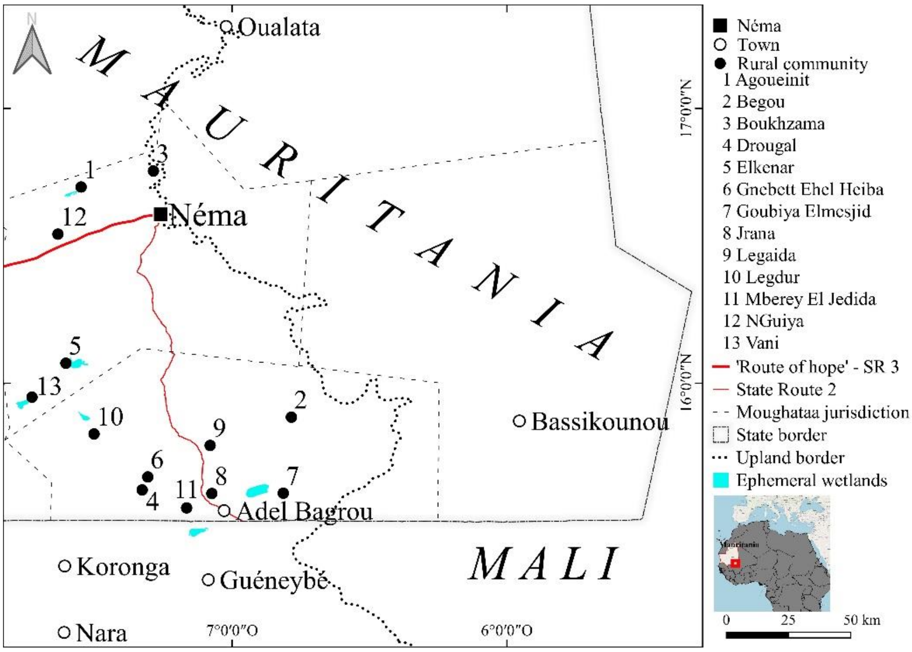


Fig. 8 The 13 rural communities of Hodh El Chargui where the multi-hazard risk assessment was developed. Map from Tiepolo et al. [2]

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]. The Hodh El Chargui is in strong demographic growth: the region increased from 212,000 inhabitants in 1988 to 431,000 inhabitants in 2013 [105]. Considering the surface of 182,700 km², the territory is still very scarcely dense inhabited with around 2.35 habitants per km².

As described by Tiepolo et al. [2], the settlements are constituted essentially by the agglomeration of stone dwellings each flanked by a construction with a twopitched roof under which life takes place during the warm months and an enclosure for the animals around a tree in the branches of which the fodder is stored.

The water resources in these communities play a central role, in fact the traditional wells (uncovered, without water pumps) are the key element of each community and they are prone to floods during the wet season or, in the dry season, they may be found some kilometers away. Having a borehole and a water reservoir in the village is not common.

During the dry season, from October to May, the shepherds go the southern pastures, and only a small part of the livestock remains in the communities for requirements of milk, cheese and meat.

The economy of the region is based on the commerce of the animals and it is quite common that the shepherds go to Senegal market, travelling up to 300 km [106].

Between June and August rain-fed agriculture is practiced with the herds return to the pastures around the villages of origin. Part of the communities have access to an ephemeral wetland at the edges of which they dig wells.

Semi-arid conditions lead communities to pick up the runoff with earth embankments to practice recession agriculture from October onward. The embankments are exposed to several risk such as the trampling by the herds which cross them or by the destructive effects of heavy rains, so in case of damages they no longer retain water for agriculture activities. Later, when the dry season takes hold, irrigated commercial agriculture commences.

These activities are constantly exposed to different types of drought. Meteorological drought, "*an abnormal precipitation deficit*" [107], has several direct and indirect effects on the availability of fodder (trees, shrubs, grass), the ephemeral wetlands water availability, the poor recharge of the surface aquifer, the poor quality of water in wells, the difficulties in irrigation for recession agriculture and irrigated gardening.

Drought can also manifest with a hydrological drought, defined as "*shortage of precipitation during the runoff and percolation season primarily affecting water surfaces*" and agricultural drought "*shortage of precipitation during the growing season which could affects crops*" [107].

So, the three forms of drought co-exist in the Region. On the other side of the rainfall anomalies, it is also important the risk dues to heavy precipitations, which could damage the earth embankments or make the wells unusable.

All these events threaten the livelihood of the Hodh El Chargui communities (*Fig. 9*) at present and future.

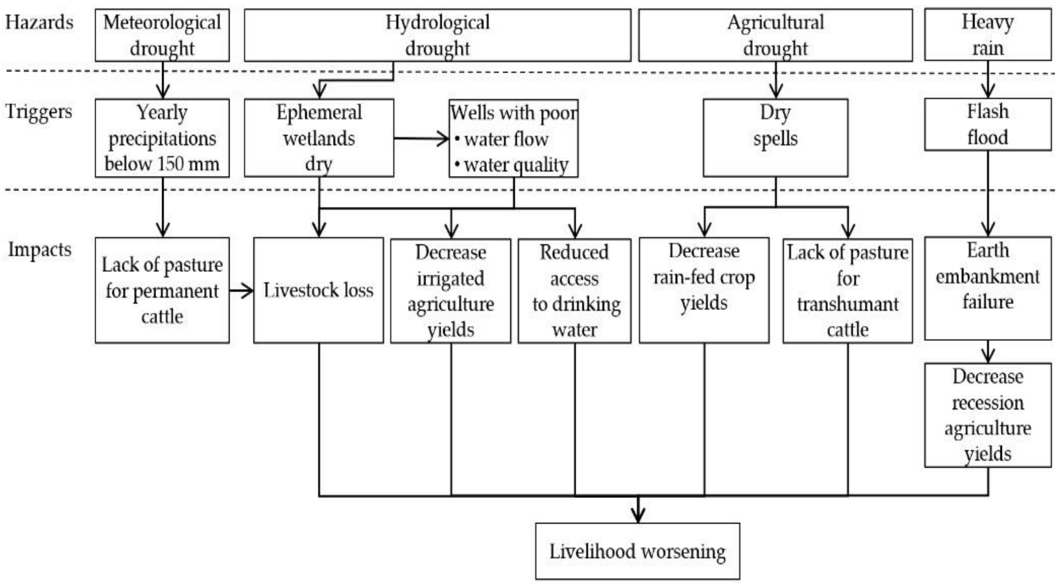


Fig. 9 Main hazards and their impacts on livelihoods in the Hodh El Chargui, Mauritania from Tiepolo et al. [2]

The four hazards, meteorological, hydrological and agricultural drought, and heavy precipitations, are combined in the MHRI respecting the same importance of each risk determinant and the quantitative measurement of the indicators [108].

The whole assessment made is organized into 4 phases which blend scientific and local knowledge at present and future scenario (*Fig. 10*).

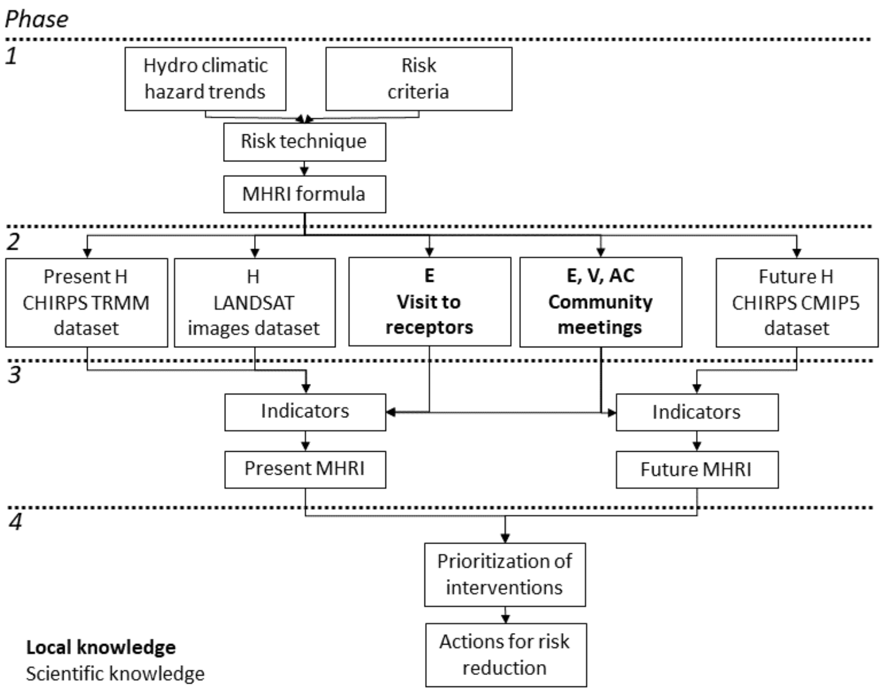


Fig. 10 Hodh El Chargui multi-hazard risk assessment flowchart

The first phase is dedicated to the identification of the context and the technique to be used. The second phase identifies the risk: which datasets to use to determine the hazard in the present and future conditions and how to ascertain exposure, vulnerability and adaptive capacity of these territories. The third phase identifies the indicators for each risk determinant in the present and future conditions, then the final phase identifies the risk reduction actions through the prioritization of the interventions.

The approach used in the MHRI assessment is characterized by its reproducibility and the interception of very different risk levels in an apparently homogeneous territory, influenced above all by rainfall distribution and extremes.

3.2 Definition of the current multi-risk zones in the Hodh El Chargui Region

The integration of the available information through the defined methodology allows the definition of the current multi-risk in the study area for each single basic unit of the analysis. The application of the methodology allows the identification of the most prone zones to natural disaster (i.e. Flood, Drought) and the combination of them. The mapping of this definition allows the classification of the basic unit of the analysis and it allows the production of a list of the priorities of intervention.

The multi-hazard risk is determined using the index technique [109]. This technique fits unskilled operators and it can be reproduced in other regions of Mauritania or West Africa [2] and these aspects represents a great advantage for its sustainability.

The literature review has determined that in risk assessments at a regional scale the indicators are chosen according to the information most easily accessible rather than according to the information that best represents the risk determinants. In particular, it is rare in these territories to find robust indicators for meteorological, hydrographical and agricultural drought while the meetings with the communities and the visits to the receptors allowed the identification of specific indicators to the Hodh El Chargui context.

The MHRI adds up the risk indices of the three types of drought and heavy precipitations. Following the methodology proposed by Tiepolo et al. [2] the index is made up of 48 indicators that scored quantitatively hazard, exposure, vulnerability and adaptive capacity. The real values found for each indicator are normalized in a 0-1 scale. Indicators are then added and normalized in a 0-1 scale for exposure, vulnerability and adaptive capacity. 29 vulnerability and exposure indicators were acquired through a survey in each community (April 2017), 15 exposure and adaptive capacity indicators were measured during a visit at the end of the dry season (May 2018), 4 hazard indicators were acquired from datasets on the daily and three-hourly rainfall and from satellite images (*Fig. 11*).

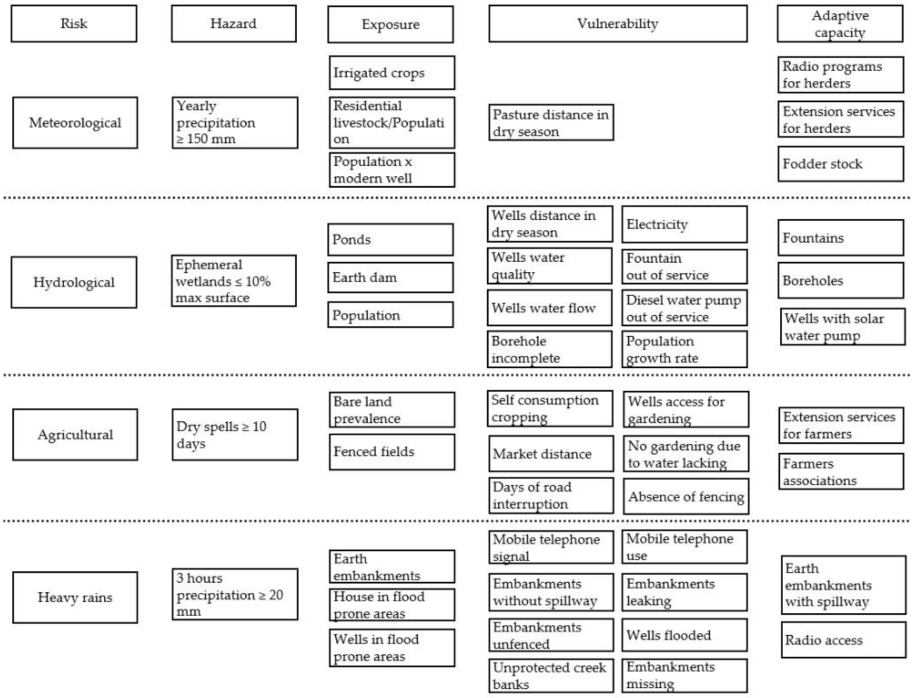


Fig. 11 Indicators used in the multi-hazard risk index for 13 communities in the Hodh El Chargui, Mauritania from Tiepolo et al. [2]

Regarding Hodh El Chargui meteorological monitoring network, for example, the only weather station with a continuous series of more than thirty years of daily precipitation data that reaches the present day is that of the airport of Nema: too little to represent a territory of more than 40000 Km². The use of the CHIRPS rainfall estimation from satellite allows the estimation of probability of meteorological, and agricultural drought while the 3-hourly TRMM dataset is used to intercept that of heavy precipitations. For hydrological drought a combination of the CHIRPS dataset with the Landsat images are able to intercept the dynamics of rainfall and the surface area of the ephemeral wetlands (Landsat images), in fact despite the low spatial resolution of the Landsat images used (30 m) this dataset is adequate to the size of water bodies observed (6 to 30 km²).

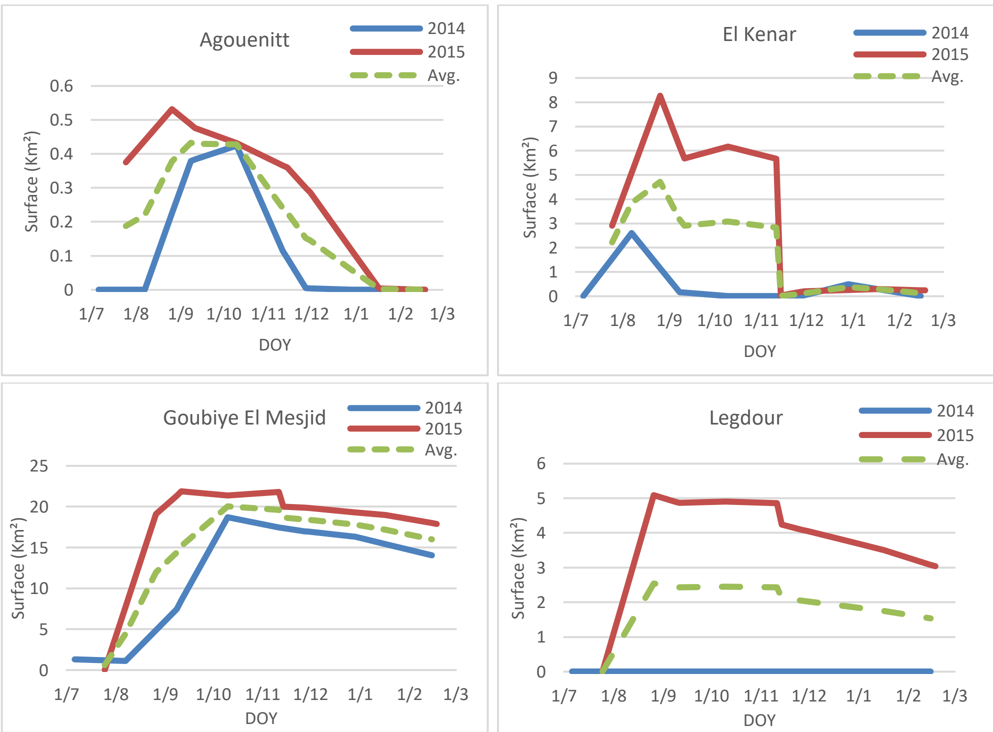
Accordingly, with Tiepolo et al. [2] the meteorological drought hazard is expressed by the probability of occurrence of rainfall accumulation during the months of July, August and September of less than 150 mm. That limit was identified based upon the quantity of rain considered the minimum amount necessary to produce plant biomass in an arid Sahelian environment [110-113]. Rainfall distribution is derived from the CHIRPS dataset in the 1981-2018 period, calculating the July-September rainfall accumulation on the 38-year historical series, it is possible to observe for how many years the cumulus falls below the identified threshold of 150 mm for each community identified by its geographical coordinates. Then the hazard drought is defined by the probability of such events in every community dividing the observed times of such low level or rainfall by 38.

The hydrological drought hazard is calculated on 6 ephemeral wetlands of reference for most of the communities considered. Its determination, due to the absence of localised information, does not use the current indices of hydrological drought [114]. The analysis proposed by Tiepolo et al. [2] is based upon the extension of the ephemeral wetlands as identified by calculating the Normalized Difference Water Index (NDWI) [115] on the Landsat satellite images. The unavailability of a complete series of images droves Tiepolo et al. [2] to the identification of the hydrological drought using the rainfall accumulation which determines the less extensive surfaces of the ephemeral wetlands and then determines the probability of that value using the 1981-2018 rainfall series. Unfortunately, as previously said, the Landsat images are taken in different moment of the rainy season, so to compare it in a time series analysis, a standardization of the values is needed to compare NDWI properly.

The first step is the evaluation of the annual surface profile of each ephemeral wetland in a dry year (2014) and in a wet year (2015). The satellite images were taken on different dates (t) each year, so it has been needed to build the annual profile by interpolating the surface data with the following formula:

$$Surface_t = Surface_{t-1} + \left(\frac{Surface_{t+1} - Surface_{t-1}}{N.Days_{[(t+1)-(t-1)]}}\right) \times N.Days_{[(t)-(t-1)]}$$

The procedure allows the construction of the wetlands profiles in the wet and dry years and it is possible to average the two values to build an hypothetical growth curve (*Fig. 12*).



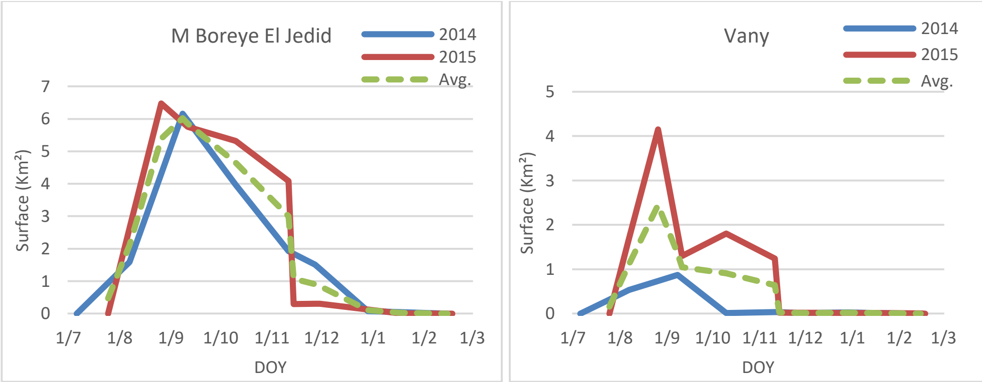


Fig. 12 Interpolated profile of ephemeral wetlands area in 2014 and 2015 and average growth curve

The use of the mean growth curve permits the production of the standardized profile of the surface of the 6 ephemeral wetlands at daily timestep for the July-November period. The standardization was calculated daily, using as a reference the maximum value recorded for each ephemeral wetland (*Fig. 13*).

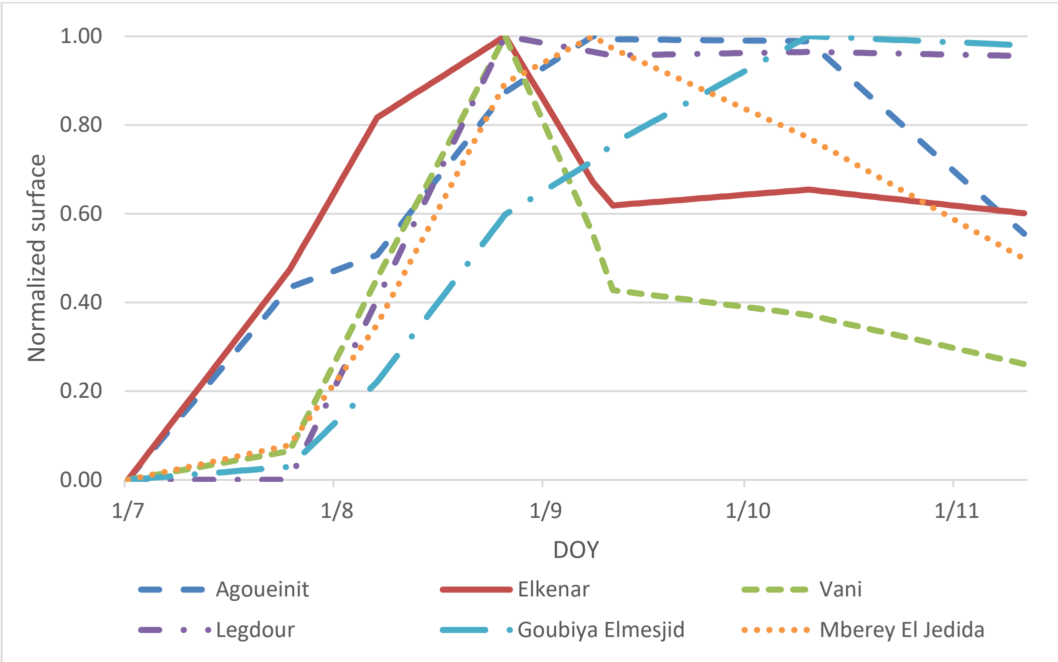


Fig. 13 Normalized growth curves of the 6 ephemeral wetlands

With 2014 and 2015 years available only, it is possible to find a rough curve of variation of the surfaces of the ephemeral wetlands; however, this method discriminates the seasonal filling evolution of the water bodies between the various ephemeral wetlands.

The following step is the determination of the period which influence the most the filling of the ephemeral wetlands. In literature none has explored this topic in the Hodh El Chargui region so it has been decided to test several intervals to find the most influencing one. Using the CHIRPS estimated rainfall dataset, the rain signal was decomposed in various accumulation lengths of 7, 14, 30 and 60 days before the measurement of the surface of the ephemeral wetland in question, the accumulation of the two central months of the rainy season (August-September) and the entire season. With those values available, the correlation between rain and water surface has been tested to understand which rainfall period influence the most the filling of each ephemeral wetland. The results are showed in Table 2.

Table 2 Correlation precipitation-ephemeral wetland surface

Ephemeral wetland	7 days	14 days	30 days	60 days	Aug-Sep	Season
Agoueinit	0.61	-0.01	0.16	-0.06	0.39	**0.40**
Elkenar	-0.44	0.02	0.48	0.32	**0.54**	0.35
Goubiye	-0.54	-0.20	0.10	0.41	0.44	**0.46**
MBoreye	-0.33	0.15	0.44	0.45	**0.58**	0.48
Vani	-0.14	0.16	**0.44**	0.28	0.42	0.13
Average	-0.33	0.15	0.44	0.45	**0.58**	0.48

Despite the different sensitivity of the ephemeral wetlands to precipitation, the period that, on average, most influences the filling of the ephemeral wetland is the August and September period. The precipitation over this period is used to identify the rainfall that characterized the three years with the minor extension of the ephemeral wetland water body. Averaging the rainfall in these three dry years is possible to identify the critical rainfall threshold and by consequence the probability of occurrence of this value on the entire series (1981-2018).

For Tiepolo et al. [2] the adopted method remains more suitable to measure changes in water bodies over time than that proposed by the European Commission Joint Research Centre, which reports the status of the individual grid point that make up the water bodies without, however, reporting the precise date to which they are observed [116].

Agricultural drought hazard is calculated with the probability of occurrence of dry spells of at least 10 consecutive days during the months of July, August and September ascertained using the CHIRPS dataset for the period 1981-2018 for each community.

The heavy precipitation hazard is expressed by the probability of occurrence of three-hourly rainfalls higher than 20 mm ascertained using the Tropical Rainfall Measuring Mission (TRMM) dataset for the 1991-2014 period at each community.

Considering the other risk components of the formula, Tiepolo et al. [2] decompose the each component (exposure, vulnerability and adaptive capacity) using the same approach of the hazard following the 4 hazards. It is important to remind that the adaptive capacity is of three types [118]: capacity to anticipate risk, to respond to risk, to recover and to change.

The information about these components is collected by a specific survey with 48 questions selected basing on the exchanges during the participatory meetings with local communities. The list could be integrated with other components, which could deeply investigate different aspects of the multi hazard risk, but there is also the need to correctly balance the list of parameters to investigate with the aim to select the most significant ones that could affect the risk impacts in the region and to avoid a too extensive list of parameters which could be difficult to retrieve data in all the communities.

For the meteorological drought the three components are defined as follows:

1. Exposure is defined by the presence of irrigated crops, the number of inhabitants per well and tropical livestock units [117] which remain in each community in the dry season;
2. Vulnerability is defined by the distance of the pastures from the village in the dry season;
3. Adaptive capacity is measured by the existence of radio programs aimed at farmers who report where vaccines and vaccination parks for livestock (anticipate), pastures, the availability of water and fodder banks (recover).

The hydrological drought presents the following components:

1. Exposure is represented by the number of ponds, earth dams and inhabitants of each community;
2. Vulnerability is expressed by distant wells, with poor water flow and quality, by the lack of boreholes, functioning fountains or by broken diesel water pumps but also by the population growth rate of the community in question, which increases demand for water;
3. Adaptive capacity the existence of boreholes, fountains or mini aqueducts (respond) which cover the demand for water by drawing from deep aquifers, especially if powered by solar water pumps, which have lower operating costs than diesel water pumps.

The three components for the Agricultural drought are the following one:

1. Exposure is given by the presence of horticultural activities protected by barbed wire fencing against the intrusion of stray cattle and the presence of pasture and arable surfaces. A proxy indicator is the share of bare land in the territory of each community: the lower it is the greater the exposure because there is a higher quota of the territory protected by fences dedicated to the agricultural activity;
2. Vulnerability is still linked to the availability and accessibility of wells for irrigation, the practice of cropping for self-consumption only, the rate of unfenced lots, the distance to market and the number of days of road interruption;
3. Adaptive capacity is higher if there are extension services (anticipate) and farmers' associations (recover).

Considering heavy precipitation, the components are listed here:

1. Exposure is given by the number of earth embankments and by the wells and houses in flood prone areas, which could become inaccessible or be flooded;
2. Vulnerability is expressed by the possibility of receiving an early warning by telephone (therefore the coverage of the area with a mobile phone signal), by the lack of protection of the earth embankments from the crossing of livestock, by the absence of spillways and locks, which reduce the pressure of flash floods on the hydraulic works, and by the presence of creeks without bank protection;
3. Adaptive capacity is measured by the radio access counts to receive early warning (anticipate) as well as spillways and locks in the earth embankments, allowing for the pressure of flash floods on the earth embankments to be regulated, preserving them from collapse (respond).

To be able to compare the different hazards Tiepolo et al. [2] took a series of assumptions. Each indicator and each determinant has the same significance. The probability of occurrence of each hydro-climatic hazard is calculated observing the same timeframe (1991-2018), except for heavy precipitations (1991-2014).

For each individual risk, the value of the individual determinants varies between 0 and 1, irrespective of the number of indicators that describe it. Each indicator has the same significance.

The elaboration of these values identifies which risk, determinant and indicators have the greatest effect on the MHRI. The indicators that present the highest value (exposure, vulnerability) or lowest value (adaptive capacity) recommend the actions to be undertaken.

Hazard

Meteorological drought

The definition of meteorological drought in the Hodh El Chargui is complex. The scarcity of observed data is insufficient to understand the quantity of precipitation that can trigger negative effects on the production system. Moreover, the production systems are naturally resistant to extreme drought conditions. In literature [110-113] 100-150 mm of precipitation are considered the minimum annual value within which herbaceous species can produce biomass even in these extreme dry conditions. Tiepolo et al. [2] use the 150 mm as threshold for meteorological drought.

The rain profile of the region can be extracted by the CHIRPS images. In the last thirty-eight years, Hodh El Chargui had its driest period during the 80s, with a minimum of 102 mm in 1983. Since 2006, there has been a recovery of rainfall with values that never dropped below 150 mm per year (Fig. 14).

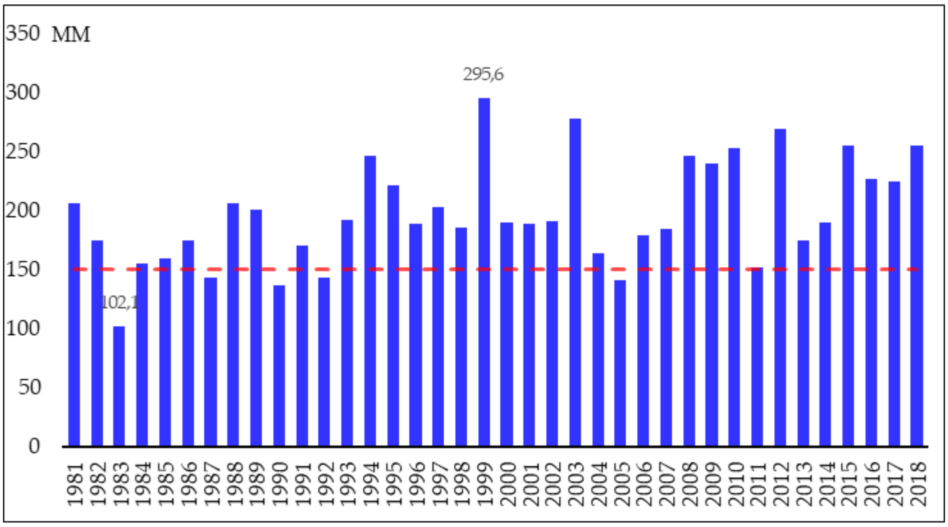


Fig. 14 Yearly precipitation 1981-2018 in the Southern Hodh El Chargui region by CHIRPS dataset and 150 mm limit

The extraction of the rainfall profile for each community shows that in Boukahzama 1, Agoueinit and NGuiya, which are the northernmost communities, the frequency of years with less than 150 mm is higher while in the five communities on the southern border with Mali (Drougal, Gnebett Ehel Heiba, Jrana, Mberey El Jedida and Goubya Elmesjid), the number of years below 150mm is very rare (Table 3).

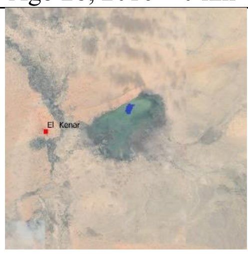
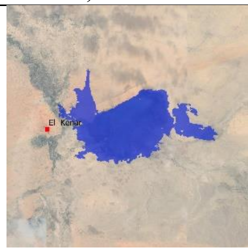
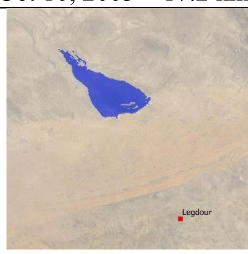
Table 3 Meteorological number of drought years and drought probability for the 13 communities of the Hodh El Chargui.

Community	**n. years ≤ 150 mm**	**Probability**
Boukhzama 1	26	0.68
Agoueinit	14	0.37
NGuiya	14	0.37
Begou	4	0.11
Elkenar	4	0.11
Legaida	3	0.08
Legdur	2	0.05
Vani	2	0.05
Mberey El Jedida	1	0.03
Goubya Elmesjid	1	0.03
Jrana	1	0.03
Drougal	0	0.00
Gnebett Ehel Heiba	0	0.00

Hydrological drought

The six ephemeral wetlands in the study area represent the water for the Hodh El Chargui communities. These are semi-permanent water bodies of maximum extension between 6 and 30 km^2. All of them are characterized by weak depth and they represent a fundamental resource for human and pastoral water supplies, for fishery resources and, in the case of Agoueinit, for the practice of the recession agriculture. Regarding the historical images, it is possible to observe that the flood regime is not the same in the 6 water bodies, in fact, it is rare for a dry or wet year to affect all 6 ephemeral wetlands at the same time.

In the historical data it is possible to identify the 2003 as the year in which the ephemeral wetlands reached in total 78% of the maximum surface, followed by 2011 (70%), 2009 (57%) and 2012 (55%). While in 1987, 5 ephemeral wetlands out of 6 have a surface reduced to less than 10% of the maximum observed extension. In 2005 there has been severe dry conditions that drop the average surface of the ephemeral wetlands to 1% of the maximum average. In 2014 there has been a hydrological drought for half of the ephemeral wetlands and in 2016 for 2 out of 6. The two southernmost ephemeral wetlands have not suffered drought in the last 8 years, while the northernmost has been dry for 6 years out of 8 and the center-south has been dry for 1 or 2 years out of 8.

Ephemeral wetland	Minimal surface	Maximal surface
Agoueinit	 Ago 28, 2016 – 0 km²	 Oct 10, 2003 – 6 km²
Elkenar	 Sep 8, 2014 – 0.2 km²	 Oct 10, 2003 – 17.2 km²
Legdour	 Sep 8, 2014 – 0 km²	 Sep 7, 2011 – 6 km²

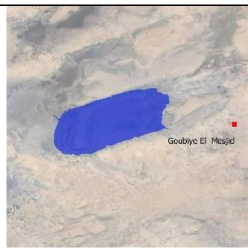
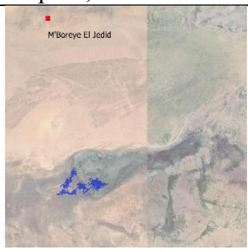
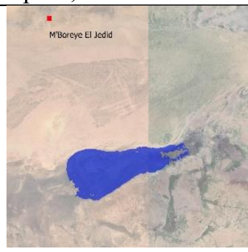
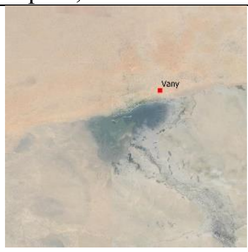
Goubiye	 Sep 15, 2002 – 0 km²	 Sep 26, 2012 – 30.3 km²
Mboreye	 Sep 15, 2002 – 1.4 km²	 Sep 26, 2012 – 13.9 km²
Vani	 Ago 28, 2016 – 0.1 km²	 Oct 10, 2003 – 8.3 km ²

Fig. 15 Minimal (left) and maximal (right) surface of six ephemeral wetlands with date and surface of the waterbody in the Hodh El Chargui, Mauritania, 2001-2018 by Tiepolo et al. [2]

As explored by Tiepolo et al. [2], the extension of 6 ephemeral wetlands is linked to the August-September rainfall, so it is possible to found the hydrological drought probability on the 1981-2018 period in each waterbody. Using data from the CHIRPS dataset in August-September period it has been possible to identify the precipitation recorded in the 3 years that records the minimum surface of the ephemeral wetlands adjusted with the use of the standardized curve of ephemeral wetlands evolution previously defined. The average precipitation in the August-September period in these 3 dry years defines the critical amount of rainfall which could trigger a stress in the ephemeral wetlands. The results are shown the following table (Table 4).

Table 4 Average of the August-Sept. rainfall during the 3 years with lowest water accumulation in the mares (mm)

Agoueinitt	*El Kenar*	*Vany*	*Legdour*	*Goubiye El Mesjid*	*M Boreye El Jedid*
106.2	113.3	131.1	112.9	135.3	113.0

The frequency of years below these thresholds in the 1981-2016 precipitation series represent the possibility to have low water accumulation then it is possible to evaluate the probability of the Hydrological Hazard for each ephemeral wetland. The values are expressed in the next Table 5:

Table 5 Hydrological drought probability for the 6 ephemeral wetlands in the Hodh El Chargui.

Ephemeral wetland	**Drought Probability**
Agoueinit	0.47
Elkenar	0.13
Vani	0.09
Goubye Elmesjid	0.09
Legdour	0.06
Mberey El Jedida	0.06

Agricultural drought

By definition agricultural drought is when it affects agricultural and pastoral production. As described by Tiepolo et al. [2], the 13 communities cultivate in rain-fed conditions, in the form of recession agriculture and irrigated gardens. The first type of agriculture is directly influenced by the rainfall distribution, while pastoral production, which plays a major role in the region's economy, is influenced by the presence of pastures for transhumant herds during the wet season. Biomass production is therefore relegated to spontaneous herbaceous and shrub species which are naturally very resistant to water stress conditions. However, lengthy dry spells during the wet season can reduce the availability of fodder. Using the CHIRPS dataset, the daily series of the different communities can be extracted and the maximum length of the dry spell during the season can be assessed (*Fig. 16*).

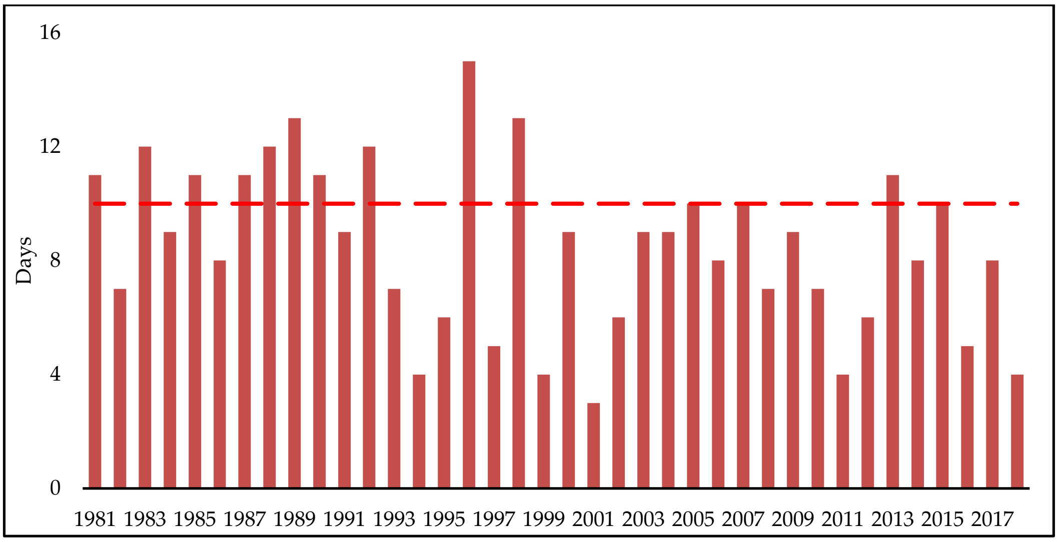


Fig. 16 Maximum dry spell length in July, August and September in the Hodh El Chargui using CHIRPS dataset.

Although from 2006 onwards rainfall is favorable, there are 3 years with dry spells equal to or greater than 10 days. The frequency of dry spells follows a north-south distribution, they are more frequent in the northern communities of Boukhzama 1, Agoueinit and NGuiya and less frequent in the southern communities of Drougal, Gnebett Ehel Heiba, Goubya Elmesjid, Jrana and Mberey El Jedida (Table 6).

Table 6 Agricultural drought probability expressed by dry spells frequency in 13 communities of Hodh El Chargui, 1981-2018.

Community	**Dry spell of 10 consecutive dry days n. years**	**Probability**
Boukhzama 1	33	0.89
Agoueinit	28	0.74
NGuiya	28	0.74
Legaida	22	0.58
Begou	21	0.55
Elkenar	17	0.45
Legdur	16	0.42
Vani	16	0.42
Jrana	14	0.37
Mberey El Jedida	14	0.37
Goubya Elmesjid	13	0.34
Drougal	12	0.32
Gnebett Ehel Heiba	12	0.32

Heavy precipitations

The definition of the critical threshold for heavy precipitation in the Hodh El Chargui is also quite challenging. The data are scarce and in literature only one study have propose a threshold of extreme rainfall (37 mm/day) [119]. That daily precipitation amount does not necessarily evolve in conditions favorable to flash floods. Flash floods are normally generated by very intense phenomena that last minutes to few hours. Using the TRMM 3-hourly estimation dataset, it has been set 20 mm/3h the threshold to identify the episodes of such dangerous intensity. The frequency of three-hourly rainfall higher than 20 mm was verified, analysing the extractions of the 3-hourly values from the TRMM dataset in the 1991-2014 period for each of the 13 communities. It follows that Boukhzama 1, Drougal and Gnebett Ehel Heiba exceed this threshold more frequently than Elkenar, Jrana and Mberey

El Jedida. In this case there is no decreasing distribution of the frequency of the hazard as it proceeds from north to south (Table 7).

Table 7 Heavy precipitations (> 20 mm in 3 hours) probability according TRMM dataset, 1991-2014.

Community	**> 20 mm in 3 hours n. of years**	**Probability**
Boukhzama 1	7	0.41
Drougal	6	0.35
Gnebett Ehel Heiba	6	0.35
Begou	5	0.29
Legaida	5	0.29
Legdur	5	0.29
Vani	5	0.29
Agoueinit	4	0.24
Goubya Elmesjid	4	0.24
NGuiya	4	0.24
Elkenar	3	0.18
Jrana	3	0.18
Mberey El Jedida	3	0.18

Exposure

The exposure component to different hazards is defined by 11 indicators. The three components for meteorological drought are:

- irrigated crops, where it checks the presence Yes = 1 and No = 0
- residential livestock, Resident TLU/Population, the values go from 1 and 217 normalized from 0 and 1and
- number of inhabitants per well, which goes from 32 to 2600 then normalized from 0 and 1.

Table 8 The exposure component for meteorological drought in each community

Community	Irrigated crops	Resident TLU/Population	Population x well	Sum	Normalized
Agoueinit	1	0.9	0.84	2.74	1
Begou		0.4	0.07	0.47	0.17
Boukhzama 1	1	0.1	0.06	1.16	0.42
Drougal	1	0	0.25	1.25	0.46
Elkenar	1	0.2	0.08	1.28	0.47
Gnebett Ehel Heiba		0.1	0.25	0.35	0.13
Goubya Elmesjid	1	0	0.03	1.03	0.38
Jrana		0.1	0.44	0.54	0.20
Legaida	1		1	2	0.73
Legdur	1	1	0.03	2.03	0.74
Mborey El Jedid		0.3	0.46	0.76	0.28
NGuyia	1	0.9	0.05	1.95	0.71
Vani	1	0.1	0.01	1.11	0.41

For hydrological drought it has been selected 3 indicators:

- the presence of ponds, Yes = 1 and No = 0
- the presence of earth dams, Yes = 1 and No = 0 and
- the population, which goes from 400 to 2600 then normalized from 0 and 1.

Table 9 The exposure component for hydrological drought in each community

Community	Ponds	Earth dam	Population	Sum	Normalized
Agoueinit	1	0.05	0.77	1.82	0.77
Begou	1	0.07	0	1.07	0.45
Boukhzama 1		0.5	0.47	0.97	0.41
Drougal			0.46	0.46	0.19
Elkenar	1		0.15	1.15	0.49
Gnebett Ehel Heiba			0.23	0.23	0.10
Goubya Elmesjid	1	0.25	0.91	2.16	0.91
Jrana		0.1	0.4	0.5	0.21
Legaida	1		0.92	1.92	0.81
Legdur		0.05	1	1.05	0.44
Mborey El Jedid			0.04	0.04	0.02
NGuyia			0.05	0.05	0.02
Vani	1	1	0.37	2.37	1.00

For agricultural drought two indicators have been selected:

- The bare land rate, Yes=1 and No=0
- The rate of fenced fields, where No=1

Table 10 The exposure component for agricultural drought in each community

Community	Bare land rate	Fenced fields	Sum	Normalized
Agoueinit	1	1	2	1.00
Begou	1	0.5	1.5	0.75
Boukhzama 1	1	0	1	0.50
Drougal	1	0	1	0.50
Elkenar	1	0	1	0.50
Gnebett Ehel Heiba	1	0	1	0.50
Goubya Elmesjid	0.5	0	0.5	0.25
Jrana	0.5	1	1.5	0.75
Legaida			0	0.00
Legdur	0.5	1	1.5	0.75
Mborey El Jedid	0.5		0.5	0.25
NGuyia	1	0.5	1.5	0.75
Vani	0.5		0.5	0.25

The three indicators investigated for heavy rains are:

- earth embankments, from 0 to 20 normalized in a scale 0-1;
- the presence of houses in flood prone area, Yes=1 No=0, and
- wells in flood prone area, Yes=1 No=0.

Table 11 The exposure component for heavy rains in each community

Community	Embankment	House in flood prone area	Wells in flood prone area	Sum	Normalized
Agoueinit	1			1	0.50
Begou	1		1	2	1.00
Boukhzama 1	1	1		2	1.00
Drougal	1			1	0.50
Elkenar	1			1	0.50
Gnebett Ehel Heiba	1			1	0.50
Goubya Elmesjid	1			1	0.50
Jrana	1			1	0.50
Legaida	1			1	0.50
Legdur	1		1	2	1.00
Mborey El Jedid	1			1	0.50
NGuyia	1			1	0.50
Vani	1			1	0.50

The highest values of exposure to meteorological, hydrological and agricultural drought and to heavy rains are reached respectively in Agoueinit, Vani, Agoueinit e Boukhzama 1. The exposure to all hazards sees Agoueinit and Legdur with the highest value and Mberey El Jedida with the lowest one.

Vulnerability

The vulnerability to the different hazards is investigated using 23 indicators. For meteorological drought the only indicator is the distance to pasture in dry season, from 8 to 200 Km normalized in a scale 0-1.

Table 12 The vulnerability component for meteorological drought in each community

Community	Pasture distance in dry season	Sum	Normalized
Agoueinit	0.1	0.1	0.1
Begou	0.75	0.75	0.75
Boukhzama 1	0.05	0.05	0.05
Drougal	0.2	0.2	0.2
Elkenar	0.08	0.08	0.08
Gnebett Ehel Heiba	0.1	0.1	0.1
Goubya Elmesjid	0.08	0.08	0.08
Jrana	0.04	0.04	0.04
Legaida	1	1	1
Legdur	0.25	0.25	0.25
Mborey El Jedid	0.04	0.04	0.04
NGuyia	0.1	0.1	0.1
Vani	0.1	0.1	0.1

Hydrological drought vulnerability is expressed by 8 indicators which are:

- Electricity (N. of photovoltaic systems), from 0 to 5 normalized in a scale 1-0 where the absence of photovoltaic system is 1 the higher vulnerability;
- distance to wells, from 0 to 3.1 Km normalized in a scale 0-1;
- boreholes incompletes, Yes=1;
- diesel water pump broken down, Yes =1;
- irregularly functioning fountain, Yes=1;
- wells water flow, Good=1;
- wells water quality, Good=1;
- population growth rate, which goes from -13 to 63, normalized in a scale 0-1.

Table 13 The vulnerability component for hydrological drought in each community

Comm.	Electric.	Wells distance	Boreh. Incompl.	Diesel water pump broken	Fountain irregular service	Well water flow	Well water quality	P growth	Sum	Norm.
Agoueinit	0.66							0.21	0.87	0.18
Begou		0.26					0.5	0.3	1.06	0.23

Boukhzama 1	0.33								0.33	0.07
Drougal	1	0.01				0.66	0.3		1.97	0.42
Elkenar	1	0.13				1			2.13	0.45
Gnebett Ehel Heiba	1	0.77				1			2.77	0.59
Goubya Elmesjid	0.66		1			0.5	0.3	0.45	2.91	0.62
Jrana	1	0.1			1	0.3	0.66	0.18	3.24	0.69
Legaida	1	0.55				0.5		1	3.05	0.65
Legdur	1	0.13						0.18	1.31	0.28
Mborey El Jedid	1							0.24	1.24	0.26
NGuyia	1			1	1	1	0.5	0.21	4.71	1.00
Vani	1	1	1			0.75		0.51	4.26	0.90

The indicators chosen for agricultural drought are 6:

- wells access for gardening, Yes=1;
- absence of gardening due to lack of water, Yes=1;
- gardens fencing, No=1;
- distance to market, from 0 to 33 Km normalized in a scale 0-1;
- cropping for self-consumption, Yes=1;
- number of days of road interruptions, which goes from 0 to 60 normalized in a scale 0-1.

Table 14 The vulnerability component for agricultural drought in each community

Community	Well access for gardening	Absence of gardening	Market distance	Gardening Fencing	Cropping for self-consumption	Road interruption	Sum	Normalized
Agoueinit			0.03			0.03	0.06	0.02
Begou			0.76			0.5	1.26	0.34
Boukhzama 1	0.5		0.82	0.5		0.05	1.87	0.50
Drougal	1			1	1	0.05	3.05	0.82
Elkenar			0.55				0.55	0.15
Gnebett Ehel Heiba			0.15		1	0.5	1.65	0.44
Goubya Elmesjid	1		0.73		1	1	3.73	1.00
Jrana			0.21			0.12	0.33	0.09
Legaida		1	0.26	0.5			1.76	0.47
Legdur			0.42	1	1		2.42	0.65
Mborey El Jedid			0.42			0.12	0.54	0.14
NGuyia			0.88				0.88	0.24
Vani			0.61			0.23	0.84	0.23

Finally, eight indicators are selected for heavy rains vulnerability:

- presence of mobile telephone signal, Yes=0, No=1;
- use of mobile telephone, Yes=0, No=1;

- earth embankment absence, Yes=1;
- presence of leaking, Yes=1;
- presence of lacking spill, Yes=1;
- presence of fence, Yes=1;
- presence of wells flooded, Yes=1.
- presence of unprotected creek banks, Yes=1.

Table 15 The vulnerability components for heavy rains in each community

Community	Mobile signal	Mobile use	Embankment missing	Embankment without spillway/lock	Embankment leaking	Embankment unfenced	Creek banks unprotected	Wells flooded	Sum	Normalized
Agoueinit				1	1	1	1		4	0.89
Begou								1	1	0.22
Boukhzama 1	1	1					1	1	4	0.89
Drougal		1							1	0.22
Elkenar			1						1	0.22
Gnebett Ehel Heiba		1		0.5	0.5	1			3	0.67
Goubya Elmesjid				0.5	0.5	0.5			1.5	0.33
Jrana									0	0.00
Legaida						1			1	0.22
Legdur		1	1	0.5	0.5	0.5		1	4.5	1.00
Mborey El Jedid		1		1		1			3	0.67
NGuyia		1		0.5		1			2.5	0.56
Vani		1							1	0.22

The highest values of vulnerability to meteorological drought are reached by Legaida, those to hydrological drought by Vani, those to agricultural drought by Goubya Elmejid and those to heavy rains by Legdur. The exposure to all hazards sees Legaida and Legdur with the highest values, and Agoueinit and Vani with the lowest ones.

Adaptive capacity

The adaptive capacity to the different hazards is represented by 10 indicators. For the meteorological drought three indicators have been selected:

- the presence of herders/farmers radio programs, Yes=1;
- the presence of extension services for herders, Yes=1;
- the presence of fodder stock, Yes=1.

Table 16 The adaptive capacity components for meteorological drought in each community

Community	Herders, farmers radio programs	Extension herders services	Fodder stock	Sum	Normalized
Agoueinit	1	1		2	1
Begou	1			1	0.5
Boukhzama 1	1			1	0.5
Drougal				0	0
Elkenar	1	1		2	1
Gnebett Ehel Heiba				0	0
Goubya Elmesjid		1		1	0.5
Jrana				0	0
Legaida			1	1	0.5
Legdur		1		1	0.5
Mborey El Jedid		1		1	0.5
NGuyia	1	1		2	1
Vani		1	1	2	1

The two indicators chosen for the hydrological drought are:

- the presence of fountain, Yes=1 and
- the presence of boreholes, Yes=1.

Table 17 The adaptive capacity components for hydrological drought in each community

Community	Fountains	Borehole	Sum	Normalized
Agoueinit	1	1	2	1.00
Begou			0	0.00
Boukhzama 1		1	1	0.50
Drougal			0	0.00
Elkenar			0	0.00
Gnebett Ehel Heiba			0	0.00
Goubya Elmesjid			0	0.00
Jrana			0	0.00
Legaida			0	0.00
Legdur			0	0.00
Mborey El Jedid			0	0.00
NGuyia		1	1	0.50
Vani		1	1	0.50

The three indicators for the agricultural drought adaptive capacity are:

- the presence of extension agricultural services, Yes=1;
- the presence of solar water pumps, Yes=1 and
- the presence of small household farmer's associations, Yes=1.

Table 18 The adaptive capacity components for agricultural drought in each community

Community	Extension agri services	Solar pump	Farmer association	Sum	Normalized
Agoueinit			0.3	0.3	0.15
Begou				0	0.00
Boukhzama 1	0.5	1	0.5	2	1.00
Drougal			1	1	0.50
Elkenar				0	0.00
Gnebett Ehel Heiba				0	0.00
Goubya Elmesjid	1		1	2	1.00
Jrana				0	0.00
Legaida				0	0.00
Legdur				0	0.00
Mborey El Jedid				0	0.00
NGuyia				0	0.00
Vani				0	0.00

The adaptive capacity for heavy rains is defined by 3 indicators:

- the presence of farmer associations, Yes=1;
- the radio access, Yes=1 and
- the presence of earth embankments provided with spillway, Yes=1.

Table 19 The adaptive capacity components for heavy rains in each community

Community	Farmer association	Farmer radio access	Spillway	Sum	Normalized
Agoueinit				0	0.00
Begou				0	0.00
Boukhzama 1				0	0.00
Drougal		1		1	0.50
Elkenar		1		1	0.50
Gnebett Ehel Heiba		1		1	0.50
Goubya Elmesjid		1		1	0.50
Jrana		1		1	0.50
Legaida				0	0.00
Legdur	1	1		2	1.00
Mborey El Jedid		1		1	0.50
NGuyia		1		1	0.50
Vani		1		1	0.50

The highest values of adaptation to meteorological drought are reached by Elkenar and NGuiya, those to hydrological drought by Agouenit, those of adaptive capacity to agricultural drought by Boukhzama 1 and those of adaptive capacity to heavy rains by Drougal, Elkenar, Gnebett Ehel Heiba, Goubya Elmesjid, Legaida, Legdur, Nguiya and Vani. The adaptive capacity to all hazards is highest in Goubya Elmesjid and lowest in Agoueinit, Begou and Legaida.

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 risk it is possible to calculate the MHRI. Starting from meteorological risk the results are shown in Table 20.

Table 20 Meteorological risk components for each community in the Hodh El Chargui

Community	Hazard	Exposure	Vulnerability	Adaptive capacity	Meteorological risk
Agoueinit	0.37	1	0.1	1	0.04
Begou	0.11	0.17	0.75	0.5	0.05
Boukhzama 1	0.68	0.42	0.05	0.5	-0.02
Drougal	0	0.46	0.2	0	0.00
Elkenar	0.11	0.47	0.08	1	-0.05
Gnebett Ehel Heiba	0	0.13	0.1	0	0.00
Goubya Elmesjid	0.03	0.38	0.08	0.5	0.00
Jrana	0.03	0.20	0.04	0	0.01
Legaida	0.08	0.73	1	0.5	0.10
Legdur	0.05	0.74	0.25	0.5	0.02
Mborey El Jedid	0.03	0.28	0.04	0.5	-0.01
NGuyia	0.37	0.71	0.1	1	-0.07
Vani	0.05	0.41	0.1	1	-0.02

In few communities the risk is negative. This is due to the high adaptive capacity in respect to the Exposure and Vulnerability component. Nevertheless, the ranking of the risk in each community is still valid. It is important to remind that the main aim is to retrieve the priorities of interventions within the region, so it becomes more important to detect the communities at higher risk and not to exactly quantify the "amount" of risk.

The same approach is made with the Hydrological risk which produces the following results (

Table 21).

Table 21 Hydrological risk components for each community in the Hodh El Chargui

Community	Hazard	Exposure	Vulnerability	Adaptive capacity	Hydrological Risk
Agoueinit	0.47	0.77	0.18	1.00	-0.02
Begou	0.06	0.45	0.23	0.00	0.04
Boukhzama 1	0.47	0.41	0.07	0.50	-0.01
Drougal	0.06	0.19	0.42	0.00	0.04
Elkenar	0.13	0.49	0.45	0.00	0.12
Gnebett Ehel Heiba	0.09	0.10	0.59	0.00	0.06
Goubya Elmesjid	0.09	0.91	0.62	0.00	0.14
Jrana	0.09	0.21	0.69	0.00	0.08
Legaida	0.06	0.81	0.65	0.00	0.09
Legdur	0.06	0.44	0.28	0.00	0.04
Mborey El Jedid	0.06	0.02	0.26	0.00	0.02
NGuyia	0.06	0.02	1.00	0.50	0.03
Vani	0.09	1.00	0.90	0.50	0.13

The hydrological risk shows that the higher adaptive capacity is reached in the community with the highest hazard. The effect is that these communities have a negative value of risk, and the interpretation possible is that the communities are aware of the risk and they already taken some measures to adapt to this threat. It is important to underline the autonomous capacity of the communities to take some actions. In fact, the areas most prone to disaster are normally the zones where population is aware and they take all the needed measure to reduce the risk. Nevertheless, the resources are often not sufficient to cope the risk so, once more, it is important to produce such analysis to address correctly the interventions in the region. Considering the agricultural drought risk the following table (Table 22) shows the results of the analysis.

Table 22 Agricultural drought risk components for each community in the Hodh El Chargui

Community	Hazard	Exposure	Vulnerability	Adaptive capacity	Agricultural risk
Agoueinit	0.74	1.00	0.02	0.15	0.64
Begou	0.55	0.75	0.34	0.00	0.60
Boukhzama 1	0.87	0.50	0.50	1.00	0.00
Drougal	0.32	0.50	0.82	0.50	0.26
Elkenar	0.45	0.50	0.15	0.00	0.29
Gnebett Ehel Heiba	0.32	0.50	0.44	0.00	0.30
Goubya Elmesjid	0.34	0.25	1.00	1.00	0.09
Jrana	0.37	0.75	0.09	0.00	0.31
Legaida	0.58	0.00	0.47	0.00	0.27
Legdur	0.42	0.75	0.65	0.00	0.59
Mborey El Jedid	0.37	0.25	0.14	0.00	0.15
NGuyia	0.74	0.75	0.24	0.00	0.73
Vani	0.42	0.25	0.23	0.00	0.20

For agricultural drought the adaptive capacity is limited to few communities. This aspect drives all the communities to be more prone to such kind of risk. The increase of the adaptive capacity of the communities could help in reducing the agricultural risk. The heavy rain risk for Hodh El Chargui communities is defined in the next table (Table 23).

Table 23 Heavy rain risk components for each community in the Hodh El Chargui

Community	Hazard	Exposure	Vulnerability	Adaptive capacity	Heavy rain risk
Agoueinit	0.24	0.50	0.89	0.00	0.33
Begou	0.29	1.00	0.22	0.00	0.35
Boukhzama 1	0.41	1.00	0.89	0.00	0.77
Drougal	0.35	0.50	0.22	0.50	0.08
Elkenar	0.18	0.50	0.22	0.50	0.04
Gnebett Ehel Heiba	0.35	0.50	0.67	0.50	0.23
Goubya Elmesjid	0.24	0.50	0.33	0.50	0.08
Jrana	0.18	0.50	0.00	0.50	0.00
Legaida	0.29	0.50	0.22	0.00	0.21
Legdur	0.29	1.00	1.00	1.00	0.29
Mborey El Jedid	0.18	0.50	0.67	0.50	0.12
NGuyia	0.24	0.50	0.56	0.50	0.13
Vani	0.29	0.50	0.22	0.50	0.06

Heavy rains impact all the communities in different ways, from the maximum in Boukhzama where it reaches 0.77 to Jrana where the adaptive capacity reach the level of the Exposure and Vulnerability component giving as result zero.

Combining the 4 risk components it is possible to produce the final MHRI table (Table 24).

Table 24 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 MHRI index could be seen as a relative index that place a community at risk in respect to others allowing the ranking of the municipalities the most at risk.

The interval between the maximum and minimum value of the multi-hazard risk index (MHRI) was divided up into four categories (from low to severe) that are equally represented in the final MHRI assessment and the following map (Fig. 17) shows the distribution of communities at severe (MHRI above 0.90), high (0.60-0.89), moderate (0.35-0.59) and low risk (MHRI below 0.35) conditions.

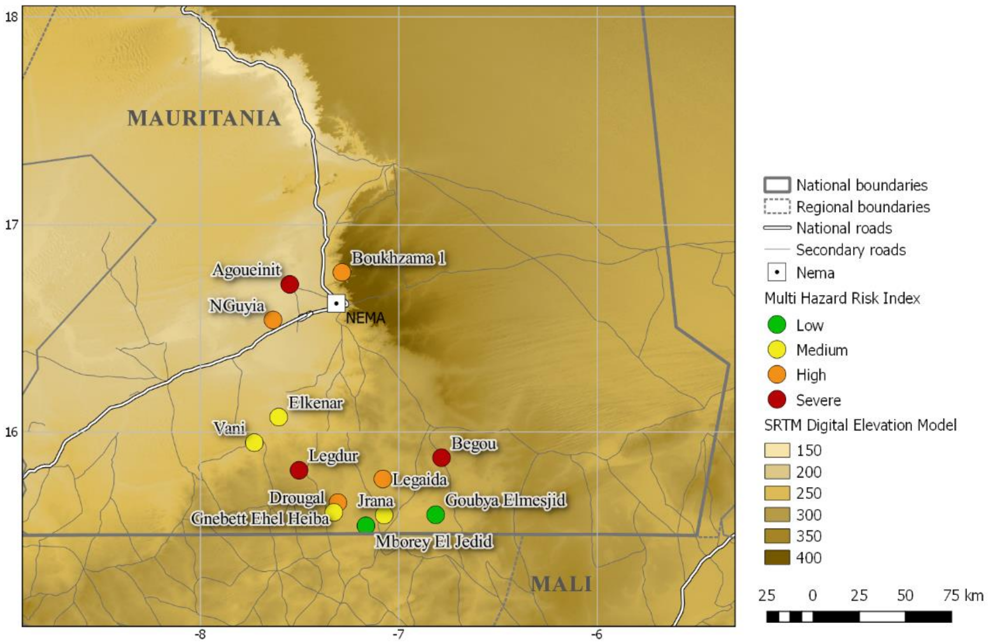


Fig. 17 The 13 rural communities at multi-hazard risk in the Hodh El Chargui, Mauritania

Begou, Agoueinit and Legdour are at a severe risk, NGuyia, Boukhzama 1, Legaida and Gnebett Ehel Heiba are at higher risk, Elkenar, Jrana, Drougal and Vani are at moderate risk and Goubya Elmesjid and Mborey El Jedid are at lower risk. Therefore, it seems that 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. This geographical distribution of the risk is somehow inversely proportional with the distribution of the amount of precipitation during the season. Considering the composition of the trhree components of risk, typically the value of the MHRI is substantially determined by that of agricultural drought and heavy rains while meteorological drought has only a very limited influence on the final risk index and the hydrological risk contributes significantly only in 3 communities out of 13 (Table 24).

3.3 Local climatic projections in the Hodh El Chargui Region

The use of different climatic evolution trajectories from CMIP5 allows to get different evolution of daily rainfall for the period 2021-2080. Every model has its intrinsic characteristics and parametrization and consequently the evolution of the rainfall in time is different. Using the ensemble approach, from the 18 models trajectories, it is possible to extract the median and the interquartile model spread (the 25th and 75th quantiles) to create 3 different scenarios for the future evolution of rainfall, the optimistic scenario, the median and the pessimistic one. This allows also to retrieve information about the uncertainty or confidence of the models in detecting some trends. Many considerations about the usability of such information by decision makers could be done, but essentially here the focus is to produce a set of information useful to take some decisions in urban or regional planning.

It is important to recall that climate models are not conceived to predict exactly the future climate but to estimate its main behaviour.

The extraction of the rainfall statistics for each community are made using the CDO tool for every single bias corrected model using the geographical coordinates of the main village. Then, the following step is to evaluate the probability of such critical meteorological conditions dividing the number of events projected in the period 2021-2080 by 60 (the number of years). The results of each model are grouped and it is possible to produce the quantiles of the results for every single index (precipitation amount, dry spell, etc.). These values are applied in the Risk formula to retrieve the MHRI for the future.

Meteorological drought projection

In analogy with the analysis of the current conditions, meteorological drought is defined by the probability of occurrence of rainfall accumulation during the period of July-September of less than 150 mm. Using the CMIP5 models series, the Hodh El Chargui region rain profile in the period 2021-2080 can be extracted.

It results 18 different configurations. The number of events with value less than 150 mm are divided by 60 to obtain the probability of occurrence of year with less than 150 mm in each model.

Initially, the current condition is compared with the models predictions to figure out how many models intercepts higher probability of meteorological hazard in future and how many predict equal or lower probability in future. This output could help in the comprehension of the robustness of the signal intercept by the models and, as consequence, the confidence that it is possible to assign to such prediction. In the following table (

Table 25) the results of such analysis for the Hodh El Chargui communities.

Table 25 Percentage of models showing future higher or lower meteorological hazard probability

Community	Current Probability	% of models with higher probability	% of models with lower or equal probability
Agoueinit	0.37	44%	56%
Begou	0.11	33%	67%
Boukhzama 1	0.68	28%	72%
Drougal	0	50%	50%
Elkenar	0.11	50%	50%
Gnebett Ehel Heiba	0	50%	50%
Goubya Elmesjid	0.03	33%	67%
Jrana	0.03	33%	67%
Legaida	0.08	50%	50%
Legdur	0.05	50%	50%
Mberey El Jedida	0.03	33%	67%
NGuiya	0.37	44%	56%
Vani	0.05	50%	50%

Generally, the models are optimistic about the future evolution of meteorological hazard with all the communities characterized by a majority of models predicting lower or equal probability in respect to present.

The grouping or the 18 models outputs makes possible the selection of the quartiles of the models' ensemble (centiles 25th, 50th e 75th) to produce three different scenarios giving the probability of occurrence of precipitation lower than 150 mm. The results are summarized in the following table:

Table 26 Hazard component of the meteorological drought risk in the Hodh El Chargui villages, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th)

Community	Probability Current	Prob. 25	Prob. 50	Prob. 75
Agoueinit	0.37	0.13	0.28	0.58
Begou	0.11	0.00	0.07	0.14
Boukhzama 1	0.68	0.27	0.45	0.68
Drougal	0.00	0.00	0.01	0.09
Elkenar	0.11	0.05	0.12	0.44
Gnebett Ehel Heiba	0.00	0.00	0.01	0.09
Goubya Elmesjid	0.03	0.00	0.01	0.03
Jrana	0.03	0.00	0.02	0.03
Legaida	0.08	0.00	0.07	0.13
Legdur	0.05	0.00	0.08	0.18
Mberey El Jedida	0.03	0.00	0.02	0.03
NGuiya	0.37	0.13	0.28	0.58
Vani	0.05	0.00	0.08	0.18

These values indicate that for many communities the future conditions of meteorological drought could be similar to the current climate. Nevertheless, if we focus the attention to the pessimistic scenario (75th centile), it is possible to observe an overall increase of the probability of meteorological drought while in the optimistic one the values are lower than in the present climate. In some villages, such as Boukhzama NGuiya and Agoueinit, the range between optimistic and pessimistic scenario is wide while in Goubya Elmesjid and Jrana and Mberey El Jedida there is only the 0.03 of difference between the pessimistic and the optimistic scenario.

Precipitation distribution shows a higher spatio-temporal variability than temperature and its response to global warming depends on the response of regional circulations to the GHG forcing and the land cover feedbacks. Moreover, regional and local forcing can deeply modulate the precipitation change signal [120], then precipitation projections are characterized by higher uncertainty than temperature projections, in particular at a regional scale.

Hydrological drought

The hydrological drought, as illustrated in the previous chapter, is defined by the critical extension of the ephemeral wetlands of reference in the Hodh El Chargui. Each ephemeral wetland is characterized by a critical threshold of precipitation in August-September period that could drive to the lowest values in these water bodies. The critic thresholds are summarized in the following table:

Table 27 Average August-September rainfall in the 3 years with lowest water accumulation in the ephemeral wetlands

Agoueinitt	El Kenar	Vany	Legdour	Goubiye El Mesjid	M Boreye El Jedid
106.2	113.3	131.1	112.9	135.3	113.0

The period 2021-2080 has been considered the future reference and for each model the 2-months cumulus (August-September) for each ephemeral wetland has been extracted. The count of the years with precipitation lower than the critical threshold defines the hydrological hazard probability.

The models have different behaviours and in some ephemeral wetlands the majority predict future conditions better than present while in others the opposite (Table 28).

Table 28 Percentage of models showing future higher or lower hydrological hazard probability

Ephemeral wetland	Current Probability	% of models with higher probability	% of models with lower or equal probability
Agoueinit	0.47	50%	50%
Elkenar	0.13	72%	28%
Vani	0.09	56%	44%

Goubye Elmesjid	0.09	61%	39%
Legdour	0.06	22%	78%
Mberey El Jedida	0.06	72%	28%

In Elkenar, Goubye Elmesjid and in Mberey El Jedida the majority of the models predict higher hydrological hazard probability while in Legdour the majority of the models predict lower or equal probability.

Grouping the results from the 18 models, it is possible to extract the 25th, 50th and 75th percentile to create the three scenarios of reference.

The results are summarized in the next table(Table 29):

Table 29 Hazard component of the hydrological drought risk in each ephemeral wetland, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th)

Ephemeral wetland	Probability Current	Prob. 25	Prob. 50	Prob. 75
Agoueinit	0.47	0.25	0.48	0.62
Elkenar	0.13	0.13	0.28	0.46
Vani	0.09	0.03	0.10	0.18
Goubye Elmesjid	0.09	0.05	0.11	0.20
Legdour	0.06	0.00	0.01	0.05
Mberey El Jedida	0.06	0.05	0.15	0.24

These ephemeral wetlands are the largest one in the region and they are the main source of water for many economic activities of the nearby communities. The assignation of ephemeral wetland to a specific community is based on the proximity of the village to the water body. So the application of the probability of hydrological drought to villages is made as described in the following table in coherence with the previous study by Tiepolo et al. [2].

Table 30 Hazard component of the hydrological drought risk in the Hodh El Chargui villages, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th)

Community	Ephemeral wetland	Probability Current	Prob. 25	Prob. 50	Prob. 75
Agoueinit	Agoueinit	0.47	0.25	0.48	0.62
Begou	Goubye Elmesjid	0.09	0.05	0.11	0.20
Boukhzama 1	Agoueinit	0.47	0.25	0.48	0.62
Drougal	Mberey El Jedida	0.06	0.05	0.15	0.24
Elkenar	Elkenar	0.13	0.13	0.28	0.46
Gnebett Ehel Heiba	Goubye Elmesjid	0.09	0.05	0.11	0.20
Goubya Elmesjid	Goubye Elmesjid	0.09	0.05	0.11	0.20
Jrana	Goubye Elmesjid	0.09	0.05	0.11	0.20
Legaida	Goubye Elmesjid	0.09	0.05	0.11	0.20
Legdur	Legdour	0.06	0.00	0.01	0.05

Mberey El Jedid	Mberey El Jedida	0.06	0.05	0.15	0.24
NGuiya	Agoueinit	0.47	0.25	0.48	0.62
Vani	Vani	0.09	0.03	0.10	0.18

Some ephemeral wetlands are specific for one single village as the case of Vany Legdour and Elkenar, while Goubye Elmesjid serves to several communities. The projected values in the average scenario is similar to the current climate conditions while the other two scenarios may differ widely such in Agoueinit.

Agricultural drought

The evaluation of dry spell in future climate conditions is made with the same approach produced following the definition of the present agricultural drought which is defined by the presence of at least 10 consecutive dry days during the rainy season (July, August and September).

The percentage of models showing an higher or lower probability of drought hazard is classified in the following table (Table 31).

Table 31 Percentage of models showing future higher or lower agricultural drought hazard probability

Community	**Current Probability**	**% of models with higher probability**	**% of models with lower or equal probability**
Agoueinit	0.74	56%	44%
Begou	0.55	61%	39%
Boukhzama 1	0.89	39%	61%
Drougal	0.32	67%	33%
Elkenar	0.45	61%	39%
Gnebett Ehel Heiba	0.32	67%	33%
Goubya Elmesjid	0.34	67%	33%
Jrana	0.37	61%	39%
Legaida	0.58	61%	39%
Legdur	0.42	61%	39%
Mberey El Jedida	0.37	61%	39%
NGuiya	0.74	56%	44%
Vani	0.42	61%	39%

In this table, it is clear an overall signal of an increased probability of drier conditions in future expected by the majority of the models except for the Boukhzama community.

Then using the extraction of the 25^{th}, 50^{th} and 75^{th} percentile, it has been possible to create the 3 future scenarios of the MHRI analysis. The results are shown in the following table (

Table 32):

Table 32 Hazard component of the agricultural drought risk in the Hodh El Chargui villages, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th)

Community	Probability Current	Prob. 25	Prob. 50	Prob. 75
Agoueinit	0.74	0.53	0.82	0.97
Begou	0.55	0.31	0.66	0.85
Boukhzama 1	0.89	0.61	0.84	0.98
Drougal	0.32	0.25	0.59	0.75
Elkenar	0.45	0.35	0.76	0.92
Gnebett Ehel Heiba	0.32	0.25	0.59	0.75
Goubya Elmesjid	0.34	0.27	0.57	0.71
Jrana	0.37	0.20	0.55	0.73
Legaida	0.58	0.31	0.62	0.81
Legdur	0.42	0.34	0.72	0.85
Mberey El Jedida	0.37	0.20	0.55	0.73
NGuiya	0.74	0.53	0.82	0.97
Vani	0.42	0.34	0.72	0.85

In this case, the average scenario shows highest values in respect to the current climate except for Boukhzama. The result is in line with the global prediction of highest probability of longer dry spells in future and, with a good level of confidence, we might expect worst conditions for agriculture and pastoralism in this region in the forthcoming years. The pessimistic scenario shows that many communities have to face the 80% of probability to have a dry spell longer than 10 days in each cropping season.

Heavy precipitations

In analogy with the present hazard definition, here the aim is to intercept the probability of occurrence of heavy precipitations that could drive to floods or damages to infrastructures.

The threshold chosen to identify such hazard is 20 mm of precipitation in three hours. With the TRMM dataset is possible to reach the 3h time-step, but climate projections are at 1day resolution. Which is the best option to maintain a similar approach for the projections?

There are several options, any of them produce an error. With the aim to minimize this error and retrieve a more prudential analysis able to compare the present conditions and the future ones, the first step has been to produce a comparative analysis of the 3h and daily rainfall cumulus in the TRMM dataset. The purpose is to understand the characteristics of intense rains for each village.

The daily amount of rain in all the episodes recorded with more than 20 mm/3h has been extracted. Then it is possible to compare the minimum rainfall amount recorded in 3 hours with the minimum amount of the daily cumulus recorded for these days. Comparing the two values is possible to find the percentage of variation between the 3h cumulus and the daily amount. Sometimes the difference could be zero and it means that the heavy rainfall in this occurrences are short and very intense. Sometimes the difference is higher which means that heavy precipitations are associated with lasting phenomena. In this case the choice is to apply this variation to the initial 20 mm/3h threshold to retrieve the homologue threshold at daily time-step. The results are shown in the next table (Table 33):

Table 33 Reconstructed daily critical threshold in the Hodh El Chargui villages

Community	Min 3h/rain above 20 mm	Min Daily rainfall	Variat ion	Reconstructed critical daily threshold
Agoueinit	20.3	20.3	0%	20.0
Begou	20.9	20.9	0%	20.0
Boukhazama	20.5	21.6	6%	21.1
Drougal	20.8	21.4	3%	20.5
El Kenar	24.9	24.9	0%	20.0
Gnebett Ehel Heiba	20.8	21.4	3%	20.5
Goubya El Mesjid	23.4	33.3	43%	28.5
Jrana	24.1	25.2	4%	20.9
Legaida	21.2	21.2	0%	20.0
Legdur	22.0	22.0	0%	20.0
Mberey El Jedida	24.1	24.1	0%	20.0
NGuiya	20.3	20.3	0%	20.0
Vani	22.0	22.0	0%	20.0

In many villages of the Hodh El Chargui region the variation between 3h and day is nil. It means that in these localities placed in a semi-arid region the episodes of heavy precipitation are singular, very intense, event and the total amount of precipitation in three hours is equivalent at the daily cumulus. Thus, for these villages the 20 mm threshold will be applied.

Meanwhile in Goubya El Mesjid the variation between the 3h and the 24h cumulus is about 43%. In this case the episodes of heavy precipitations last more than 3 hours and typically they drive to higher amount of precipitation at the end of the day. Despite this could be a statistical artifact in a semi arid region such as in the Hodh El Chargui, following the proposed methodology, the application of the correction coefficient to the initial threshold drives to a critical value of 28.5 mm/day.

Using the extraction of the series in the 18 models, the table resuming the future probabilities of heavy rains has been produced (

Table 34).

Table 34 Percentage of models predicting future higher or lower heavy rains probability

Community	Current Probability	% of models with higher probability	% of models with lower or equal probability
Agoueinit	0.24	22%	78%
Begou	0.29	56%	44%
Boukhzama 1	0.41	6%	94%
Drougal	0.35	78%	22%
Elkenar	0.18	78%	22%
Gnebett Ehel Heiba	0.35	78%	22%
Goubya Elmesjid	0.24	39%	61%
Jrana	0.18	100%	0%
Legaida	0.29	61%	39%
Legdur	0.29	72%	28%
Mberey El Jedida	0.18	100%	0%
NGuiya	0.24	22%	78%
Vani	0.29	72%	28%

With the exception of Agoueinit, Boukhzama, Goubya Elmesjid and NGuiya, all the communities are predicted to have higher probability to have conditions favorable for heavy precipitation. It is interesting to note that the increase of hazard risk for agricultural drought and heavy precipitations are in line with the overall trend of the extremization of the climate stated by the IPCC in its special report SREX [121].

The creation of the 3 scenarios for the future evolution of heavy precipitation is made with the same approach of the previous hazard using the 25^{th}, the 50^{th} and the 75^{th} centiles.

Table 35 Hazard component of the heavy precipitation risk in the Hodh El Chargui villages, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th)

Community	Probability current	Prob. 25	Prob. 50	Prob. 75
Agoueinit	0.24	0.10	0.14	0.23
Begou	0.29	0.23	0.33	0.48
Boukhzama	0.41	0.08	0.12	0.18
Drougal	0.35	0.39	0.55	0.67
El Kenar	0.18	0.18	0.22	0.36
Gnebeit Ehel Heibe	0.35	0.39	0.55	0.67
Goubya El Mesjid	0.24	0.16	0.21	0.35
Jrana	0.18	0.38	0.46	0.69
Legaida	0.29	0.23	0.33	0.56
Legdur	0.29	0.29	0.43	0.60
Mberey El Jedida	0.18	0.45	0.53	0.73
NGuiya	0.24	0.10	0.14	0.23
Vani	0.29	0.29	0.43	0.60

The results follow the general increase of such hazard in future while for some communities the risk is lower in respect to the current conditions. One of the possible explication of such behaviour is related to the methodology chosen to pass from the 3-hours to the daily critical threshold. An overestimation of critical episodes using the daily threshold is expected due to the underestimation of the episodes which reach the 20mm in more than 3 hours. Nevertheless, climate models do not correctly reproduce the physics of very intense precipitations for its coarse resolution and a larger uncertainty is expected in these intense phenomena analysis. However, the results obtained shows a distribution of future probability around the present values with an overall tendency in the increasing of episodes in coherence with the future intensification of the phenomena stated by IPCC [8] and it gives a uniform method in all the communities allowing to correctly compare the results obtained among the region. Considering that the main aim of the study is to produce a ranking of risk in the region, the results produced using this approach are considered functional. Still, more investigation in the passage from 3-hours to daily resolution threshold are needed.

3.4 Application of future projections to the current multi-hazard risk characterization in the 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 climate scenarios developments: the 25^{th}, the 50^{th} and the 75^{th} 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.

The final result is a different distribution of risk in respect to present in the study areas with some additional information about the range of future possible change of climate conditions.

Looking at the Table 36 it is possible to make a comparison between the current conditions and the future ones.

Table 36 Multi Hazard Risk Index in the 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 current risk between the future optimistic and pessimistic scenarios except for Mborey El Jedid which have 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 critic threshold defined by the methodology proposed in this work heavily underestimate the heavy precipitation risk in this site. But again, this represents the only exception because in the other communities the method seems to fits the expected result of future risk distribution very well.

It is interesting to observe some changes in the ranking of the municipalities in the MHRI classification. Apart the mentioned exceptions, the rest of the municipalities have a similar placement in the ranking of risk. Nevertheless, these dynamics are quite interesting to observe, for instance, Legdour will become the community most at risk while Drougal, Gnebett Ehel Heiba and Mberey El Jedida are relatively increase risk level while it's observed a decrease of risk in Agoueinit.

In the author opinion, these dynamics represent a useful information for decisions makers because with this information it is possible to represent not only the magnitude of risk but also its trend. In general, communities are used to deal with their structural level of risk, so the strategies adopted by local populations in risk reduction are driven by the knowledge of these conditions. In a context of changing climate, the expected variation of risk level in a range given by the three different scenarios, as showed in Table 36, become an important asset for the future climate adaptation process for these communities.

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

The differences in the level of agricultural drought and heavy rains risks among the 13 communities drives to a differentiated multi-hazard index. The northernmost communities have greater probability of agricultural drought risk compared to the five southern communities, these on the border with Mali. However, the communities at risk in the north are also closer to the large market of Nema (22,000 inhabitants in 2013) which demands horticultural products in a semi-arid region. Therefore, these communities have greater opportunities to diversify their livelihood with commercial gardening if they are able to increase the water availability. 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.

Using the projected climate scenarios it is possible to map the comparison among the present and the three future scenarios (Fig. 18).

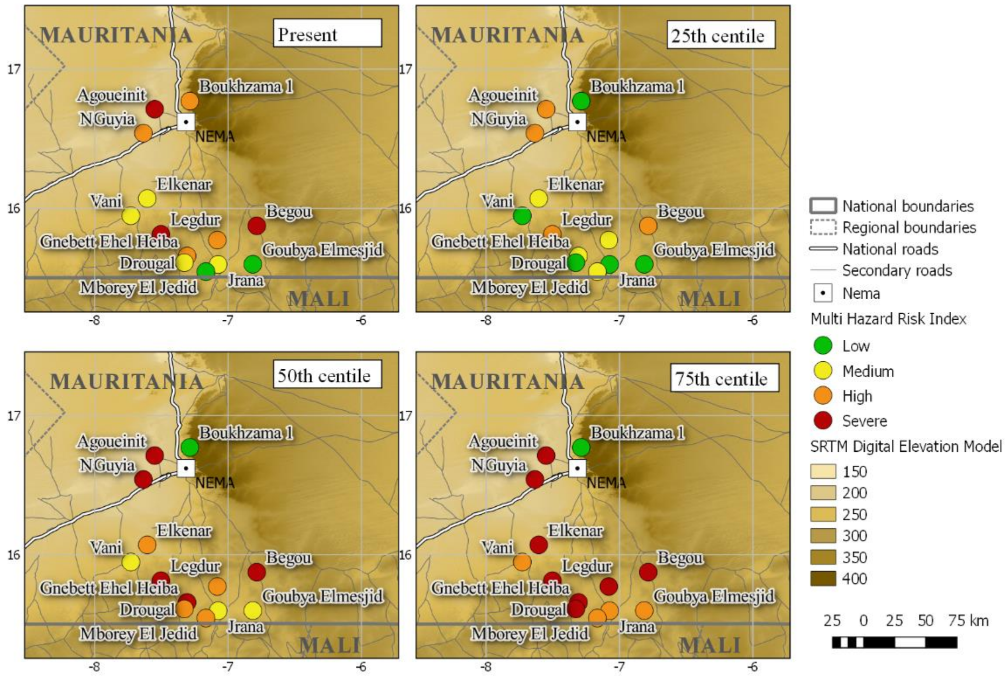


Fig. 18 Multi Hazard Risk Index in the Hodh El Chargui communities, comparison between present (1981-2016) and 3 future scenarios 2021-2080 (centiles 25th, 50th e 75th)

The optimistic scenario shows a quasi-total reduction of the level of risk, with only 3 communities out of 13 still at high risk. While in the pessimistic one, with the exception of Boukhzama, there is an overall increase of the risk. Probably in Boukhzama the heavy precipitation projections component is not sufficiently well described to intercept efficiently intense rainfall hazard.

Future climate has a strong impact on Hodh El Chargui communities and, as showed in the Fig. 18, 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.

Trends in MHRI characterization are also important. The following figure (Fig. 19) 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 flag as trend in decrease, while if the difference is above +0.1 the flag is trend in increase, otherwise the risk is stable.

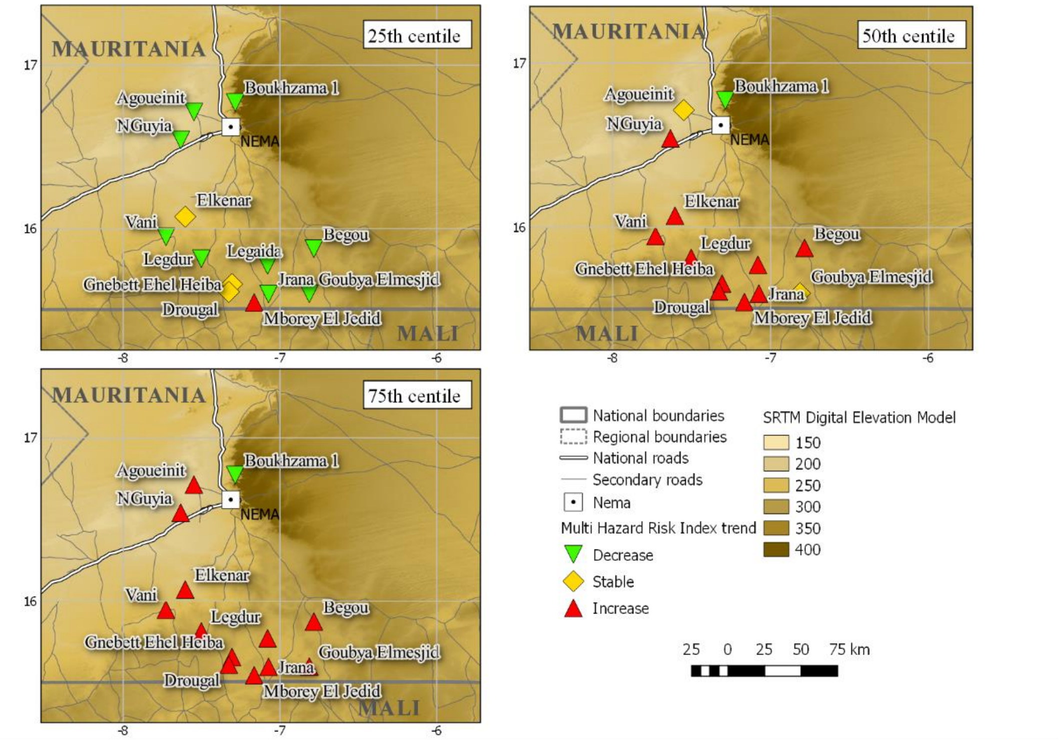


Fig. 19 Trends in MHRI index for the 3 future scenarios.

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 level.

To rank the priorities of intervention, the next output with the overlapping of current 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 37.

Table 37 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 the Hodh El Chargui region it is possible to produce the following maps (Fig. 20) for the 3 scenarios.

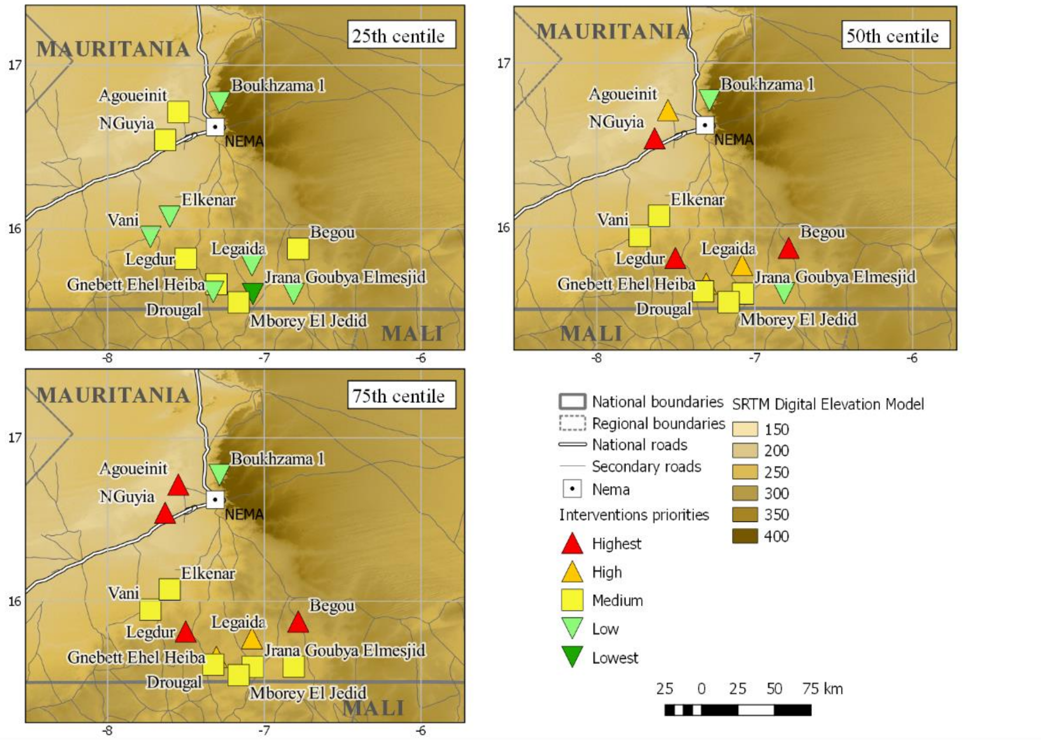


Fig. 20 Intervention priorities in the Hodh El Chargui for the 3 future scenarios

The maps show that Nguyia, Legdur and Begou are the communities with the highest priority of intervention even 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. Boukhzama 1 remains the only community with a low priority of intervention even in the worst case scenario. As previously noted in this chapter, this community must be deeply investigated to confirm its level of risk. The southern communities exhibit the lower priority of intervention.

3.6 Discussion about the Hodh El Chargui Region case study

The analysis face with common problems to the majority of risk assessments published in tropical Africa proposing a multi-hazard approach with the integration of local and scientific knowledge. One of the priority in this study is to define a sustainable methodology that would allow to produce a priority risk ranking among the communities and therefore supporting decision making in taking actions for the communities most at risk. Thus, it was necessary to refer to specific communities with their own characteristics and not to general communities represented as points on a risk map constructed by a simple superposition of information layers.

Conscious of the limits in the definitions of the different components of the MHRI, this holistic approach integrated with the field visits to the exposed items have helped the determination of the exposure, vulnerability and adaptive capacity components with indexes able to better reproduce the real local conditions.

Far from wanting to intercept exactly the value of the risk, the method is valuable to determine which of the four hazards most threaten the sustainable development of livelihoods in rural Hodh El Chargui. The integration of local and general knowledge is still unusual on a regional scale in contradiction to the indications of the Sendai framework (2015) [122]. The review produced by Tiepolo et al. [1] highlighted that only one assessment out of four published on tropical African regions estimates the probability of flooding or drought [123-127]. Most likely this is due to poor access to local data.

The case study represents a possible assessment methodology of interest for other semi-arid, agro-pastoral regions of the Tropics with similar conditions.

Nevertheless, the replication of this work must take in consideration the following limits:

1. The weak literature basis available;
2. The simplification of the hydrological hazard assessment;
3. The difficulties in critic rainfall threshold methodology definition;
4. The qualitative measure of some exposure and vulnerability indexes;
5. The method to intercept the future critical intense phenomena;
6. The projection of the vulnerability, exposure and adaptive capacity components.

The Mauritania, and its semi-arid environment, is not strongly investigated by the scientific literature. Grey literature available contains other assessments but its dissemination is temporary and it has a marginal effect on long term assessment practices. This works contributes to fill this gap and promote more efforts by the scientific community in supporting these marginal communities in understanding their risk, its roots and future dynamics.

The simplification of the hydrological hazard is essentially due to the scarcity of data. The study follows the approach defined by Tiepolo et al. [2] to calculate the hydrological hazard. The link between the dynamics of the surface of water bodies and precipitations in tropical regions has been questioned by literature, particularly due to the dynamics of the vegetation cover and the erosive processes that have increased the runoff over time [129-131]. In general, the Hodh El Chargui region presents an almost flat orography with the exception of a local relief of less than 300m in the eastern part of the region, so this could limit the uncertainties in the proposed methods about the erosive processes. Some differences could be more evident in areas at the foot of the uplands which are Boukhzama 1 and Begou communities [131] and regarding the results of the MHRI, these communities show a different behaviour comparing to others.

Thirdly, the absence of a climatic observation network is an enormous limit. The investigation of the more intense phenomena is based only on estimated dataset by satellite in a short period. In fact, here it has been used a shorter series 1991-

2014 to define the occurrence probability of heavy precipitations, due to the time limitations of the 3-hourly dataset used.

The estimation of the exposure and vulnerability components are made by using qualitative measures such as water flow and quality of the wells. The measure of these parameters is possible at very high cost and would give further solidity to the assessment. However, the more the number of investigations increases the lower is the sustainability and replicability of the analysis which was instead the objective of the assessment.

Regarding the uncertainties in the representation of very intense phenomena, some model errors can be traced in representation of processes (parameterizations). Climate modelling, with its limited understanding and measure of very complex processes, produce biases in mathematically representing them at very high resolution. Cloud processes, and in particular convection and its interaction with boundary layer and larger-scale circulation, remain one of the major sources of uncertainty in climate modelling. Moreover, insufficient length and quality of observational data makes model evaluation difficult or impossible, and it is a frequent problem in the evaluation of simulated variability or trends regarding extreme precipitations.

Knowing this, the future projections of precipitations for the aim of studying heavy precipitations pattern is quite challenging and its outcomes must be taken with caution. Nevertheless, the method is objective and it allows comparison between different communities giving the option to rank the priorities of interventions in the region.

One of the most delicate aspects of the analysis is the projection of the vulnerability and exposure adaptive capacity components. Here we develop a future risk analysis without projecting this information over time. It's evident that the introduction of such projection could contribute to the robustness of the analysis but it is also obvious that such effort needs a lot of resources. Moreover, it is quite difficult to find the way to estimate by modeling every single component of the analysis especially due to the lack of historical database about the evolution of each indicator. For this reason, one recommendation is to promote initiatives to start this data collection with the aim, in future, to add the exposure, vulnerability and adaptive capacity in the multi-hazard risk analysis process.

The main target subjects of this study are decision makers involved in the Disaster Risk Reduction activities of developing countries. The study contributes in the use of remote sensed data and data from the climate models in defining risk areas and risk evolution in time. The scenario approach applied in this study contributes also the research community in the definition of end user oriented products for the definition of the possible future evolution of climate and the inherent management of the uncertainties. The method shows a quite good sensitivity in the future ranking of the priority intervention zones.

Secondly, the research could help farmers and breeders in their strategical choices in the adaptation process to climate change. They could receive a benefit by the knowledge of the future level of risk of their own activities, allowing a redefinition of the choice of main crops or in the composition of the production to reduce the effects of the global warming.

The selection of the most efficient way to communicate such risk to local communities is another critical issue in the whole process. In fact, uncertainties in the risk levels communication could drive to misleading and too pessimistic or optimistic choices. Clearly more investigations are needed in this topic especially in context such Hodh El Chargui region where local communities are not used to deal with such climate risk information.

As showed by Tiepolo et al. [2] the consultations with the communities and the visit to the receptors enabled the identification of 13 actions for the six communities at severe and high risk which are rarely found in literature [128]. These concern firstly the improvement of access to water: wells deepening, apron elevation, covering, providing a pedal or a solar water pump, a water through for cattle watering, facilitating access in flood prone area during the wet season. Secondly, they concern earth embankments (creation of spillways and locks, protection with metal barbed wire) and the creek banks (gabions).

Section 4

Case study analysis in the Dosso Region

4.1 The multi-risk approach in the Dosso Region

The Dosso region (31,000 km$^{2)}$ in Niger has a population about of two million (*Fig. 21*), and, whitin its country, it is one of the most affected regions by floods [54]. Moreover, Niger has the highest hydro-climatic risk in West Africa [132].

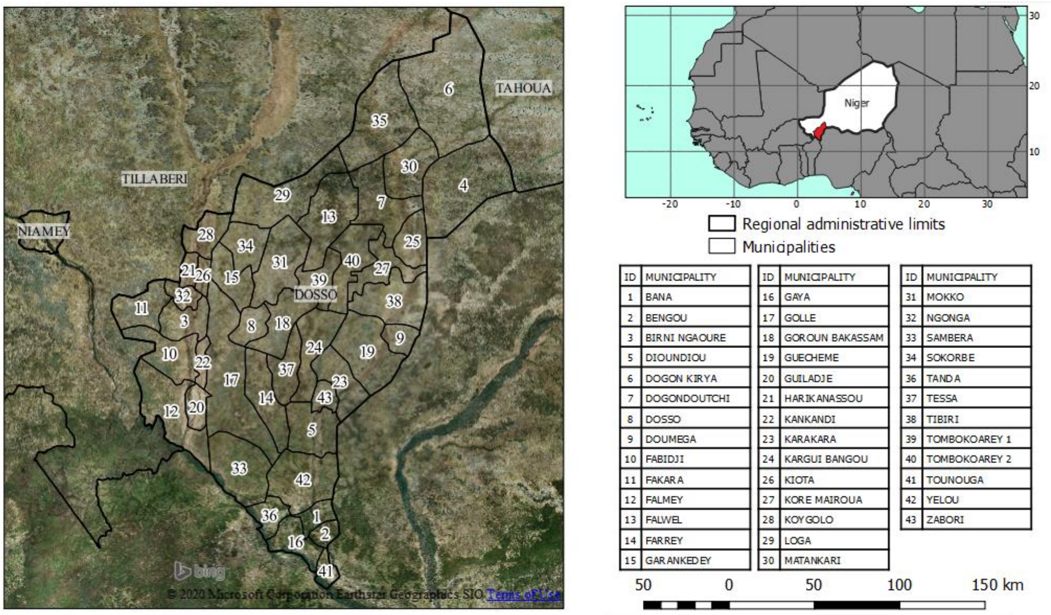


Fig. 21 The 43 municipalities of the Dosso Region, Niger.

Similarly, to the previous case study in Mauritania, the case 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 stations placed in the region that have been recording rainfall for decades. This represent a better condition compared to the previous case study and it leads to a different approach.

The Dosso region's climate is arid and semi-arid and it is characterized by four types of seasons:

- A dry cold season (December to February);
- A dry and hot season (March-May);

- A rainy season (June-mid-October);
- A hot season without rain (mid-October to November).

Rainfall shows a strong interannual variability illustrated here below (
Fig. 22) by the curve of evolution of the anomalies of precipitation from 1960 to 2005 with an alternation of average sequences from 5 to 7 years very distinct from wet years (from 1960 to 1968), dry years (from 1969 to 1974), wet (from 1975 to 1981) and very dry (from 1982 to 1987) with the most significant drought in 1984. But the manifestations of climate change perceived at these latitudes at the end of the 1980s, as we can see on the curve from 1988, witness a very marked interannual variability giving the impression of a shock of the normal climate regime. This increased variability in precipitation requires a continuous climate monitoring to regularly update information about climate evolution, moreover because these years are also marked by recurrent incidences of severe floods and a changing wet season profiles.

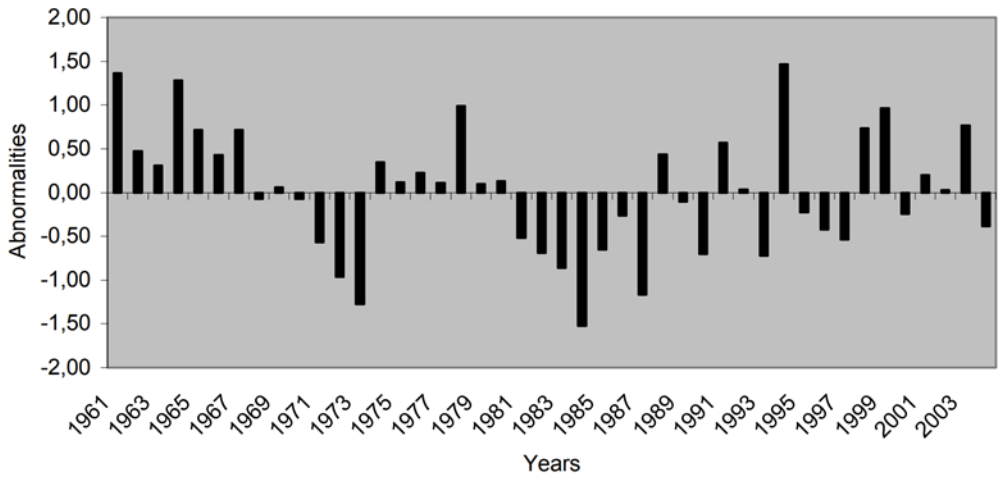


Fig. 22 Evolution curve of the average annual rainfall from 1961 to 2005 compared to normal (Source PANA-Niger[133])

The Dosso region is experiencing an increase in annual precipitation, even if it seems to show a slight gradual decrease over the past five years. The average annual precipitation ranges from 350 mm in the north to 800 mm in the south. Furthermore, considering to the agrometeorological parameters of the rainy seasons, most of the localities experience a delay in the start and end of the rainy season [134].

Regarding temperatures, like in the rest of the country, Dosso region is experiencing a sustained increase of warming conditions [133].

With a limited territory, such as the region of Dosso, climatic analysis needs to be done at high resolution. The study combines the measurements by the Directorate National for Meteorology through the observation network with the high-resolution CHIRPS rainfall estimation dataset by satellites at 0.25'. The integration of these two datasets has its origin in the inadequate number of weather stations distributed in the territory characterized by a timeseries longer than 30 years. With the aim of performing a more robust analysis, climatic analyses derive by the combination of the two dataset. The characterization of rainfall distribution changes and associated extreme events statistics has made using the 1981-2010 period as climatic reference.

Comparing the last 7 years with the climatic reference it is possible to observe that there has been a reduction in rainfall of 20-40 mm/year throughout the region in the 2011-2017 period (*Fig. 23*).

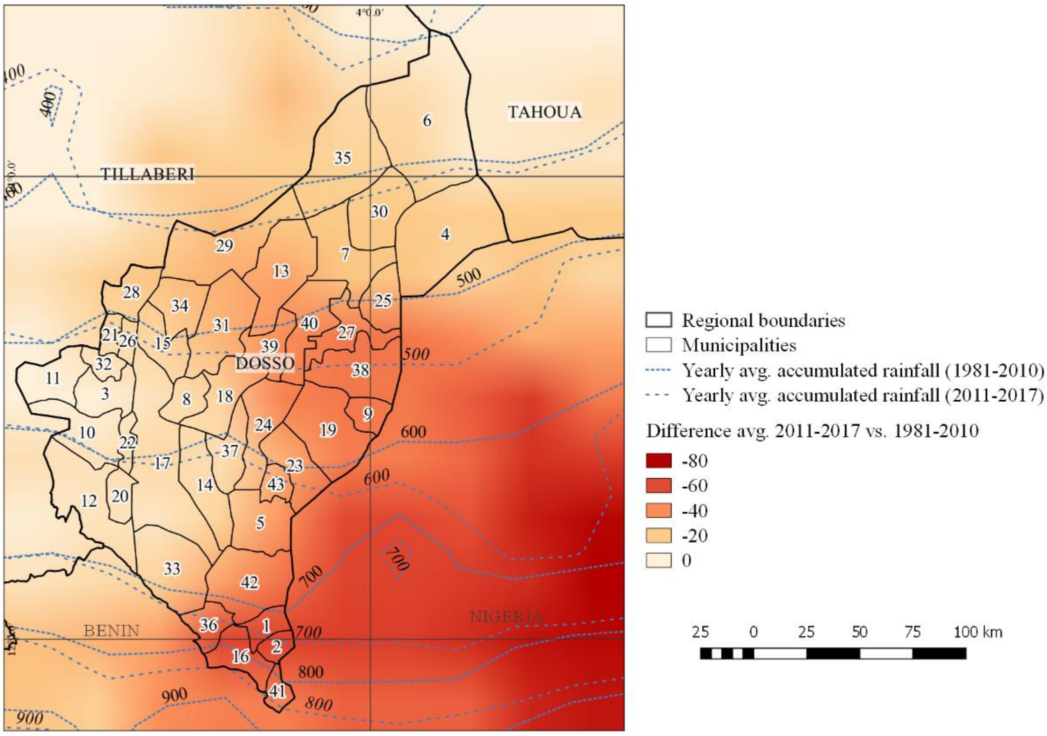


Fig. 23 The average difference in accumulated yearly rainfall during 2011-2017 and 1981-2010 (rainfall data source from CHIRPS).

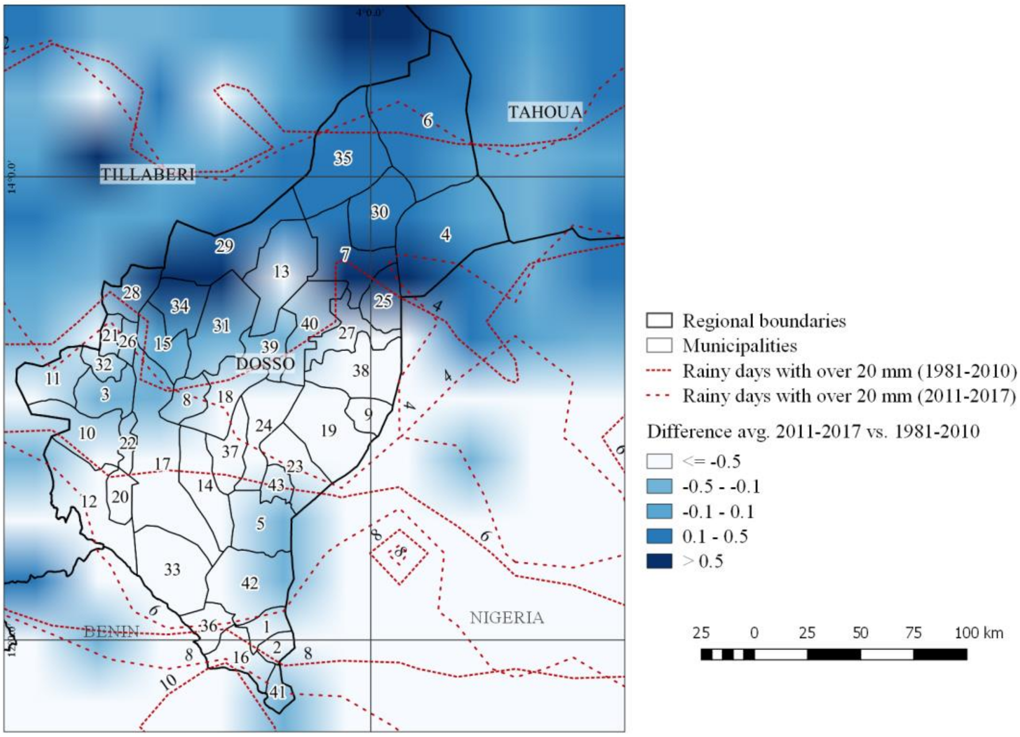


Fig. 24 The difference in the average number of rainy days with over 20 mm in the 2011-2017 and 1981-2010 periods (rainfall data source from CHIRPS)

Nonetheless, in the municipalities of Birni N'Gaoure, Dan Kassari, Dogon Kirya, Loga, Matankari, N'Gonga and Soucoucoutane, despite the decrease in annual accumulated rainfall, the amount of extremely heavy precipitation days (>20 mm) increased (*Fig. 24*). Consequently, pluvial flooding hazard results higher in these municipalities with the growth in the frequency of extremely heavy precipitation days.

Considering drought assessment, two aspects of the rainfall distribution during the wet season was explored. With the aim to intercept the most intense phenomena, the distribution of the maximum number of dry days during the cropping season (from June to September) in the recent years (2011-2017) was compared with the climatological reference (1981-2010). Moreover, the persistence of dry spells, which could impact yield, was explored through the comparison of the number of spells with at least five dry days during the growing season comparing the two periods. The results shows an heterogeneous rainfall distribution throughout the region, with figures a rise up to +2 days in the longest dry spell and +1 dry spell period of at least five days during the growing season (*Fig. 25*).

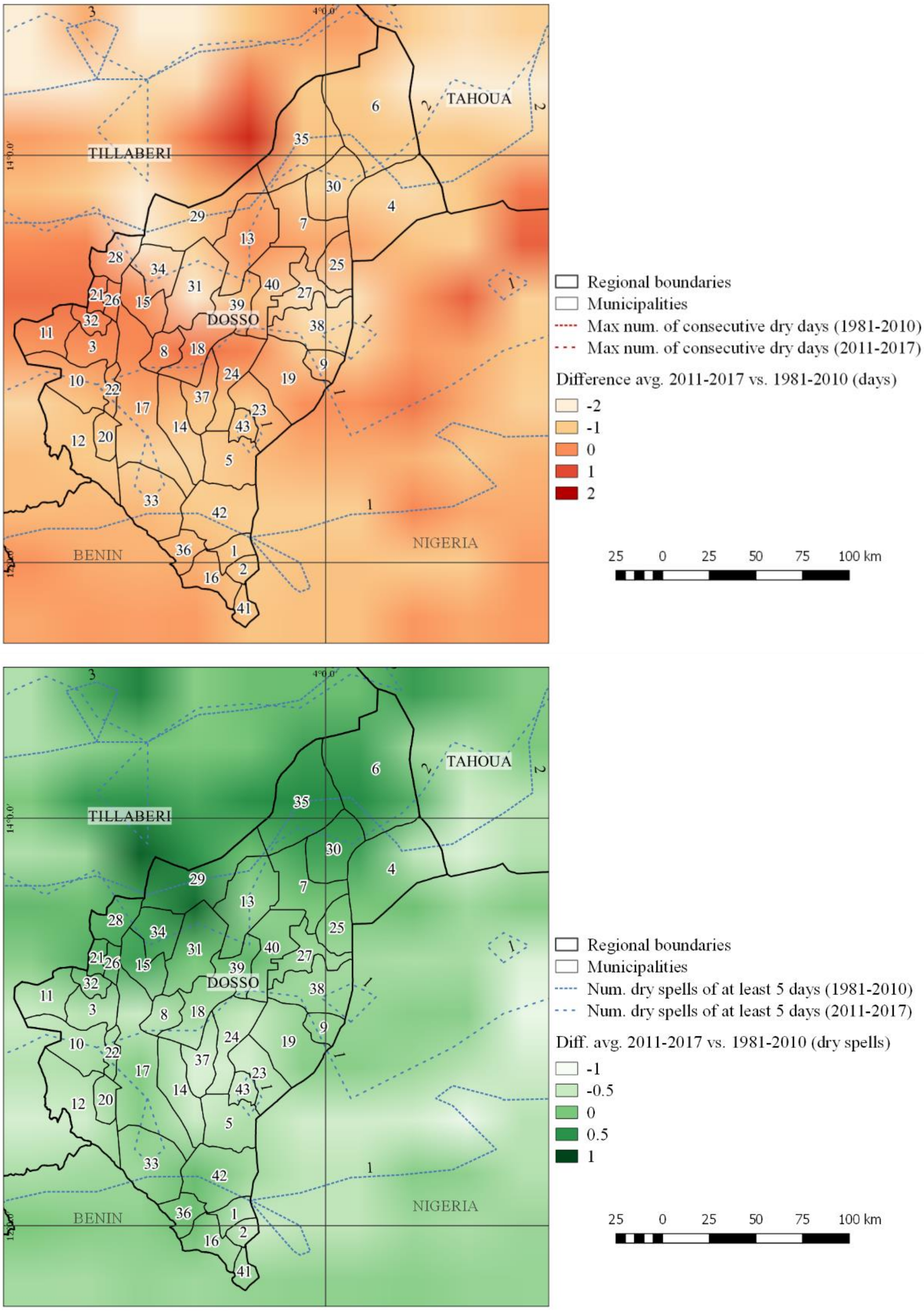


Fig. 25 The difference in the maximum number of consecutive dry days between 2011-2017 and 1981-2010 (top); the difference in the number of spells of at least five dry days between 2011-2017 and 1981-2010 (below) (rainfall data source from CHIRPS).

The northern and western parts of the region, in recent years, suffer from more drought conditions. Moreover, in future, the rainfall projections are expected to increase the drought hazard risk. GCM and RCM could intercept consistent trends in drought distribution which could lead to an accurate definition of the adaptation measures priorities.

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 flood and drought events turn into disasters.

The analysis of risk determinants, notably i) hazard, ii) exposure and iii) vulnerability, is made through an historic method [135]. As defined by Mach et al. [136] hazard is the '*potential occurrence of a natural physical event that may cause loss of life, injury or damage to property*'; exposure is the '*presence of people, livelihoods, assets in places adversely affected*'; and vulnerability as '*the propensity to be adversely affected*'. As regards vulnerability field literature addressing risk in West Africa, the indicators most frequently used (soil perviousness, land gradient, building materials, drainage density, population density, poverty, literacy) are not factors that turn flooding into a catastrophic event. Many measures are taken by local population to prevent heavy rainfall or flooding from becoming a disaster such as raising houses, wells, fountains and latrines above ground level, raised entrances to houses, create safe storage areas for animals and farm. Regarding drought monitoring, local rain gauge allows to accurately characterize local climatic conditions, which leads to an improved technique by local farmers using the most appropriate agronomic strategies for rain-fed crops. All of these components normally are not included in risk analysis and do not become risk indicators. Considering vulnerability indicators, they do not always have the same weight, particularly over a vast region.

Finally, remote sensing dataset, available at high resolution used up to now in risk analysis in West Africa, could be sufficient to intercept the most critical areas at the regional scale but not at the municipality scale. In fact, for two of the most common dataset used for floods characterization, SRTM [97] and *Advanced Spaceborne Thermal Emission and Reflection* (ASTER) [137], the accuracy (the difference between a point on the model and the same point on the ground) is about 16-20 meters for SRTM and 4 meters in the second. Similarly, *Moderate Resolution Imaging Spectroradiometer* (MODIS) images [138], which have often been used to identify flooded areas, have a spatial resolution of 250–1,000 m which end up including settlements that are not prone to flooding.

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. The identification of L&D information was done by using three global open-access datasets (Desinventar, NatCatService, EM-DAT) and three local limited-access datasets (the food security survey, flood L&D, cereal deficit).

The MHRI assessment considers pluvial flood, fluvial flood and meteorological drought risks. Other climatic hazards affecting Dosso (i.e. heat waves) are not systematically recorded at a municipal scale so they are not considered in this study.

Then, the three risks are combined in a multi-hazard risk index that respects the consistency of the period of time observed [139], the occurrence probability (1981-2017), the weight of risk determinants, the range of risk classes, the minimal unit of analysis (municipality) and the indicator measure (quantitative).

4.2 Definition of the current multi-risk index in the Dosso Region

The multi-hazard risk assessment in the Dosso Region is made up of three steps [140]:

1. climate characterization,
2. risk identification (type, impacts and factors) and
3. risk analysis (risk formula, hazard, exposure, vulnerability, risk level and uncertainty).

Climate characterization is made using two datasets: the weather stations by the DMN's network and the CHIRPS v2p0 daily-improved global 0p25 dataset. The choice of using these two different source of data is due to the needs of the study. While weather stations by the DMN's network calculate more accurate rainfall figures, CHIRPS estimates daily rainfall on an almost global scale (50°S–50°N, 180°E–180°W), with a resolution of 0.25° [141] and it considers the distribution of rainfall uninterruptedly for the 1981-2017 period.

In pluvial flooding the amount of rainfall is determinant for the generation of the conditions that could trigger a flood so it is important to measure the precipitation with the high accuracy of the observation network while for drought phenomena the use of a gridded dataset allows to retrieve more information about the spatial distribution of precipitation configuration.

Risk identification

In the Dosso region, there are 3 main types of flooding: the river flooding, the pluvial flooding and the upwelling flooding. Firstly, the river flooding is due to the highest peak of the Niger river. The second type is the pluvial flooding (caused by the runoff of rainwater and/or its insufficient drainage). Finally, the third type, the upwelling flood is characterized by a rise of water through the alluvial aquifers by siphon effect in lowlands. This is a frequent phenomenon in the Dallols (fossil river in Peulh language), geological stream-beds which descend from the Aïr mountains, cross the region of Tahoua, then Dosso, to flow into the Niger river. There are three: Dallol Bosso, Dallol Fogha, Dallol Maouri. The Dallol crosses the Dosso region from north to south for more than 300 kilometers. They are ancient river valley which carries surface water during the rainy season, but maintains subsurface water in dry season, making it an attraction for human settlements because these zones are characterized by fertile soils and water availability throughout the year. Their width varies from a few hundred meters to more than ten kilometers.

Niger river

The Niger runoff regime is affected by two different types of recurring floods: the Guinean flood and the Red flood.

The Guinean flood originates in the Guinean highlands. From here, the Niger and Bani Rivers flow into the Inner Niger Delta (IND). The IND covers an area of approximately 36,000 km² in central Mali and comprises lakes and floodplains that are regularly flooded with large annual variations. It influences the hydrological regime of the Niger significantly by flattening and slowing down the peak of the annual flood [142,143]. Due to the increasing distance and the buffering/retention effect of the wetlands, the flood peak leaves the IND with a delay of approximately three months. Therefore, it arrives in the middle section of the Niger around January, although rainfall in the Sahelian region falls at the same time as in the Guinean highlands. Thus, here the Guinean and Sahelian regimes generate a flood which can usually be clearly distinguished.

The "Red Flood", due to the color of the sediment carried by the water, has its peak during the rainy season in Niger. The red flood originates by the inflow in the middle section of the Niger River Basin which comes primarily from the plateaus of the right-bank subbasins. The vast subbasins to the left-bank subbasins reach up into the central Sahara but only contribute a minor amount of inflow, and local tributaries are endorheics most of the time.

River peak variations were taken into consideration, along with the river height observed at the Malanville gauge (Benin) from 1981 to 2017. Over the past six years, red floods have considerably exceeded the levels of Guinean floods and reached particularly high levels compared to the previous years (*Fig. 26*).

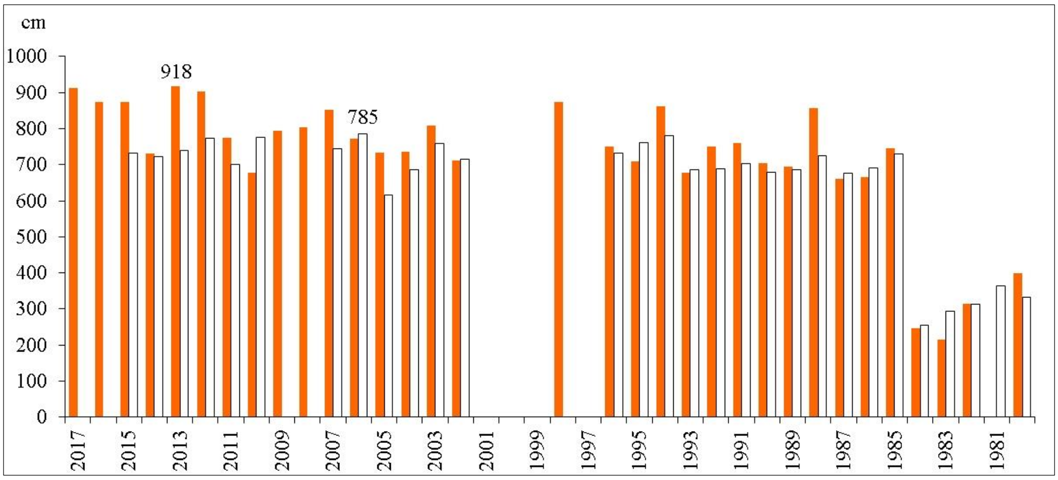


Fig. 26 Peaks of river Niger at Malanville (Benin), during Red floods (orange bars) and Guinean floods (white bars) with highest levels respectively in 2013 and 2006, period of observation: 1981-2017 [1]

This trend is confirmed by the number of people affected by catastrophic floods which increased drastically and more extreme flood magnitudes become more probable. Climate change induced flood risk are complex. In order to account for dynamics of the entire basin detailed modelling studies on a sub-regional level are a prerequisite to project future flood risks in the entire Niger river basin and discuss uncertainties. Nevertheless, the relationship between the climatic drivers, land cover and land use dynamics and discharge is complex and they vary inhomogeneously among different regions of the basin. The application of climate projection in such conditions become very difficult.

The five municipalities in the south of the Dosso region are interested by the Niger river. They are partly exposed to seasonal overflow of waters. The Guinean flood, which after weeks reaches the Dosso region where it peaks in January, in the dry season, and the red flood normally reaches its maximum in the months of August and September. The latter is caused by precipitation in the basin on the right bank of the River collected by its tributaries on the right bank: Gorouol, Dargol, Sirba, Tapoa, Gourbi, Mekrou in Niger, Kompa-Gourou, Pako, Alibori and Sota in Benin. It also causes more damage because the early warning time is shorter and the stakes are compounded by rain-fed crops, such as millet and sorghum, which are absent during the dry season.

In the municipality of Tanda, the village of Albakayzé (395 inhabitants) was flooded in 2013 and 2015. However, the municipalities bordering the river are large and have locations far from the river which are flooded for other reasons.

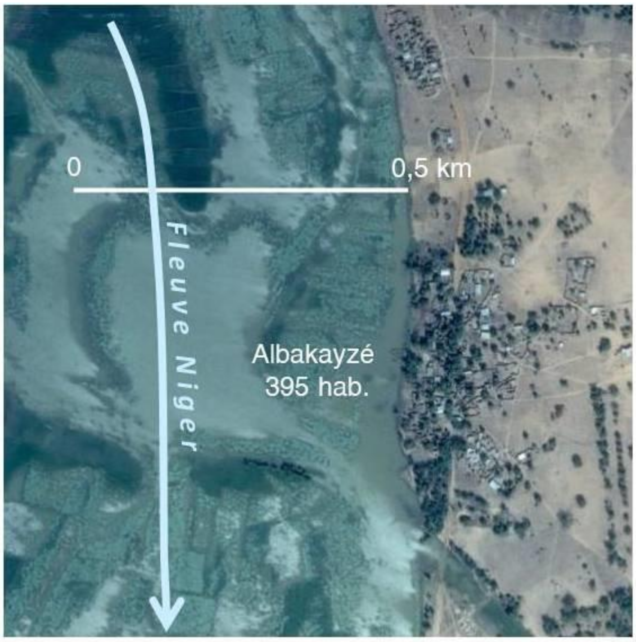


Fig. 27 Municipality of Tanda, 2016. Village of Albakayzé flooded by Niger river in 2013 and 2015

In this study, considering the limited number of municipalities prone to the river floods (5 out of 43) and the uncertainty related in the application of climate projection to the pluvial flood hazard component, it has been decided to maintain the current values of river flood hazard also for future scenarios.

Fig. 28 Municipality of Tounouga. The administrative village of Gondorou (1,696 inhabitants) twice flooded

Pluvial flooding and upwelling flooding

Pluvial flooding is caused mainly by local precipitation. This type of flooding comes from an insufficient capacity to retain or evacuate water in a certain place due to the local terrain morphology or due to the urban environment. In the municipality of Tounouga, which is located between the Niger river and the Dallol Maori, several flooded areas are recorded also in localities far from the river and main cause is the local rains, as in the case of Gondorou (1,696 inhabitants) which is flooded twice. In these places, the aspect that worsens the exposure of these villages is related to fact that the water table is shallow, so infiltration process is limited and flood causes huge damages to settlements, which are not protected by a fence and the concession have mud walls: once the water enters inside, the house collapses in few minutes.

The upwelling flooding is caused by local precipitation, which can occur further upstream from the flooding area. Water rapidly flows in the lowest terrains and floods crops and houses. This phenomenon is amplified by the effects of sahelian hydrological paradox. Descroix et al. [144] found that water table level rise over the last several decades despite the strong reduction in rainfall observed after 1968. Essentially the changes in land use drives to an excess in runoff which significantly increased the number of ponds. While ponds are the main zones of deep infiltration, their increase explains the rise of the water table level which is outcropping with increasing frequency. Pluvial flooding and upwelling flooding coexist in the dallols. In this context, the flood causes several damages because the Dallol, being humid throughout the year, is intensely cultivated and occupied by settlements and infrastructure (wells, boreholes and sometimes schools). The phenomenon is evident in many places.

Falwel (5,069 inhabitants), capital of the homonym municipality, is located in the lower part of the Dallol Fogha and is very exposed to flooding.

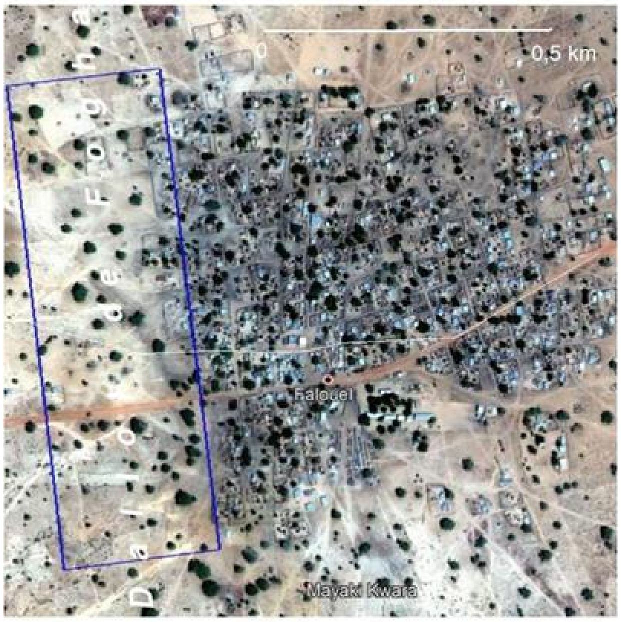


Fig. 29 Falwel location on the edge of Dallol Fogha (blue outline)

The town of Tombokoirey I (3,792 inhabitants) is placed in the middle of the Dallol Fogha, 11 up to 15 m below the surrounding land. Therefore, it suffers the upwelling and pluvial floods typically from streamflow in the eastern side, which is slightly higher.

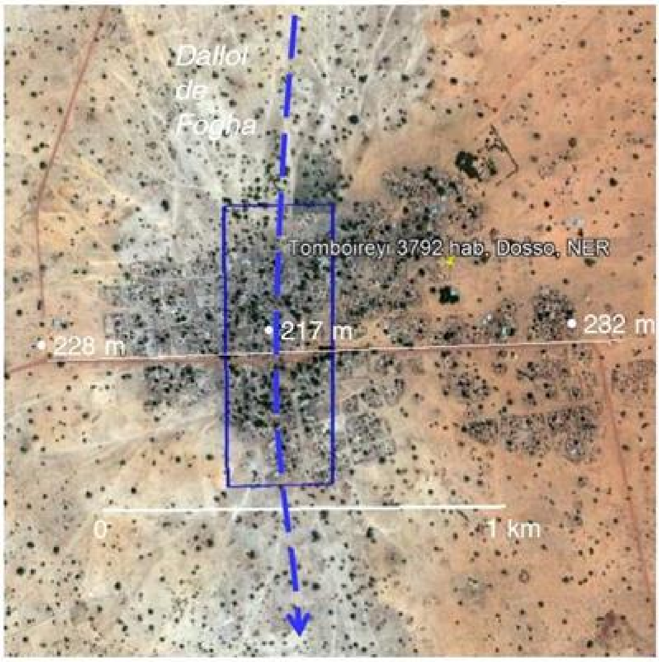


Fig. 30 Tombokoirey I and the Dallol Fogha (blue outline)

The characterization of the exposure and vulnerability components is made using and comparing: six datasets:

1. Desinventar by UNISDR [145], it is an open-access global database on disasters. In the Dosso region, Desinventar covers the 1988-2013 period, and therefore only part of the period considered in the study (2011-17), during which eight floods and one drought were recorded.
2. EM-DAT [146] by Louvain Catholic University, it noted 12 events at country scale during the 2011-17 period.
3. NatCatService [147] by Munich RE, it recorded five hydro-climatic events in Niger from 2011 to 2017.
4. The Joint Survey on Vulnerability to Food Insecurity [148] by the Coordination Unit of the Early Warning System (CC/SAP) on a national scale, it contains information on the victims and causes of flooding. In the Dosso region, the survey is conducted through interviews with households. It does not produce electronic data on a municipal scale and does not cover the region's seven urban areas.
5. The Flood dataset [149-150] was compiled from 1998 to 2011 by the CC/SAP on a national scale in conjunction with the National Device for the Prevention and Management of Food Crises, which operates on the ground with the Community Early Warning System (EWS)
6. Emergency Response (SCAP-RU) and the Observatories for Vulnerability Monitoring (OSV). From 2012 to 2015, this task was handed to the Humanitarian Coordination Unit and subsequently to the Ministry of Humanitarian Action and Disaster Management (MAHGC). The dataset records flooded settlements, their geographical coordinates, the date flooding took place (20 events from 2011 to 2017), the duration of the event, loss (victims) and damage (houses, fields, livestock, infrastructure).

The Ministry of Agriculture and Livestock (MAE) produces every year the list of deficit settlements [151] and it produces an estimation of the crop yields in sample villages chosen randomly. Comparing the annual production with the per capita consumption (which is defined with the amount of 231 Kg of cereal per year) they figure out the food deficit. Additionally, they give information about the causes of deficit cause by drought such as the late start or the early end to the growing season, the frequency of dry spells or other causes. In the period from 2011 to 2017, in the Dosso Region drought occurred every year. The MAHGC and MAE datasets have the greater detail and more up-to-date information about this threat.

In Tiepolo et al. [1] the risk identification has been processed by the counts of the settlements hit by each type of hydro-climatic event, how often and what factors can turn an event into a disaster using the different dataset available. The following table resumes the amount of the settlements hit by natural disasters in the Dosso Region.

Table 38 Human settlements in the Dosso region flooded and affected by agricultural drought from 2011 to 2017 by Tiepolo et al. [1]

	Settlements number	Settlements hit (% of total)	Population number	Population (% of total)
Pluvial flood	277	6%	345859	17%
River flood	36	1%	32167	2%
Drought	1135	24%	987842	48%
Multi hazard	121	2%	235826	12%

Going deeply in the records it is interesting to see that in the same year 38 settlements are hit by pluvial floods and drought, meaning that one disasters do not exclude others. In this case the vulnerability to the second disaster is higher due to the previous effects of the first hit. In the Dosso region all urban settlements are affected by disaster and the 29% of settlements located in a buffer zone of 500 meters from the banks of the River Niger and 20% of those found in the dallols have been flooded over the past seven years.

Looking at the spatial distribution of the settlements hit by natural disaster it is possible to see the different configuration of the most prone areas (*Fig. 31*).

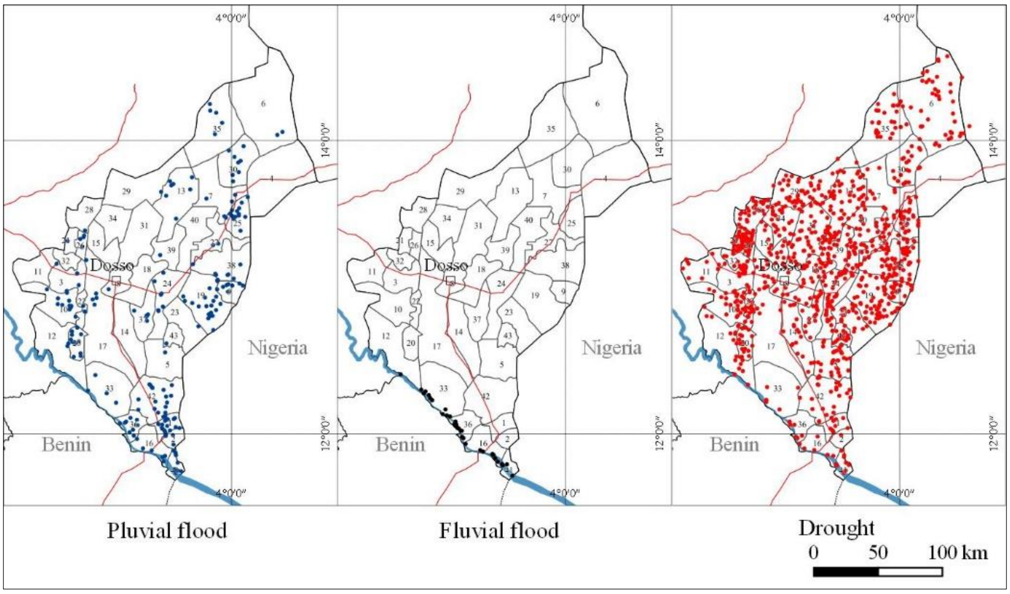


Fig. 31 Settlements of the Dosso region affected more than one year (dots) by pluvial flooding, fluvial flooding and drought from 2011 to 2017 (Tiepolo et al. [1]).

For the pluvial flood it is possible to see that almost the settlements affected are clustered in the Dallols. These areas are prone to run-off when extreme rains occur. Moreover, fluvial flood concerns essentially the settlements along the Niger river banks while drought spread its effect in almost all the territory of the region.

Tiepolo et al. [1] find that the factors that turn flooding into a disaster were ascertained (Table 39) using focus groups organized in five settlements that represent the various different regional environments. It seems that the critical factors in the case of pluvial floods are the absence of protection for receptors, while in the case of fluvial floods, it is the absence of an EWS, and in the case of drought, it is the lack of a rain gauge.

Table 39 Factors contributing to disastrous flooding as ascertained in five settlements representing the various different regional environments (*Tiepolo et al. [1])*

Hazard*	**Disaster factors**
F	Lack of early warning
F, P	Lack of house, well, fountain raised basement
P	Lack of water and soil conservation
P	Lack of elevated threshold at house entrance
P	Lack of corrugated iron as roof material
P	Lack of plaster
D	Lack of rain gauge

* F-Fluvial flood, P-Pluvial flood, D-Drought

In analogy with Tiepolo et al. [1], for Dosso case study it has been chosen to carry out risk analysis using the multi-hazard risk index (R), whose determinants are hazard (H), exposure (E) and vulnerability [152-153]:

$$R = H \times E \times V$$

Decomposing the multi hazard risk index (MHRI) the pluvial flood hazard component of a municipality is defined by the probability of return of rain (called critical) which caused floods with damage in each municipality in the observed period 1998-2017 compared to the series of daily precipitation from 1981 to 2017 as recorded in the 20 rainfall stations owned by the DMN in the region.

The methodology adopted to define the flood risk in the Dosso region has been adapted to the lack of systematic records on this subject. This limit guided to the ex-post study of the episodes included in the information available from the CC/SAP/PC. The list of available floods covers the period 1998-2017 but the events for which information is certainly available and the exact date of the flood (day/month/year) are concentrated in the period 2008-2017. Indeed, data with no clear spatial and temporal reference are not included in the analysis. Finally, the data were organized by municipality listing the dates of the noted floods for each administrative unit.

The preparation of the meteorological data went through the selection of stations useful for the analyses. The stations selected are those with at least a 30-year series of recordings in the Dosso region. This limitation is due to the production of a solid statistical analysis with a sufficient climatic reference.

The municipality was chosen as the minimum unit of detail, in coherence with the rest of the analysis process, so with the list of floods organized by municipality, it is possible to check the recorded weather conditions in the days around the date of the flood in the closest weather observation station.

Therefore, the flood hazard value is determined by calculating the inverse of the return period of such rainfall using the methodology proposed by Gumbel [154] considering the 1981-2017 as climatological reference. This choice is due to the need of identifying the lowest rainfall amount which potentially trigger a flood. This quantity of rain could be reached several time during a year, but not each time it causes a flood. In fact, several determinants can increase or decrease the danger of these events. First of all, the intensity of rain. The same amount of rain fallen in 1 hour or in 24 hours has different effects on the hydrological discharge. Moreover, an intense rain during the night time is more dangerous than during the daytime because people could alert more rapidly and take the necessary actions to prevent flood damages. Unfortunately, it is not possible to reach such temporal scale because of the absence of pluviographs in the region. In any case, the method allows to obtain a measure of hazard component in a homogeneous way for all the municipalities obtaining a ranking of the risk.

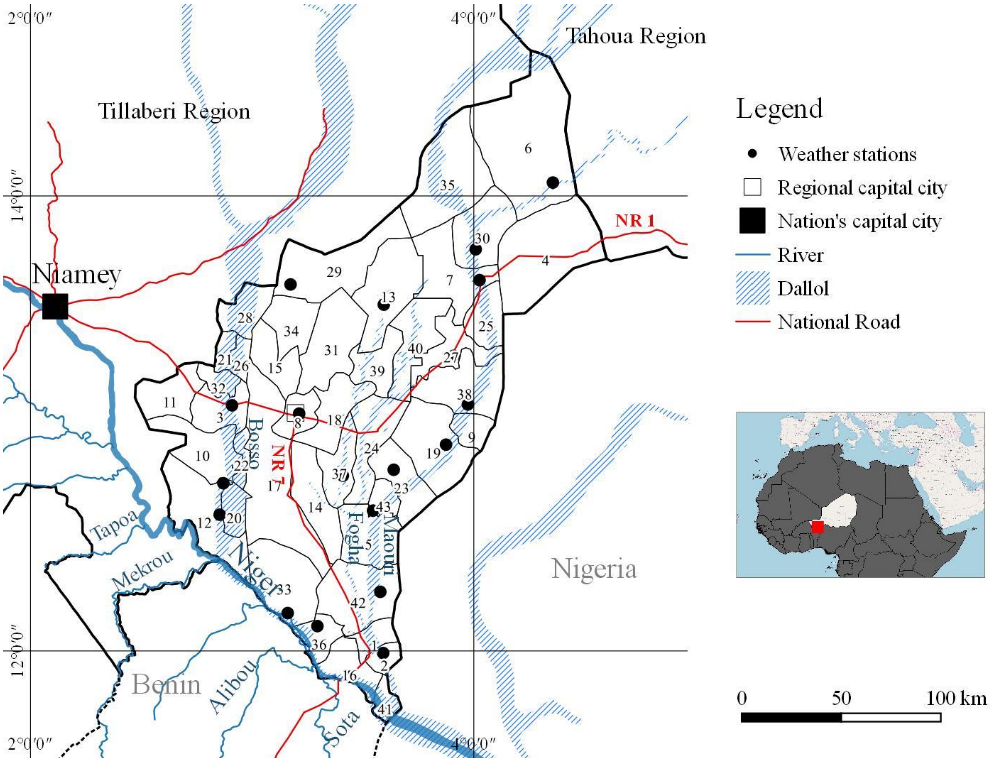


Fig. 32 Weather stations (black dots) with 30 years of daily registrations in the Dosso region.

The fluvial flood hazard component for a municipality is defined by the probability of occurrence of the minimum level of water in the River Niger at the Malanville gauge (Benin), opposite the city of Gaya (Niger), which from 2001 to 2017 caused L&D. This is determined as the inverse of the recurrence interval:

$$R = \frac{n+1}{m}$$

where *n* is the number of years on record and *m* is the number of occurrences of flooding. This measure is the most efficient one because a long time series is available and the Niger river has the same effects along its path in the Dosso region. Changes in the river banks or hydraulic infrastructures made alongside the river are not taken in account because there is not available studies or datasets which could measure the effect of these on the river floods dynamic. In any case, this effect could be overlooked for the minimal consequences it can bring in this context where Niger river discharge could reach a peak of more than 2000 m^3/s.

The drought hazard component in a municipality is defined by the probability of occurrence of at least two months during the cropping season (June-September) with an SPI value equal to or less than -0.5. The SPI index is calculated in the period 1981-2017 using the CHIRPS dataset using the 1981-2010 as climatological reference period. This dataset has the advantage to cover the entire Dosso region uninterruptedly, so it is possible to characterize each municipality of the region in a consistent way. Rain-fed crops can be damaged if this limit is exceeded. SPI is not a direct measure of the agricultural drought, but instead is a measure of the persistency of dry conditions in the area. Severe and intense drought phenomena, that could lead to yield loss, are not easily to measure and, still, there is no sufficient data to evaluate correctly, during a long period over the entire region, the consequences of drought on crops. SPI is more simple and robust than other measures (i.e. the rainfall deficit) and it can detect long-lasting periods of stress. The threshold used in this study, two months during the wet season with SPI below the -0.5, has been defined by Tiepolo et al. [1] comparing the agricultural statistics available for the region and the SPI values. It has been observed that the lowest values of yield in the time series, in the majority of cases, match with the presence of at least 2 months below this SPI's threshold in the same year. Lowest yield could be the result of pest or other plant diseases, but often the two effects, pathogen and drought stress, are combined.

Following the choices of Tiepolo et al. [1], exposure component takes in consideration all the settlements hit by flooding and drought from 2011 to 2017. This because in these recent years a centennial flood has been recorded with the heaviest rainfall seen for 30 years and widespread drought. As a result, we can assume that the settlements hit coincide with disaster-prone zones.

In coherence with hazard, vulnerability component is measured for the three components of the MHRI. Flood vulnerability is measured using three loss and damage indicators recorded by the MAHGC following 20 catastrophic floods that took place in the Dosso region from 2011 to 2017:

1. the number of victims (L),
2. the number of houses destroyed and the surface area of flooded fields (D).

Drought vulnerability (DV) is measured by a proxy indicator using the 'cereal deficit' estimated by the MAE every year for each settlement. For the purposes of the assessment, the deficit of each municipality is quantified as the average quota of people can't be fed with local production of cereals:

$$DV_{year\ x} = \frac{P_i}{P_{tot}} \times 100$$

Where P_i is the population that can't be fed with local production at year x and P_{tot} is the Population settlement at the census year 2012.

The L&D for each municipality is linked to its population because the total number of houses and the extent of fields in the Dosso region and its municipalities is unknown and the resulting figure is related to the comparison between regional L&D and the region's population from the 2012 national census [155]:

$$R_{municipality\ x} = H_{municipality\ x} \times \frac{\frac{L\&D_{municipality\ x}}{P_{municipality\ x}}}{\frac{L\&D_{region}}{P_{region}}}$$

Where:

H = probability of occurrence of the rainy day having caused L&D during the 2011-17 period

L&D = 2011-17 Loss and Damage

P = 2012 Population

L&D is compared to the population of each municipality in the region to get relative values demographic weight which consents the comparison of municipalities at risk. The MHRI is obtained by summing up the risks of individual hazards for each municipality of the Dosso region (*Fig. 33*).

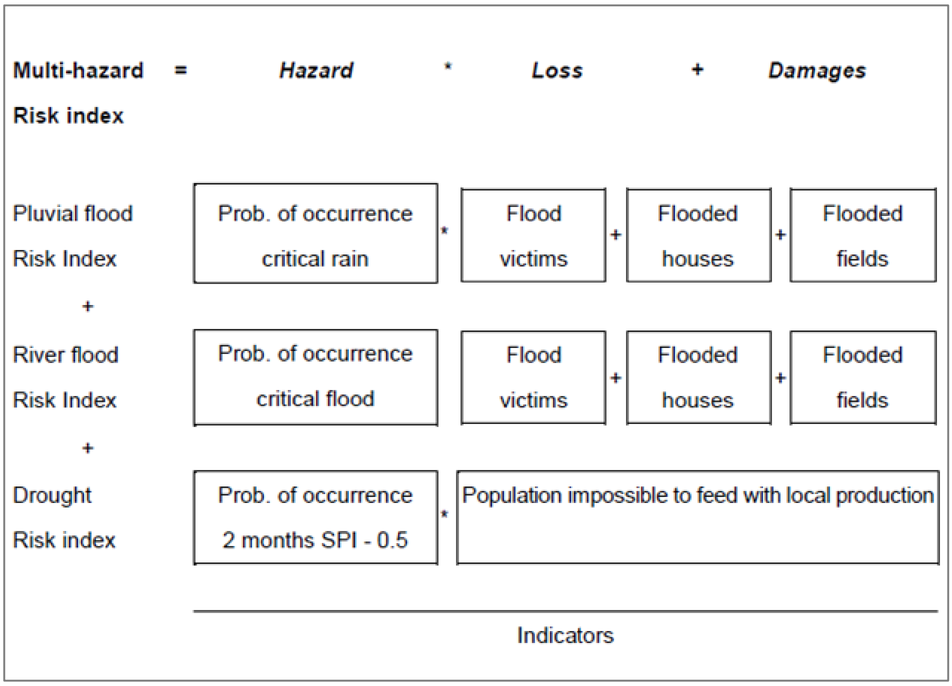


Fig. 33 Risk determinants and indicators from Tiepolo et al. [1]

The multi-hazard risk level was divided up into five categories (from very low to very high risk) that are equally represented in the final MHRI assessment. These values are applied to each single component in the risk formula allowing an easy comparison of the contribution to final risk. The figure of 3 risk components quantifies, for each community, a level of multi-hazard risk that is proportional to the demographic weight of the municipality in the region. The MHRI index could be seen as a relative index that place a community at risk in respect to others in the Dosso region allowing the ranking of the municipalities the most at risk.

Pluvial flood risk Index (PFRI)

Flash floods are intense and rapid phenomena which occurs before the rainfall runoff enters any water course or drainage system. These phenomena are directly linked to very intense rainfall that creates critical conditions in the water catchment by the soil and they trigger a rapid flooding of low-lying areas. Normally, pluvial floods generate localized losses but those events are more frequent and unpredictable than fluvial floods.

The probability of flooding is elaborated from the identification of the critical rain, i.e. the precipitation threshold which triggers a flood with damage, and it is determined in each municipality in the Region. It should be remembered that we are concentrating in defining the probability of having future weather conditions which, at least once, have caused damage. In the definition of the hazard it does not matter the magnitude of the impact which will be evaluated by the exposure and vulnerability components. In fact, very intense phenomena could not drive to loss and damages simply because the population is aware of the risk of flooding and they take all the actions to reduce the effects of flooding. The date of each flood that produced damage in the period from 1988 to 2016 is identified from the CC/SAP database. In the cases of very frequent episodes of floods (i.e. 4 floods recorded over a period of analysis of 5 years) it is obvious that the probability of the critical rain is around the year or less. Then, the following step is to transform the critical rain value identified for each municipality with the return period of this rain.

Using the stations with an observation period of at least 30 years, it has been possible to identify the rainfall amounts of daily rain that could trigger a flood (critical rainfall) for each disaster recorded in the Dosso Region database. In case of absence of a weather station in the Municipality we choose the nearby uphill station as reference station (

Table 40).

Table 40 The weather station assignments for each municipality

Municipality	***Weather station reference***
1 Bana	Bengou
2 Bengou	Bengou
3 Birni N'Gaoure	Birni N'Gaouré PTT
4 Dan Kassari	Dogondoutchi
5 Dioudiou	Dioundiou
6 Dogon Kiria	Dogonkiria
7 Dogondoutchi	Dogondoutchi
8 Dosso	Dosso
9 Doumega	Tibiri Doutchi
10 Fabidji	Beylandé
11 Fakara	Birni N'Gaouré PTT
12 Falmey	Falmeye
13 Falwel	Falaouel
14 Farrey	Tessa
15 Garankedey	Dosso
16 Gaya	Gaya
17 Golle	Dosso
18 Gorouban Kassam	Dosso
19 Guéchémé	Guéchémé
20 Guilladjé	Falmeye
21 Harikanassou	Loga
22 Kankandi	Beylandé
23 Kara Kara	Kara Kara
24 Kargui Bangou	Tessa
25 Kieché	Dogondoutchi
26 Kiota	Birni N'Gaouré PTT
27 Kore Mairoua	Koré Mairoua
28 Koygolo	Loga
29 Loga	Loga
30 Matankari	Matankari
31 Mokko	Loga
32 N'Gonga	Birni N'Gaouré PTT
33 Sambera	Ouna
34 Sokorbé	Loga
35 Soucoucoutane	Dogonkiria
36 Tanda	Sia
37 Tessa	Tessa
38 Tibiri	Tibiri Doutchi
39 Tombo Koarey I	Falaouel
40 TK II-Sakadamna	Falaouel
41 Tounouga	Bengou
42 Yelou	Yélou
43 Zabori	Kara Kara

It has been investigated, in the surrounding days of the disaster event, the amount of rain recorded at the nearby weather station to the municipality that reported damage to intercept the critical rainfall able to trigger a flood able to produce damages. In the series of daily precipitation recorded by the 20 rainfall stations in the Region provided by the DMN, the daily precipitation (mm) on the flood dates (with deviation of ± 2 days) is entered. In case of more than one flood episode, the minimum of the critical daily precipitation is used as the threshold able to trigger damages in the given municipality (critical rain). The probability (1 / return time) of such critical rain is verified in the climatological dataset (1981-2017) using the Gumbel method. The obtained value gives the probability of return of a similar episode and it is the indicator of flood hazard.

Sometimes the disaster database records a flood in a certain date but in the days surrounding this date there is no significant amount of precipitation in the assigned weather station. Likely the main causes of this discrepancy are to be found in the wrong transcription of the date or in the huge variability of the very intense rainfall pattern that could show significant differences in few kilometers. In such cases, the choice is to adopt the highest value recorded in the year of the flooding as proxy of the critical value. Only in Fakara municipality it has been adopted the choice to select the highest value recorded in the 2002-2017 series because in the disaster database there is one flood record for this municipality without the date. The following Table 41 resumes the critical rainfall threshold assigned for each municipality.

Table 41 Critical rainfall threshold (mm) characterizing each municipality

Municipality	***Critical rainfall***	***Note***
1 Bana	132	
2 Bengou	47	
3 Birni N'Gaoure	60	
4 Dan Kassari	48	
5 Dioudiou	30	
6 Dogon Kiria	52	
7 Dogondoutchi	40	
8 Dosso	30	
9 Doumega	42	
10 Fabidji	92	* daily max 2013
11 Fakara	111	* daily max in 2002-2016
12 Falmey	36	
13 Falwel	34	
14 Farrey	41	
15 Garankedey	59	
16 Gaya	48	* daily max 2015
17 Golle	34	
18 Gorouban Kassam	30	
19 Guéchémé	61	
20 Guilladjé	50	* daily max 2012

21 Harikanassou	41	
22 Kankandi	75	* daily max 2012
23 Kara Kara	46	
24 Kargui Bangou	41	
25 Kieché	42	
26 Kiota	44	
27 Kore Mairoua	45	
28 Koygolo	48	
29 Loga	46	* daily max 2012
30 Matankari	42	
31 Mokko	46	* daily max 2012
32 N'Gonga	61	
33 Sambera	43	
34 Sokorbé	46	* daily max 2012
35 Soucoucoutane	40	
36 Tanda	42	
37 Tessa	56	
38 Tibiri	42	
39 Tombo Koarey I	34	
40 TK II-Sakadamna	84	* daily max 2010
41 Tounouga	47	
42 Yelou	45	* daily max 2012
43 Zabori	46	

Sometimes the observation network does not catch any intense phenomena in the days surrounding the flooding date, so it has been chosen to reject these episodes instead focusing only on rainy days greater than 30mm, a threshold considered sufficient to trigger floods. This approach is strictly dependent on the quality of data in the disaster dataset available, in fact, an error in the date of flood do not allow to rebuild properly the critical rainfall for that event. Moreover, the erratic distribution of very intense phenomena could lead to very different precipitations conditions in few kilometers, then a weak observation network, as in the case of Niger, is not sufficient to intercept these phenomena.

Critical precipitation varies between 30 and 132 mm, depending on the rainfall stations. It is interesting to observe that critical precipitation threshold in 36 out of 43 municipalities is quite low and its return period is less than or equal to one year. This, in other words, means that normally we can assist a more than 1 episode, potentially able to produce damages, per year. In Tiepolo et al. [1], it has been decided to set to 1 the hazard value in all these cases which means that every year there is at least 1 episode which potentially could trigger a flood. We are talking about daily precipitation which ranges between 30 and 60 mm/day. The highest precipitation (75 to 132 mm) has a return period between 3 and 48 years. They concern two municipalities in the south, five in the west and two in the north-extreme center of the Dosso Region

Due to its strict dependency to very intense precipitations, the method uses the inverse of the return period of the critical rainfall as the Hazard components while

L&D are evaluated by Tiepolo et al. [1] using the disasters datasets available. The result is the creation of a PFRI for each municipality in the region as showed in Table 42

Table 42 Pluvial flood risk (PFRI) level in the Dosso region at municipal level

Municipality	H	L&D	PFRI
1 Bana	0.04	22.8	0.91
2 Bengou	1	45.17	45.17
3 Birni N'Gaoure	1	1.41	1.41
4 Dan Kassari	1	0.64	0.64
5 Dioudiou	1	0.97	0.97
6 Dogon Kiria	0.99	0.03	0.03
7 Dogondoutchi	1	3.37	3.37
8 Dosso	1	0	0
9 Doumega	1	4.05	4.05
10 Fabidji	0.1	4.8	0.48
11 Fakara	0.08	0	0
12 Falmey	1	2.14	2.14
13 Falwel	1	0.78	0.78
14 Farrey	1	0	0
15 Garankedey	0.93	1.13	1.04
16 Gaya	1	3.03	3.03
17 Golle	1	0.14	0.14
18 Gorouban Kassam	1	0	0
19 Guéchémé	1	5.07	5.07
20 Guilladjé	1	8.98	8.98
21 Harikanassou	1	0.02	0.02
22 Kankandi	0.33	1.24	0.41
23 Kara Kara	1	0.83	0.83
24 Kargui Bangou	1	6.84	6.84
25 Kieché	1	2.8	2.8
26 Kiota	1	1.59	1.59
27 Kore Mairoua	1	1.43	1.43
28 Koygolo	1	0.48	0.48
29 Loga	1	0	0
30 Matankari	1	2.98	2.98
31 Mokko	1	0	0
32 N'Gonga	0.92	1	0.92
33 Sambera	1	1.55	1.55
34 Sokorbé	1	0	0
35 Soucoucoutane	1	1.33	1.33
36 Tanda	1	4.97	4.97
37 Tessa	1	1.96	1.96
38 Tibiri	1	1.01	1.01
39 Tombo Koarey I	1	1.03	1.03
40 TK II-Sakadamna	0.1	0	0
41 Tounouga	1	21.51	21.51
42 Yelou	1	4.36	4.36
43 Zabori	1	0	0

The municipalities characterized by a risk level above 1 determine a risk higher than their demographic weight in the region. Pluvial risk affects 34 municipalities out of 43 and it ranges from severe risk in Bengou (PFRI=45.2), high in Tounouga (21.5), elevated in municipalities crossed by the dallols, particularly in Guilladje (8.9), Kargui Bangou (6.8) and Guechémé (5.1) to nil in 9 municipalities.

The recurrence period of pluvial flooding varies from 0.04 to 1. The maximum amount of 1 indicates that conditions favorable to the generation of a flood could re-occur on an annual basis.

The uncertainties in the proposed method are due to the inadequacies of the information used: not all the municipalities have a rainfall station with sufficient time-series of data (at least 30 years). Moreover, 28% of the localities that suffered flood damage according to the CC/SAP database cannot be found in the National Directory of Localities 2013, thus, we do not know the population of these localities. Consequently, they do not contribute to the calculation of damage at the municipal level which is sometimes underestimated. In general, the choices made during data processing drives to an underestimation of the risk level using a prudential approach.

Nonetheless, the methodology has several advantages. First of all, it has been. built on data (precipitation, damage) collected regularly, so there is the possibility to shift from a special analysis to a monitoring process. Secondly, the collection of information by permanent structures, which operate at national scale and the method of calculation within the reach of a non-expert operator, offers the possibility of scaling up the index. Finally, this study contributes in highlighting the lacks and the improvements that are needed to establish a more robust observation network in the region showing the potentialities of such a kind of analysis in supporting decision making process.

Fluvial Flooding Risk Index (FFRI)

The level of risk of fluvial flooding is mostly determined by its vulnerability (L&D) component. For pluvial flood and drought, the measure of the loss and damages recorded for each threat is less widespread than for the fluvial flooding. In the case of the fluvial flooding the decisive indicator are flooded fields that could reach very high level such in the case of the municipality of Tanda. This feature could represent a criticality in the process because the overestimation of the effects of flooded area by the river is high. When a river such Niger overflow over a vast area the fields suffers damages but at the same time it gives the possibility to perform recession agriculture in these lands and the soil becomes more fertile. These benefits partially recover the losses from the direct effect of the river overflow. Moreover, it is difficult to compare the value of a house or other human settlement destroyed by the pluvial flood with the losses of the flooded agricultural fields the first one is much higher than the second one and the final results could change. In any case the difficulty to correctly estimate the economic value of the losses in Niger context drives Tiepolo et al. [1] to choose a simplified approach.

Table 43 Fluvial flood risk (FFRI) level in the Dosso region at municipal level, 2011-17

Municipality	**Fluvial flood**		
	H	**D**	**FFRI**
12 Falmey	0.33	2.7	0.9
16 Gaya	0.33	18.4	6.1
33 Sambera	0.50	7.8	3.9
36 Tanda	0.33	69.3	22.9
41 Tounouga	0.67	20.4	13.7

Fluvial flood risk affects five municipalities and is severe in Tanda (FFRI = 22.9) and high in Tounouga (13.7). As showed in

Table 43 Tanda results the municipality most at risk because of the L&D component which reach 69.3, while its Hazard is between the lowest ones. The explication given by Tiepolo et al. [1] is that the small amount of population drives the calculus of the FFRI to an overestimation of the L&D components. While Tounouga, where the Hazard component is the highest one and the damages represents the second highest value, it could be probable to be the municipality most at risk for the fluvial flood.

Drought Hazard Risk Index (DHRI)

Drought is a recurring climate phenomenon spatially distributed characterized by water deficit over a period, from days to years. Extreme drought conditions influence agriculture, environment and health generating severe socio-economic repercussions. In the Dosso region the main concern is about food security and consequently, due its main source of food income, agricultural drought.

The approach in identifying the drought hazard characterization is based on the monthly Standardized Precipitation Index (SPI) [156], in the period June-September, using the CHIRPS dataset. The SPI index measure the deviance from normal rainfall conditions. The prolonged presence of negative values identifies persistent drought conditions that lead to losses to rain-fed crops yield. The advantage in using the CHIRPS images is to provide coherent monthly SPI in each grid point in the region so each municipality can be associated with the grid point that falls within its bounds and consequently characterizes drought hazard on a municipal scale.

The SPI also gives an idea of the trend in the presence of drought conditions in time. The next

Table 44 shows the differences between the probability evaluated in all the period of study (1981-2017), the climatological reference (1981-2010) and the last 7 years (2011-2017).

Table 44 Probability of 2 months with SPI lower or equal to -0.5 in three different period

Municipality	*1981-2017*	*1981-2011*	*2011-2017*	*Trend*
1 Bana	0.38	0.37	0.43	0.06
2 Bengou	0.41	0.40	0.43	0.03
3 Birni N'Gaoure	0.43	0.40	0.57	0.17
4 Dan Kassari	0.51	0.50	0.57	0.07
5 Dioudiou	0.41	0.40	0.43	0.03
6 Dogon Kiria	0.46	0.43	0.57	0.14
7 Dogondoutchi	0.35	0.33	0.43	0.10
8 Dosso	0.43	0.40	0.57	0.17
9 Doumega	0.41	0.37	0.57	0.20
10 Fabidji	0.46	0.43	0.57	0.14
11 Fakara	0.38	0.40	0.29	-0.11
12 Falmey	0.43	0.40	0.57	0.17
13 Falwel	0.38	0.33	0.57	0.24
14 Farrey	0.41	0.40	0.43	0.03
15 Garankedey	0.41	0.37	0.57	0.20
16 Gaya	0.32	0.30	0.43	0.13
17 Golle	0.43	0.40	0.57	0.17
18 Gorouban Kassam	0.41	0.37	0.57	0.20
19 Guéchémé	0.41	0.37	0.57	0.20
20 Guilladjé	0.43	0.40	0.57	0.17
21 Harikanassou	0.38	0.30	0.71	0.41
22 Kankandi	0.46	0.43	0.57	0.14
23 Kara Kara	0.43	0.40	0.57	0.17
24 Kargui Bangou	0.43	0.40	0.57	0.17
25 Kieché	0.46	0.40	0.71	0.31
26 Kiota	0.38	0.30	0.71	0.41
27 Kore Mairoua	0.46	0.43	0.57	0.14
28 Koygolo	0.38	0.37	0.43	0.06
29 Loga	0.35	0.33	0.43	0.10
30 Matankari	0.43	0.43	0.43	0.00
31 Mokko	0.32	0.27	0.57	0.30
32 N'Gonga	0.43	0.40	0.57	0.17
33 Sambera	0.32	0.33	0.29	-0.05
34 Sokorbé	0.41	0.37	0.57	0.20
35 Soucoucoutane	0.49	0.50	0.43	-0.07
36 Tanda	0.43	0.40	0.57	0.17
37 Tessa	0.41	0.37	0.57	0.20
38 Tibiri	0.43	0.43	0.43	0.00
39 Tombo Koarey I	0.41	0.37	0.57	0.20
40 TK II-Sakadamna	0.41	0.37	0.57	0.20
41 Tounouga	0.41	0.40	0.43	0.03
42 Yelou	0.43	0.40	0.57	0.17
43 Zabori	0.41	0.40	0.43	0.03

Despite the increase of precipitation, the probability to assist at prolonged drier conditions in the Dosso region is evident. Only 3 out of 43 municipalities show a negative trend.

Since hazard quantifies the probability of occurrence of a potentially damaging phenomenon, here the probability of two months with SPI below -0.5 is defined using the longest period available (1981-2017). The L&D component is the same adopted by Tiepolo et al [1]. The next Table 45 shows the values of DHRI for all the municipalities in the Dosso region.

Table 45 Drought risk index (DHRI) level in the Dosso region at municipal level

Municipality		**Drought**	
	H	**L&D**	**DHRI**
1 Bana	0.38	2.4	0.91
2 Bengou	0.41	0	0.00
3 Birni N'Gaoure	0.43	0.4	0.17
4 Dan Kassari	0.51	1.1	0.56
5 Dioudiou	0.41	0.2	0.08
6 Dogon Kiria	0.46	0.8	0.37
7 Dogondoutchi	0.35	0.7	0.25
8 Dosso	0.43	0.2	0.09
9 Doumega	0.41	9.2	3.73
10 Fabidji	0.46	1.9	0.87
11 Fakara	0.38	1.7	0.64
12 Falmey	0.43	0.3	0.13
13 Falwel	0.38	1.6	0.61
14 Farrey	0.41	0.5	0.20
15 Garankedey	0.41	1.7	0.69
16 Gaya	0.32	0.1	0.03
17 Golle	0.43	0.4	0.17
18 Gorouban Kassam	0.41	0.9	0.36
19 Guéchémé	0.41	1.3	0.53
20 Guilladjé	0.43	0.4	0.17
21 Harikanassou	0.38	1.9	0.72
22 Kankandi	0.46	0.3	0.14
23 Kara Kara	0.43	1.7	0.74
24 Kargui Bangou	0.43	0.9	0.39
25 Kieché	0.46	0.7	0.32
26 Kiota	0.38	1.7	0.64
27 Kore Mairoua	0.46	1.6	0.74
28 Koygolo	0.38	1	0.38
29 Loga	0.35	1	0.35
30 Matankari	0.43	0.8	0.35
31 Mokko	0.32	1.4	0.45
32 N'Gonga	0.43	0.4	0.17
33 Sambera	0.32	0.1	0.03
34 Sokorbé	0.41	0	0.00
35 Soucoucoutane	0.49	0.9	0.44
36 Tanda	0.43	0.2	0.09
37 Tessa	0.41	1.1	0.45
38 Tibiri	0.43	0.7	0.30

39 Tombo Koarey I	0.41	1.5	0.61
40 TK II-Sakadamna	0.41	0.7	0.28
41 Tounouga	0.41	0.5	0.20
42 Yelou	0.43	0.5	0.22
43 Zabori	0.41	1.3	0.53

The probability of consistent drought conditions is quite high in the region (Table 45); the majority of drought hazard values goes between 0.4 and 0.5 which means that normally almost 1 year out of 2 shows critical SPI values. The magnitude of risk depends largely on the L&D components and the municipality of Doumega results the most at risk. It is interesting to observe that the municipalizes near the river Niger, Falmey, Gaya, Sambera, Tanda and Tounouga exhibit among the lowest values of DHRI. It is probable that the productions systems of these municipalities are more related to the Niger river which reflects in a lower dependence to the rainfall for their agriculture production.

From Single to Multi-Hazard Risk Levels

The combination of the individual hazards (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 46 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 46).

Using the mapping tools, it is possible to plot the distribution of the different hazard risks (Fig. 34).

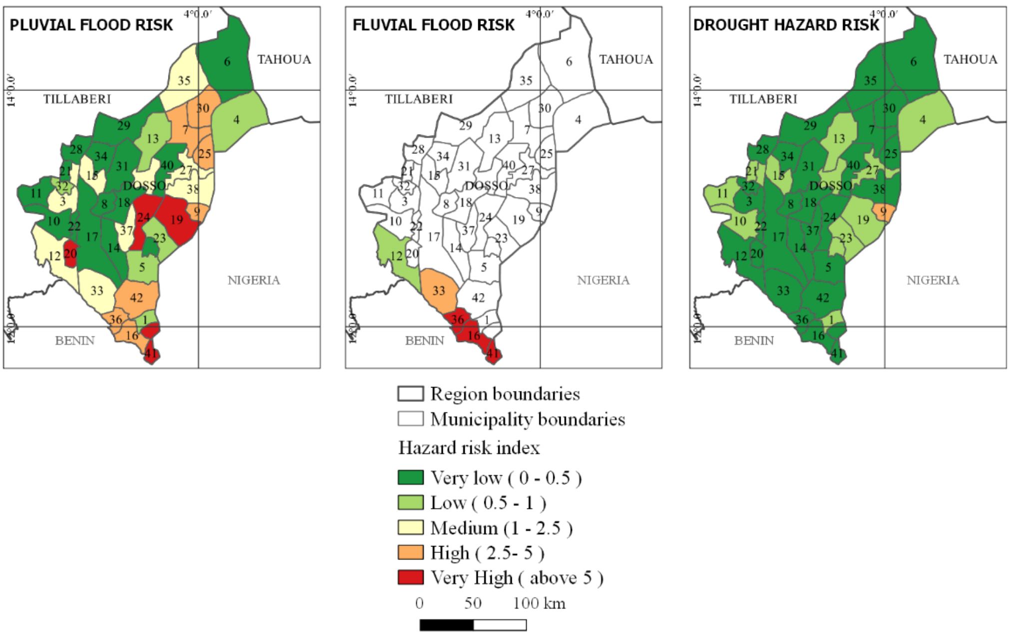


Fig. 34 Pluvial flood (left), fluvial flood (center) and drought (right) risk index levels in the Dosso region

The spatial combination of the different hazard risk levels provides the final MHRI results (Fig. 35).

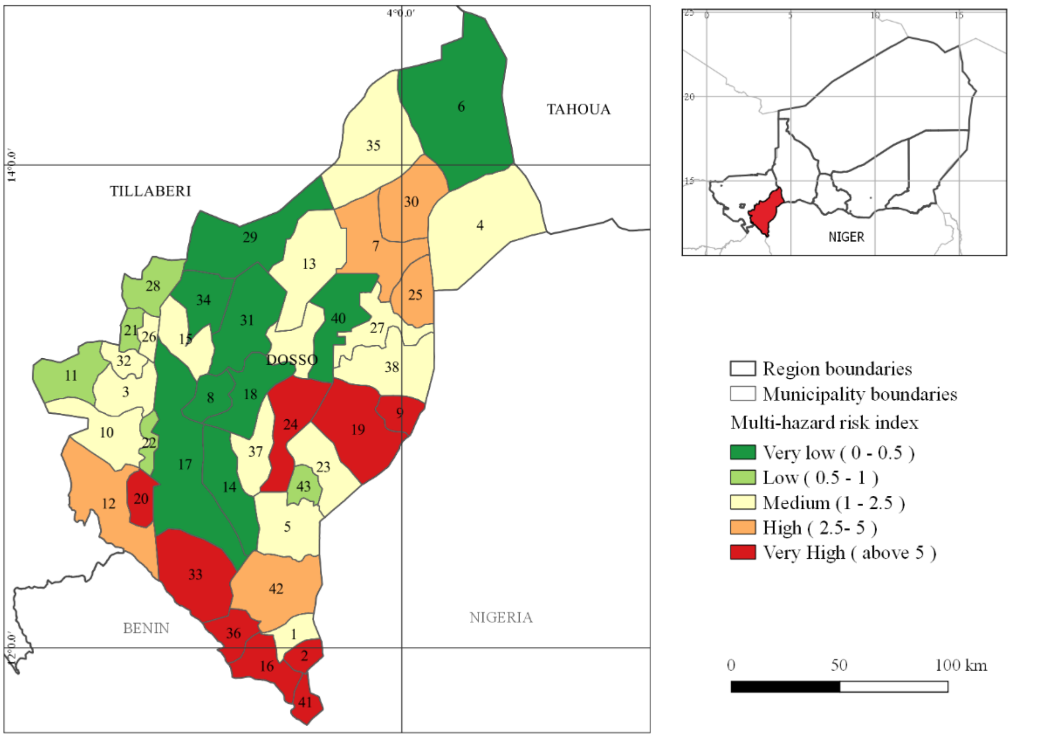


Fig. 35 Multi-hazard risk index at municipal level in the Dosso region.

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.

4.3 Local climatic projections in the Dosso Region

The evolution of daily rainfall for the period 2021-2080 in the Dosso region has been extracted using 18 models by CMIP5 retrieving a set of data sufficient to discriminate the possible future evolution of climate. In a consistent way in respect to the Hodh El Chargui case study, here an ensemble approach has been used, choosing from the 18 models trajectories the median and the interquartile model spread (the 25th and 75th quantiles) to create 3 different scenarios for the future evolution of precipitation: the optimistic, the median and the pessimistic scenarios. The choice is useful to retrieve information about the uncertanty of the models in detecting some trends.

Climate models are not build to predict exactly the future evolution of climate, then the major aim is to build an interval of confidence where the decision makers can get information about the future evolution of climate

With the CDO tool it has been extracted the rainfall statistics for each municipality through its geographic centroid using the 18 bias corrected climate models' outputs. These rainfall datasets are used to calculate the probability of critical meteorological conditions in each municipality. The results from all the models are grouped to perform the elaboration of the quantiles for every single index (precipitation maximum daily amount, SPI, etc.) extracted. These values are applied in the Risk formula to retrieve the MHRI.

For the evaluation of the future risk, the L&D values remains the same of the current conditions. This choice is due to the uncertainties in the future evolution of this component due the lack of information and studies about its possible trends and evolutions. For sure, demographic growth could increase the exposure component but the progress in forecast systems and telecommunications could easily and early alert population which could increase the capacity of saving their goods and lives. So it becomes quite puzzling understand the final projection of the L&D components balance.

Pluvial flood risk index

The extraction of the statistics from the 18 CMIP5 models has been performed on daily basis on the 43 grid points of the Dosso municipalities. Using these dataset, it has been extracted the yearly daily maximum of rainfall for each time series (2021-2080). Then we obtain the new reference for the computation of the return period of the critical rainfall for each municipality for each model.

The current condition is compared with the models predictions to figure out how many models intercept higher probability of meteorological hazard in future and how many predict equal or lower probability. This information could help the comprehension of the robustness of the signal intercepted by the models and, as consequence, the confidence that it is possible to assign to such a prediction. In the following Table 47 the results of this analysis.

Table 47 Percentage of models predicting future higher or lower critical rainfall probability

Municipality	Present Probability	% of models with higher or equal probability	% of models with lower probability
Bana	0.04	16.7%	83.3%
Bengou	1.00	38.9%	61.1%
Birni N'Gaoure	1.00	5.6%	94.4%
Dan Kassari	1.00	5.6%	94.4%
Dioudiou	1.00	100.0%	0.0%
Dogon Kirya	0.99	0.0%	100.0%
Dogondoutchi	1.00	22.2%	77.8%
Dosso	1.00	88.9%	11.1%

Doumega	1.00	5.6%	94.4%
Fabidji	0.10	16.7%	83.3%
Fakara	0.02	22.2%	77.8%
Falmey	1.00	83.3%	16.7%
Falwel	1.00	55.6%	44.4%
Farrey	1.00	33.3%	66.7%
Garankedey	0.93	0.0%	100.0%
Gaya	1.00	55.6%	44.4%
Golle	1.00	88.9%	11.1%
Goroun Bakassam	1.00	83.3%	16.7%
Guecheme	1.00	0.0%	100.0%
Guiladje	1.00	16.7%	83.3%
Harikanassou	1.00	44.4%	55.6%
Kankandi	0.33	11.1%	88.9%
Karakara	1.00	0.0%	100.0%
Kargui Bangou	1.00	5.6%	94.4%
Kieche	1.00	16.7%	83.3%
Kiota	1.00	22.2%	77.8%
Kore Mairoua	1.00	11.1%	88.9%
Koygolo	1.00	0.0%	100.0%
Loga	1.00	5.6%	94.4%
Matankari	1.00	11.1%	88.9%
Mokko	1.00	11.1%	88.9%
Ngonga	0.90	5.6%	94.4%
Sambera	1.00	33.3%	66.7%
Sokorbe	1.00	5.6%	94.4%
Soucoucoutane	1.00	11.1%	88.9%
Tanda	1.00	50.0%	50.0%
Tessa	1.00	0.0%	100.0%
Tibiri	1.00	11.1%	88.9%
Tombokoarey 1	1.00	50.0%	50.0%
Tombokoarey 2	0.10	16.7%	83.3%
Tounouga	1.00	38.9%	61.1%
Yelou	1.00	33.3%	66.7%
Zabori	1.00	11.1%	88.9%

At the first sight the overall result is that the models are more optimistic about the future evolution of meteorological hazard with 3/4 of the municipalities predicting a lower probability in respect to current climate while, in some municipalities, the majority of models predict more dangerous conditions such in Dioudiou, Dosso, Falmey, Falwel, Gaya, Golle and Goroun Bakassam. But it is important to underline that the majority of the municipalities are characterized by the upper threshold of probability (value = 1) in current conditions and, moreover, the critical rainfall threshold is placed in the extremes of the rainfall event distribution which is quite challenging to reconstruct for the future climate projections. For the latter consideration, in the author opinion, the transfer functions, which has been used for the bias correction of the models, could hinder the perfect reconstruction of future extreme daily values, first of all, by the doubtful correct representation of the extreme events in the CHIRPS dataset that has been used as reference for the current climatology. In such dataset the extremes distribution could differ in respect to the ground observations values triggering discrepancies in the perfect estimation of the return period of the critical rainfall for the forthcoming years.

The grouping or the 18 models outputs makes possible the selection of the quartiles of the models' ensemble (centiles 25th, 50th e 75th) to produce three different scenarios giving the probability of critical rainfall episodes. The results are summarized in the following

Table 48:

Table 48 Hazard component in pluvial flood risk index (PFRI) in the Dosso region at municipal level 2021-2080 – 3 scenarios

Municipality	*Centile 25*	*Centile 50*	*Centile 75*
Bana	0	0	0.01
Bengou	0.5	0.85	1
Birni Ngaoure	0.16	0.25	0.37
Dan Kassari	0.16	0.33	0.5
Dioundiou	1	1	1
Dogon Kirya	0.04	0.19	0.26
Dogondoutchi	0.47	0.76	0.96
Dosso	1	1	1
Doumega	0.28	0.45	0.63
Fabidji	0.01	0.04	0.06
Fakara	0	0.01	0.02
Falmey	1	1	1
Falwel	0.72	1	1
Farrey	0.63	0.87	1
Garankedey	0.05	0.11	0.25
Gaya	0.79	1	1
Golle	1	1	1
Goroun Bakassam	1	1	1
Guecheme	0.03	0.09	0.13
Guiladje	0.52	0.63	0.72
Harikanassou	0.6	0.69	1
Kankandi	0.03	0.1	0.15
Karakara	0.16	0.32	0.45
Kargui Bangou	0.31	0.52	0.69
Kieche	0.26	0.46	0.58
Kiota	0.5	0.59	0.89
Kore Mairoua	0.3	0.52	0.65
Koygolo	0.12	0.24	0.42
Loga	0.2	0.41	0.57
Matankari	0.34	0.52	0.69
Mokko	0.22	0.37	0.48

Ngonga	0.15	0.23	0.34
Sambera	0.69	0.87	1
Sokorbe	0.22	0.35	0.54
Soucoucoutane	0.2	0.49	0.53
Tanda	0.73	1	1
Tessa	0.11	0.23	0.29
Tibiri	0.32	0.49	0.62
Tombokoarey 1	0.8	0.98	1
Tombokoarey 2	0.01	0.01	0.05
Tounouga	0.53	0.87	1
Yelou	0.54	0.81	1
Zabori	0.34	0.5	0.8

Considering the cutting threshold of 1, which means that every year there is a condition favorable to pluvial flood, it is possible to observe no difference among the three scenarios, as in the case of Dioundiou, Dosso, Falmey, Golle and Goroun Bakassam, losing the sensitivity of the analysis to future changes. But again, the main concern is to assure the coherence of the analysis between future and current conditions.

Appling these values to L&D component we obtain the 3 PFRI scenarios for the 2021-2080 period (Table 49)

Table 49 Pluvial flood risk (PFRI) level in the Dosso region at municipal level 2021-2080 – 3 scenarios and present

		PFRI		
Municipality	*Present*	*Centile 25*	*Centile 50*	*Centile 75*
1 Bana	0.91	0.00	0.00	0.23
2 Bengou	45.17	22.59	38.39	45.17
3 Birni N'Gaoure	1.41	0.23	0.35	0.52
4 Dan Kassari	0.64	0.10	0.21	0.32
5 Dioudiou	0.97	0.97	0.97	0.97
6 Dogon Kiria	0.03	0.00	0.01	0.01
7 Dogondoutchi	3.37	1.58	2.56	3.24
8 Dosso	0.00	0.00	0.00	0.00
9 Doumega	4.05	1.13	1.82	2.55
10 Fabidji	0.48	0.05	0.19	0.29
11 Fakara	0.00	0.00	0.00	0.00
12 Falmey	2.14	2.14	2.14	2.14
13 Falwel	0.78	0.56	0.78	0.78
14 Farrey	0.00	0.00	0.00	0.00
15 Garankedey	1.04	0.06	0.12	0.28
16 Gaya	3.03	2.39	3.03	3.03
17 Golle	0.14	0.14	0.14	0.14
18 Gorouban Kassam	0.00	0.00	0.00	0.00
19 Guéchémé	5.07	0.15	0.46	0.66
20 Guilladjé	8.98	4.67	5.66	6.47

21 Harikanassou	0.02	0.01	0.01	0.02
22 Kankandi	0.41	0.04	0.12	0.19
23 Kara kara	0.83	0.13	0.27	0.37
24 Kargui Bangou	6.84	2.12	3.56	4.72
25 Kieché	2.80	0.73	1.29	1.62
26 Kiota	1.59	0.80	0.94	1.42
27 Kore Mairoua	1.43	0.43	0.74	0.93
28 Koygolo	0.48	0.06	0.12	0.20
29 Loga	0.00	0.00	0.00	0.00
30 Matankari	2.98	1.01	1.55	2.06
31 Mokko	0.00	0.00	0.00	0.00
32 N'Gonga	0.92	0.15	0.23	0.34
33 Sambera	1.55	1.07	1.35	1.55
34 Sokorbé	0.00	0.00	0.00	0.00
35 Soucoutane	1.33	0.27	0.65	0.70
36 Tanda	4.97	3.63	4.97	4.97
37 Tessa	1.96	0.22	0.45	0.57
38 Tibiri	1.01	0.32	0.49	0.63
39 Tombo Koarey I	1.03	0.82	1.01	1.03
40 TK II-Sakadamna	0.00	0.00	0.00	0.00
41 Tounouga	21.51	11.40	18.71	21.51
42 Yelou	4.36	2.35	3.53	4.36
43 Zabori	0.00	0.00	0.00	0.00

These values demonstrate that for many communities the future meteorological drought conditions could be similar to the current climate. Still, in many municipalities, such as Bengou, Dogondoutchi, Doumega, Falmey, Gaya, Guilladjé, Kargui Bangou, Matankari, Sambera, Tanda and Tounouga, even in the optimistic scenarios the PFRI is higher than 1 while for some municipalities, characterized by a current PFRI higher than 1, the PFRI in the pessimistic scenarios is below 1 as in the case of Birni N'Gaoure, Garankedey, Guéchémé, Kore Mairoua, Soucoutane, Tessa and Tibiri.

Here, once again, it is important to underline that the absence of a consistent observation network limits the robustness of the analysis. The adoption of data from weather station placed in the nearby municipality reduce the accuracy of the analysis and, when we apply these values for the future conditions, using the extraction of the time series using the centroid of the municipality, the result is affected by errors and uncertainties due to the simplification of the process coupled with the complexity of the spatial pattern of the rainfall. Nevertheless, the results are objective and comparable for an intra-municipality ranking. So, for the aim of supporting decision making process, the analysis gives some important output and, as more crucial aspect, this method is replicable and upgradable with the introduction of updated time series and more weather observation stations.

Fluvial flood risk index

Fluvial flood is the most difficult risk to project. The future prediction of the hydrology of Niger River is very difficult due to the uncertainties of the evolution of the rainfall distribution over the entire basin, the land use change and the hydraulic infrastructures that upstream other countries could build on the river.

Moreover, in the Dosso region, only 5 municipalities out of 43 are touched by the effects of river floods, so the overall effect of the projection fluvial flood risk in the final result of the regional MHRI is secondary.

For these reasons here it has been adopted a simplified approach using the current value of FFRI also for the future projections.

Table 50 Fluvial flood risk (FFRI) level in the Dosso region at municipal level, 2011-17

Municipality	**Fluvial flood**		
	H	**D**	**FFRI**
Falmey	0.3	2.7	0.9
Gaya	0.3	18.4	6.1
Sambera	0.5	7.8	3.8
Tanda	0.3	69.3	22.9
Tounouga	0.7	20.4	13.7

An alternative method could be to produce an arbitrary change of these values by applying different values for the three scenarios. In absence of an objective and robust criterion, it has been chosen to use the application of the same values for the 3 scenarios in the final MHRI index.

Drought hazard risk index

The evaluation of monthly SPI for future climate is made calculating the monthly cumulus in each municipality then, over the entire series, we evaluate the SPI in each municipality for the growing period. Then the evaluation of the number of months below -0.5 has been produced in every municipality to retrieve the final drought risk index assessment.

The first step in the process is the comparison of the models which show higher probability that future shows drier conditions for agriculture in respect to current climate.

The percentage of models showing an higher or lower probability of drought hazard is classified in the following table (Table 51).

Table 51 Percentage of models predicting future higher or lower drought probability

Municipality	Present Probability	% of models with higher or equal probability	% of models with lower probability
Bana	0.38	50.0%	50.0%
Bengou	0.41	44.4%	55.6%
Birni Ngaoure	0.43	27.8%	72.2%
Dan Kassari	0.51	22.2%	77.8%
Dioundiou	0.41	55.6%	44.4%
Dogon Kirya	0.46	27.8%	72.2%
Dogondoutchi	0.35	38.9%	61.1%
Dosso	0.43	38.9%	61.1%
Doumega	0.41	38.9%	61.1%
Fabidji	0.46	33.3%	66.7%
Fakara	0.38	33.3%	66.7%
Falmey	0.43	44.4%	55.6%
Falwel	0.38	50.0%	50.0%
Farrey	0.41	33.3%	66.7%
Garankedey	0.41	38.9%	61.1%
Gaya	0.32	50.0%	50.0%
Golle	0.43	38.9%	61.1%
Goroun Bakassam	0.41	33.3%	66.7%
Guecheme	0.41	38.9%	61.1%
Guiladje	0.43	44.4%	55.6%
Harikanassou	0.38	50.0%	50.0%
Kankandi	0.46	33.3%	66.7%
Karakara	0.43	55.6%	44.4%
Kargui Bangou	0.43	38.9%	61.1%
Kieche	0.46	27.8%	72.2%
Kiota	0.38	50.0%	50.0%
Kore Mairoua	0.46	33.3%	66.7%
Koygolo	0.38	55.6%	44.4%
Loga	0.35	38.9%	61.1%
Matankari	0.43	38.9%	61.1%
Mokko	0.32	44.4%	55.6%
Ngonga	0.43	27.8%	72.2%
Sambera	0.32	38.9%	61.1%
Sokorbe	0.41	33.3%	66.7%
Soucoucoutane	0.49	33.3%	66.7%
Tanda	0.43	50.0%	50.0%
Tessa	0.41	38.9%	61.1%
Tibiri	0.43	33.3%	66.7%
Tombokoarey 1	0.41	38.9%	61.1%
Tombokoarey 2	0.41	38.9%	61.1%
Tounouga	0.41	66.7%	33.3%
Yelou	0.43	38.9%	61.1%
Zabori	0.41	33.3%	66.7%

The slightly majority of models seems to predict an overall signal of lower probability of drier conditions in future except for the Tounouga, Koygolo, Karakara and Dioundiou municipalities.

Then using the extraction of the 25th, 50th and 75th percentile, it has been possible to create the 3 future scenarios of the MHRI analysis. The results are shown in the following table (Table 52):

Table 52 Hazard component in Drought hazard risk index (DHRI) in the Dosso region at municipal level 2021-2080 – 3 scenarios

Municipality	*Present*	*Centile 25*	*Centile 50*	*Centile 75*
Bana	0.38	0.22	0.41	0.59
Bengou	0.41	0.22	0.37	0.55
Birni Ngaoure	0.43	0.20	0.29	0.45
Dan Kassari	0.51	0.20	0.36	0.43
Dioundiou	0.41	0.30	0.46	0.57
Dogon Kirya	0.46	0.12	0.30	0.45
Dogondoutchi	0.35	0.20	0.29	0.47
Dosso	0.43	0.22	0.33	0.51
Doumega	0.41	0.24	0.38	0.55
Fabidji	0.46	0.18	0.30	0.49
Fakara	0.38	0.13	0.30	0.44
Falmey	0.43	0.21	0.36	0.53
Falwel	0.38	0.25	0.38	0.48
Farrey	0.41	0.18	0.25	0.50
Garankedey	0.41	0.21	0.33	0.46
Gaya	0.32	0.19	0.31	0.50
Golle	0.43	0.23	0.30	0.54
Goroun Bakassam	0.41	0.20	0.31	0.52
Guecheme	0.41	0.20	0.31	0.52
Guiladje	0.43	0.16	0.31	0.49
Harikanassou	0.38	0.22	0.37	0.49
Kankandi	0.46	0.18	0.30	0.49
Karakara	0.43	0.29	0.43	0.57
Kargui Bangou	0.43	0.28	0.39	0.58
Kieche	0.46	0.19	0.30	0.45
Kiota	0.38	0.21	0.36	0.48
Kore Mairoua	0.46	0.24	0.37	0.49
Koygolo	0.38	0.26	0.39	0.53
Loga	0.35	0.14	0.24	0.42
Matankari	0.43	0.22	0.37	0.52
Mokko	0.32	0.18	0.29	0.49
Ngonga	0.43	0.18	0.28	0.45
Sambera	0.32	0.13	0.26	0.49
Sokorbe	0.41	0.19	0.27	0.45
Soucoucoutane	0.49	0.24	0.38	0.55
Tanda	0.43	0.20	0.41	0.53

Tessa	0.41	0.28	0.35	0.57
Tibiri	0.43	0.20	0.32	0.53
Tombokoarey 1	0.41	0.24	0.38	0.52
Tombokoarey 2	0.41	0.21	0.33	0.51
Tounouga	0.41	0.34	0.52	0.64
Yelou	0.43	0.19	0.35	0.50
Zabori	0.41	0.25	0.33	0.55

For drought hazard, the current climate shows highest values in respect to the median future climate projections with few exceptions, while the pessimistic scenario shows probabilities almost everywhere above the current conditions. The agriculture could benefit of a more humid climate but, in coherence with other projections, the rainfall distribution in future is quite uncertain. These inputs could lead agricultural communities in adopting a more prudential approach for future productions choosing the most resistant species in order to minimize the possible loss of production or rather invest in a diversified production to take advantage of the wettest years.

Considering the L&D component it is possible to calculate the Drought hazard risk index series for Dosso (Table 53).

Table 53 Drought hazard risk index (DHRI) in the Dosso region at municipal level 2021-2080 – 3 scenarios and present

	DHRI			
Municipality	*Present*	*Centile 25*	*Centile 50*	*Centile 75*
1 Bana	0.91	0.53	0.98	1.42
2 Bengou	0.00	0.00	0.00	0.00
3 Birni N'Gaoure	0.17	0.08	0.12	0.18
4 Dan Kassari	0.56	0.22	0.40	0.47
5 Dioudiou	0.08	0.06	0.09	0.11
6 Dogon Kiria	0.37	0.10	0.24	0.36
7 Dogondoutchi	0.25	0.14	0.20	0.33
8 Dosso	0.09	0.04	0.07	0.10
9 Doumega	3.73	2.21	3.50	5.06
10 Fabidji	0.87	0.34	0.57	0.93
11 Fakara	0.64	0.22	0.51	0.75
12 Falmey	0.13	0.06	0.11	0.16
13 Falwel	0.61	0.40	0.61	0.77
14 Farrey	0.20	0.09	0.13	0.25
15 Garankedey	0.69	0.36	0.56	0.78
16 Gaya	0.03	0.02	0.03	0.05
17 Golle	0.17	0.09	0.12	0.22
18 Gorouban Kassam	0.36	0.18	0.28	0.47
19 Guéchémé	0.53	0.26	0.40	0.68
20 Guilladjé	0.17	0.06	0.12	0.20
21 Harikanassou	0.72	0.42	0.70	0.93

22 Kankandi	0.14	0.05	0.09	0.15
23 Kara Kara	0.74	0.49	0.73	0.97
24 Kargui Bangou	0.39	0.25	0.35	0.52
25 Kieché	0.32	0.13	0.21	0.32
26 Kiota	0.64	0.36	0.61	0.82
27 Kore Mairoua	0.74	0.38	0.59	0.78
28 Koygolo	0.38	0.26	0.39	0.53
29 Loga	0.35	0.14	0.24	0.42
30 Matankari	0.35	0.18	0.30	0.42
31 Mokko	0.45	0.25	0.41	0.69
32 N'Gonga	0.17	0.07	0.11	0.18
33 Sambera	0.03	0.01	0.03	0.05
34 Sokorbé	0.00	0.00	0.00	0.00
35 Soucoucoutane	0.44	0.22	0.34	0.50
36 Tanda	0.09	0.04	0.08	0.11
37 Tessa	0.45	0.31	0.39	0.63
38 Tibiri	0.30	0.14	0.22	0.37
39 Tombo Koarey I	0.61	0.36	0.57	0.78
40 TK II-Sakadamna	0.28	0.15	0.23	0.36
41 Tounouga	0.20	0.17	0.26	0.32
42 Yelou	0.22	0.10	0.18	0.25
43 Zabori	0.53	0.33	0.43	0.72

The overall result of the DHRI for the Dosso region highlight a distribution of the future climate around the current values. The pessimistic scenario in fact shows higher risk than the actual climate with the exception of 4 municipalities (Dan Kassari, Dogon Kirya, Kieche and Sokorbe) while in the optimistic scenario all the Municipality have a lower drought risk index.

In conclusion, despite the overall signal of humid conditions in future, there are still uncertainties linked to the rainfall distribution, so it is not possible to exclude significant interannual variability in the rainfall distribution which could lead to high interannual variability of agricultural production.

4.4 Application of future projections to the current multi-risk characterization in the 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 evolution of climate scenarios: the 25th, the 50th and the 75th centile.

Looking at the following Table 54 it is possible to make a comparison between the actual conditions and the future ones.

Table 54 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 55 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

It is possible to observe that the future multi hazard risk index spreads around the actual values with only few exceptions where the current risk is higher than the predicted one (also using the pessimistic scenario). The variability of the rainfall distribution cannot retrieve clear signals but, analyzing each municipality, it is possible to observe different behaviours.

The mapping tool helps in the comparison of the distribution of the risk in the region intercepting the differences among the 3 scenarios (Fig. 36).

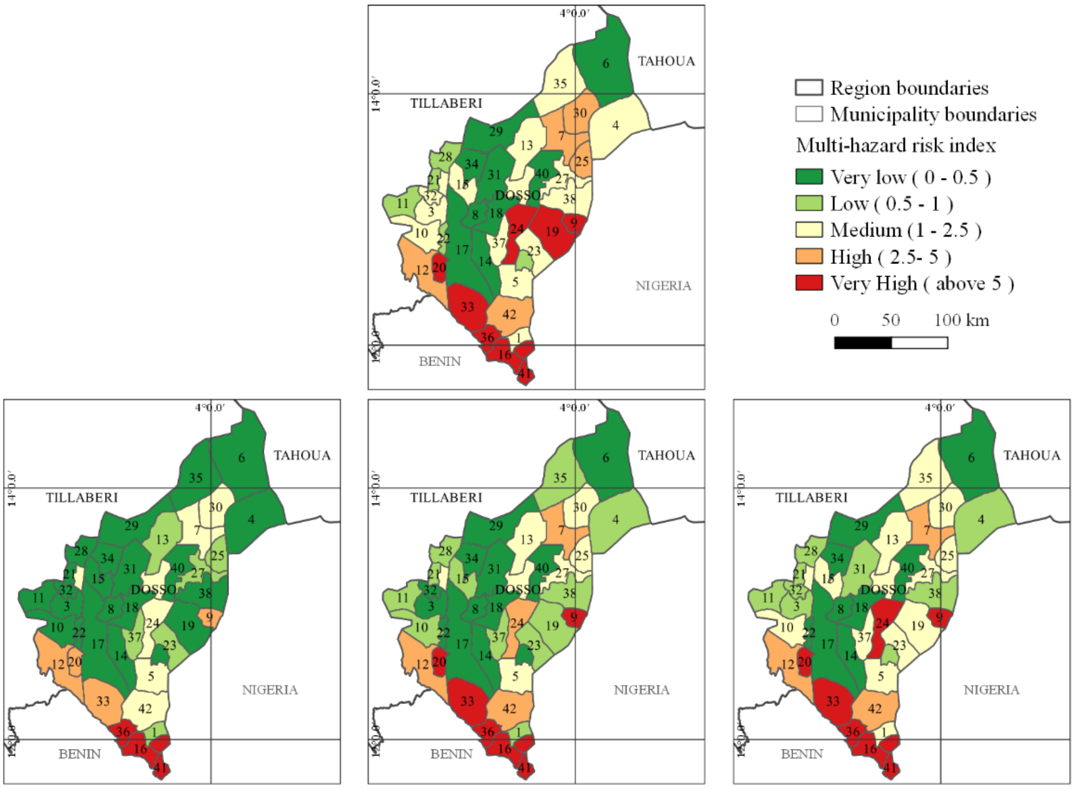


Fig. 36 MHRI comparison Present and 3 futures scenarios (in the bottom line, from left to right the 25th, 50th and 75th centile scenarios)

The future scenarios comparison analysis offers the chance to immediately intercept the most important signals. The municipalities along the Niger river will show 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.

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

The comparison of the different levels of risk, from the current 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. 37) will add more information for decision makers.

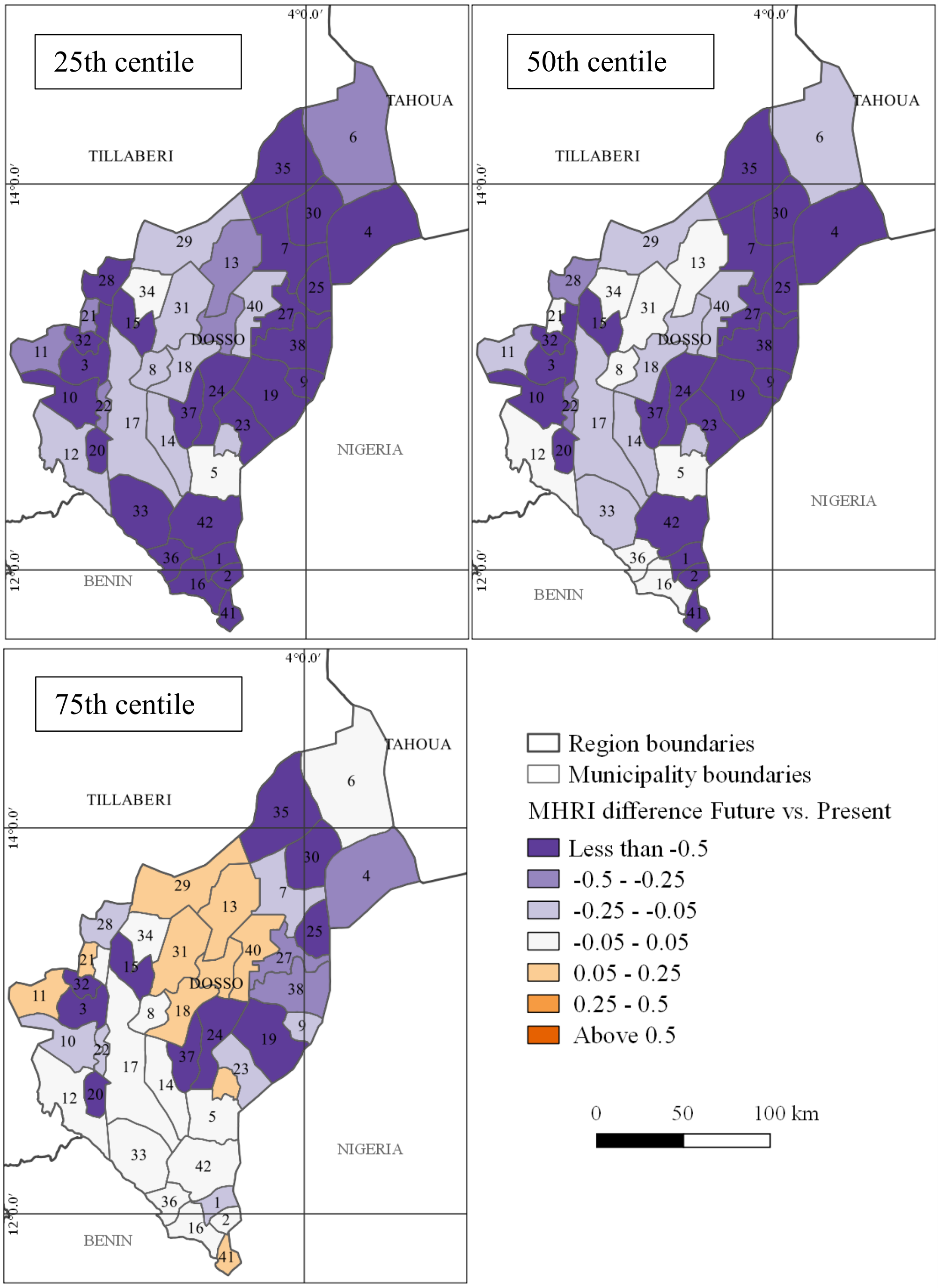


Fig. 37 MHRI trends in the Dosso region, comparison of the MHRI in the 3 scenarios in respect to present conditions

The figure illustrates the three MHRI differences with respect to current 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 show a higher MHRI with respect to the present status. The municipalities with higher increase of risk are concentrated in the western and central part of the region. It is interesting to observe that many of these municipalities are not the most at risk, so the use only of the information about the future level of MHRI could hide dangerous trends in risk evolution.

Essentially, if the aim of decision makers is to prevent a risk, knowing which municipality has the higher trend of increase of risk is crucial. While the municipalities in which the future conditions are less at risk, demonstrate that they can recover autonomously the risk level without any significant additive intervention by local authorities.

Trying to summarize 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 needs the highest priorities of intervention, hence the following contingency table was created (Table 56) to try to combine these two components.

Table 56 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. 38) .

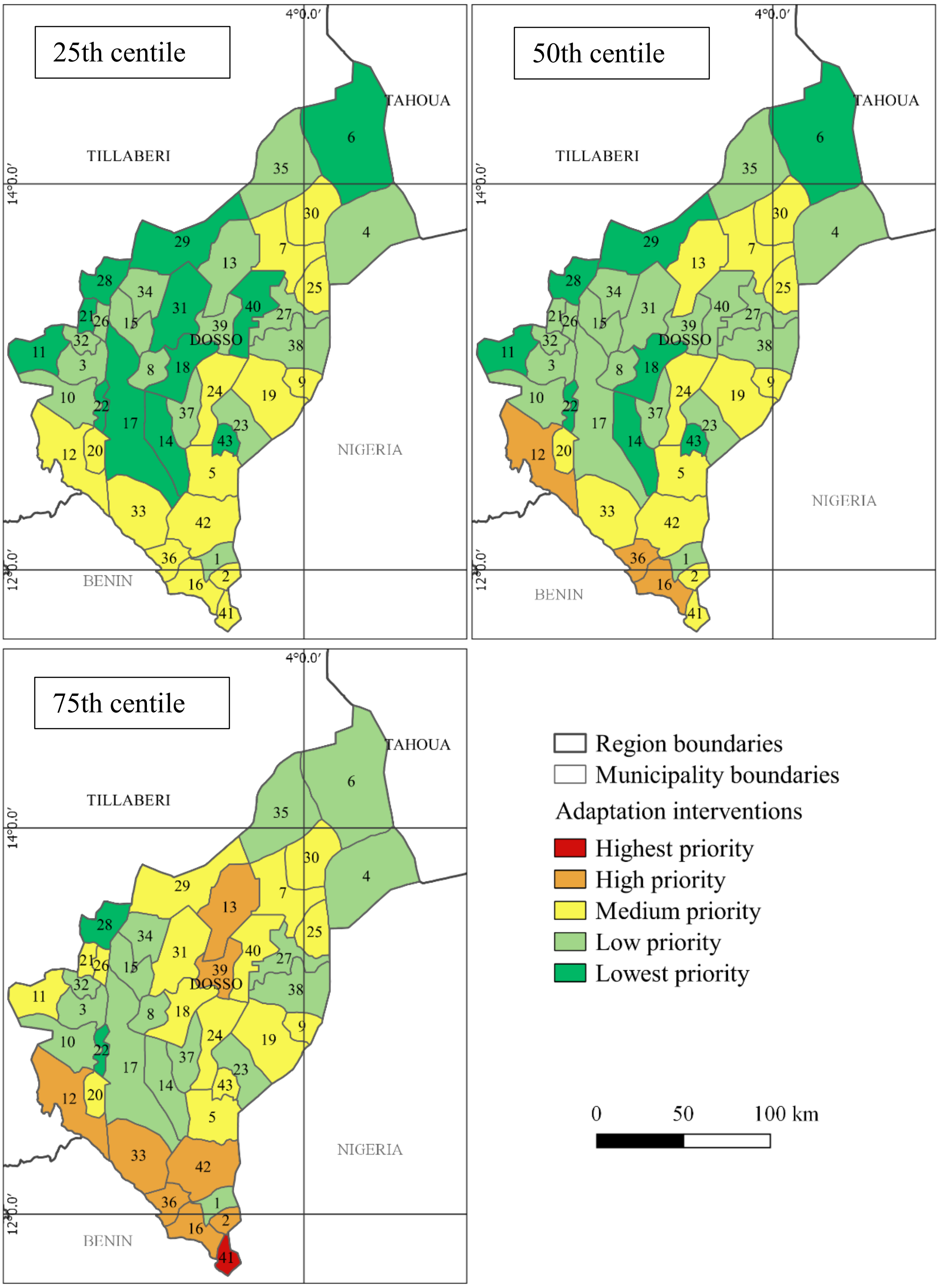


Fig. 38 Priorities of adaptation interventions in the Dosso municipalities in the 3 future scenarios

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 in the average case scenarios they show a low priority.

4.6 Discussion about the case study in the Dosso Region

The effort made in this study aims to help local communities in the CC adaptation plan and project development because normally they do not have access at decision-making oriented analyses about local hydro-climatic risk at high resolution. Nonetheless, it is quite challenging organize a multi-hazard risk assessment at a regional scale useful for decision makers especially in environments where basic data are scarcely available.

The use of a gridded dataset, in this case the CHIRPS daily dataset but it is possible to select others, has the great advantage to analyze the main indicators in extreme events characterization for each municipality in a consistent way. The production of intercomparable results is a great advantage even if they are not extremely accurate. Decision making process is guided by the comparison of the single unit of the analysis respect the global. The risk ranking affected by a systematic error could not have substantial effects on the decisions. For sure, the ideal hypothesis of a dense observation network and the availability of ground measured data could improve the outcomes adding more accuracy, but unfortunately this is not the case of the most countries of the tropics.

The limitations of the vulnerability indicators are enormous in this context of poor institution measurement network and data availability and it represents, in the author's opinion, the main limiting factor in the risk analysis, but following the use of the L&D approach proposed by Tiepolo et al. [1] it is possible to overcame this measure by applying directly the effects of the disasters in the risk assessment formula.

While in West Africa could be difficult to estimate the monetary impacts of disasters, the use of the population information could better weight the risk allowing a better comprehension of the risk level.

The highest uncertainties in the study concern basic information availability (i.e. the low geographical density of weather stations, the position and population of settlements that were hit, the level of cereal deficit in drought years). The strategies to reduce these uncertainties are many, for instance the municipalities lacking a weather station with a dataset of at least 30 years were attributed the rainfall measurement of the nearby uphill weather station. The flooding event recorded without a clear temporal reference, it was given the maximum rainfall value of the year. These are the main two but, in the author opinion, the method still remains valid for the purposes of the multi-hazard risk assessment considering the alternative option: do not produce analysis. As previously said, this work support decision making process with two main features, first, the setting of a method that could be replicable to assess a ranking of interventions in the region, secondly it was possible to understand the effects of the lack of data for the analysis and, hopefully, aware local communities in take actions to set up or improve the measurement network, not only the weather stations installation but promote a holistic system able to monitor natural disasters and their impacts in the region.

Far from the idea of produce the perfect assessment of the multi hazard risk in the Dosso region, this case study aims to contribute in the debate about the multi-hazard risk assessment in regions characterized by a systematic lack of data and resources. The proposed method to overcome the absence of information could be improved by further studies introducing new methods, data and tools. Nevertheless, it is important to take in consideration the capability of local institution in replicating the process. This must be the priority in the development of similar analysis.

The increased frequency of extreme rainfall events in the municipalities of Birni N'Gaoure, Dan Kassari, Dogon Kiria, Loga, Matankari, N'Gonga and Soucoucoutane means that these communities have to adapt to new climate conditions. The reduction of risk could be done, among others, by the reduction of the vulnerability of the population with the construction of more efficient water drainage, the revision of buildings' materials and avoid the impact of floods on water reservoirs and latrines at ground level. The increased number of river flooding and the prevalence of Red floods require the protection of rain-fed crops during the cropping season and the increase of Niger flood early warning systems which allows the population to store equipment and livestock in a safe place during floods.

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 monitoring rainfall distribution activities and particularly in the adoption of adaptation strategies such as the introduction of drought-resistant cultivars, crop diversification, changes in cropping patterns and sowing dates.

In the Dosso region, throughout the recent years, in adaptation and resilience projects rarely use local rainfall monitoring, warning for farmers (agro-meteo bulletins) and green infrastructures. Moreover, aid projects in Niger have priorily focused on food security in an area where most of the regions are affected by drought. Projects often operate at national level and extend the same actions to all areas of intervention, by applying the same method for drier regions, i.e. Tillaberi, and wetter regions, i.e. Dosso, which explains the inconsistencies of results and their sustainability. This work shows the differences in risk assessment in a small portion of the territory with the need of tailored intervention to reduce the effects of climate threats.

One thought must be given to the option of the extension of the assessment to other regions and its repetition over time, while normally it represents the weakness of other studies. The large use of public information gathered by national and local authorities with the integration of freely accessible climatic gridded dataset, currently available at sufficient resolution to discriminate the analysis at the municipal level, combined with relatively simple calculation methods, allow personnel lacking advanced skills to carry out risk tracking in any region with few days of dedicated training.

The assessment allows to list some lesson learnt during the whole process. The first one is that a clear understanding of the factors that turn a local hydro-climatic event into a disaster is needed to produce tailored vulnerability indicators. In the case of information missing, the L&D approach is promising, if L&D dataset are available.

The second lesson learnt is that to identify flood-prone areas at higher resolution, the methods that use low-resolution DEM and satellite images are not able to produce sufficient detail, such in the case of the municipality level in Niger, for assessment purposes. The application of buffer technique or DEM to identify areas prone to flooding along the River Niger and the dallols, drive to an overestimation of the effects of the floods: in fact, Tiepolo et al. [1] find in over the past seven years, only 29% of the settlements along the River Niger, and just 20% of those in the dallols, have ever been flooded. Moreover, the study evidence also that in the case of local assessment the lack of coverage provided by global, open-access databases regarding flooding and drought compared to local versions is quite high. The global database record only 18-44% of the events listed in local databases and have proved to be particularly unreliable when it comes to drought. An interesting result of the assessment were the 123 settlements prone to multi-hazard (flood and drought) scattered over no fewer than 31 municipalities, which means that the importance of the multi hazard risk assessment approach is important to catch the real risk level to which populations are prone. Focusing in only one threat could lead to dangerous underestimations in the risk assessment.

The concentration of fluvial flooding L&D interests few municipalities, which produces high levels of vulnerability, while for drought the vulnerability is more generally distributed. Drought adaptation in recent years seems to not have the attention that it needs for adaptation actions that have rarely addressed this threat while in the ’80 and in the ’90 the projects are more addressed to early warning of drought conditions. Often, the media coverage and the international community attention is placed to the most “fashionable” phenomenon while all the natural hazards must to be assess to get the most accurate picture of the natural risk in a study area.

The limitations of the assessment include the use of incomplete information (L&D), consequentially this implies an underestimation of the risk level in some municipalities. The origin of flooding in the single settlements that have been hit (watershed surge, flash floods, ponds, the impact of extreme rains on receptors) is still unidentified. Rarely the intervention projects in the area aim to find the hydrological causes of a flood to prevent the effects of future hazards but instead they focus on recover the damages and losses. To reach a higher level of disaster prevention in the region, more investigations are needed, but such kind of studies requires high investments and often local government do not have sufficient resources to found them. The origins of drought are clearer but its magnitude and effects is not detailed for all settlements because the intrinsic resilience to water shortages of a specific production system. The inclusion of such information in the assessment would be an improvement.

A second possible improvement would be the estimation of L&D in monetary terms, which would be possible if surveys specified the types of buildings, crops and cattle affected and the cost to recover it. This would allow next studies to include the cost-effectiveness analysis in the assessment process of risk reduction and adaptation for the municipalities.

A third improvement would be to include projections of L&D for future scenarios. The use of possible trajectories of evolution of the society and its capability to absorb shocks in the medium- and long-term would allow to assess in more complete way the future evolution of natural risk. In this way, the planning process would be based on more realistic development models. But, it is important to pay attention in this process because there is the possibility to insert more uncertainty than signal, with the final result of a scattered result. The aim is to find the right balance between quality and quantity of information available for the multi-hazard risk assessment.

Two main comments arise from the conclusion of this exercice.

The first one is that adding the outcomes of this study to available information, decision makers could benefit of a large set of material that could change drastically the priorities' ranking in respect of using only the current climate MHRI analysis. The second one is about the option to give to decision makers three different options for their decisions. If decision makers want to be more prudential they could benefit of the worst case scenario, if they are looking for the maximization of the investments they could look at the best case scenario. In any case they could choose to invest their resources in the most efficient way following their own strategical choices.

These two aspects represent an undoubted advantage for who needs to produce a medium and long term planning. For this reason, the author recommends to pursuit this approach in further studies of multi-hazard risk assessment.

Section 5

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 administration. 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 built 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 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.

For instance, in the Hodh El Chargui region, Tiepolo et al. [2] propose some measures at a very detailed scale in the communities the most at risk. It is a simple list of action easily applicable but they can improve a lot the adaptive capacity of these communities. The measures are listed in Table 57:

Table 57 Risk treatment for the 5 communities at severe and high risk of the Hodh El Chargui, Mauritania

Community	Exposure	Vulnerability	Risk reduction
NGuiya	Borehole	Diesel pump out of service	Solar powered water pump
	Wells	Poor water flow No basement No pump No water trough	Well deepening Basement Pedal powered pump Water through construction
	Earth embankments	Deteriorated No fence in barbed wire	Reshaping the earth embankment Fence in barbed wire
Agoueinit	1st earth embankment	Lack of spillway and lock	Spillway and lock construction Fence in barbed wire
	2nd earth embankment	Spillway deteriorated	Spillway reparation
Begou	Wells	Wells flooded	Well deepening Elevating the apron Solar powered water pump Access to well in wet season
Legdur	Wells	Wells flooded	Covering the well Elevating the apron Solar-powered water pump
	Earth embankments	Lack of spillway, lock	Spillway and lock
Boukhzama 1	House, wells	Creek bank erosion	Gabions
	Wells	No water trough	Water through for cattle
Legaida	Wells	Poor water flow	Well deepening Apron construction Water through for cattle watering Solar-powered water pump

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 current data and knowledge regarding multi-hazard risks, the potential impacts of related economic losses, and potential threats to human life and safety [157]. Therefore, the multi hazard risk assessment is necessary for a rational decision making in the adaptation and spatial planning processes [158]. 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 materials of buildings and water management, which play a crucial role in flow accumulation and inundation [159]. The so-called best management practices (BMPs) and low impact development practices (LID) are examples of adaptation measures [160].

The Potential Use of Risk Assessment: Planning with Climate

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 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) [161-166] 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. For instance, Tounouga municipality, which has been hit several times by fluvial and pluvial flooding, actions envisaged by intervention projects focus on reducing the impact of drought. The same in Tanda municipality, which has been hit several times by fluvial flooding, the proposed actions focus on reducing run-off and drought. While in Doumega municipality, characterized by drought episodes and pluvial flooding, the actions are well planned and they focus on water and soil conservation (WSC) and gardens. In Dogondoutchi, Falmey and Guéchémé, hit by pluvial flooding, the main actions consist correctly in reducing run-off with reforestation, reinforcing the banks of local streams and improving water drainage. Unfortunately, raise awareness campaigns or the monitoring of rainfall measurement at a local level are not take in account among the possible intervention options in these municipalities.

Comparing the quota of the total budget of the six LDPs set aside for CC adaptation actions in the Dosso region with the raking of the municipality most at risk it is possible to observe that in Tounouga, a Municipality at a severe risk (MHRI=35.4) the budget allocated is quite low while it is relatively high (about 1.5 million of $) in Guecheme characterized by a MHRI=5.6. (

Table 58).

Table 58 Actions scheduled by LDPs for municipalities at hydro-climatic risk (values expressed in thousands of US$) adapted by Tiepolo et al. [1]

	Municipality					
Actions	**Tounouga**	**Tanda**	**Douméga**	**Guéchémé**	**Dogondoutchi**	**Falmey**
*Hazard**	*PF*	*PF*	*DF*	*F*	*F*	*F*
MHRI	***35.4***	***28***	***7.8***	***5.6***	***3.6***	***3.2***
Training					1	
OSV-SCAPRU				29	1	
WSC		58		550	545	507
Tree planting			75	81	8	4
Stoves			18			
Culverts				64		
Creeks				190		
Drainage					28	
Weir				319		
Latrines						49
Seeds					4	
Gardens		86	120	214	23	
Input bank	11	28	26		8	
Cereal bank	11	47	73		19	
TOTAL	*58*	*247*	*321*	*1453*	*641*	*563*

*D-drought, F-Fluvial flood, P-Pluvial flood.

The following step involves the verification of the consistency between risk level and number of projects. As explored in Tiepolo et al. [1] twenty-three municipalities out of 43 municipalities benefit from RR, adaptation and resilience actions put in place by 14 projects, finding that the geographical distribution of projects is indifferent to the MHRI level.

The following

Table 59 is made by comparing the municipalities assessed by this study a with those that have benefitted from the 12 development aid projects in the risk reduction, adaptation and resilience to CC areas [167-178]. Information regarding actions was sourced from the intermediate and final evaluation reports of individual projects by Tiepolo et al. [1]. The actions were grouped to make the analysis of consistency easier according to the categories defined by Biagini et al. [179].

Table 59 Municipalities benefitting from adaptation, resilience and MHRI projects.

Municipality	***MHRI***	***Sum of .Projects.***	***ANADIA 2.0***	***PARC-DAD***	***DC***	***GOMNI***	***PGRC DU***	***PFSS***	***CAP CR***	***LoCal***	***PADAD***	***RRC***	***PANA R***	***FLEUVE***
41 Tounouga	35.41	2	1								1			
16 Gaya	9.16	1					1							
9 Doumega	7.78	0												
24 Kargui Bangou	7.23	1												1
19 Guéchémé	5.6	2	1								1			
7 Dogondoutchi	3.62	3			1		1	1						
30 Matankari	3.33	1			1									
12 Falmey	3.17	2	1								1			
25 Kieché	3.12	4	1		1						1	1		
37 Tessa	2.41	1	1											
35 Soucoucoutane	1.77	2		1	1									
15 Garankedey	1.73	1				1								
3 Birni N'Gaoure	1.58	1					1							
13 Falwel	1.39	2							1					1
38 Tibiri	1.31	1						1						
4 Dan Kassari	1.2	1			1									
28 Koygolo	0.86	1				1								
6 Dogon Kiria	0.4	3		1	1					1				
29 Loga	0.35	4						1	1				1	1
17 Golle	0.31	1				1								
14 Farrey	0.2	1				1								
8 Dosso	0.09	2					1	1						
34 Sokorbé	0	3				1			1	1				

ANADIA 2.0 – Adaptation au changement climatique, prévention des catastrophes et développement agricole pour la sécurité alimentaire, 2017-20, CAP-CR – Community Action Project for Climate Resilience, 2013-18, DC - Doutchi-Climat, 2017-19, FLEUVE - Front Local Environnement pour une Union Verte, GOMNI – 2017-19, LoCAL - Mécanisme financement Adaptation au Changement Climatique au niveau Local, 2015-16, PADAD - Programme d'Appui Développement Agricole Dosso, 2014-16, PANA-R - Programme d'Action National pour l'Adaptation-Résilience, 2010-14, PGRC-DU – Projet de Gestion des Risques de Catastrophe et de Développement Urbain, 2013-19, PARC-DAD - Projet d'appui à la Résilience Climatique pour un Développement Agricole Durable,2015-20, PASEC - Projet d'Appui à l'Agriculture Sensible aux Risques Climatiques, 2016-22, PFSS - Projet Filets de Securité Sociale, 2011-19, RRC – Renforcement de la Resilience Communautaire, 2014-16.

Placing the number of Projects above of the current MHRI assessment it is possible to obtain the following map (*Fig. 39*).

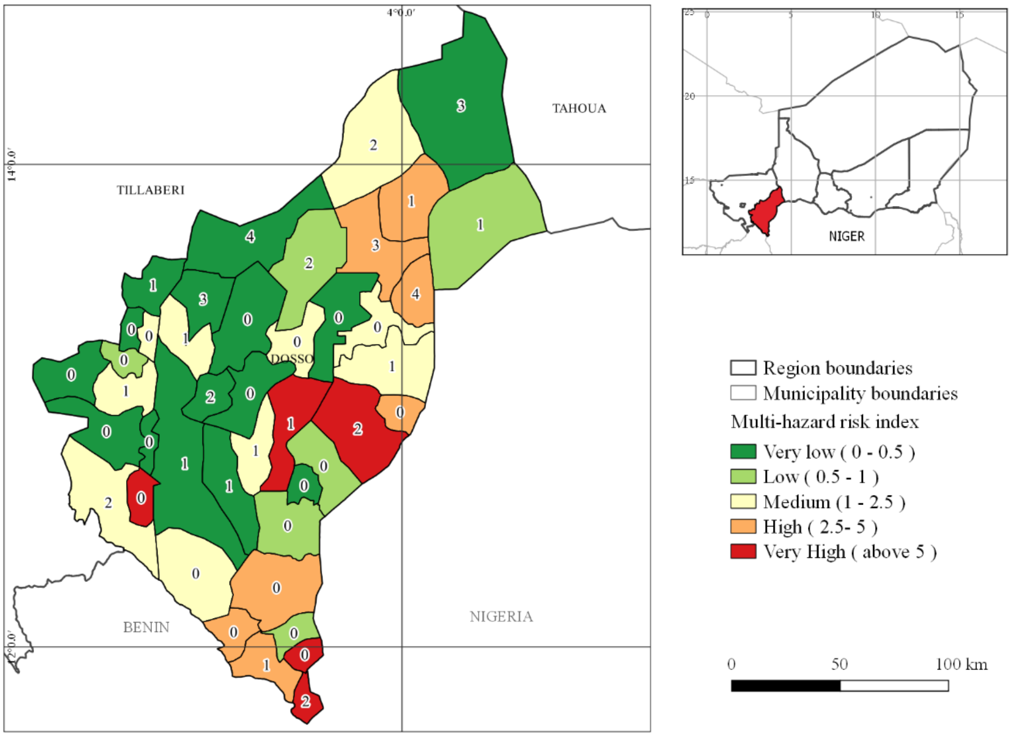


Fig. 39 Current Multi-Hazard Risk Index in the Dosso Region and number of interventions per each municipality

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. 40) 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.

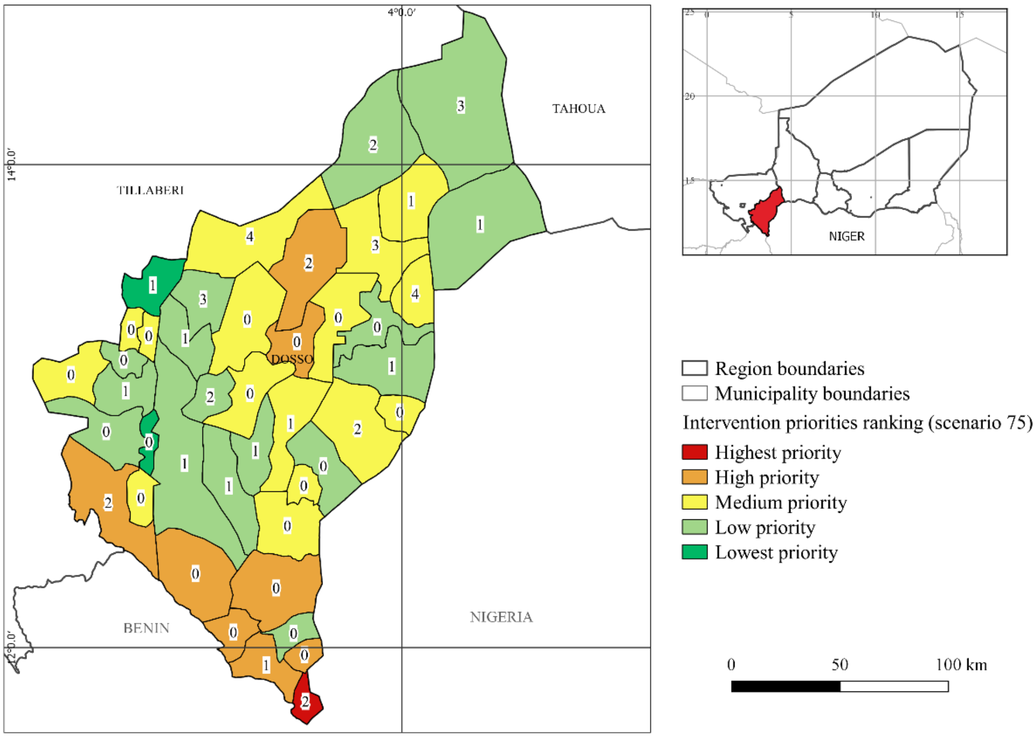


Fig. 40 Intervention priorities for the worst case scenario and number of Projects

The map shows 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.

Finally, in the next

Table 60, it was assigned the category of adaptation actions to each municipality grouping the actions in 7 classes to analyse the types of intervention that are made in the Dosso Region. The results demonstrate that projects follow a traditional approach focusing on improving practices/behaviours and infrastructure while planning is less common. Field data and observations reinforcement, warnings and capacity building are even less common. Financing initiatives and technology improvement that reduces deforestation and, consequently, run-off, are entirely absent. Only 3 out of the 15 municipalities at severe and elevated MHRI are gathering, or have gathered, information or early warning data regarding potentially disastrous hydro-climatic events, adaptation best practices and behaviour or disaster-protection infrastructure.

Table 60 Categories of adaptation actions according to the level of multi-hazard risk

Municipality	**MHRI**	**Adaptation category**						
		1	**2**	**3**	**4**	**5**	**6**	**7**
41 Tounouga	35.41		2		1	1	1	
16 Gaya	9.16	1	1	1				
24 Kargui Bangou	7.23	1		5		2		
19 Guéchémé	5.6		2		1	1	1	
7 Dogondoutchi	3.62	3	2	4		2		1
30 Matankari	3.33	2	2	2		2		1
12 Falmey	3.17		2		1	1	1	
25 Kieché	3.12	1	5	3	1	6	1	1
37 Tessa	2.41	1	1	3	1	2	1	
35 Soucoucoutane	1.77	2	2	2		2		1
15 Garankedey	1.73			1				
39 Tombo Koarey I	1.64	1		2		2		
3 Birni N'Gaoure	1.58		1					
13 Falwel	1.39	1	1	4				
38 Tibiri	1.31			1				1
4 Dan Kassari	1.2	1	2	2		2		1
28 Koygolo	0.86			1				
31 Mokko	0.45	1		2		2		
6 Dogon Kiria	0.4	2	2	4		2	1	1
29 Loga	0.35	2	1	6		3		1
17 Golle	0.31			1				
40 TK II-Sakadamna	0.28	1		5		2		
14 Farrey	0.2			1				
8 Dosso	0.09			1				1
34 Sokorbé	0	1	1	3				
Sum		*21*	*27*	*54*	*5*	*32*	*6*	*9*

1 Capacity building (best practices, study trip), 2 Management and planning (pond fish training, RR plans, CC integration into LDPs), 3 Practices and behaviour (WSC, selected seeds, improved stoves), 4 Information on climate change (local rainfall monitoring), 5 Infrastructure (irrigation, pastoral wells), 6 Warning (agro-meteo bulletin), 7 Green infrastructures (village nursery).

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. In particular, with the data available through the 3-hour 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.

Nevertheless, as previously said, the ranking of the municipalities has its coherence. This meant that it is possible to discriminate, with this assessment, the municipalities the most at risk. While it is evident that intervention projects do not always follows this raking of priorities in the choice of the areas of intervention.

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 model 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.

This is the approach chosen by the author taking in mind the operational application of the study. A long debate has been conducted to produce the final synthesis of the outcomes of the study. In fact, it becomes difficult to find the most appropriate way to display a clear and useful result when the process deals with a large amount of data. The effort made during the process in producing this synthesis is part of the analysis and only a feedback from final users could fine tune the entire process.

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, that we still make them without a perfect knowledge, in climate analysis these are a synonymous to inaccuracy. It is clear that we cannot reproduce a perfect evolution of the daily climate from now until the 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 hav in climate change projections, 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 [180]. And this common behaviour is quite dangerous in disaster risk prevention.

While the risk concept is quite familiar in our lives. It is possible to find it in the language of the insurance, in the health and national security sectors. So, for many audiences, from politicians to general public, talking about the risks of climate change seems to be more effective than talking about the uncertainties [181-182].

The more that the risks of climate change can be brought to life through vivid 'mental models', the better. The use of simple and practical examples of the risk of a village flooding or a farmer's crops being destroyed could help in raising awareness. Especially in West Africa, referring to specific historical episodes of bad years could help in clearing the concepts of the climate change risk and its effects.

More far in the future potential risks and hazards are the easier they are to 'discount' or ignore. For most people climate change is an abstract and distant concept and the uncertainty intrinsic in climate predictions opens the door to optimistic thinking about how dangerous climate change really is [183-185].

Ballard and Lewandowsky [186] states that the simple switch in the framing of the uncertain information increase support for government action on climate change, and the focus on 'certain' events also helps to bridge the psychological distance between climate change and people's everyday lives making it seem more tangible, less abstract, and more relevant. When uncertainty was used to indicate that losses might not happen if preventative action was taken (i.e. the positive frame), then people were more likely to indicate stronger intentions to act in a pro-environmental way. It's also important to emphasize that acting on climate change, even under conditions of uncertainty, entails many cobenefits that most people would support.

In my decadal experience in West Africa, referring the future scenarios with tangible experiences that arise from extreme weather events recoded in a specific year or location reduce the 'abstraction' of climate change effects, allowing local communities to relate more easily to the issue, as they will have to deal with similar risks in the future.

Another aspect to take in consideration when dealing in communication of the uncertainties is about the typical attitude in the West Africa community to climate models which is the "what is the best model?" approach. Clearly this is an impossible answer in an ex-ante condition but still they rather prefer to think in a deterministic way in respect to a probabilistic scenario. For this, in the author opinion, the transfer of knowledge must be part of the communication process increasing the basic knowledge of climate process in the local communities.

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 and more sophisticated tools. The presented methodology offers 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, 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 in discussion, all the West Africa window has been already elaborated for the purposes of the study. Therefore, it could 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 executed 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 option to retrieve data from specific field surveys could update the exposure and vulnerability risk components 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 a 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 risk components 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.

Section 6

Conclusions

The study explores the possibility to improve the risk assessment in Sub-Saharan territories 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 municipal scale.

The ability to describe phenomena at municipal level and the identification of significant changes in risk distribution provides an objective and useful information to support regional and urban development in these territories.

The efficiency of the intervention must be maximized and only a previous assessment with the ranking of the areas the most at risk is able to address correctly the adaptation options.

The results of the study are promising. They show that future climate condition might 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 precipitation is intercepted by the models, placing the current risk between the future optimistic and pessimistic scenarios with few exceptions which require 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. But again, considering the scarcity of data available, it is possible to be optimistic that, in future, it will become possible to access to more data from observation network and accurate GCM and RCM models' outputs.

The comparison between present and future scenarios allows to observe the changes in the ranking of the municipalities considering the MHRI sorting. These dynamics are quite interesting to observe. In the Mauritania case study, it results that in the Hodh El Chargui, Legdour will become the community most at risk while Drougal, Gnebett Ehel Heiba and Mberey El Jedida are relatively more at risk while it's observed a decrease of risk in Agoueinit. This information is relevant and it becomes an important additional input for decisions makers involved in the medium and long term planning. In a context of changing climate, the measurement of expected changes in three different scenarios is an important additional information for these subjects.

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 gardening 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.

The identification of several actions for the communities at risk, such as the improvement of access to water or the installation of early warning systems, supports local communities in facing climate threats increasing their awareness and prevention to climate risks.

While Mauritania's case study is characterized by a territory scarcely inhabited, the Dosso region, with more than two million of inhabitants, requires a different approach. Here, 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.

Nevertheless, the method allows to produce analysis valid for the purposes of this assessment. The main finding is the production of a detailed list of the municipalities at risk and their specific risk level. The study highlight 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.

The other important aspect is about the capacity of the study to highlight the weakness in the observation network. This also could guide decision makers in investing in such domain to produce, in future, more accurate analysis.

The method is conceived to easily introduce new elements of knowledge. This means that it could be possible to relaunch the procedure with more details on the risk components retrieving more accurate results. Moreover, the method allows to insert other climatic risks in the analysis path, such as locust, extreme heats stress or other diseses, if the study area is affected by one or more of these threats. In this case the limiting factor is if there are sufficent data or information available able to characterize the basic unit of the analysis.

In general, the approach aims to design a way to produce analysis through a participative approach tailoring the study on the local specific carachteristics.

The collection of data by the field surveys is always made in collaboration with the local authorities and local communities that are the persons who know best the territory and its fragility and they have the sensitivity to catch the information needed for the assessment.

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, 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.

The most effective way to propose complex results in a simple way to decision makers is challenging. This is true especially when it deals with very different actors, from the national decision makers in the ministries to the field farmers' level. This study dedicates a lot of attention in presenting the results in a simple and the most exhaustive way, focusing the attention on the important features of the multi-hazard risk analysis. Surely, the next works on the same topic would take advantage of this study and, hopefully, from the feedbacks on it by local communities. It is important to underline that a result incomprehensible for end users in climate risk prevention is useless.

This study ends by making some recommendations.

The first is addressed to the Public bodies ad ministries in charge of the climate adaptation process in these countries. Ground data from the meteorological and hydrological observation network and statistics about disasters are the main input of disaster risk analysis. Without them it is impossible to build robust analysis. The recommendation concerns the completion and extension of information network regarding natural disaster. This could ensure that the geographical coordinates of the places hit by a disaster are always specified, as well as the origin of the disaster (i.e. Pluvial flooding or river flooding), the type and size of buildings hit and the type of crops affected. This allows the international scientific community to improve the analysis and complete our assessment with a robust evaluation.

The second recommendation is addressed to the Ministry of Agriculture and Livestock. It is important to monitor constantly the causes and extent of cereal deficit in all settlements linking this information to the most common agrometeorological information such as the sowing date, types of crops and the use of any water management techniques used by the farmers. This would allow to improve the evaluation of the drought risk level.

The third recommendation is addressed to the Ministry for Community Development and Territorial Planning and to the Regional Directorates so that they may consider risk assessment and make it open access, updating it every few years to produce a regular monitoring of interventions and supporting local authorities in using it regularly in Regional Development Plans and in LDPs.

The final recommendation is addressed to international aid organisations and donors. They are encouraged to use risk assessment in identification and evaluation phases of the projects, since CC and natural disasters could influence the results of the interventions planned.

Section 7

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