FACULTY OF HUMANITIES AND SOCIAL SCIENCES
DEPARTMENT OF GEOGRAPHY
West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL)
Doctorate Research Programme in Climate Change and Disaster Risks Management

Modeling Household Flood Risk Management in the Lower Mono River Basin, Togo–Benin (WEST AFRICA)

Thesis Submitted in partial fulfillment of the requirements for the degree of **DOCTOR of PHILOSOPHY** (Ph.D.) of the University of Lomé (Togo Republic) in Climate Change and Disaster Risks Management

Presented and publicly defend by:

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October 2023

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The University of Lomé do not intend to give any approval or disapproval to the opinion expressed in this thesis. They should be considered as the authors ‘own.

Summary

Dedication

This work is dedicated to God the Father, God the Son, God the Holy Spirit, and my parents.

Acknowledgments

The thesis is a long journey with many ups and downs that lead to the completion of the objectives. As a result, the current effort would not be feasible without the people I would want to recognize. First and foremost, I praise God for his grace, which has been expressed and refreshed throughout this thesis. My thanks also go to the BMBF, through the WASCAL scholarship program, for providing me with a scholarship and the financial support I needed throughout this thesis.

A special thanks to Associate Professor Komi AGBOKA and, Associate Professor Prosper BEGEDOU, the Director and Deputy Director of WASCAL Lomé, respectively, and all the staff, especially Dr. Idrissou Mouhamed, Mrs. Sefako Segbe, Folly Kuevi, and Koudjo Akpene, for allowing me to conduct this work in a good environment and for their availability for assisting and supporting me throughout this thesis.

My heartfelt gratitude goes to Professor Masamaéya D. T. GNAZOU, Full Professor in Hydrogeology at the Department of Geology (Faculty of Sciences/University of Lomé), who agreed to supervise this research. Thank you for your availability, comments, lessons, and suggestions for improving this work, Professor. May God bless you with it.
I would also like to thank Professor Euloge K. AGBOSSOU, Full Professor CAMES in Water Sciences at the University of Abomey Calavi, for his availability, openness, help, guidance, and support throughout this long voyage. Thank you for your assistance in completing this assignment. Please find my expression of gratitude here.

Thank you so much to Dr. Grace VILLAMOR, Dr. in Geography at the University of Bonn, for making yourself fully accessible despite your busy schedule. She made herself available even at late hours to monitor the work, provide suggestions and better supervision, and improve the quality of the work. She has been patient with me and has taught me a lot about socioeconomic analysis as well as how to be consistent. I'm particularly grateful to Dr. Sophie THIAM, who has never failed to support, assist, and guide me. Thank you for the technical assistance and support provided by the Center for Development Research (ZEF).

My gratitude also goes to the CLIMAFRI project, particularly to Dr. Yvonne WALZ and the entire crew for selecting me to conduct this topic and for the technical help and guidance they gave. Many thanks to Simon Wagner for his involvement and technical assistance during this journey.

I would like to use this opportunity to offer my heartfelt gratitude to the rest of the Jury members: President: Professor KOLA Edinam, University of Lomé, Togo; Examiner: Professor GNANDI Kissao, University of Lomé Togo; and Professor ADOUNKPE Julien, University of Abomey-Calavi, Benin for their availability and for taking the time to make improvements while increasing the scientific quality of this document.

I would also like to thank everyone in Batch 4 of Climate Change and Disaster Risk Management, especially for this wonderful partnership and for assisting and encouraging me. Thank you very much to all of my colleagues especially to Marcel KOUAKOU, Elvire KISSI, Peter OYEDELE, and Eric YAO KOMLANGAN for their assistance.

My heartwarming gratitude and appreciation go to my family members and relatives, especially my parents, Emmanuel DOSSOUMOU and Dorcas DJAGOUN; my sisters, Estelle DOSSOUMOU and Corile AINA; my fiancé, Michée ADANDE, and his parents, Paulin and Beatrice ADANDE; my aunt, Marceline ALLOBA; and my brothers, Alain and Jerome. AGUE.

Finally, to all the people who assisted me in any way whom I did not mention here, please forgive me and accept my greetings and gratitude.

List of acronyms and abbreviations

Acronyms and abbreviations		Definition
ABM	:	Agent Based Model
BMBF	:	Federal Ministry of Education and Research
CAMES	:	Conseil Africain et Malgache pour l'Enseignement Supérieur
CEDEAO	:	Communauté Economique Des États de l'Afrique de l'Ouest/ Economic Community of West African States
CEIWR-HEC	:	Hydrologic Engineering Center's
CLIMAFRI	:	Implementing CLIMate-sensitive Adaptation strategies to reduce Flood RIsk in the transboundary Lower Mono River catchment in Togo and Benin
CLIMATE-ADAPT	:	European Climate Adaptation Platform
CO^2	:	Carbon Dioxide
CRED	:	Centre for Research on the Epidemiology of Disasters
CRU TS	:	Climatic Research Unit Time Serie
DEM	:	Digital Elevation Model
DGMN Togo	:	Direction Générale de la Météorologie Nationale du Togo
DRP	:	Doctoral Research Programme
DREF	:	International Federation's Disaster Relief Emergency Fund
DSM	:	Digital Surface Model
EC	:	Europian Commission
EMDAT	:	The International Disaster Database
FAO	:	Food and Agriculture Organization
FCFA	:	Franc des Colonies Françaises d'Afrique
GFDRR	:	Global Facility for Disaster Reduction and Recovery
GIZ	:	German Agency for International Cooperation
Gov.UK	:	United Kingdom Government
GRASS-GIS	:	Geographic Resources Analysis Support System - Geographic Information System
HEC-RAS	:	Hydrologic Engineering Center River Analysis System
i.e	:	That is
IFRC	:	International Federation of Red Cross and Red Crescent
IPCC	:	Intergovernmental Panel on Climate Change
INSAE	:	Institut National de la Statistique et de l'Analyse Economique
IUCN/PACO	:	International Union for Conservation of Nature/ Program Central and West Africa
KCA	:	K-Mean Clustering Analysis
km^2	:	Kilometer square
LMR	:	Lower Mono River
LULC	:	Land Use and Land Cover
m	:	Meter

MPDEPP-CAG	:	Ministère de la Prospective, du Développement, de l’Evaluation des Politiques Publiques et de la Coordination de l’Action Gouvernementale
NASA	:	National Aeronautics and Space Administration
NN-Join	:	Nearest Neighbor Join
ORSTOM	:	Office de la Recherche Scientifique et Technique Outre-Mer
PCA	:	Principal Component Analysis
PGICT	:	Projet de gestion intégrée des catastrophes et des terres
Q10	:	10 years discharge return periods
Q100	:	100 years discharge return periods
QGIS	:	Quantum Geographic Information System
SPI	:	Standardized Precipitation Index
SPSS	:	Statistical Package for the Social Sciences
SWMM	:	Storm Water Management Model
UCL	:	Université Catholique De Louvain
UNDP	:	United Nations Development Program
UN/ISDR	:	United Nations International Strategy for Disaster Reduction
UNDRR	:	United Nations Office for Disaster Risk Reduction
UNOSAT	:	United Nations Satellite Centre
UNISDR	:	United Nations International Strategy for Disaster Reduction
UNITAR	:	United Nations Institute for Training And Research
USD	:	United States Dollar
WASCAL	:	West African Science Service Center on Climate Change and Adapted Land Use
ZEF	:	Center For Development Research

List of figures

List of tables

General Introduction

Abstract

The catchment of Lower Mono River, shared between two West African countries, Togo and Benin, used to overflow each year, threatening the community surrounding it. This situation is likely to increase and exacerbate the damages of climate change and urbanization without suitable adaptative strategies. In this study, we used the HEC RAS model to test structural measures that are effective from the point of view of households to cope with flood risk. To this end, a survey was conducted in twenty-four (24) villages in the basin to identify: the socio-economic causes and vulnerabilities of households in the study area, the existing adaptation and mitigation strategies developed by households, identification of factors influencing households to adapt and choose a particular measure and simulate the flood risk based on household decision making. Also, historical flood data in the area and geospatial data were collected. Using the powerful tool HEC-RAS, helped model the potential flooding areas and test structural measures, hence, enabling to proposal of effective adaptive measures to cope with flood risk in the Lower Mono River basin. The results of the different analyses showed that climate change and bad management of Nangbeto dam represent the hydrological drivers to flooding and the presence of households in low land areas and close to the river, having less income and education level are the social drivers to flood. Households rather choose less costly measures such as having other commercial activities, modifying their agricultural calendar or diversifying their crops to cope with the flood-related impact on their agricultural land. The choice of the household to adapt and choose a specific adaptive measure is positively influenced by their experience of past flood events and the exposure of their agricultural plot. The results of the HEC-RAS model confirm that this model is capable of modeling potential flooding areas and also allows testing structural measures. Indeed, the effectiveness of the drainage system and the water retention basins were tested with the HEC-RAS model. The results show that these measures can reduce the risk of flooding in the basin. It can be used by decision-makers in the implementation of suitable adaptive strategies for the well-being of the population. A combination of structural measures (drainage systems and retention basins) and structural measures (capacity building, awareness raising) can significantly reduce the impact of flooding in the study area.

Key-words: Lower Mono River basin, Flood, HEC RAS, household decision making, adaptive strategies.

Résumé

Le fleuve Mono, partagé entre deux pays d'Afrique de l'Ouest, le Togo et le Bénin, déborde chaque année, menaçant les communautés environnantes situées dans la partie inférieure du bassin du Mono. Cette situation est susceptible d'augmenter et d'exacerber les dommages causés par le changement climatique et l'urbanisation en l'absence de stratégies d'adaptation appropriées. Dans cette étude, nous avons utilisé le modèle HEC RAS pour tester les stratégies d'aménagement qui sont efficaces du point de vue des ménages pour faire face au risque d'inondation. À cette fin, une enquête a été menée dans vingt-quatre (24) villages du bassin afin d'identifier : les causes socio-économiques et les vulnérabilités des ménages dans la zone d'étude, les stratégies d'adaptation et d'atténuation existantes développées par les ménages, l'identification des facteurs qui influencent les ménages à s'adapter et à choisir une mesure particulière et à simuler le risque d'inondation sur la base de la prise de décision des ménages. En outre, les données historiques sur les inondations dans la zone et les données géospatiales ont été collectées. Le modèle HEC-RAS a été utilisé pour cartographier les risques d'inondation et tester certains systèmes d'aménagement hydraulique (système de drainage et rétention des bassins) pour faire face au risque d'inondation. Les résultats des différentes analyses ont montré que le changement climatique et la mauvaise gestion du barrage de Nangbeto représentent les facteurs hydrologiques d'inondation et que la présence de ménages dans les zones de basses altitudes et proches du fleuve, ayant de faible revenus et un faible niveau d'éducation, sont les facteurs sociaux d'inondation. Les ménages préfèrent choisir des mesures moins coûteuses ou ne pas en prendre, comme avoir d'autres activités commerciales, modifier leur calendrier agricole ou diversifier leurs cultures pour faire face à l'impact des inondations sur leurs terres agricoles. Le choix des ménages de s'adapter et de choisir une stratégie d'adaptation spécifique est positivement influencé par leur expérience des inondations passées et l'exposition de leur parcelle agricole. HEC-RAS est un outil puissant qui peut être utilisé pour proposer des mesures d'adaptation efficaces pour faire face au risque d'inondation dans le bassin inférieur du fleuve Mono. Les résultats du modèle HEC-RAS confirment que ce modèle est capable de modéliser les zones d'inondation potentielles et permet également de tester des mesures structurelles. En effet, l'efficacité du système de drainage (canalisation en augmentant (remblai, digue) ou en diminuant (excavation) la hauteur des berges du fleuve) et des bassins de rétention d'eau a été testée avec le modèle HEC-RAS. Les résultats montrent que ces mesures peuvent réduire le risque d'inondation dans le bassin. Ils peuvent être utilisés par les décideurs dans la mise en œuvre de stratégies d'adaptation appropriées pour le bien-être de la population. Nous recommandons une combinaison de mesures structurelles (systèmes de drainage et bassins de rétention) et de mesures structurelles (renforcement des capacités, sensibilisation) peut réduire de manière significative l'impact des inondations dans la zone d'étude.

Mots-clés : Partie inférieure du Bassin du fleuve du Mono, Inondation, HEC RAS, Prise de décision des ménages, stratégies d’adaptation.

- **Introduction**

Chaque année, les inondations menacent les communautés installées dans le bassin inferieur du fleuve de Mono, un bassin versant partagé par deux pays d'Afrique de l'Ouest (Bénin et Togo), causant d'importants dégâts aux populations environnantes (EM-DAT, 2019), et le changement climatique risque d'exacerber ce phénomène. Il est nécessaire d'implémenter des mesures d'adaptation pour faire face aux risques d'inondation, qui pourraient devenir plus fréquents à l'avenir en raison du réchauffement climatique et de l'urbanisation. Ceci peut être réalisé en utilisant des outils de prise de décision qui peuvent tester l'efficacité de différentes mesures structurelles et mettre en œuvre les plus efficaces pour obtenir des résultats concrets. De nombreuses études ont été menées dans le bassin afin d'évaluer la vulnérabilité des communautés aux inondations et le risque d'inondation, d'évaluer l'utilisation et l'occupation des sols, et de caractériser le climat actuel et futur et la manière dont il affecte les inondations mais peu d'intérêt ont été accordé aux stratégies d'adaptation. Cette étude a été menée pour donner dans un premier temps un meilleur aperçu de l'impact de l'inondation sur les communautés, les causes de ce risque dans le contexte du changement climatique, et aussi le point de vue des communautés. Dans un second temps, les mesures d'adaptation existantes ont été analysées et le risque d'inondation a été modélisé en considérant les mesures les plus efficaces du point de vue des ménages à l'aide du modèle HEC-RAS.

- **Méthodologie**

Pour atteindre ces objectives escomptés, différentes données et méthodes d'analyse ont été utilisées. Le tableau suivant présente les données collectées et leurs sources, ainsi que les méthodologies d'analyse utilisées, pour chaque objectif spécifique.

Tableau : Données collectées et méthode d'analyse

Objectif spécifique	Données	Méthodes d'analyse
SO1 : *Évaluer les facteurs socio-hydrologiques et la vulnérabilité des ménages face aux risques d'inondation.* • *Caractérisation climatique et hydrologique du bassin ;*	Données pluviométriques, données hydrologiques, données socio-économiques des ménages, perception du risque d'inondation, données biophysiques.	-Variabilité annuelle des paramètres climatiques par le biais de la statistique descriptive ; variabilité interannuelle des précipitations, indice standardisé des précipitations (SPI) ; -Analyse en composantes principales (ACP) et analyse en clusters pour la typologie et les caractéristiques d'un ménage ;

• *Typologie des ménages et de leurs vulnérabilités aux inondations ;* • *Facteurs socio-hydrologiques du risque d'inondation dans le cours inférieur du fleuve Mono*		-Analyse de régression pour identifier les facteurs de risque d'inondation ; -Analyse de régression pour identifier les facteurs de risque d'inondation ; -Carte de vulnérabilité et de risque.
<u>Objectifs spécifiques (SO2)</u> : Évaluer les stratégies d'adaptation et les processus de prise de décision des ménages à la lumière des impacts négatifs des inondations. • *Impact de l'inondation sur le ménage ;* • *Stratégies d'adaptation existantes ou comportements développés par le ménage face au risque d'inondation ;* • *Prise de décision des ménages pour faire face au risque d'inondation et réduire l'impact des inondations.*	Perception des inondations par les ménages et leur comportement face au risque ; Données socio-économiques ; Données biophysiques.	- Statistiques descriptives pour identifier l'impact des inondations sur les ménages et les stratégies d'adaptation existantes ; -Régression binaire et multinomiale pour le choix des ménages de s'adapter et de choisir une mesure particulière ;
<u>Objectifs spécifiques (SO3)</u> : 3. Modéliser les risques d'inondation pour explorer les impacts futurs de différents scénarios d'écoulement et de prise de décision (mesures structurelles) par les ménages sur l'étendue des inondations.	La prise de décision par les ménages ; Données secondaires (données climatiques historiques, scénarios pluviométriques, données hydrologiques et géospatiales, cartes des dangers et des risques) ;	Modeling with HEC-RAS -Délimitation des sous-bassins ; -Estimation des débits ; -Modélisation sous HEC-RAS

• *Cartographier les potentiels risques d'inondation ;* • *Tester l'efficience de certaines mesures d'adaptation ;* • *Evaluer l'utilité de ces mesures dans la réduction des impacts dû aux inondations.*		

- **Résultats et recommandations**

Objectif de recherche 1 : évaluer les facteurs socio-hydrologiques et la vulnérabilité des ménages aux risques d'inondation

Dans cet objectif, les facteurs et la vulnérabilité des ménages au risque d'inondation ont été évalués. La comparaison entre la perception du risque d'inondation par les ménages et les données hydrologiques et pluviométriques a révélé que, dans la partie supérieure, les précipitations sont liées aux inondations, tandis que dans la partie inférieure, en plus des précipitations, d'autres facteurs tels que la gestion du barrage de Nangbeto contribuent aux inondations. Outre les précipitations extrêmes, d'autres causes majeures d'inondation, telles que la gestion du barrage de Nangbeto, ont également été signalées par les ménages enquêtés. De nombreuses autres études ont confirmé ces résultats. Aussi, deux types différents de ménages ont été identifiés dans la zone d'étude, à savoir les ménages vulnérables aux inondations et les ménages moins vulnérables. En fait, les ménages vulnérables aux inondations se caractérisent par une faible main d'œuvre et une exposition aux inondations. Les ménages vulnérables aux inondations sont davantage impliqués dans la gestion des risques de catastrophe au sein de la communauté et dans la formation à la gestion des inondations. Leur parcelle est plus proche de la rivière, située dans les zones à basses altitudes, ce qui les rend plus exposés aux inondations que les ménages moins exposés. Les ménages exposés aux inondations sont également caractérisés par un faible taux d'alphabétisation et des revenus moins élevés.

Ces résultats montrent que dans la zone d'étude, différents groupes sont présents et peuvent être affectés différemment par les inondations. En outre, en dehors des précipitations qui représentent la cause principale de l'inondation, la présence d'un barrage (évacuation des eaux excédentaires de l'eau du barrage) représente, selon les ménages, une autre cause importante qui doit être prise en compte. De plus, les ménages de la partie inférieure du bassin sont plus touchés parce qu'ils reçoivent l'accumulation d'eau provenant de la partie supérieure. Ainsi, à partir de cet objectif, le changement climatique et la gestion des barrages de Nangbeto représentent les facteurs hydrologiques des inondations, et la présence de ménages dans les zones de basse altitude et près de la rivière, ayant moins de revenus et un niveau d'éducation plus bas, sont les facteurs sociaux des inondations. Les stratégies d'adaptation doivent accorder plus d'attention à la combinaison de mesures d'aménagement, de sensibilisation et de renforcement des capacités des communautés afin de réduire l'impact des inondations dans la partie inférieure du bassin de Mono. La proposition de stratégies d'adaptation efficaces doit accorder plus d'attention à la participation des communautés locales afin de réduire l'impact des inondations dans le bassin.

Objectif de recherche 2 : Évaluer les stratégies d'adaptation et le processus de prise de décision des ménages face aux impacts négatifs des inondations

Pour ce deuxième objectif, l'impact des inondations sur les ménages a d'abord été évalué, suivi de l'identification des stratégies d'adaptation existantes et de l'analyse de la prise de décision des ménages face aux inondations dans le bassin. Les inondations ont un impact sur les ménages dans différents secteurs d'activité et de vie, notamment l'agriculture, le commerce, le matériel (maisons) et la santé. Les dégâts agricoles sont plus fréquents et plus graves. Les stratégies d'adaptation les plus importantes développées par les deux types de ménages (les ménages plus vulnérables et moins vulnérables) pour faire face aux inondations dans l'agriculture comprennent : avoir d'autres activités commerciales, la modification du calendrier agricole, la diversification des cultures, l'évacuation du bétail avant les inondations et la substitution des cultures. Ces mesures nécessitent moins d'investissements et certaines d'entre elles sont proactives. Le choix des ménages de s'adapter et de choisir une stratégie d'adaptation spécifique est positivement influencé par leur expérience des inondations passées (niveau d'eau, pourcentage élevé de perte de surface cultivée, durée de l'inondation, expérience de l'inondation) et l'exposition de leur parcelle agricole (dans les basses terres). La sensibilisation aux inondations et l'exposition aux inondations influencent la prise de décision des ménages sur la manière de faire face aux inondations. D'autres activités commerciales et systèmes de drainage permettent aux ménages de se remettre financièrement du risque d'inondation, ce qui n'est pas le cas de la modification du calendrier agricole. Cela peut s'expliquer par le fait que ces mesures peuvent être mises en œuvre avant et pendant l'inondation. En outre, les ménages à faibles revenus sont susceptibles de choisir d'autres activités commerciales et la modification du calendrier agricole plutôt que les systèmes de drainage. Les ménages mettent en œuvre les mesures principalement avant (de manière proactive) et pendant l'inondation, et les mesures d’aménagement telles qu'un système de drainage sont mises en œuvre par les ménages ayant des revenus élevés.

Nous recommandons une meilleure préparation, le renforcement des capacités et la diversification des moyens de subsistance comme moyens d'améliorer l'adaptation. Ainsi, en période d'inondation, les communautés pourraient développer d'autres activités, telles que la pêche. En ce qui concerne les activités agricoles, il convient de modifier les calendriers agricoles, de diversifier les cultures afin d'éviter l'impact des inondations et aussi installer des systèmes d’aménagement hydro-agricoles. Pour cette raison, il serait important de mettre en place un système de sensibilisation et de préparation des ménages. Il faudra donc mettre en place un système de renforcement des capacités de préparation mais aussi d'atténuation des ménages par la diversification de leurs activités et de nouvelles pratiques agricoles afin qu'ils soient informés en temps réel des prévisions climatiques.

Objectif de recherche 3 : Modéliser les risques d'inondation pour explorer les impacts futurs de différents scénarios d'écoulement et de prise de décision par les ménages sur l'étendue des inondations.

Dans ce dernier objectif, HEC-RAS a été utilisé pour cartographier les risques d'inondation dans la partie inférieure du fleuve Mono pour différentes périodes de retour et pour tester certaines mesures d’aménagement hydrauliques, y compris le système de drainage et le bassin de rétention. D'après les résultats, les ménages (maisons et parcelles) qui ont été déclarés touchés par l'inondation lors de l'enquête se trouvaient dans la zone touchée par l'inondation.

En outre, différents systèmes d’aménagement ont été testés notamment les digues, les systèmes de drainage et les bassins de rétention en utilisant HEC-RAS. Ces systèmes d’aménagement ont été trouvé utiles et efficace pour la réduction des risques d’inondations dans le milieu d’étude. En effet, l’implémentation du système de drainage permet une réduction significative de la surface affectée par les inondations de 50% pour les inondations cause par le débit de temps de retour de 10 ans et 64 % pour le temps de retour de 100 ans. La régulation et l'amélioration du système de drainage combinées à des bassins de rétention peuvent réduire le risque d'inondation des ménages, leur permettre de pratiquer leurs activités agricoles et de développer d'autres activités telles que la pêche. Ces mesures doivent être cependant combines avec les mesures de préparation, de sensibilisation et de renforcement des capacités des ménages pour leur durabilité et garantir une réduction effective des impacts des inondations dans le milieu d'étude.

- **Conclusion et recommandation**

Le but de cette étude était d'étudier les impacts du changement climatique et les décisions prises par les ménages sur le risque d'inondation en utilisant le modèle HEC RAS. On peut résumer que, pour le premier objectif, le changement climatique et la gestion des barrages de Nangbeto représentent les facteurs hydrologiques des inondations, et la présence de ménages dans les zones de basse altitude et près de la rivière, ayant moins de revenus et un niveau d'éducation plus bas, sont les facteurs sociaux causant les inondations. En ce qui concerne le deuxième objectif, les inondations ont un impact sur de nombreux secteurs d'activité dans la zone d'étude, en particulier l'agriculture. Pour faire face à cet impact, les ménages ont mis en œuvre différentes stratégies d'adaptation qui sont plus proactives et réalisés manuellement. En outre, la sensibilisation aux inondations et l'exposition ont influencé la prise de décision des ménages sur la façon de faire face aux inondations. Enfin, dans le cadre du troisième objectif, les risques d'inondation ont été cartographiés pour des périodes de retour de 10 et 100 ans, et les mesures d'aménagement hydrauliques ont été testées. Plus le débit augmente, plus la surface touchée par l'inondation est élevée et plus la probabilité que les ménages soient touchés augmente. La mise en œuvre d'un système de drainage combiné à un bassin de rétention réduit la zone touchée par l'inondation. Les aménagements combinés à la sensibilisation, la cartographie des zones potentielles et le renforcement des capacités des ménages représentent une mesure potentielle qui peut réduire le risque d'inondation dans le milieu d'étude.

Les populations dans la partie inférieure du bassin, étant plus vulnérables aux inondations, il est important de renforcer les système d'information et d'alerte précoces afin de leur permettre de se préparer à temps avant le relâchement des eaux du barrage de Nangbeto, puis, les informer sur les prévisions climatiques. Avec l'avancement des technologies, mettre en place une application sur portable qui puisse permettre d'informer les points focaux et au moins les chefs de village sur les prévisions climatiques ainsi que les conséquences de celles-ci sur leurs différentes activités et les précautions à prendre.

Pour ce faire, il convient d'améliorer le niveau d'éducation et d'alphabétisation dans ces villages. De même, un renforcement de capacité des agents responsables des prévisions climatiques et l'augmentation des agents de terrain sont requis. Dans le contexte actuel où la plupart des communautés ne veulent pas quitter leurs villages pour d'autres endroits à cause de raison sociales et familiales (terres natales, manque de moyen financier, etc.), il serait important de penser au renforcement ou à la construction des maisons résilientes aux inondations et à l'installation des aménagements hydro agricoles afin de réduire considérablement les impacts futurs des inondations.

Les berges des fleuves du Mono bénéficient par endroits des collines et l'aménagement de ses berges constituerait une grande zone touristique pour les deux pays. Ces projets peuvent commencer ou privilégier la partie inférieure du bassin par l'installation des digues couplées avec des surcreusements par endroits et des points de prise des systèmes de drainage/irrigation dans les champs. Il faudra également, d'une part, former les agriculteurs sur les pratiques de diversification agricole et par rapport aux cultures tolérantes aux inondations et d'autre part, supporter et faire la promotion d'autres activités dans le bassin telles que la pêche, le commerce, etc. Ces projets peuvent être implémentés par les ministères en charge d'agricultures d'élevage et de pêche de chaque pays en collaboration avec l'ANPC, les organisations internationales telles que la FAO, le PNUD, la Banque Mondiale et d'autres ONG tel que Caritas, Croix rouge, etc. Il est également important d'insérer le monde scientifique.

Cela permettra aux communautés de pratiquer leurs différentes activités avec plus d'aisance et réduira considérablement la pauvreté et la faim. De même, leur santé sera préservée. Il est aussi important, sur la base de la cartographie des zones potentielles d'inondation, que l'Etat interdise l'installation des ménages dans ces zones par l'application des sanctions. Il faudrait donc en amont qu'il y ait des sensibilisations/informations des communautés et autorités locales afin que cette interdiction soit respectée. Cela contribuera à l'atteinte de certains objectifs du développement durable comme la réduction de la pauvreté et de la faim, la préservation de la santé, l'éducation de qualité et les mesures relatives à la lutte contre les changements climatiques.

À l'endroit de la population, nous leurs recommandons de :

- développer une franche collaboration avec les acteurs impliqués dans la gestion des risques d'inondation ;
- changer leur système de penser, s'unir et décider que la situation doit changer pour leur bien-être et les générations futures ;
- respecter les recommandations et instructions des élus locaux ou des décideurs dans le cadre de la gestion des risques d'inondation ;
- gérer de façon efficiente les dispositifs d'accompagnement ou les infrastructures mises à leur disposition ;

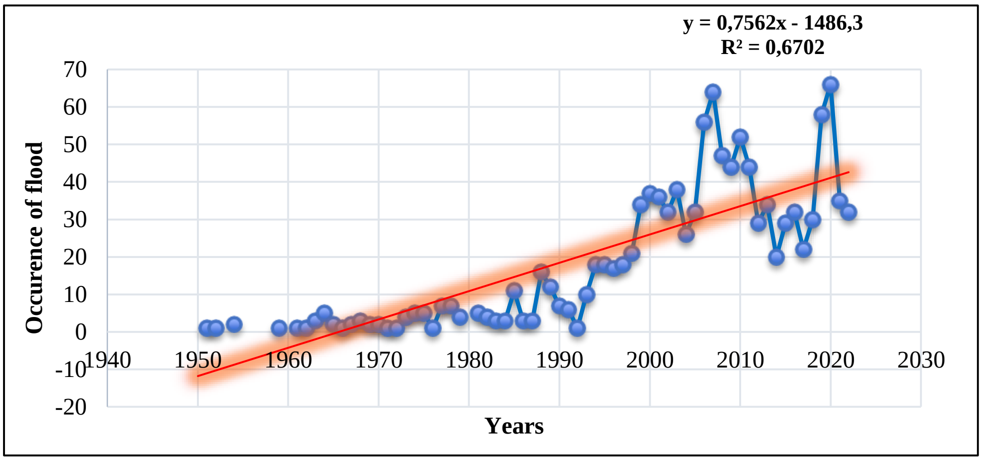
- s'associer et s'entraider afin de mettre en place des mesures perçus plus efficientes ;
- Renforcer des aptitudes de prévention des risques plutôt que réactives en s'informant sur les prévisions climatiques et en y associant leurs connaissances des indicateurs locaux d'alerte pour prendre les mesures idoines afin de ne pas être surpris par les inondations puisque cela se produit chaque année.

General introduction

1. Background

Flooding represents one of the most frequently occurring and damaging disaster events worldwide. CRED (2022) reported that in the first half of the year 2022, the flood was ranked as the most frequent and damaging disaster worldwide. It was also ranked as the first climate-related event that occurred more than any other type of disaster in the 21st century (EM-DAT, 2020).

Flood event occurrence (all types of floods) is increasing in Africa (Figure 1), causing massive damage to the population. One of the parts of Africa most impacted by floods is West Africa. Floods were the second-deadliest disaster type in this region after drought, making up 64% of disaster incidents between 2000 and 2019 (EM-DAT, 2019). Flood frequency and severity have increased to the point where floods with a 100-year return period have become annual events in developing countries (Alho et al.,2008; Klijn 2009 as cited in Els, 2011). Global warming, which is characterized by an increase in temperature resulting from anthropogenic activities, will jeopardize the occurrence of extreme events such as floods provoked by heavy rain. In fact, Africa's temperature will rise by 4.8 °C by 2100, causing rainfall to vary and a rise in the frequency of extreme weather events (Lawin et al., 2019; Adegoke et al., 2019). Furthermore, changes in land use (Nka et al., 2015), rapid population growth, population settlement in flood-prone areas, (Bastviken, 2016; Douglas, 2017; Frick-trzebitzky et al., 2017; Hounkpè, 2019 in Adegoke et al., 2019), and diverse economic settings are likely to exacerbate the impact of this phenomenon in the coming decades (EM-DAT, 2019). This situation may increase people's vulnerability to extreme hydro-meteorological conditions (Baldassarre et al., 2010) and cause more intense and frequent river flooding (Gado, 2019).



Source : EM-DAT, 2022 (https://public.emdat.be)

Figure 1: Trend of flood in Africa;

Every year, this phenomenon threatens the Lower Mono River, a catchment shared by two West African countries (Benin and Togo), causing significant damage to the surrounding population (EM-DAT, 2019), and climate change is likely to exacerbate this phenomenon.

2. Problem statement and justification

Rivers are very important to the well-being of the population. "*They have the potential to provide a wide range of societal benefits*” (Parker & Oates, 2016). However, rivers, on the other hand, can be a source of disservices, such as flood risk, which cause significant damage to the population. It is the case of the Lower Mono River populations, which are threatened each year by the river's overflow. As reported by Floodlist (2019), the levels of the Mono River at Athiémé in Benin rose to 8.5 meters in October and have affected many communities and infrastructures. In Togo areas of the Maritime Region, the Lacs prefecture, in particular, was the worst hit, involving around 2,000 households and 8,000 people (Floodlist, 2019), despite all the efforts made by the governments of the two countries to protect them. Recently, it was also reported by IFRC (2022) that in 2022, the Mono River will overflow its banks. The sudden increase in water levels occurred when the waters in the Nangbéto dam in Togo were released and intense rains fell. Due to climate change and urbanization, climate model projections, land use changes, rapid population growth and settlement in flood-prone area, are expected to exacerbate the impact of flooding over the next decade (Adegoke et al., 2019; Hounkpè, 2019; Douglas, 2017; Frick-trzebitzky et al., 2017; Bastviken, 2016; EM-DAT, 2019). Previous studies in the Lower Mono River highlight the vulnerability and high flood risk faced by all communities in the Lower Mono River basin and the necessity to adapt (Amoussou et al., 2020 ;Lawin et al., 2019; Lawin et al., 2019a ; Gado, 2019; Batablinle et al., 2018; Ntajal et al. (2017) ;, Kissi et al., 2015).

From the above, it clearly appears that there is an urgent need for adaptive measures to deal with flood risk, which may become more prevalent in the future as a result of global warming and urbanization. It then advocates for the construction of a good flood management system that incorporates adequate adaptation methods and capacities to empower and support people or households in dealing with present and future flood hazards. This can be accomplished by using decision-making tools that can test the effectiveness of different structural measures and implement the most effective ones for concrete results. Many studies were conducted in the LMR basin to assess the vulnerability of communities to flooding, and the flood risk, to evaluate land use and land cover, and to characterize the actual and future climate and how it affects the flood event (Wetzel et al., 2022; Parkoo et al., 2022 ; Thiam et al., 2022 ; Biao et al., 2021 ; Hounguè et al., 2021 ; Ernest Amoussou et al., 2020 ; Lawin et al., 2019a; Koubodana, 2019; Lawin et al., 2019b; Lawin Agnidé et al., 2019 ; Gado, 2019 ; Batablinle et al., 2018; E Amoussou et al., 2017; Ntajal et al., 2017a; Ntajal et al., 2017c; Ntajal et al, 2016 ; Kissi et al., 2015; Amoussou, 2015 ; Amoussou et al., 2014 ; Rossi, 1996). However, there is very limited literature focusing on the existing adaptive strategies and that tested, suitable structural measures such as embankment heightening and channel modification to reduce flood losses through flood mitigation. It is therefore important to also test the effectiveness of structural measures to see what impact they would have on reducing flood risks. Several hydraulic models can be used to this end, including Delft 3D, HEC-RAS, Flood Modeler, SWMM (Storm Water Management Model), etc. For this study, HEC RAS was chosen based on the goals of the study, data availability, being a free tool, and ease of use.

The goal of this study is to assess flood-prone areas and generate a hazard map that predicts high-risk regions while also examining the effectiveness of various structural measures in mitigating flood risk. This will be accomplished through the use of HEC-RAS to model the impact of these measures and accurately map potential flood areas. Many studies used HEC-RAS to estimate the flood hazard for different return periods, for flood mapping, and to estimate the future flood hazard (AL-Hussein et al., 2022; Ogras & Onen, 2020; Khalfallah and Saidi, 2018; Azouagh et al., 2018; Al-Zahrani et al., 2016; Yerramilli, 2012). Also, other studies conducted tested different structural measures, including channel diversion (Sholichin et al.,2019). Khalfallah & Saidi (2018) concluded in their studies that HEC-RAS is "an important guideline for decision-makers, especially when coupled with skills, experience, and proper judgments, to plan accordingly for future probable flood disasters and represents an important tool for studying and understanding flood events". Furthermore, they also stated that HEC-RAS can be used to analyze possible flood management strategies.

The existing adaptive strategies implemented by households in the Lower Mono River that the government or other stakeholders may employ to mitigate the effects of flooding will be investigated in greater detail to improve their resilience at the local scale. By using the HEC-RAS, we will demonstrate how the risk will change with the preferred adaptation of households, and measure the efficiency of the existing adaptive strategies.

3. Research questions

The research questions addressed in this study are stated as follows:

1. What drives the socio-hydrological systems that make households vulnerable to flood risk?
2. What is the existed adaptive measure implemented by the household in the study area?
3. What possible interventions can reduce the future flood risks of the communities in the Lower Mono River basin in the future?

4. Hypothesis

The following hypotheses are derived from these research questions:

1. The socio-hydrology system is influenced by the perception of risk and the degree of exposure of communities, as well as the high-water level, which makes households vulnerable to flood risk;
2. Because existing adaptive strategies are weak and mostly retroactive, they do not reduce flood risk in the LMR basin;
3. An integrated engineering system can contribute to the reduction of flood risk because the river is still largely unmodified.

5. Aim and research objectives

This study aims to optimize the effectiveness of flood risk management in the LMR basin in order to enhance community resilience and reduce flood impacts.

The specific objectives are to:

1. Assess the socio-hydrological drivers and vulnerability of households to flood risk;

2. Assess existing adaptative strategies and decision-making processes of households toward the negative impacts of floods;
3. Model flood hazard for exploring future impacts of different discharge scenarios and evaluate household decision-making (structural measures) on flood extent.

6. Expected result

At the end of our study, the following results are expected to be achieved:

1. Drivers and impacts of flood events on household's livelihoods and management efforts are determined;
2. Adaptation strategies and decision-making process of households toward the negatives impacts of flood are assessed;
3. Measures are proposed based on the household's decision-making.

7. Value or significance of the study

In the Lower Mono River basin, several studies have been carried out, but little attention has been given to the analysis of the current adaptation measures to suggest an appropriate approach to deal with the risk of flooding in the research region. Thus, the findings of the current study come to fill these gaps. It should serve as new guidelines for ongoing and future comprehensive flood risk management in the basin and must be properly absorbed by those in charge of making policies and decisions in both of the countries (Benin and Togo), for the West African area as a whole and the Mono River basin in particular.

8. Thesis outline

The dissertation is structured into five chapters starting with a general introduction and finishing with a general conclusion. The general introduction presented the problem statement and aims of the study. Chapter 1 provides a literature overview of flood risk in general, adaptive flood risk management strategies, and the application of an agent-based model to flood risk. The study area and the methodology to conduct this study are presented in Chapter 2. It also describes the study area's location, biophysical parameters, and socioeconomic characteristics The Objective 1 outcome is presented in Chapter 3, which focuses on the socio-hydrological drivers of floods and the vulnerability of households in the Lower Mono River basin. The second specific objective is addressed in Chapter 4. It describes the existing adapting strategies used by families, as well as the decision-making process used by households to decide to adapt and choose a specific adaptive measure to deal with flood risk. The results of particular objective 3 are presented in Chapter 5. Flood risk was simulated in this chapter using household flood decision-making and biophysical data. Lastly, the general conclusion focuses on a summary of the research findings as well as the study's conclusions and suggestion.

Chapiter 1: Literature Review

CHAPTER 1: Literature Review

1.1. Introduction

In the face of increasing climate variability and the heightened frequency of extreme weather events, understanding and effectively managing household flood risk have become paramount. This chapter embarks on a comprehensive exploration of the literature and concepts that underpin the modeling of household flood risk management. Floods, being one of the most destructive and recurring natural disasters, pose a significant threat to households and communities. In response to this, various strategies have emerged to mitigate, adapt, and manage flood risk at the household level. The development and application of flood risk management models play a pivotal role in these efforts, allowing for proactive planning and response.

This chapter is devoted to unraveling the intricate web of knowledge surrounding the modeling of household flood risk management. Through an extensive review of existing literature, we will trace the evolution of ideas and approaches in this field, providing insights into the key concepts and methodologies employed by researchers and practitioners. We will begin by defining different concepts, the fundamental components of household flood risk, examining the factors that contribute to vulnerability, and evaluating the diverse strategies employed for risk reduction and resilience building. As we journey through the literature, we will identify the gaps and challenges that exist in the current body of knowledge, setting the stage for our own research and modeling endeavors. By the conclusion of this chapter, readers will have a solid foundation in the concepts and theories that inform the modeling of household flood risk management, preparing them for the subsequent chapters where we will apply these insights to real-world scenarios and methodologies.

1.2. Definitions of Concepts

1.2.1. Flood

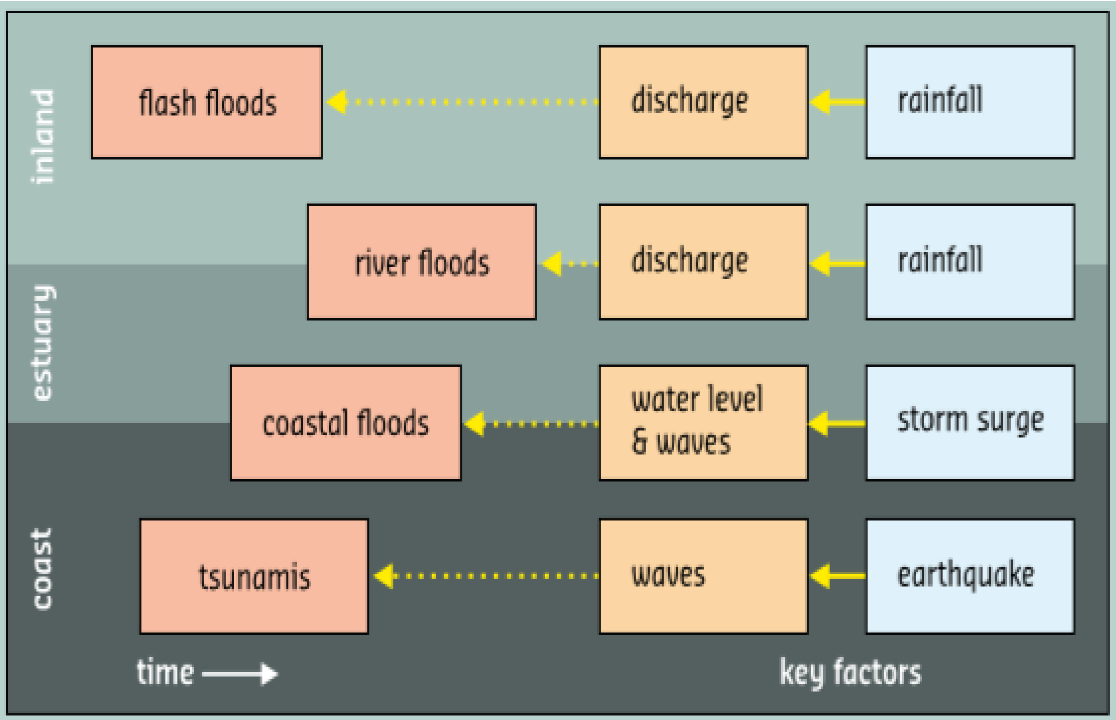
The word flood stems from the old English word Flōd related to the Dutch word vloed and German Flut all of which means "to flow"."Flood can be defined as the overflow of water beyond a normal level that submerges adjoining land areas, which are usually dry. Floods are termed disasters when submergence in the adjoining areas affects human beings or animals with associated loss" (Prasad, n.d.). According to Klijn et al. (2009), flood can be defined as "a temporary covering of land by water outside its normal confines". In the Intergovernmental

Panel on Climate Change's (IPCC, 2012) Glossary of Terms, "flood refers to the overflowing of the normal confines of a stream or other body of water or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods".

There are different types of floods depending on the nature, severity, and sources of inundation (Prasad, n.d.). It can be distinguished by the following types of flooding:

- **Coastal floods,** which can occur on the coast and along the banks of large lakes, are due to the occurrence of events like cyclones and associated storm surges, high tides, tsunamis, etc., wherein the low-lying areas in coastal tracts are inundated, as a result of which losses occur on a larger scale. In addition, salinity increases in the coastal groundwater and wells;
- **River floods or riverine flooding** occurs seasonally for various reasons but is primarily due to heavy precipitation or glacial melt that fills river basins too quickly with the resultant runoff. The increased discharge in river channels with decreasing carrying capacities leads to overflow, causing inundation in the adjoining low-lying areas;
- **Flash floods**: This type of flood is an unprecedented situation that occurs without any warming, especially in hilly regions and sloping lands where torrential heavy precipitation, thunderstorms, or cloud bursts commonly occur. They represent short-term floods in a small region, such as part of the city, which mostly kills and create huge losses in lives and damage to properties (Balica 2007, as cited in Nasiri et al., 2016; " Prasad, n.d.);
- **Urban flood or very large runoff in an urbanized impermeable zone:** it is due to the lack of efficient developmental planning that is in tune with the geo-morphological, ecological, and environmental setup that result in the increased vulnerability of urban areas. Then, even after moderate rainfall, flooding occurs. The situation aggravates when rainwater mixes with drain water, causing additional problems, including the spread of epidemics;
- **Glacial Lake Outburst Flood (GLOF)** "occurs in the downstream of glacial regions, where glaciers holding large quantities of water suddenly release them due to the melting of ice jams."(Prasad, n.d.);

- **Cloud Burst Flooding** "is the manifestation of climate change and hydrological imbalance that primarily occurs in the form of sudden heavy rainfall. Cyclonic circulations in the monsoon may also lead to cloud bursts. Cyclone and storm surge flooding mainly occur in coastal areas due to rainstorms associated with low-pressure systems. Movement of cyclonic storms in quick succession leads to severe flooding, especially in low-lying coastal areas" (Prasad, n.d.).
- **The overflow or the consequences of the rupture of hydraulic structures** such as reservoirs, dams, dikes, and pipes (agricultural, drinking water, sanitation) causing a sudden flood and
- **the emergent rise of a water table**. As illustrated in Figure 2, we can see that there are numerous reasons for floods. Floods can be produced by the natural environment, such as excessive rainfall, storms, and cyclones, but human activities, such as development and settlement design, are also important contributors. Yet, climate change has emerged as one of the most significant causes of floods, with experts predicting that rising global temperatures will cause severe flooding in various locations throughout the world (Munyai et al., 2019). The river flood will be researched in the Lower Mono River basin in this publication.



Source: *Klijn et al. (2009)*

Figure 2: Causes of flood

In this study will be talking about river floods or riverine flooding.

1.2.2. Risk and flood risk

Risk is an important concept in a number of scientific fields, yet there is no consensus on how it is to be defined and interpreted (Aven, 2011 as cited in Šotić & Rajić, 2015). The definition of risk is based on probabilities, expected value, uncertainty, and objectives (Šotić & Rajić, 2015). Šotić & Rajić, (2015) explained that "some authors regard risk as subjective and epistemic, depending on the knowledge available; some regard it as aleatoric, due to the probabilistic character of certain parameters; while yet others give risk the ontological status independent from the person assessing it". The Cambridge Dictionary defines risk as the possibility of something bad happening. Šotić & Rajić, (2015) classified the definition of risk into different groups in which it expressed itself firstly through uncertainty and expected values, secondly through events and consequences, and finally in relation to objectives.

In consideration of a hazard, risk can be defined as the exposure of something of human value to a hazard (a naturally occurring or human-induced process or event with the potential to create aloss), and it is often considered as the combination of probability and loss. It is a combination of three components: hazards, exposure, and vulnerability. Data from each of these categories can be used to paint a picture of risk in a certain location and over time (GFDRR, 2019).

Flood risk includes the risk of flooding from all causes, including rivers and the sea, direct rainfall on the ground surface, rising groundwater, overburdened sewers and drainage systems, reservoirs, canals, lakes, and other manmade sources. Flood risk takes into account the relationships between these many sources (Gov.UK, 2021). Flood risk is defined as "a measure of the combination of the likelihood of flooding happening and the related implications on people, the economy, and the environment" by the Scottish Environment Protection Agency, (2012). Flood risk is related to the second aspect of the risk group. Flood risk can be defined as a combination of the probability (likelihood or chance) of a flood event happening and the consequences (impact) if it occurred (Local Government Association, 2022). If the probability of a major flood is high and the consequences are severe, you speak of a "high" risk. For instance, when a flood causes many victims and a lot of damage. If the probability of a flood is small and the consequences are small, then the risk is also "small" (Environmental Agency, 2005). In this study, risk is defined as the probability of and the exposure of households and their properties to a hazard. Flood risk is considered in this study as the probability of households being affected by flood hazards. Flood risk occurs when water levels rise in households ‘properties and goods.

1.2.3. Hazard

A hazard is defined 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" (UNDRR, 2017). “Hazard is a potential threat to humans and their welfare, and risk (or consequence) is the probability of occurrence of a specific hazard (Sahni et al. 2001 as cited in Proag, 2014).

It may be natural (natural processes and phenomena), anthropogenic (induced by human activities), or socio-natural in origin (both natural and human) (UNDRR, 2017). Different types of hazards include biological, environmental, geological, hydrometeorological, and technological processes and phenomena (Wicaksana, 2016). For example, climate-related hazards can be defined as "natural hazards" constituted by climate events or phenomena that could threaten or provoke human (injury, loss of life), physical (destruction of houses, road infrastructure, etc.), social (reduction or loss of income, interruption of income-generating activities, displacement, etc.), psychological (fear, etc.), and environmental (destruction or degradation of vegetation cover, soil, etc.) damage. It is constituted by environmental and hydrometeorological hazards. In this study, flooding is a hydrometeorological hazard.

1.2.4. Vulnerability

Vulnerability comes from the Late Latin vulnerabilis "wounding," from Latin vulnerare "to wound, hurt, injure, maim," from vulnus (genitive vulneris) "wound," perhaps related to vellere "pluck, to tear". Vulnerability is the state of being open to injury or appearing as if you are. In referring to hazards and disasters, the notion of vulnerability draws attention to the risky relationship between people and their natural environments. Vulnerability is the inability to resist a hazard or to respond when a disaster has occurred, and it depends on different factors. For instance, people who live on the plains are more vulnerable to floods than people who live higher up. Vulnerability is defined by Schneiderbauer et al. (2017). as the susceptibility of assets such as objects, systems (or parts thereof), and populations exposed to disturbances, stressors, or shocks, as well as the lack of capacity to cope with and adapt to these adverse conditions. Proag, (2014) considers vulnerability as a concept that implies some risk combined with the level of social and economic liability and the ability to cope with the resulting event. It has been defined as the degree to which a system, or part of a system, may react adversely during the occurrence of a hazardous event. It represents the risk measure associated with the physical, social, and economic aspects and implications of a given system's ability to cope with an event. Vulnerability represents then socioeconomic and physical factors that can cause or threaten damage to communities or populations in the case of a hazard. These factors were defined by Damas and Israt (2004) as those that undermine the capacity for self-protection, block access to social protection, delay or complicate recovery, or expose some groups to greater or more frequent hazards than other groups. These factors include social, political, environmental, and physical So, the vulnerability can vary for different groups based on their characteristics.

Table 1 shows the definition of different factors that make populations vulnerable to a hazard.

Table 1: Type of vulnerability

Vulnerability	Description
Physical	The physical vulnerability relates to buildings, infrastructure and agriculture. Although the focus is on physical assets, it also includes the potential loss of crops, and other infrastructure necessary for livelihood. It is also related to the physical characteristics of a landscape, such as its topography, geology, hydrology, and land use can significantly influence the vulnerability to flood.
Social	Vulnerability analysis should examine the risk faced by critical facilities, which are vital to the functioning of societies in disaster situations, such as hospitals and dispensaries, emergency services, transport, communication systems, essential services, etc. Vulnerable groups for instance include women, mentally and physically handicapped persons, children, and elderly persons, poor people, refugees, and livestock. It is also composed of rapid population growth, poverty and hunger, poor health, low levels of education, gender inequality, fragile and hazardous location, and lack of access to resources and services, including knowledge and technological means, and disintegration of social patterns.
Economic	Economic vulnerability assesses the risk of hazard-causing losses to economic assets and processes. These fall into two groups: Direct. Damage to or destruction of physical and social infrastructure and its repair or replacement cost, as well as crop damage. Indirect loss to production, employment, vital services, income disparities. This is based on the following factors: trade and foreign exchange earnings, aid and investments, international prices of commodities and inputs, production and consumption patterns.
Political	Lack of access to information and knowledge, lack of public awareness, limited access to political power and representation.
Environmental	The environmental vulnerability concerns land degradation. Earthquakes, floods, hurricanes, droughts, storms, water scarcity, deforestation, and other threats to biodiversity

Source :Proag, (2014); Damas & Israt, (2004) Vulnerability is important for understanding, assessing, and reducing risk and for determining the impact severity on different assets when a hazardous natural, technological, or man-made origin event occurs (Schneiderbauer et al., 2017).

1.2.5. Exposure

Exposure can be defined as the state of having no protection from something harmful. Exposure is defined as "the situation of people, infrastructure, housing, production capacities, and other tangible human assets located in hazard-prone areas". It is stated in the UNDRR glossary that "measures of exposure can include the number of people or types of assets in an area. It represents the location or presence of attributes and the value of assets that are important to communities and that could be affected by a hazard (UNDRR, 2017). These communities value and have assets including agriculture production, buildings, company registers, critical infrastructure, economic activities, land cover, and population (GFDRR, 2019).

1.2.6. Disaster

UNDRR, (2020) defines disaster as a "serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability, and capacity, leading to one or more of the following: human, material, economic, and environmental losses and impacts. The effect of the disaster can be immediate and localized, but is often widespread and could last for a long period of time. The effect may test or exceed the capacity of a community or society to cope using its own resources and therefore may require assistance from external sources, which could include neighboring jurisdictions or those at the national or international levels". For example, flooding represents a source of disaster that can cause a halt to different human activities on the basis of their different socio-economic and physical conditions.

1.2.7. Adaptation and adaptive strategies

IPCC, (2018) defines adaptation in two different ways. In human systems, adaptation represents the process of adjustment to the actual or expected climate and its effects in order to moderate harm or exploit beneficial opportunities. In natural systems, it refers to the process of adjustment to the actual climate and its effects, and human intervention may facilitate adjustment to the expected climate and its effects. These adjustments or interventions by humans can be implemented through many actions or decision-making processes and represent adaptation options. The "adaptation option is the array of strategies and measures that are available and appropriate for addressing adaptation. They include a wide range of actions that can be categorized as structural, institutional, ecological, or behavioral (IPCC, 2018). Adaptive strategies or measures can be defined as a set of structural, non-structural, and institutional actions or decision-making that the human system implements toward the expected climate and its effects.

In cases of flooding, adaptive measures include structural and non-structural measures. The structural measures or protection solutions include dams, dikes, channels, storm surge defenses, and barriers in general. The non-structural measures include sustainable land use practices, managed retreat from flood-prone areas, improvement of water retention through the preservation and requalification of floodplains and wetlands, as well as controlled flooding of certain areas in the case of a flood event. Other solutions that can reduce the exposure of people and assets to floods also include awareness raising, early warning, and the use of insurance schemes (Climate-ADAPT, 2016).

1.2.8. Behavior

The Cambridge Dictionary defines behavior as the way that a person, an animal, a substance, etc. behaves in a particular situation or under particular conditions. It represents the reaction of a living being or thing to a situation, event, or set of conditions. When talking about a flood, the behavior of households, for instance, can be considered the decision-making, action, or measures implemented by them to cope with and reduce the flood-related impact on people's safety and livelihood.

1.2.9. Drivers to flood

Driver is defined by the Cambridge dictionary as something that makes other things progress, develop, or grow stronger. Drivers of flooding can be defined as factors that permit or make flooding to increase and develop in occurrence. Depending on the flood type, drivers of flooding can be classified into four categories, including meteorological drivers, hydrological drivers, land use change drivers, and societal drivers (Hossain et al., (2021); Ngo et al., (2020); Elmer et al., (2012)). Ngo et al., (2020) found in their study a significant association between flood and different drivers such as climate change risk perceptions with individuals' flood experiences, climate change knowledge, and frequency of community participation. Elmer et al., (2012) identified land use as the main driver of urban flood risk in their area study.

1.2.10. Decision-making

Decision making represents the act or process of deciding something especially with a group of people. Decision-making is the process of making choices by identifying a decision, gathering information, and assessing alternative resolutions.

1.2.11. Cross-section

Cross-sections are key inputs to HEC-RAS. Cross-section Xlines (cutlines) are used to extract the elevation data from the terrain to create a ground profile for channel flow computation. It is important to create an adequate number of cross-sections to produce a good representation of channel beds and floodplains (United & Nations, 2023).

1.2.12. Flow path

The flow path lines are used to determine the reach lengths between cross-sections, in both the main channel and over bank areas (United & Nations, 2023).

1.2.13. Climate change

IPCC, (2018) defines climate change as "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycle, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use".

1.2.14. Method of GRADEX

Method that makes it possible to substitute a frequency distribution of floods with a frequency distribution of rains, corresponding to a given time interval; it is based on the exponential behavior of distribution curves for rare frequencies and assumes showers large enough to saturate the terrain (https://vitrinelinguistique.oqlf.gouv.qc.ca/fiche-gdt/fiche/26521365/methode-du-gradex).

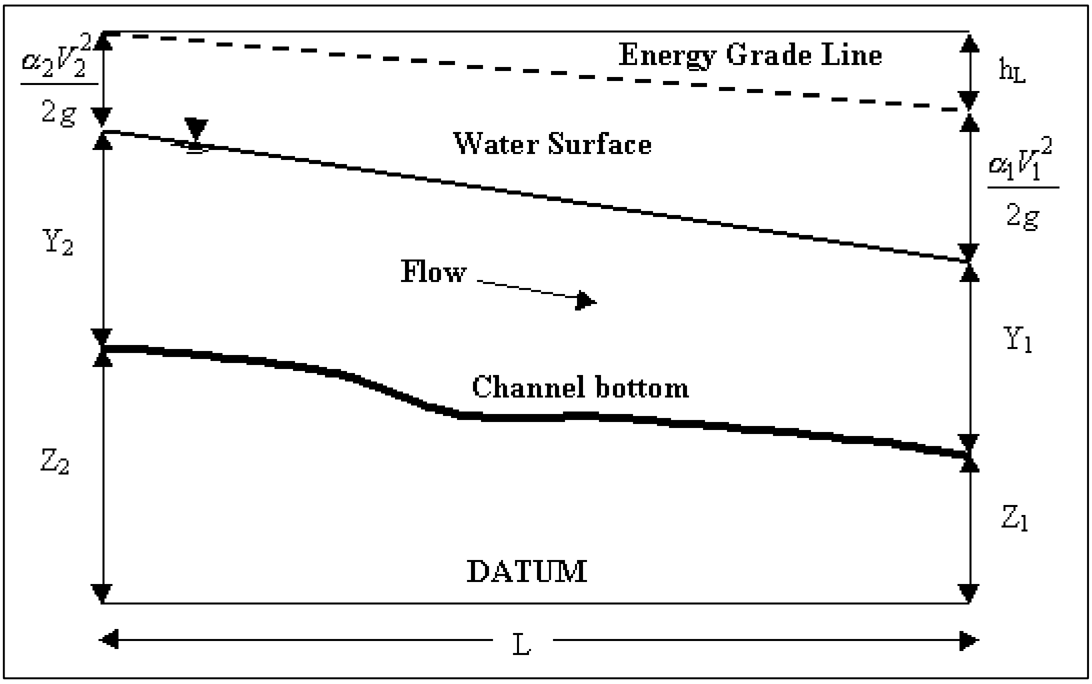
The Gradex method can be used to estimate rare and exceptional frequency flows. The method uses rainfall information to extrapolate the frequency distribution of flows. The method assumes that when the flow exceeds a certain value, the soil is saturated. This value called the threshold flow (or pivot point), can vary from the ten-year flow to the fifty-year flow, depending on the soils and the characteristics of the catchment area. Thus, during the basic runoff time D (assimilated to the characteristic duration), any increase in rainfall induces the same increase in flow (Egis Eau, 2013)

1.2.15. HEC-RAS model

HEC-RAS is a one-dimensional steady-flow hydraulic model that is used by hydraulic engineers to help with channel flow analysis and floodplain determination. The model's results can be used in floodplain management and flood insurance studies. In hydraulics, steady flow refers to conditions in which the depth and velocity at a given channel location do not change over time (Eric Tate, 1999). Surface water profile modeling in HEC-RAS assumes a steady, gradually varying flow scenario. The basic computational procedure is based on solving the energy equation iteratively:

H=Z+Y+〖∝V〗^2/2g

which states that the total energy (H) at any given location along the stream is the sum of potential energy (Z + Y) and kinetic energy 〖∝V〗^2/2g. The change in energy between two cross-sections is called head loss (h_L). The energy equation parameters are illustrated in the Figure 3.



Hydrologic Engineering Center, (2010)

Figure 3: Illustration of energy equation

The goal of the direct step method is to compute the water surface elevation at the adjacent cross-section given the flow and water surface elevation at one cross-section. The flow regime determines whether the computations are performed upstream or downstream. To characterize flow regimes, the dimensionless Froude number (Fr) is used, where:

$Fr < 1$ denotes subcritical flow;

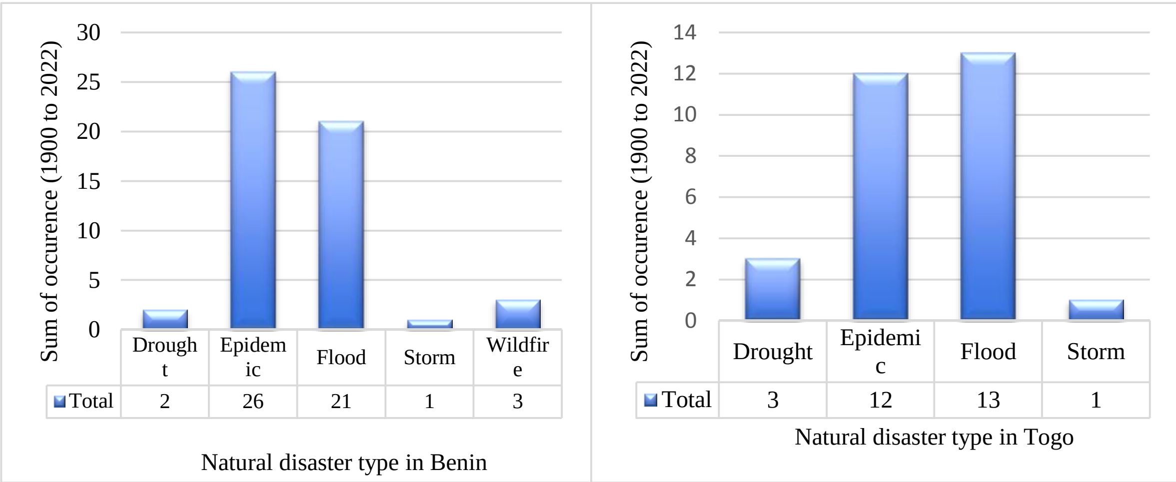
$Fr > 1$ denotes supercritical flow;

$Fr = 1$ denotes critical flow.

Direct step computations would begin at the downstream end of the reach and progress upstream between adjacent cross-sections in a subcritical flow scenario, which is very common in natural and man-made channels. The computations for supercritical flow would start at the upstream end of the reach and work their way downstream (Eric Tate, 1999).

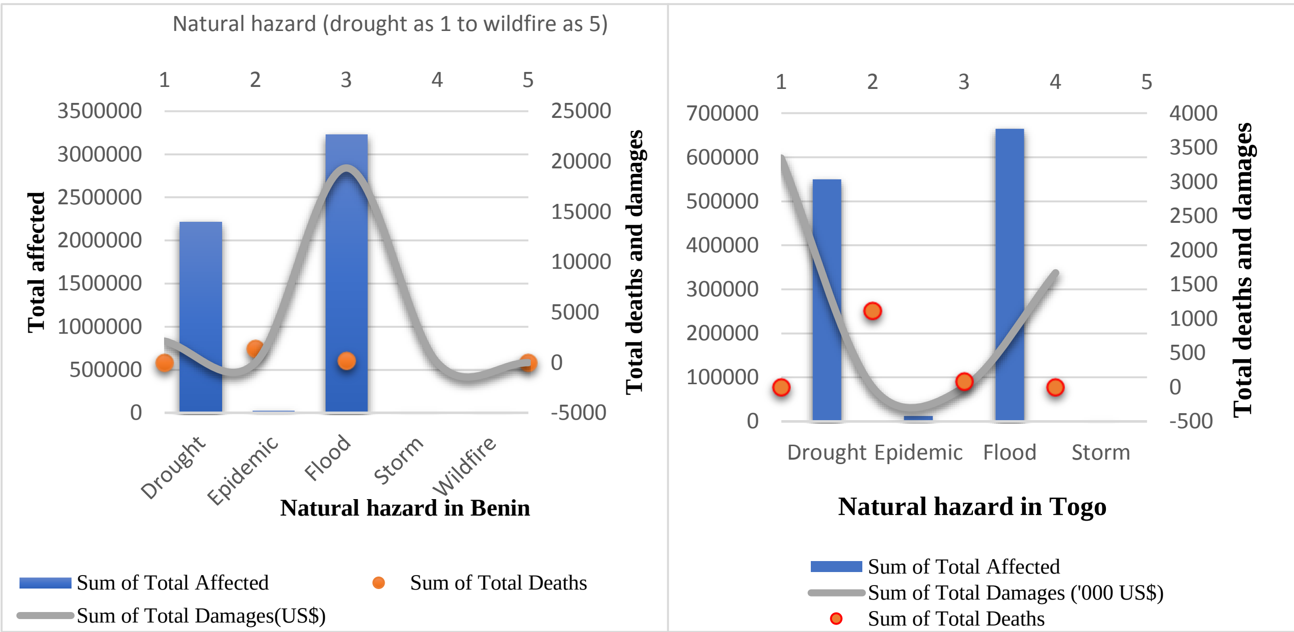
1.3. Floods in Africa

Floods represent one of the most frequent and damaging natural disasters in the world (United Nations Office for Disaster Risk Reduction (UNISDR, 2017). In developing countries, the majority of people are at risk, and the rate is growing each year due to the high levels of poverty making them more vulnerable to disasters (UN/ISDR ((United Nations International Strategy for Disaster Reduction)), 2004 as cited in Munyai et al., 2019). Therefore, in Africa, the flood hazards are likely to exacerbate due to the rapid growth in population, and the Intergovernmental Panel on Climate Change (IPCC) has opined that "Sub-Saharan Africa has experienced more frequent and intense climate extremes in previous decades as a result of climate change, a trend that is likely to continue as the impacts of climate change intensify" (EM-DAT, 2019). Various climate projections over West Africa indicated an exacerbating occurrence of flood events in the future (Adegoke et al., 2019). In Benin as well as in Togo, both countries in West Africa are also experiencing this event. Figures 4 and 5 show, respectively, the effective number of floods and the number of people affected by floods, flood damage, and flood-related deaths from 1970 until 2022 in Togo and Benin.



Source: EM-DAT: The Emergency Events Database, Universite catholique de Louvain (UCL), CRED, D. Guha-Sapir, www.emdat.be, Brussels, Belgium (Octobre, 2022)

Figure 4: Sum of natural disaster occurrences in Benin and Togo



Source: EM-DAT: The Emergency Events Database, Universite Catholique de Louvain (UCL), CRED, D. Guha-Sapir, www.emdat.be, Brussels, Belgium (October, 2022)

Figure 5: The percentage of people affected by floods in Benin and Togo

From these figures, flood represents the hazard that affects many people and causes more damage than any other hazard. It was also shown that riverine floods occurred more than any other type of flood in the two countries (EM-DAT, 2022). Therefore, it is suggested that "stronger disaster management, early warning systems, and adequate flood-control infrastructures are needed to combat the consequences of these intense extreme precipitation events fueled by the changing climate regime" (Adegoke et al., 2019). Flooding represents a natural disaster that occurs more after epidemics and affects more people (59% in Benin and 52% in Togo of the total people affected by natural disasters between 1970 and 2019) than any other natural disaster in both countries.

1.4. Flooding in the Lower Mono River basin

Each year, communities located within the LMR basin are affected by flooding. This situation is caused by the overflow of the river Mono from its bank. The occurrence of floods in the Mono basin increased after the installation of the Nangbeto Dam in 1987. Since then, sometimes dramatic floods are still recorded downstream, with great magnitude according to the populations causing enormous material damage and numerous losses of human life. Often thousands of hectares of fields are submerged in both Togo and Benin (Ago et al., 2005). Given the magnitude and frequency of these crises and disasters, the State of Benin, as well as the Togolese, have prioritized the issue of civil protection of populations in their various development policies in order to contribute to the well-being of the population and provide them with assistance. As a result, the National Civil Protection Agency (ANPC) was established and is in charge of crisis and catastrophe management in coordination with its dispersed branches throughout the territory, several ministerial cells, and other organizations. The ANPC also receives support from humanitarian NGOs such as Caritas-Benin, Care, IFRC and Plan-Benin, the Red Cross, and the United Nations System in general in the operationalization of the policy before, during, and after. Among them, it can be cited, that the elaboration of the cartography of the zones at risk in Benin was made in the basin of Mono. To boost the early warning system, the United Nations Development Program (UNDP) created a flood risk map, a web application, and a GIS database (UNDP, 2021). This mapping will enable the National Civil Protection Agency to establish a platform for progressive multisectoral response planning in order to give priority to the town halls of the communes in terms of instruments of territorial management and modern prevention with regard to the management of flood risks and situations. This will allow the extent of the damage in terms of the number of villages, city districts, and victims, as well as the areas at risk, to be easily identified, allowing progressive planning and effective coordination of humanitarian actions and responses. Similar to this, the agency warns communities ahead of time when water will be released from the Nangbeto dam and urges them to exercise vigilance. In addition, the community early warning system, consisting of beacons (green, yellow, and red. Picture in appendix), risk maps, action plans, and preparation, allows local communities easy reading and autonomy of the water level in rivers, streams, and any other plane of water, thus helping to save people and property (ANPC-TOGO, 2022). In Benin, the agency is also charged with assessing the impact of floods on the population in order to rescue them and reduce the impact on them (ANPC-BENIN, 2019). Thus, ANPC in both countries is in charge of informing communities about the risk of flooding through sensitization in order for them to displace the risky area or change their agricultural calendar.

The Red Cross, both in Benin and Togo provides relief assistance to people affected by floods and distributes non-food items including soap, blankets, plastic buckets, water purification tablets, and Insecticide Treated Mosquito Nets (ITN) to the affected people. In addition, they sensitize communities to preparedness and good hygiene practices, treatment of potable water, and the code of conduct (DREF, 2009). Other projects are also implemented to cope with flood risk in the basin. For example, the project "Transboundary Biosphere Reserve (TBR) in the Mono Delta" aims at the conservation and sustainable use of biodiversity and ecosystem services in the Mono Delta by introducing measures for the sustainable management of forest and fisheries resources while at the same time contributing to the sustainable development of the local communities and increasing their resilience to the existing climate challenges such as floods and drought (GIZ, 2017). Another project, called Projet de gestion intégrée des catastrophes et des terres (PGICT), was also developed by the World Bank in the village of EDOH-WOWUIKOKPE (BAS-MONO)(World Bank, 2016). The PGICT is an example of collaboration between different development agencies. It has received support from the Global Facility for Disaster Risk Reduction and Recovery (GFDRR), the Global Environment Facility (GEF), the European Union under the ACP-EU Disaster Risk Reduction, and other partners such as TerrAfrica. Managed by the World Bank, GFDRR is a global partnership funded by 22 donors. The communities in this village were negatively impacted by the flood caused by the overflowing of the river, especially agriculture (picture in appendix). The communities mobilized to build a water reservoir and related infrastructure that made it possible to drain the flooded areas and clean up the environment. From now on, periods of rain no longer cause fear of floods and the destruction associated with them. Displaced people were able to return, resume their agricultural activities, or take part in the economic activities generated by the work (World Bank, 2016).

Despite these efforts, people in the study region are still at risk of flooding. The review of the various steps performed by some institutions reveals that prevention is generally about sensitizing the population and encouraging them to leave the potentially hazardous location. It is crucial to consider effective actions prior to the flood occurrence, such as offering alternative land to communities or implementing structural and non-structural flood risk control measures in the LMR basin.

1.5. Responses or decision making of human to flood risk

To cope with any environmental or climatic hazard, humans need to adapt or mitigate. Thus, in order to reduce the flood-related impact on human assets, different actions are taken before, during, and after the event to lessen or avoid its impact through mitigation or adaptation. The decision or response of humans to flood risk is the choice made by an impacted human system to develop or implement measures to cope with flood-related impact. Adaptation is defined in the Cambridge dictionary as the process in which a living thing changes slightly over time to be able to continue to exist in a particular environment or a change, and mitigation is reducing the risk of loss from the occurrence of any undesirable event. Adaptation and mitigation to flood risk can be then defined as the response or decision-making of humans or living beings for being able to live with and cope with flood, and mitigation represents the response or decision-making implemented by humans or living beings to reduce the risk related to the occurrence of flood. These actions or responses can be implemented by the system directly impacted by the flood event (for instance, the human system, including households, business owners, etc.) or by an external agent (government intervention). Adaptation can be classified as private and public, simple and complex, before (precautionary) and after (reactive), hard and soft, autonomous and planned. It is also classified based on timing (short-term and long-term adaptation strategies) (Case & Baylie, 2022).

Many studies were conducted to identify the measures implemented by farmers, households, or any other agent. Atinkut & Mebrat, (2016) identified crop diversification, soil and water conservation, and seasonal migration as farmers' choices of adaptation to climate variability in Dera woreda, south Gondar zone, Ethiopia. In their study, Marfai et al., (2015) identified raising the housing level, building terraced housing, and building small dikes as the measures implemented by households to prevent water from entering the settlements. Indigenous practices in the Ada East District of Ghana included sandbags as barriers, raised foundations, reinforced windows using trampolines, the creation of platforms for packing valuables, pathways for floodwater, and livelihoods and diversification were implemented to prevent coastal flood-related impacts on their goods (Cudjoe & Kwabla Alorvor, 2021). Other studies were also conducted to identify the measures implemented by households to adapt or mitigate flood impacts, including relocation of family and valuables, construction of flood diversion trenches, and seeking relief from the government and other agencies (Masese et al., 2016;

Mondal, 2021). Regarding the decision-making process, many studies were conducted on the factors that influenced the decision-making of households or agents regarding flood risk based on the three classes presented above. In their studies, Atinkut & Mebrat, (2016) identified many factors that significantly influenced the choices of crop diversification and soil and water conservation, including the age of the household head and family, while age and farm size have a negative but significant association with soil and water conservation and seasonal migration. Seasonal migration is positively associated with agroecology (midland), the sex of the household head, and access to extension services. The decision of evacuation from flooded areas by households at risk was found to be positively influenced by disabled or ill members, the water level, and flood experience, while age, education, income, and an early warning message negatively influenced the decision of households to evacuate (Mondal, 2021). Flood water depth, location of home, household affected by disease, age, gender, agricultural land use, and nonfarm incomes are the determinants of post-disaster coping strategies on the right bank of the Teesta River, Bangladesh (Mondal et al., 2021a). On the other hand, the perceived probability of flooding perceived preparedness, flood experience, exposure to flooding, membership, the household head's sex, income source, and landownership significantly influenced households' decisions to implement mitigation measures in the post-disaster period (Mondal et al., 2021b). Many other studies were conducted to identify the determinants or factors that influence the decision-making of human beings to implement short- and long-term strategies and solve flood-related impact problems accordingly (Ao et al., 2022; Padhan & Madheswaran, 2022; Champonnois & Erdlenbruch, 2021; Alhassan, 2020; Bahinipati, 2015; Tu & Nitivattananon, 2011).

These findings allow for the identification of the factors that need to be promoted or ameliorated to enhance their capacity to cope with flood impact. For instance, if the income or gender of a woman influences negatively the choice of a particular measure, it means that the community does not have the means or that women do not have the capacity to mitigate or adapt. Thus, promoting livelihood diversification or ameliorating other activities will be helpful. When livelihood or crop diversification represents the most implemented measure, this means that there is a need to promote other activities in the study area and make the seed more accessible to them. In addition, knowing the size of the household informs on the different existing measures that the household is used to. When a project installs it, they will then be able to maintain it. In this study, we analyzed the existing adaptive strategies and the factors that influenced the decision-making of households to adapt or select a particular adaptive measure. This firstly comes to fill the gap created by the lack of studies conducted on that topic and also to direct the decision-maker in the choice of efficient and sustainable measures to cope with flood impact.

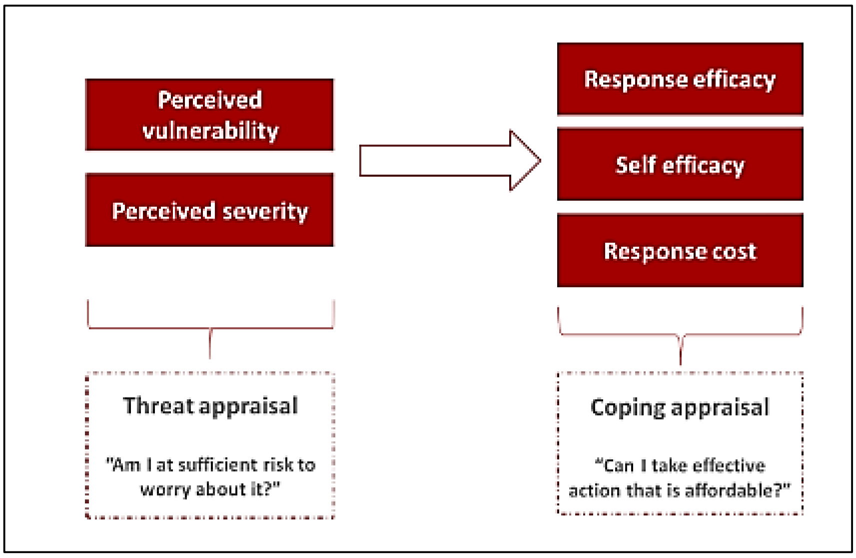
1.6. Decision-making theories in flood risk management

Oxford Languages dictionary define decision making as the action or process of making important decisions. Decision-making is then the way for people to make a choice that will lead to an action in a certain situation or circumstances.

Theory means also from Oxford Languages dictionary, a supposition or a system of ideas intended to explain something, especially one based on general principles independent of the thing to be explained. Theory represents a set of principles that can explain a process. From both of the above decisions, the decision-making theory can be defined as the set of principles that explain the process of making a choice or decision regarding a particular situation. It plays a pivotal role in understanding the processes governing human choices in personal, organizational, and societal contexts. They are relevant in comprehending human behavior. "*Decision-making theory is a theory of how rational individuals should behave under risk and uncertainty. The theory suggests that decision-making means the adoption and application of rational choice for the management of a private, business, or governmental organization in an efficient manner*" (Alijoyo, 2021).

In the domain of flood risk management, decision-making is how individual or floodplain managers behave or make decisions under flood risk to effectively reduce flood losses, respectively, on their activity or their community. They are theories that help in understanding the choice of household, community, decision-maker, etc, given information about flood risks.

Decision-making theories play a pivotal role in understanding the processes governing human choices in personal, organizational, and societal contexts. They are relevant in comprehending human behavior. In this section, we present some theories used in the domain of flood risk management to understand how decision are made by households, decision-maker to cope or act toward the flood risk. Protection motivation theory is most used in the field of flood risk and disaster risk management. Protection motivation theory is used to identify what motivate people to response or act to a disaster or a health issue (Markanday & Galarraga, 2021). It has been used by to identify the cognitive process which induce people, stakeholder or decision-maker to react against threat. Two main processes represent the foundation of this theory including threat appraisal and coping appraisal as presented by the Figure 6.



Source: Oakley et al., (2020)

Figure 6 : An illustration of Protection Motivation Theory

The threat appraisal relates to perceived vulnerability, that is, perceptions of how likely the threat is to occur, and; perceived severity, that is, perceptions of how severe the effects of that threat will be. The coping appraisal relates to how effectively individuals feel they would be able to cope with a threat, and is comprised of three features: i) self-efficacy, which refers to the extent to which individuals feel their actions will make a difference; ii) response efficacy, which relates to how effective a response is perceived to be, and; iii) response costs, that is, how much it would cost to respond to a threat (Markanday & Galarraga, 2021). Markanday & Galarraga (2021) used the protection motivation theory to understand how different flood risk framings and experience of impacts influence cognitive and experiential processes, and to determine the effect that this may have on investments in adaptation. Protection Motivation Theory was found as a suitable scientific framework for predicting the behaviors of coping with the harmful effects of natural disasters in the households in the south of Iran in 2022 (Faryabi et al., 2023). They found that the higher the perceived vulnerability, perceived severity, self-efficacy, response efficiency, fear and protection motivation, and the lower the rewards and cost of the perceived response, the more people take preventive measures. The perception of people on flood risk existing coping capacities, previous experience, and reliance on public and private flood risk reduction interventions were assessed by using PMT (Ansari, 2018). Ansari et al., (2022) also used PMT to identify the factors which influence and motivated people in different status or different probability a flood risk occurrence (existed hard measures, soft measure, no measure), to act and their perceptions regarding the future flood risk. Weyrich et al. (2020) used a dynamic protection motivation framework combine to the transtheoretical model (TTM) to explore the current state of homeowners' readiness (emergency group, structural group and avoidance group) to undertake risk reduction.

Prospect Theory, was developed for the description of individual decisions under risk, and most of these decisions were met rather spontaneously (Papers, 2013). This theory was used by Reynaud & Aubert (2019) to investigate whether and how experiencing a natural disaster affects individual attitudes toward risks in Vietnam.

Games theory is as games used for a purpose other than purely entertainment and it is used in different domain including in operations research and management science, marketing, health care and medicine, public policy, environmental sustainability, most often for training and education, and also in natural hazards including flooding (Gordon & Yiannakoulias, 2020). Serious game allows interactive simulation games that permit to the players to firstly explore environments and learn; secondly players can take unfamiliar identities to understand problems in new manner and thirdly it is a persuasive game with purpose to change real-world behavior (Gordon & Yiannakoulias, 2020). Game theory is also used to resolve conflict by creating game in which people taking their own responsibilities (Moosakhaani et al., 2022). Moosakhaani et al., (2022) used Games Theory to develop comprehensive financial model has been for sharing players' financial responsibilities in flood risk management plans. In fact, this study was conducted to resolve the existed conflict in the flood risk management between the governments, insurance companies and people as players in sharing financial responsibilities because of how calculate insurance premium, compensation and governmental assistances. Serious Game approach was used by Gordon & Yiannakoulias, (2020) to understand the factors that influence flood risk mitigation decisions of household about whether or not to structurally mitigate or insure.

Protective Action Decision approach (PADM) is a theory based on how individuals react to environmental threats and disaster by combining the processing of data from environmental and social cues with messages that social sources convey to individuals who are vulnerable via communication channels (Lindell & Perry, 2012). It gives researchers a tool for analysing three types of respondent perceptions: threat perceptions, protective action perceptions, and stakeholder perceptions. It outlines three crucial predecision processes that come before any additional processing including exposure, attention, and interpretation of environmental/social signals; reception, attention, and comprehension of warnings (Liddell et al., 2020). The updated model outlines three fundamental perceptions that serve as the foundation for judgments on how to react to either a short-term or long-term threat: views of the threat, perceptions of protective actions, and perceptions of stakeholders. A behavioral reaction is the result of the protective action decision-making process combined with situational facilitators and obstacles (Lindell & Perry, 2012).

This section synthesizes the diverse decision-making theories, offering a nuanced perspective on the multidimensionality of decision-making. While these theories may appear distinct, they often complement and intersect with one another, providing a holistic understanding of the decision-making process.

1.7. HEC-RAS application in flood risk management

HEC-RAS is software that allows users to determine one-dimensional steady flow, one- and two-dimensional unsteady flow, sediment transport and mobile bed calculations, water temperature, and water quality modeling (CEIWR-HEC, 2023). The Flood Hazard Mapping Recommended Practice aims to use the basic functions of RAS Mapper in HEC-RAS to create a 1D model of a river system that can be used to map the potential inundation extent. This is critical for identifying flood-prone areas and assisting decision-makers in taking action to mitigate the effects of flooding. It also permits the evaluation of model results, which is critical for improving the accuracy of future flood forecasting and risk assessments. HEC-RAS plays an important role in guiding flood management decisions and developing effective flood prevention and mitigation strategies by providing accurate and reliable information on flood risks and inundation extents (United Nations, 2023). Basnet and Acharya (2019) suggested that the flood maps produced by HEC-RAS could be used by government authorities for planning, decision-making, early warning systems, and disaster risk management. HEC-RAS is also a tool that could test some structural measures for reducing flood risk by modifying the ground elevation. Many studies were conducted using HEC-RAS to map flood s for different return periods and to estimate the future flood hazard.

HEC-RAS combined with the HEC-GeoRAS extension in ArcGIS was used to calculate the volume and flow rates of water on the Earth's surface and evaluate the depth of rain for different return periods to assess flood risks in villages near the Khazir River's floodplains(AL-Hussein et al., 2022). According to the findings of the study, HEC-HMS and HEC-RAS have a strong correlation in assessing flood risks and reliably forecasting future floods in the study area. Jagadeesh & Veni (2021) combine HEC-RAS with GIS tools especially Arcgis, and Hec-Georas for flood plain modeling of Krishna Lower Basin. AL-Hussein et al. (2022) in their study used HEC RAS to determine the hydraulic characteristics of the flood bed and the water surface profiles of the Q25, Q50, Q100, and Q500 recurring floodplain analyses and the one-dimensional floodplain analysis of the Tigris River. The analysis of the results of the study conducted by Ben Khalfallah & Saidi (2018) reveals that HEC-RAS permits a good correlation between simulated parameters and those measured. Also, there is a flood of the river exceeding and more flowing sections are observed in the future simulations; for return periods of 10yr, 20yr, and 50yr. HEC-RAS and HEC-GeoRas were used by Sholichin et al. (2019) for flood mapping and classification of risk areas. Basnet & Acharya (2019) conducted a study using HEC-RAS for modeling floods for the different return periods in Seti River (Ramghat area of Pokhara, Nepal). They found in their study that the 50-years flood in Ramghat could inundate three cemetery shades situated along the river banks. In addition, 100-year peak flood was found more vulnerable to population. Other studies used HEC-RAS itself or combined with other GIS tools to map flood hazards for different return periods (Khattak et al., 2016; Farooq et al., 2019). Other studies also tested structural measure effectiveness in reducing flood risk. Sholichin et al., (2019) in their study analyzed the effectiveness of diversion channels in reducing flood risks in the on the Ciliwung River located in Kalibata, Kebon Baru, and Kampung Melayu respectively. They found that there is a reduction in inundation area and a decreasing in water level by testing different diversion channels in reducing flood risk. HEC-RAS combined with GIS was used to identify flood risk zones and assess the extent of impact of the hazard and depth of water levels. This permit to estimate the vulnerability of different facilities including material plants, potable water waste, water facilities, transportation, hospital, and school (Yerramilli, 2012). In other studies, HEC-RAS is used to test the controversial effect of structural measures such as dams in provoking risks such as flooding. HEC-RAS combined with HEC Life models was used to assess the potential flood risk associated with Malleh dam rupture in Marrocco (El Bilali et al., 2021). Different dam breach and flood scenarios, where the water flows over man-made structures, settlements, and olive tree cultivations, were also examined in the study conducted by Psomiadis et al. (2021).

1.8. Partial Conclusion

This chapter clarifies various flood concepts and provides an overview of floods in Africa in general and the research area in particular. It also demonstrated how people react, respond, or make decisions in response to flood danger, as well as the usage of HEC-RAS modeling in flood risk management. All of this information contributes to a better understanding of the data and the approaches that must be used to achieve the goals. Ogras & Onen, (2020) highlighted HEC-RAS as one of the software packages that have been developed for facilitating the analysis and calculation of water surface profiles.

CHAPITER 2: Data, materials and methods

CHAPTER 2: Data, materials and methods

2.1. Introduction

In this chapter, the study area is presented including its location, climate, hydrography, soil type, land use, land cover, vegetation, and the different ethnic and socio-economic activities encountered within the catchment.

To meet the study's goal, data were collected in the study area and evaluated using several approaches described in this chapter. The study area, type of data, their sources, and the analysis methods are presented in this chapter.

2.2. Location of the study area

The study was conducted in the Lower Mono River (LMR) basin, located in the southern part of the Mono Basin, a shared basin between two West African countries, Togo and Benin (Figure 7).

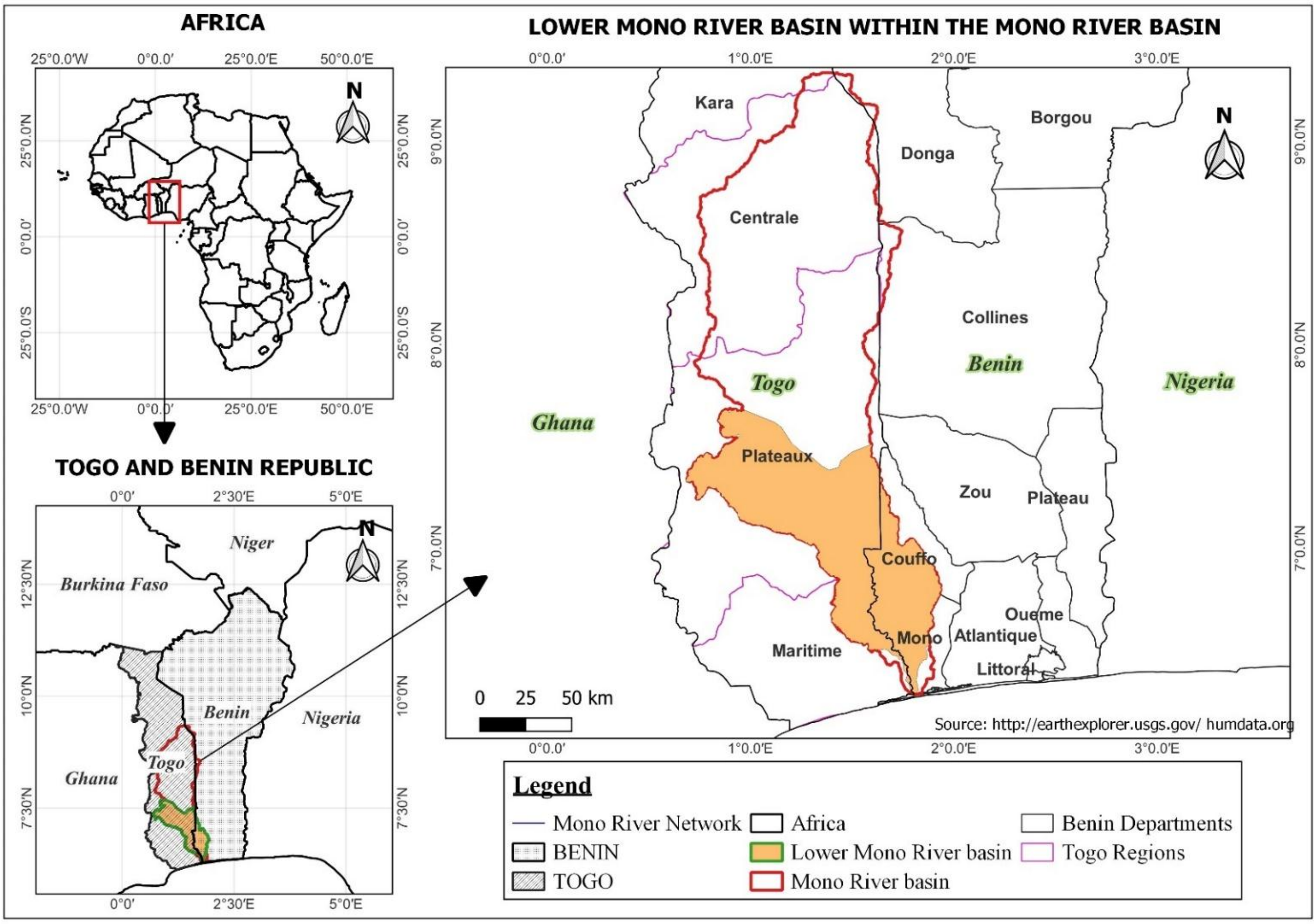


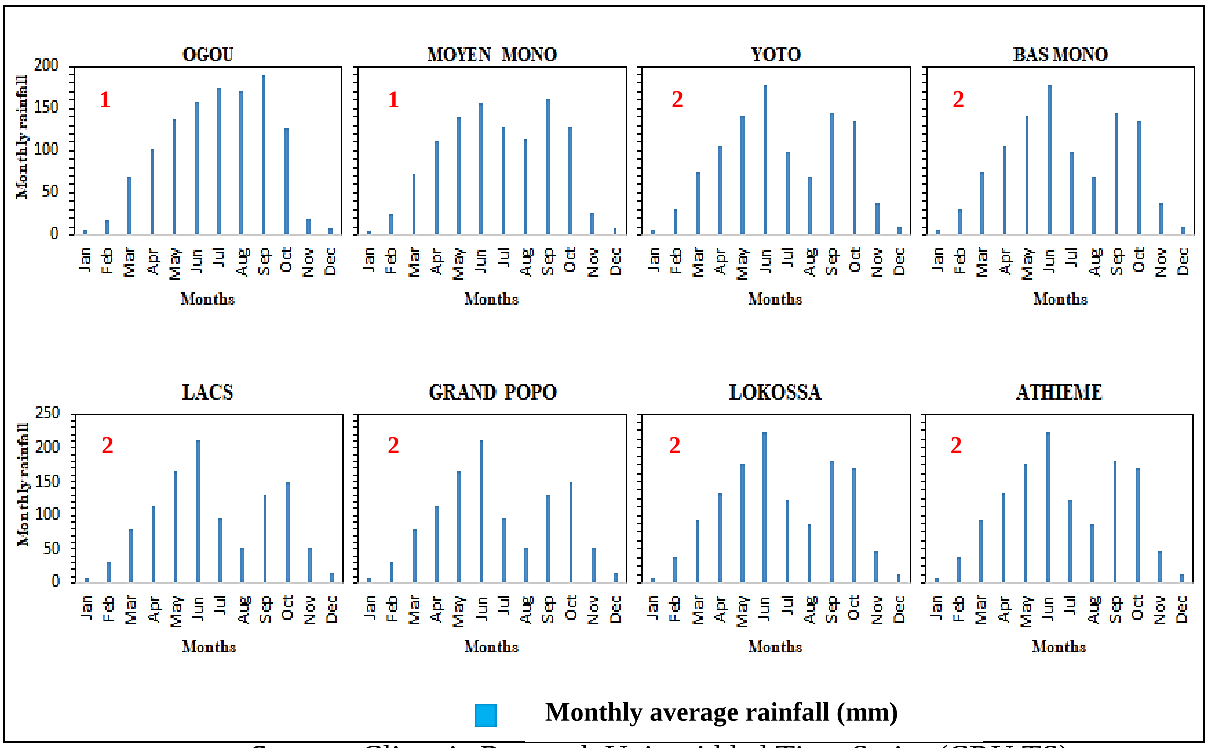
Figure 7 : Location of lower Mono River

The LMR basin combined different prefectures (Amou, Bas-Mono, Danyi, Haho, Kpele, Lacs, Moyen-Mono, Ogou, Vo, Wawa, and Yoto) of Togo and communes (Aplahoue, Klouekanme, Lalo, Tovoklin, Athiémé, Bopa, Cove, Houeyogbe, Lokossa, Djakotome, Dogbo-tota, and Grand-Popo) of Benin. The basin is drained by the Mono River to the outlet at Athiémé in Benin. It is located between 06°30’ and 7°30' northern latitude and 0° 30' and 2° 0' eastern longitude, and covers an area of 8136.78 km^2. Two dams (Nangbéto and Adjarala) were constructed on the river waterway in the Mono River basin, located in the upper part of the LMR catchment (Koubodana, 2019).

2.2.1. Climate and climate change

Two types of climates are found in the LMR catchment:

- (1) Sudan tropical with one rainy season and one dry season in the upper part, represented by the prefectures of Ogou and Moyen Mono in the study area; and
- (2) sub-equatorial with two rainy seasons and two dry seasons downstream, represented by the prefectures/communes of Yoto, Agome Glozoun, Lacs, Grand Popo, Athiémé, and Lokossa in the study area (Figure 8).

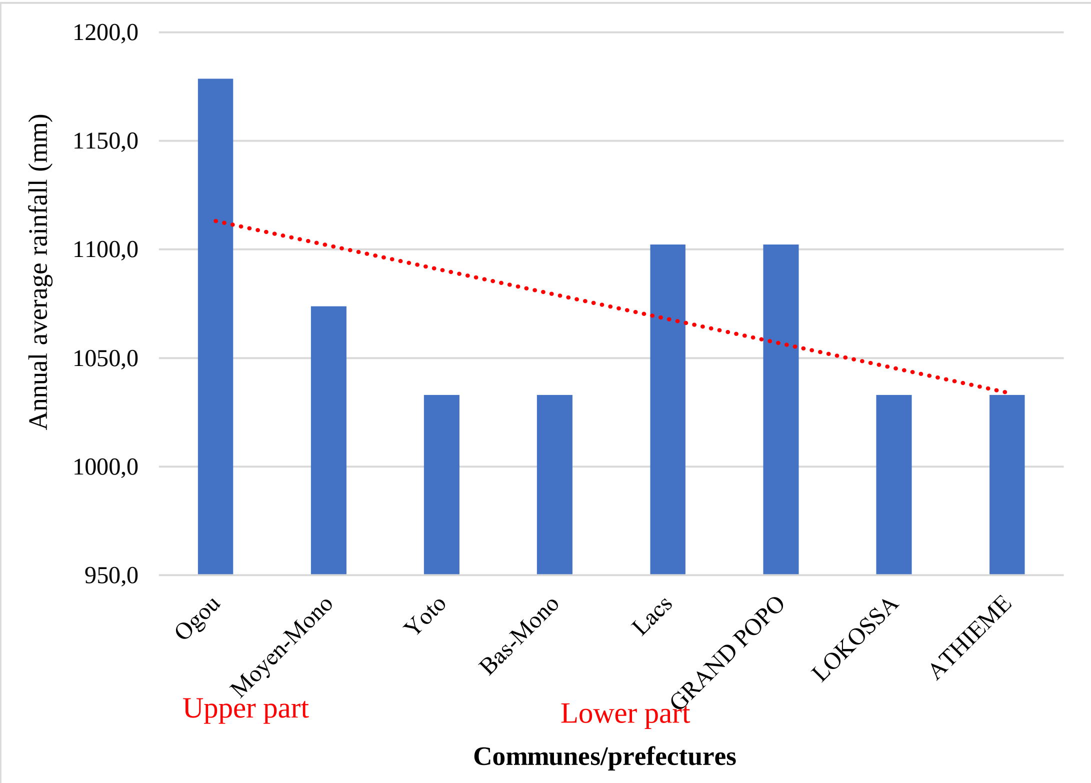


Source: Climatic Research Unit gridded Time Series (CRU TS)

Figure 8: Monthly rainfall in the LMR catchment

The Climatic Research Unit gridded time series (CRU TS) was used because of the lack of ground-based data. It was used by previous studies and presented satisfactory responses concerning observational datasets (Quenum et al., 2019; Quenum et al., 2021). These data were used because of the lack and accessibility of the ground data. The monthly precipitation from 1979 to 2019 was collected for each commune/prefecture. In the upper part of the basin, the rainy season begins from March to October with the maximum monthly precipitation of 188.63 mm in September (prefecture of Ogou) and 160.96 mm (prefecture of Moyen Mono). It is important to notice that the prefecture of Moyen Mono tends to the Sudan tropical climate. Whereas in the lower part, the two rainy seasons are from March to July (long rainy season) and from August to November (short rainy season). During the long rainy season, the maximum monthly precipitation ranges between 177.61 mm and 210.22 mm in June depending on the prefectures or commune; whereas, during the short rainy season, the maximum monthly precipitation ranges between 145.20 mm and 147.88 mm in September for Athiémé, Lokossa, Bas Mono and Yoto and October for Lacs and Grand Popo.

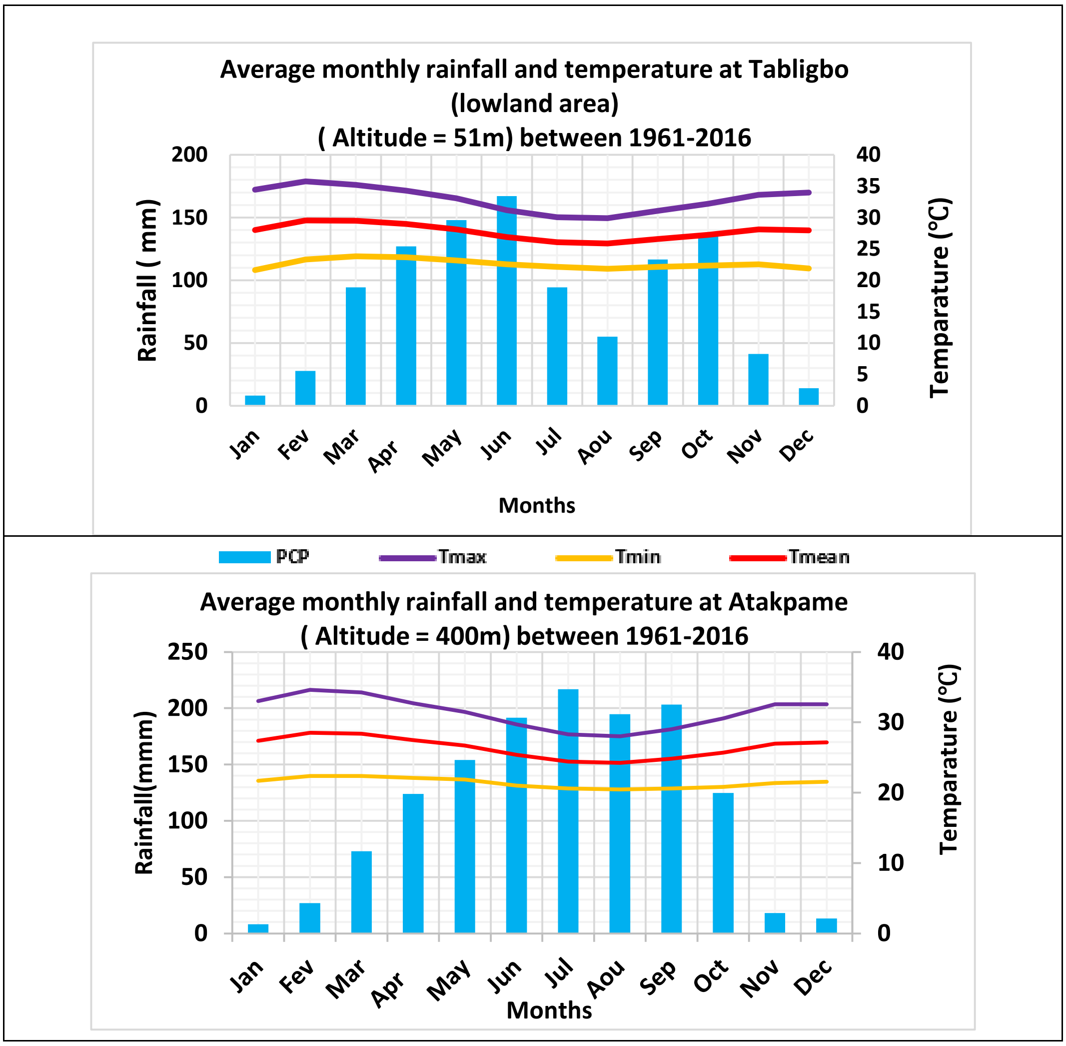
Figure 9 depicts the variation in yearly precipitation from 1979 to 2019. The graphic shows that the annual rainfall decreases slightly as one moves from the upper to the lower area of the watershed.



Source: Climatic Research Unit gridded Time Series (CRU TS)

Figure 9 : Annual rainfall variation per commune (1979 - 2019)

Regarding the temperatures, lowland areas have temperatures between 19 ° C and 34° C, while the upper areas of the Lower Mono River basin vary between 18 ° C and 30 ° C (Figure 10).



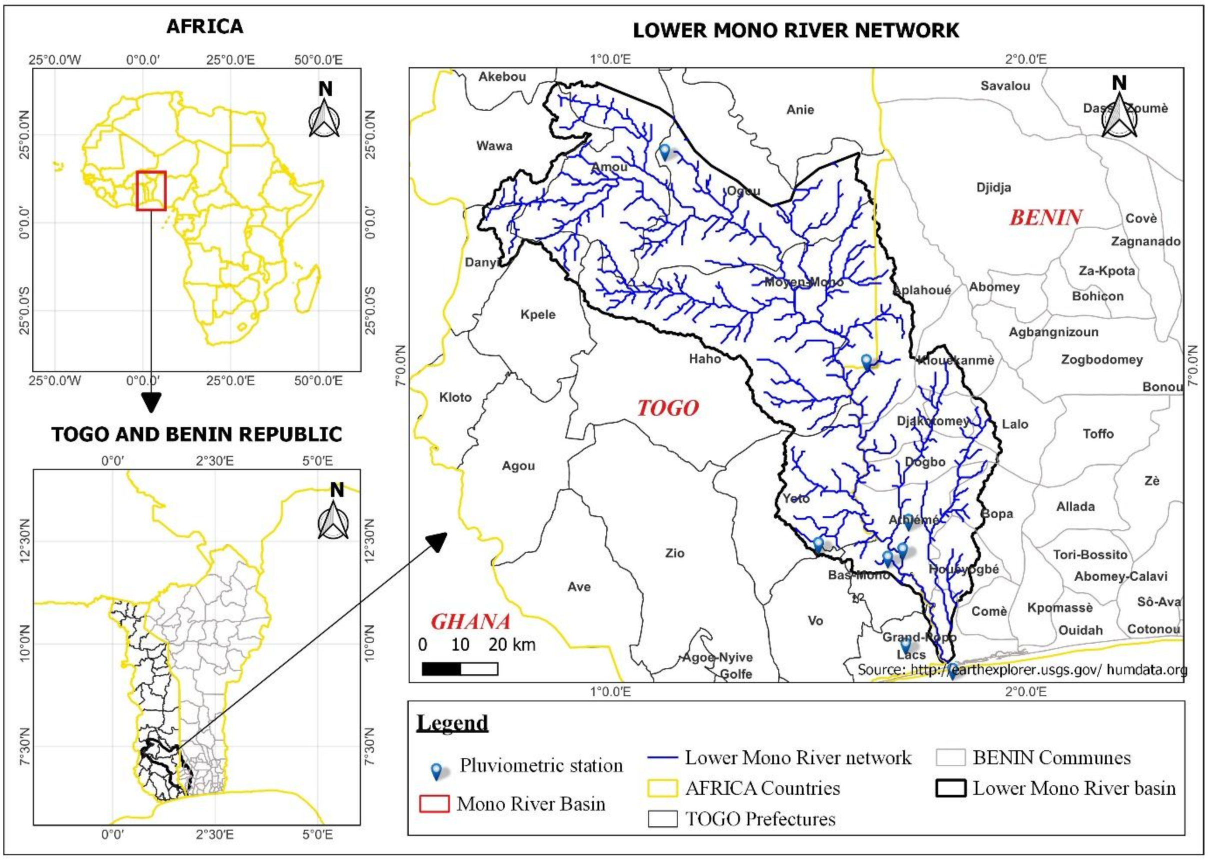
Source: DGMN-Togo, 2018 (cited in Koubodana, 2019)

Figure 10 : Average monthly rainfall and temperature at Tabligbo and Atakpame (1961-2016)

Climate and climate change: Analysis of data covering the period from 1961 to 2010 (daily flows, evapotranspiration, and average precipitation over the basin) shows a variation in precipitation marked by an increase in daily annual maxima followed by an increase in ETP (Ernest Amoussou, 2014). Models predict a temperature rise of 1 to 1.5°C by 2050, compared with the period 1988-2010. In 2050, cumulative precipitation would remain stable, but exceptional rainfall events would tend to increase, as would maximum daily precipitation. The July-September period would see the most intense rainfall, with a peak in September. Downstream flooding is likely to increase (Ernest Amoussou et al., 2020). Whatever the assumptions, the scenarios developed show that climate change is a real concern for the country and that warming trends are set to increase in the short and long term, with consequences that would be highly damaging if appropriate measures are not taken in times (Akakpo et al., 2021).

2.2.2. Hydrography

The Lower Mono River basin is drained by the Mono River, which takes its source at Alédjo in the north of the Benin Republic in the Koura Mountains. Its direction follows the east-west axis before changing direction at the 8th latitude to reach the Athiémé outlet, where the river is joined by its main tributaries (Figure 11).



Source: http://earthexplorer.usgs.gov/ humdata.org

Figure 11: Hydrographic network of the LMR basin

The Mono River, 530 km long, rises at Alédjo in northern Benin in the Koura mountains and flows east-west to the 8th parallel, then north-north-west/south-southeast, and eastward to its mouth. The Mono's main right-bank tributaries are: the Aou (55 km); the Anié (161 km); Amou (114 km), enlarged by the Amoutchou (62 km); and the Kra (69 km). On the left bank, the Ogou (207 km) is the main tributary. With the exception of the perennial Amou, all these rivers have:

- a highly variable flow rate throughout the year and from one year to the next,

- a consistently high "flood flow/low flow" ratio,

- long low-water periods, typical of exclusively rain-fed basins.

As a result, the Mono has a highly irregular hydrological regime (Akakpo et al., 2021). The river's flow regime is a tropical rainfall hydrologic regime from rainfall characteristic of the Sudanian zone (Koubodana, 2019). The river mostly presents one peak of discharge at Athiémé between August and October (Figure 12.A). The annual average is respectively 97.35 and 139.48 m3 /s from 1979 to 2010 at the outlets of Nangbeto and Athiémé (Figure 12.B). The monthly discharge peaks are observed during the months of August, September, and October (Figure 12.A).

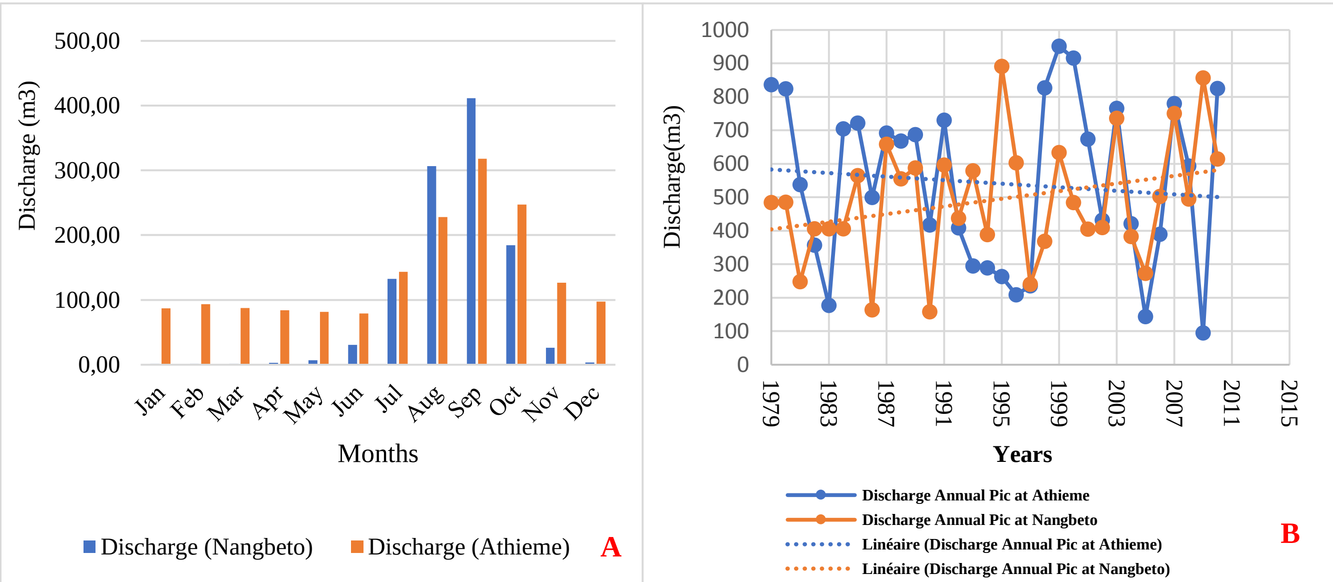
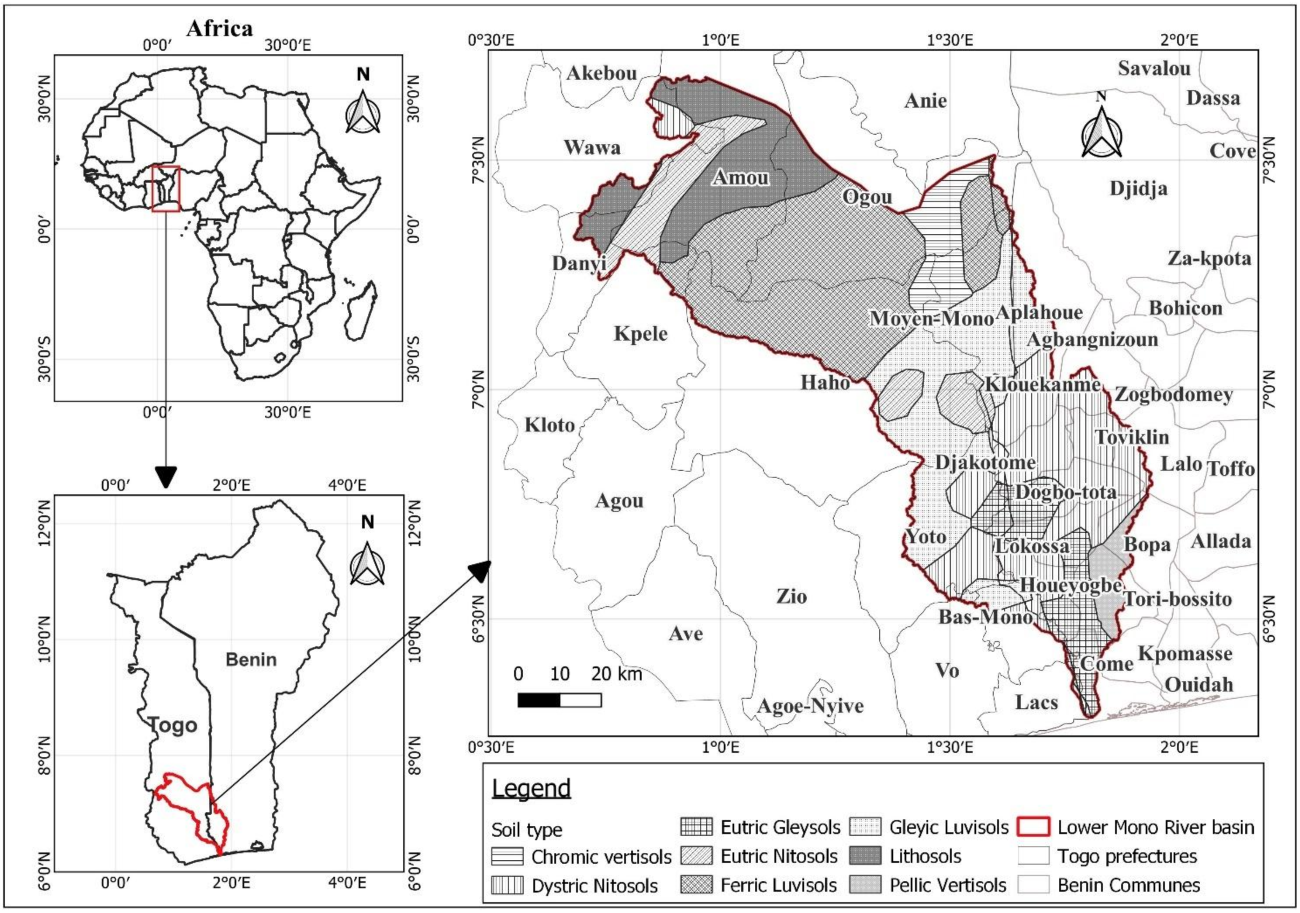


Figure 12: Monthly (A) and annual discharge with linear trend at the outlet of Nangbeto and Athiémé (B)

The annual flows reported at Athiémé's discharge are generally higher than those observed at Nangbeto. This is explained by the fact that the lower basin receives runoff from the upper basin.

2.2.3. Soil

Schoonover & Crim, (2015) define soil as "a non-renewable, dynamic, natural resource that is essential to life. Water movement, water quality, land use, and vegetation productivity all have relationships with soil". Soil then plays a key role in the absorption of water, depending on its properties. The Lower Mono River basin is constituted of tropical soil types (http://www.fao.org/soils-portal). According to FAO-UNESCO, (2003), five (5) categories of soil are encountered in the LMR basin, including Gleysols, Lithosols, Luvisols, Nitosols, and Vertisols (Figure 13). Luvisol is the dominant soil in the LMR basin, followed by Nitosols, Vertisols, Gleysols, Lithosols, and Vertisols (Figure 13).



Source: FAO-UNESCO (2003)

Figure 13: Soil type map in the Lower Mono River basin

2.2.4. Relief and geology

In terms of relief, the basin is blurred, with altitudes below 200 m in the south and above 300–400 m in the north (Autorité du Bassin du Mono, 2023.). The table shows that, given its compactness coefficient, the basin has an elongated shape. The table also provides information on the relief of the basin. There are 3 classes of relief, depending on the slope of the catchment. The classification according to the value of Ds is:

- Low relief: Ds < 50 m;
- Moderate relief: Ds between 50 and 100 m;
- Strong relief: Ds > 100 m.

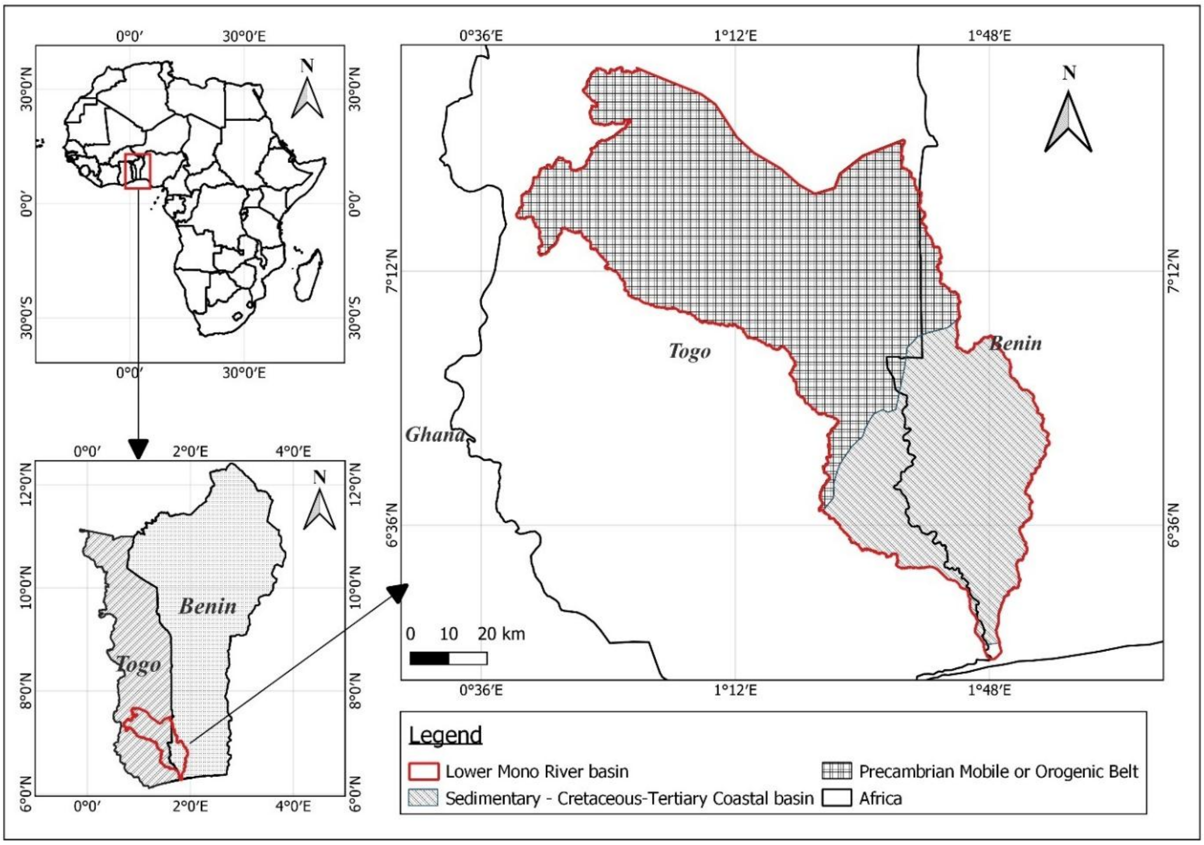
Considering the Ds value obtained for the watershed under study, the Mono basin is characterized by strong relief. The relief is generally flat, with the exception of the eastern and northeastern massifs. The very narrow lower part of the basin lies in the coastal sedimentary basin, often covered by alluvial deposits. The transition between the ancient massif and the recent sediment is marked by rapids. The geology of the basin comprises three morpho-structural units: the Atakora chain (Atacorian), the Precambian or internal Dahomeyen units, and the sedimentary basin as presented in the Table 2 (ONU-SOFRELEC, 1964; ORSTOM, 1969; Autorité du Bassin du Mono, 2023). Hydrogeologically, the Mono basin stretches from the coastal zone of the coastal sedimentary basin to the basement zone. The coastal zone includes aquifers from the Paleocene (limestone or sandy) and Cretaceous (sandy), which are 300 to 500 m deep or more, as well as aquifers from the Terminal Continental and Quaternary, which are semi-deep to shallow (0 to 50 m). The basement zone has fewer aquifers, mostly limited to faults and fissures.

Table 2: The geology of the basin

Group	Constitution
Precambian or Dahomeyen	**Ectinites**: these are metamorphized precambrian rocks without granite. There are micaschist zones dominated by sericite schists with miscorite or biotite. Other zones are gneissic, consisting of biotite paragneiss and orthogneiss with biotite and amphibole. The Ectinites occupy the northern part of Benin, with their southern limit roughly corresponding to the valley of the OGOU;

	Migmatites: they are the result of the metamorphism of rocks that have undergone significant granitic input. Located to the south of the Ectinites, their crystalline outcrops disappear with the peneplain, at the limit of the sedimentary terrain. Their hard forms are at the origin of the ADJARALA waterfalls on the MONO, 20 km from PARAHOUE.
Atacorian	**Granites:** origin injected into the Dahomeyen and Atacorian masses. They form a vein 10 km wide, elongated in a north-east-south-west direction along the ATAKPME-KLOUTO axis. These granites form a vigorous relief deeply cut by the valleys of the AMOUCHOU and its tributaries; **Basalts**: in isolated pockets that appear in the Dahomeyen at the limit of the Ataconian. The largest is located on the right bank of the MONO, halfway between BLITTA and SOKODE
Tertiary	**Lama and Locogba**: two series alternate marl clays with limestone beds and sands. Their thickness can reach up to 400 meters. **Terminal continental series**: the previous series, which can be traced back to the Eocene, were gullied by so-called terminal continental sands, some 80 m thick. These sands are covered with bar soil and a ferruginous cuirass in this very dry region, is ideal for these superficial formations

The Figure 14 shows the geology of the LMR basin.

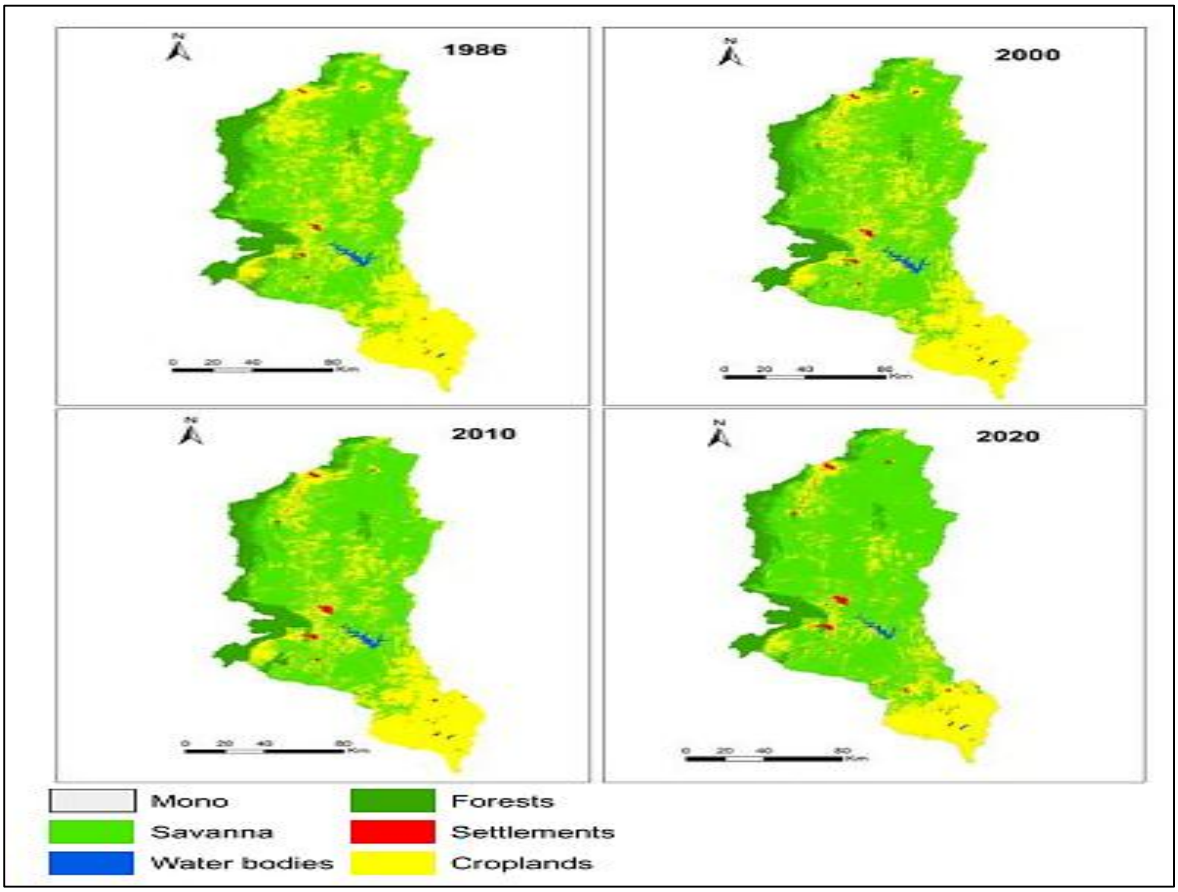


Source: Africa Groundwater (bgs.ac.uk)

Figure 14: Geology map of the LMR basin

2.2.5. Land use, land cover and settlement

Land use and land cover in the Mono River Basin are characterized mainly by forest, savannah, bare soil, wetland, water bodies, cropland, and settlements (Koubodana, 2019). In the same vein, the study conducted by Thiam et al. (2022) identified five land uses and land covers within the Mono River Basin, including savannah, cropland, settlements, forests, and water bodies (Figure 15).

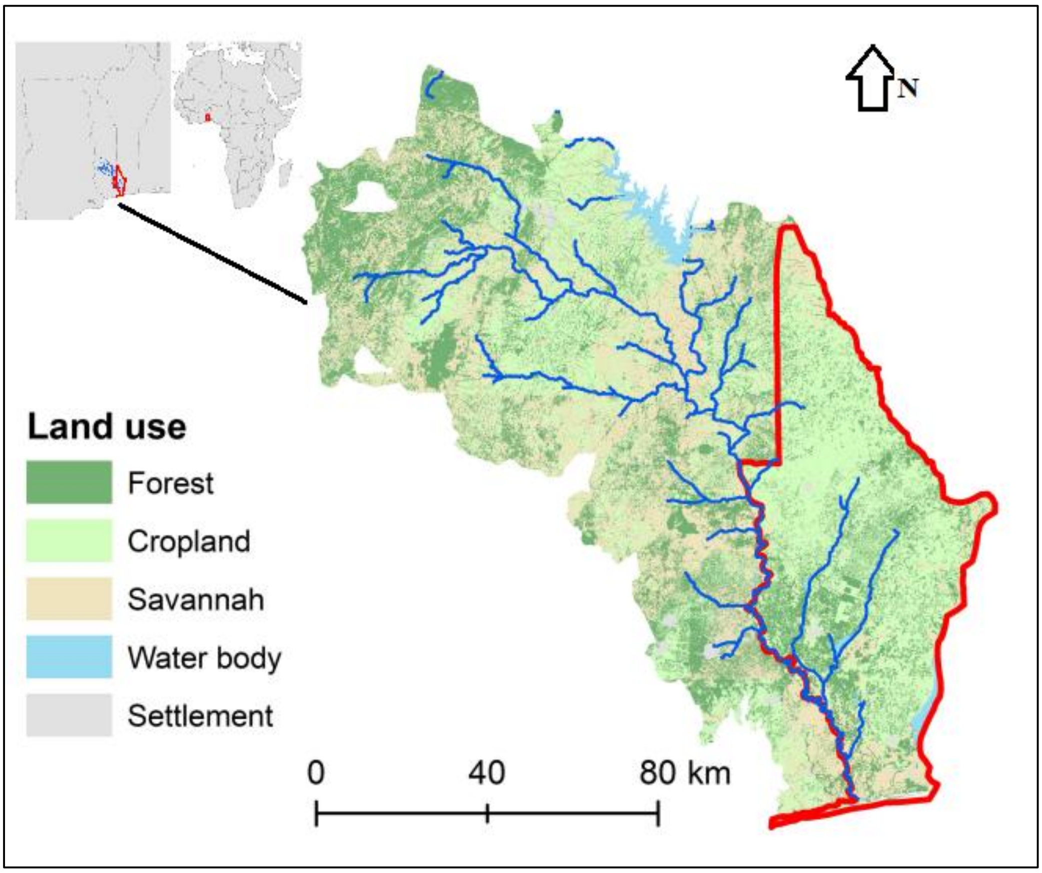


Source: Thiam et al. (2022)

Figure 15: LULC maps of the Mono River basin for the years 1986, 2000, 2010, and 2020

It can be observed that cropland and savannah represent the dominant land use types within the LMR basin (Figures 15 and 16). The natural vegetation is dominated by savannah (grassland interspersed with shrubs and trees), and forest (forest administrative park, mall dense forest, and gallery forest). It was also mentioned that from 1986 to 2020, a decreasing trend of cropland and forests was observed during all periods, while savanna and settlements were increasing (Thiam et al., 2022). Croplands and forests areas declined from 1986 to 2000 with a highest loss with 46.1% and 33.3%, respectively in contrast to savanna which registered the highest gain (75.1%). During the period 2000–2010, cropland registered the largest loss (59.7%) followed by savanna (29.3%).

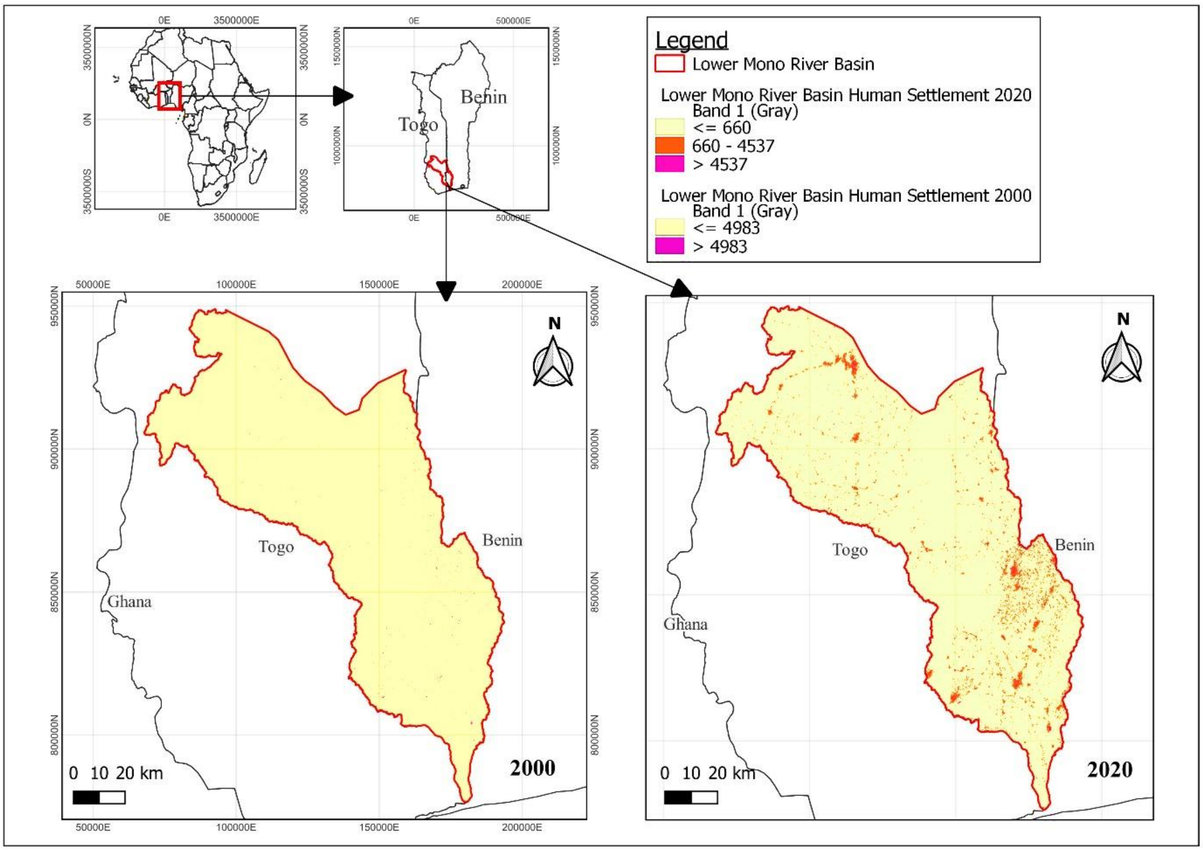
However, during this same period, we noticed an improvement of the vegetation cover; forest increased to 20.7% compared to the first period (9.6%). In the last time interval (2010–2020), the highest loss of croplands (80%) was observed compared to the previous periods. Similarly, savanna increased by 27.3%. Throughout all the periods, the water bodies and settlements recorded the lowest losses. This means that there is more and more settlement of the population in the Lower Mono River Basin.



Source:(Wetzel et al., 2022b)

Figure 16 : Land use and Land cover map of the LMR basin

Figure 17 depicts the housing land in the basin.



Source : http://ghsl.jrc.ec.europa.eu/documents/GHSL_Data_Package_2023.pdf

Figure 17: Human settlement within the LMR basin

This figure's analysis shows that the area around the river and its affluents is more populated. The occupation has evolved over time (from 2000 to 2020). According to projections, the area around the river will have a large population by 2030 (http://ghsl.jrc.ec.europa.eu/documents/GHSL_Data_Package_2023.pdf) The population will become more susceptible to flooding as a result (GIZ, 2017).

2.2.6. Vegetation

The vegetation of the basin is generally degraded. Segments of mangrove vegetation, forest reserves, gallery forests, grassy savannahs, and fallows are the vegetation types that characterize the basin. (CEDEAO, 2015). Most of the basin is covered by grassland north of the 8th parallel, and shrub or tree savannah to the south. Crops, unevenly distributed, can cover large areas locally. Forest vegetation is rare. It is concentrated along watercourses in the form of narrow forest galleries, as well as in a few small massifs. The forest is essentially dry and relatively open. Classified forests, the most extensive of which is the Fazao forest north of the Atacorian chain, are made up of fairly sparse stands (Akakpo et al., 2021).

2.2.7. Human population

The basin's population is made up of several ethnic groups. The basin's primary ethnic groups are Adja, Fon, Ewé, Kabye, Kotokoli, Anna, Tèm, Akposso, Tchamba, Xla, Peda, Tchi, Dendi, Yoruba, Bariba, Sahoué, and Katafon (CEDEAO, 2015). The survey results revealed the following ethnic groups: Ife, Ana, Ewe, Fon, Mina, Kotafon, Ouatchi, and Adja. Adja, Ouatchi, and Kotafon are the three most prevalent ethnic groupings (Figure 18 A). The different religions practiced by the populations in the basin include animism, Islam, and Christianity (Figure 18 B).

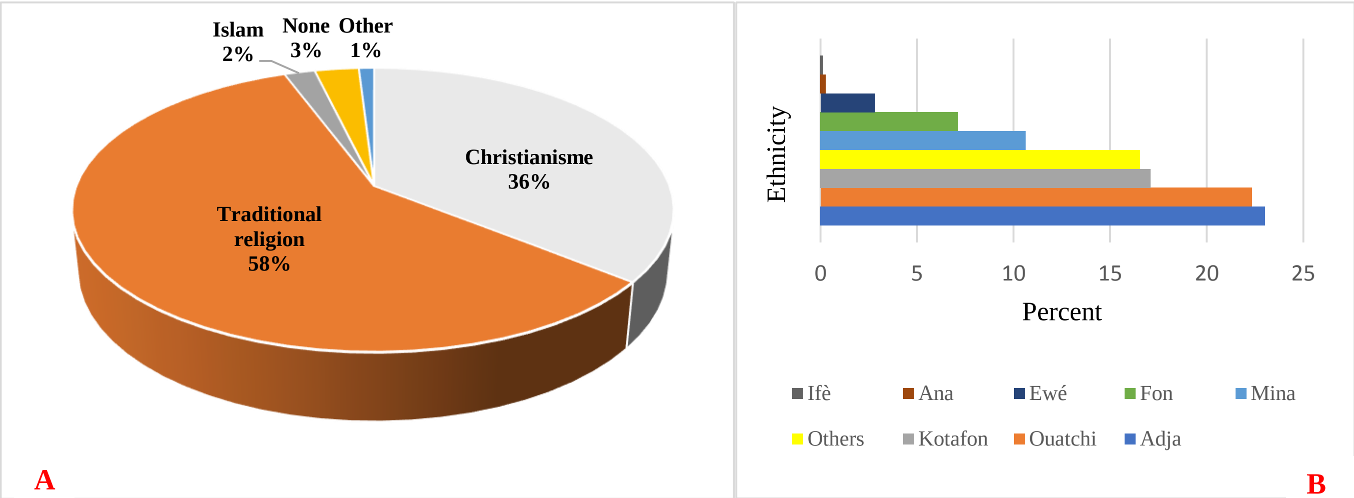


Figure 18: Religions (A) and ethnicity (B) of population

Religion and ethnicity can significantly influence flood risk management in Africa through their impact on cultural practices, social cohesion, access to resources, communication, conflict dynamics, governance, and migration patterns. To effectively address flood risks, it is essential for policymakers, humanitarian organizations, and local communities to consider these factors and work collaboratively to develop context-specific and culturally sensitive risk management strategies. For instance, regarding to cultural practices, religious beliefs and practices can affect how communities perceive and respond to natural disasters like floods. Some religious communities may attribute natural disasters to divine will or punishment, which can influence their willingness to take preventive measures or adapt to changing flood patterns. Ethnic groups often have distinct cultural practices and belief systems. These practices may include rituals or ceremonies related to natural events, which can influence how different ethnic communities view and respond to floods. Understanding and respecting these cultural aspects is vital for effective risk management. Religious communities often have strong social bonds and networks and can be used for community resilience. Religious leaders can play a critical role in mobilizing resources and guiding their congregations in times of crisis. Ethnic groups may have strong social cohesion and community ties, which can be leveraged for disaster risk reduction. These networks can be instrumental in disseminating information, organizing evacuations, and providing support during and after a flood.

2.2.8. Economic framework

- **Hydropower**

A dam has been built upstream of the LMR basin since 1987. The purpose of the dam was to generate electricity, irrigate 43,000 hectares of farmland, partially regulate flooding, and promote fishing to support the efforts of rural communities. The Nangbeto hydroelectric dam on the Mono River supplies between a quarter and a third of Benin and Togo's electricity needs. Does the construction of this dam have negative impacts on downstream populations and ecosystems? (Akakpo et al., 2021).

For the local population, the dam has led to a depletion of fish stocks, caused flooding following unexpected releases, and so on. In terms of hydrology and ecology, the dam has led to increased bank and bottom erosion, as well as an increase in the solid load. In addition, the modification of the hydrological regime through a reduction in the five-year flood but an increase in low-water flows, erosion, and bed sinking were identified (Rossi (1996)). It was therefore proposed that the various developments should be coordinated with all stakeholders, including the dam manager, to ensure sustainable management of the basin.

To develop the basin's hydroelectric potential, one (01) project for a second dam downstream of the Nangbéto dam concerns the Adjarala site, and three (03) other dam projects are being studied in the basin: Tététou, Kpéssi, and Kolokope.

- **Agriculture**

Agriculture in the Mono basin is rain-fed and subsistence farming. Agriculture remains the most important economic sector in the area, employing over 70% of the population (CEDEAO, 2015). The principal crops farmed by the communities in the basin include maize, sorghum, peanuts, beans, yams, and cassava. Trade, handicrafts, and small-scale industries are also present to support this sector (CEDEAO, 2015). The sector employs around 80% of the population of the entire Togo coast basin (Akakpo et al., 2021). Agriculture is the main source of household income. Cultivation techniques are not always environmentally friendly and do not protect natural resources (water, vegetation, soil). Irrigation is rarely used. On a national scale, the Plateaux and Centrale regions have the lowest proportion of the farming population practicing irrigation (< 5%) (Akakpo et al., 2021). Crops grown are mainly food crops (maize, beans, sorghum, groundnuts, beans, cassava, and yams) and cash crops (cocoa and coffee).

➢ **Breeding**

Livestock farming activities are characterized by poor control of zootechnical parameters by producers, and are highly exposed to epidemics; transhumance practices generate conflicts with farmers over issues of land use and access to water resources (Akakpo et al., 2021). Small-scale livestock farming (poultry, sheep, goats, pigs, etc.) is often carried out by women. Modern commercial poultry farming is developing on the outskirts of the major cities in both countries, which share the same basin (Akakpo et al., 2021; INSAE, 2004).

➢ **Fishing and river transport**

Like agriculture, fishing is also an important economic sector that keeps people busy in the Mono cross-border basin (INSAE, 2004). The rural fishing population is mainly located in the far south of the basin and, to a lesser extent, in the prefectures of Yoto and Est Mono prefectures (Akakpo et al., 2021).

➢ **Industrial and mining activities**

The following activities are found in the Mono watershed in Togo:

- Phosphates are mined in Vo Prefecture (Hahotoé) and transported by rail to the Kpémé wharf (1200 m long), where they are cleaned with borehole water. The large phosphate deposit accounted for 27% of export revenues in 2013 (versus 40% in the 80s and 90s).
- Limestone is the second most important mineral product mined in the basin. Limestone deposits are currently mined on an industrial scale at the Sika-Condji and Tabligbo quarries (around 45 km northeast of Lomé, in the Yoto prefecture) for clinker and cement production in Tabligbo and Lomé. Cimenterie de la Côte Ouest Africaine (Cimco) is a major player in the sector. Despite their significant contribution to the country's economy, the mining and extraction of phosphate and limestone ores has an impact on

the environment through uncontrolled effluent discharges and gas and dust emissions. Process wastewater discharged directly into the sea pollutes the ocean with a yellowish color linked to heavy metal toxicity. Data on private groundwater drilling and discharges are not available.

- Building materials such as sand and gravel are abundant in the basin. They are mined using mechanized or semi-mechanized techniques. These materials, which are generally destined for the construction and railroad industries, are produced by operators for on-site consumption.
- Gold production from the basin's mining sites was relatively low and exclusively artisanal. This is the case in the Agbandi area, on the Klabè Azafi site (Badou). Numerous exploration and mining licenses have recently been awarded to various companies (including Jun Hao Mining, and Panafrican Gold Corporation Togo PGCT SARL).

Numerous mining permits have been granted in the basin and are distributed throughout the area. Mining activities can pose a risk to water quantity and quality, public health and safety, and the conservation of aquatic ecosystems. The opening of mining sites is accompanied by abusive felling of trees. This massive deforestation is partly responsible for the disappearance of the vegetation cover that is so vital to the survival of the populations living in the areas exploited. The soil profile is disturbed, and erosion by run-off water reduces fertility. The Sinto sugar factory (Chinese capital), located in Anié, discharges its effluent into the Anié River. The nature of these discharges is not known. Using an integrated approach, Sinto is developing sugarcane cultivation on 2150 ha, using around 10 Mm3/year (strong intra- and inter-annual variations). The resource comes from a dam built on the Anié River, which is also used to supply the population of Anié with drinking water. Brasserie du Togo operates the Vitale bottled water plant near Aného (Anfoin), on the edge of the watershed. More hotels in the Lacs, Ogou, and Tchaoudjo prefectures have also been reported (Akakpo et al., 2021).

2.3. Data collection

Secondary data acquisition (DEM, meteorological data, hydrological discharge, and soil map), survey data collected from households, and household agriculture plot data were all part of the data collection process. For the three specified aims, all types of data were employed.

Table 3 shows the data collected and its sources, as well as the analysis methodologies used, for each specified purpose.

Table 3: Data collection and analysis

Specific Objectives (SO)	**Data**	**Analysis methods**
SO1: *Assess the socio-hydrological drivers and vulnerability of households to flood risk.* • Climatic and hydrological characterization of the basin; • Typology of households and their vulnerability to flooding; • Socio-hydrological drivers of flood risk in the Lower Mono River	Rainfall data, discharge data, socio-economic data of households, perceptions on flood risk, biophysical data	-Annual variability of climate parameters through the descriptive statistic; interannual rainfall variability, Standardized Precipitation Index (SPI); -Principal component analysis (PCA) and cluster analysis for a household's typology and characteristics; -Regression analysis to identify the drivers of flood risk; -Vulnerability and risk map
Specific Objectives (SO2): *Assess the adaptation strategies and decision-making processes of households in the light of the negative impacts of floods.* • Impact of flood on the household; • Existing adaptive strategies or behaviors developed by the household toward the flood risk; • • Decision-making of households to cope with flood risk and reduce the impact of floods.	Household perceptions of flooding and their behavior toward the risk; Socio-economic data; Biophysical data.	- Descriptive statistics for identifying the impact of flooding on households and existing adaptive strategies; -Binary and multinominal regression for household choice to adapt and choose a particular measure;
Specific Objectives (SO3): *Modeling flood hazard for exploring future impacts of different discharge scenarios and decisions making (structural measure) from households on flood extent.* • Mapping the potential area of flood risk within the catchment; • Testing effectiveness of some adaptive measures; • Evaluate the utility of some measures in reducing flood effect on population.	household decision making; Secondary data (historical climate data, hydrological and geospatial data, hazard and risk maps);	HEC-RAS - Sub basin delimitation; - Discharge estimation; - Modeling with HEC RAS by testing some structural measures.

2.3.1. Secondary data

The digital elevation models of 12 m resolution were downloaded from NASA Earth Observation Data (https://search.asf.alaska.edu/). It helps create the sub-basin within the LMR basin and generate the river network. Also, it permits defining the river's geometry and cross-sections. Manning's Roughness Coefficient values (n) were collected to characterize the Mono River and its affluent channels. These values were collected from the FishXing platform (Manning's N Values, orst.edu). Land use maps were collected from Esri's "Esri Releases New 2020 Global Land Cover Map (Esri Land Cover (arcgis.com)). Streamflow data were estimated. The DEM was also used to extract household 'houses and plot elevations. The Food and Agricultural Organization of the United States (FAO) soil portal (https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/) was used to extract the soil type of each plot.

The CLIMAFRI documentary provided a vulnerability map of the Lower Mono River watershed. The geographical data allowed us to analyze the hazards' dangers and identify the elements that were at risk. Monthly meteorological (rainfall) and daily hydrological (discharge) data were gathered for at least thirty (30) years (see appendix). The precipitation and discharge data came from the Climatic Research Unit gridded time series (CRU TS) version 4, the monthly high-resolution gridded multivariate climate dataset, and the "Direction Générale de l'Eau (DGEau)" in Benin. The information was gathered in each of the eight (08) communes or prefectures. Monthly precipitation was gathered for each commune or prefecture from 1979 to 2019.

The water discharges of the Nangbeto dam and the Athiémé outlet were obtained from the "Direction Générale de l'Eau" from 1979 to 2010. (DGEau). These data were first utilized to characterize the research area's climate and flood trends. The households' constitution, socioeconomic activities, views of climate change and flood impact, risk, and exposure were all collected. Plots of household production and productivity data (yield, crop kind, conservation strategy, and so on) were also gathered. Households' existing adapting techniques and the most effective adaptive methods in their perceptions were also collected.

Each household's plot's biophysical parameters, such as elevation, soil qualities, flood depth, and distance to the river, were collected and merged with survey data to discover the socio-hydrological causes of flooding in the LMR. Each home plot's elevation was surveyed on the ground. The NNjoin plugin in QGIS was used to calculate the distance between the residential plots and the river. Households reported the water level or flood depth in their plots in the event of flooding. The water level in each plot of houses was determined using the digital elevation model for the hazard map for the 2010 flood event. Using statistical analysis, these data assist in identifying the causes of flooding in household plots.

2.3.2. Survey data

Sampling design

Based on previous studies (Ntajal et al., 2017, Kissi et al., 2015), newspaper reports of flood-affected areas and field investigation, and a flood map from UNITAR-UNIOSAT at http://floodlist.com/africa/togo-benin-mono-river-floods-october-november-2019/, a total of eight (8) prefectures or communes (respectively 5 in Togo and 3 in Benin) were purposely selected within the LMR catchment (along the river) in relation to their flood risk level and experience. As a result, three (3) villages were chosen from each prefecture or commune, for a total of 24 villages identified (15 in Togo and 9 in Benin) (Figure 19).

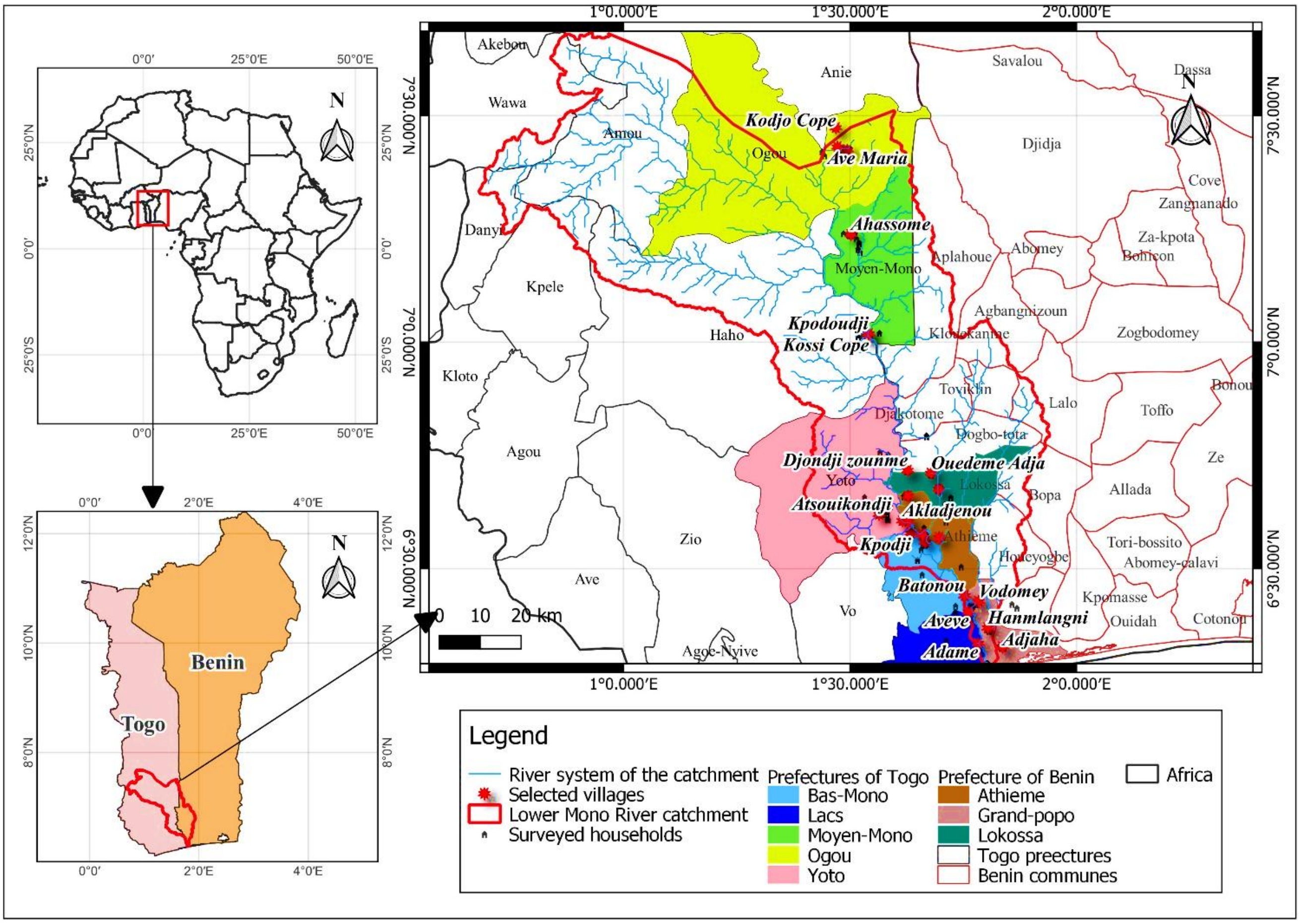


Figure 19 : Study area (Lower Mono River Basin) and villages surveyed

Based on the following criteria, these settlements were chosen to represent the entire study area: their location inside the basin; ii) their proximity to the river/Nangbeto dam; iii) the degree of flood risks; v) agriculture as the primary economic activity; and vii) the presence of some flood-related projects.

A censored proportional sample with a minimum number of 10 was used to determine the sample size. The numbers of interviewees per village and their respective communes/prefectures are presented in Table 4.

Table 4 : Number of respondents per village

Country	Commune / Prefecture	Villages	Number of respondents
Benin	Grand-Popo	Djanglamey	20
		Adjaha	33
		Vodomey	22
	Athiémé	Adjove	20
		Ahoho	34
		Sevotinou	35
	Lokossa	Doukonta	29
		Gankpatchahoue	27
		Ouedeme Adja	28
TOGO	Ogou	Ave Maria	10
		Kodjo Cope	10
		Totsagni	21
	Moyen Mono	Kossi cope	31
		Kpodoudji	31
		Ahassome	30
	Yoto	Akladjenou	31
		Athshouikondji	32
		Kpodji	30
	Bas-Mono	Agome-Glozoun	95
		Batonou	21
		Togbadji	18
	Lacs	Agbanakin	85
		Adame	23
		Aveve	28
Total			**744**

Systematic random sampling of households was used to select the households interviewed. A central point in the village was selected, and a random direction for walking was chosen (North, East, South, or West) by the interviewer. A systematic interval of selecting households was chosen from the starting point in the randomly selected direction (North, East, South, or West) and selected, for example, every 2nd house. In case the selected house is non-residential, the interviewer selects the next house opposite on the other side of the street. When the end of the village is reached in the chosen direction without having yet reached the number of households required for the village, they can repeat the process from the central point again by going back to the central point until the number of households is reached. A total of 744 households were surveyed (Some pictures of the survey are presented in the appendix). The localization of the surveyed villages and households interviewed is presented in Figure 19.

2.4. Materials and methods

2.4.1. Descriptive statistics

The analysis of the quantitative data was done and summarized in the form of tables and graphs using descriptive statistics. Descriptive statistics were then performed to identify the impact of flooding on households and existing adaptive strategies. The percentage of flood impact in different domains and the existing adaptive strategies were then extracted. The ranking of this percentage allowed us to identify the domain most affected by the flood as well as the most effective adaptive strategies from the point of view of households. Data were analyzed using Excel and the Statistical Package for Social Science software version 26 (SPSS 26).

2.4.2. Climatic and hydrological characterization of the basin

The monthly and annual averages of rainfall and discharges were computed using Excel. From the interannual rainfall variability, the Standardized Precipitation Index (SPI) was generated to monitor hydrological and climatological conditions in river basins (Guerreiro et al., 2008) and helped to detect and monitor droughts (McKee et al., 1993). The SPI can also be applied to perceive wetter than normal conditions (Guerreiro et al., 2008). Liu et al., (2013) used the SPI and found it appropriate to analyze drought and flood variation. The standardized precipitation index (SPI), which uses rainfall as the single input variable, is particularly successful in the assessment of flood hazards and its subsequent analysis in predicting flood risk (Olanrewaju & Reddy, 2022). The development of the circumstances that led to the occurrence of flood disasters is adequately explained by SPI (Olanrewaju & Reddy, 2022).

The SPI is calculated using the following equation:

$$I(i) = \frac{x_i - x_m}{\sigma}$$

Where, $I(i)$, x_i, x_m and σ are the standardized index of year i, the value for the year i, the average and the standard deviation of the time series, respectively.

From the generated SPI values, drought and flood conditions were classified as shown in Table 5 (Liu, Zhang, and Wang, 2013).

Table 5 : Drought and flood classification by SPI

Code for drought or flood classes	SPI values	Cumulative probability	Drought and flood classes
1	≤ - 2.0	0.0228	Extreme drought
2	(-2.0, -1.5]	0.0668	Severe drought
3	(-1.5, -1.0]	0.1587	Mild drought
4	(-1.0, -0.5]	0.3085	Near Normal
5	(-0.5, 0.5]	0.5000	Normal
6	(+0.5, +1.0]	0.6915	Near normal
7	(+1.0, +1.5]	0.8413	Mild flood
8	(+1.5, +2]	0.9332	Severe flood
9	≥ + 2	0.9772	Extreme flood

Source : Liu, Zhang, and Wang (2013)

Moreover, a correlation analysis was done to analyze the relation between the household perception of the flooded months and monthly rainfall to determine whether rainfall represents the main cause of flooding from the household's perspective.

2.4.3. Typology of households and their vulnerability to flood

- **Principal component analysis or factor analysis**

In order to characterize the different households in the study area, a principal component analysis (PCA) or factor analysis was performed. From the survey, 36 variables were identified, including households' socio-economic characteristics (household constitution, education, member, labor, and incomes), households' agricultural plot characteristics (plot biophysical characteristics, production, etc.), households' perceptions on flooding, and households' capacity to cope with and reduce flood risk impact, as detailed in the table list of variables. The PCA allowed for the reduction of the large set of variables by creating new ones called principal components, which represent the linear combinations of the original variables (Abdi & Williams, 2010). The first component obtained has the greatest total variance (i.e., inertia), and therefore this component will "explain" or "extract" the largest part of the inertia of the data table (Abdi & Williams, 2010)) followed by the second one, and so forth. Table 6 presents the list of variables on which the analysis was done.

Table 6: Independent variables

PLOT INDEPENDENT VARIABLES	
Household size	Plot distance to river
Household education	Household capacity risk reduction
Household incomes	Risk reduction costly
Household literate person	Adaptive strategies to agriculture
Household dependent members	Flood year rain characteristic
Membership in disaster risk management comity	Frequency of agriculture damage
Plot soil type	Severity of agriculture damage
Plot elevation	Future flood perception
Plot probability to be affected (perception of household)	Household taking risk
Plot position (slope)	Risk perception
Household participate to flood training	
Conservation technique on plot	
Multiple cropping on plot	

- **K-Mean clustering analysis (KCA) using PCA scores**

The PCA scores were used to perform KCA in order to identify the types of households in the study area and the specific factors that characterize them. The goal of KCA analysis is the partitioning of a given observation p into k groups or clusters, with each group constituting similar observations having as many common characteristics as possible (Wu 2012; Villamor 2012), while observations in different groups or clusters are as dissimilar as possible.

2.4.4. Multiple linear regression

Linear regression was computed to identify the social and biophysical drivers of flooding in the LMR basin in the household's perception. The dependent variable is the water level for the 2010 flood event. The independent variables were selected from the different factors obtained from the factor analysis. Regression analysis is used to predict the value of a variable called a dependent variable based on the values of other variables called independent variables. The multiple linear regression was performed to identify the relationship between two or more independent variables and one dependent variable as presented by the following formula (Bevans, 2020):

$$y = \beta_0 + \beta_1 X_1 + \cdots + \beta_n X_n + \varepsilon$$

With y = the predicted value of the dependent variable

β_0 = the y (water level)-intercept (value of y when all other parameters are set to 0)

$\beta_1 X_1$= the regression coefficient β_1 of the first independent variable (X1) (the effect that increasing the value of the independent variable has on the predicted (y which is the level of water) value).

… = do the same for however many independent variables you are testing

$\beta_n X_n$ = the regression coefficient of the last independent variable

ε = model error (a.k.a. how much variation there is in our estimate of y).

The factors were then used to perform multiple linear regression to identify the social factors that contribute to flooding in the LMR basin. The dependent variable is the water level for the 2010 flood event. All the analysis was performed in SPSS version 26 on the different variables, or socio-economic, plot characteristic, and biophysical data, for each household plot.

2.4.5. Modelling households' decisions

Household-making decisions were analyzed by using two cases: 1) the desire of the household **to adapt** or **not to adapt** to flood impact (*the decision to adapt to flood* sub-model); and 2) the household choice to select a particular adaptive measure (the *adaptive strategies choice*). These models were estimated using, respectively, binary and multi-nominal (M-logit) regression.

- **Binary logistic regression analysis**

Binary logistic regression analysis was used to identify the factors that influence households' ability to adapt (Villamor, 2012; Thiam, 2019) and cope with flood impacts. The model characterizing the decision to adapt to flooding is specified as follows:

$$n_{ij} = \beta_{0j} + \beta_{1j}X_{1ij} + \beta_{2j}X_{2ij} + \cdots + \beta_{pj}X_{pij}$$

Where n_{ij} is the logged odds: $log\left(\frac{\emptyset_{ij}}{1-\emptyset_{ij}}\right)$; i represents the i^{th} observation in the sample. Pi is the predicted probability of households' perception, which is coded as a dummy variable. Take the value 1 when a household has a positive (yes) response regarding the perception to adapt, and 0 when a household has a negative (no) response $(1 - \emptyset_{ij})$.

β_0 is the intercept term, and β_1, β_2, and β_k are the coefficients associated with each explanatory variable X1, X2 and Xk.

- **Multi-Nominal Logistic Model**

The M-logit was performed to model the decision of households to choose a particular type of adaptive measure. The M-logit is used to estimate the probabilities for the most effective strategies using different explanatory variables. It allows for the identification of the factors that influence households to select a specific adaptive measure. The M-logit is estimated by following this equation:

$$P_r(Y_{ik}) = P_r\,(Y_i = k|x_i; \beta_1, \beta_2, \dots, \beta_m) = \frac{\exp(\beta_{0k} + x_i\beta_k')}{1 + \sum_{j=1}^{m} \exp(\beta_{0j} + x_i\beta_j')}$$

With $k = 1, 2, \dots, m$ to predict the probability (P) of a specific adaptive measure to be chosen (Y_{ik}), x_i is a vector of the i-th observations of all explanatory variables, where β_j' is the row vector of regression coefficients in the j-th regression.

Table 7 shows the different explanatory variables used for the binary and M-logit models, where *A-decision* and *AS-choice* are respectively the dependent variables for the binary and M-logit regressions. The dependent variable in the binary model is represented by the households' responses to adapt, which is a dummy variable equal to 1 when a respondent was affirmative (yes) regarding the implementation of a measure and 0 when the respondent's answer was negative (no). The binary logistic regression was also used by Villamor (2012) and Thiam (2019) to identify the factors that influenced households to adapt. Depending on the household typology, there are different adaptive strategies based on variables for the M-logit regression (Table 7).

- **Explanatory variables**

Table 7 also shows the independent variables used for the models. The following explanatory variables were used: age, gender of household header, household size, household education level, households' header literate, household flood experience, household incomes of the household as the socio-economic characteristics; the fact that households in part of disaster risk management group as institutional variables, the households 'plot and house elevation and the soil type as environmental variables.

Table 7: Dependent and independent variables used for the model

Variables	Description	Sources	Direct linked module
Dependent variable: Household decision to adapt			
A-decision	1 when a respondent was affirmative (yes) regarding the implementation of a measure and 0 for both of the household type	Field survey and observation	Agricultural plot
Dependent variables: household decision to choose a particular adaptive measure			
AS-choice	**For Household type 1**: other commercial activities (1), drainage system (2), earth protection dike (3) and modification of agricultural calendar (4) **Household type 2**: other commercial activities (1), drainage system (2), change soil use (3), crop diversification (4) and modification of agricultural calendar (5)	Field survey and observation	Agricultural plot
Explanatory variables			
Variables	**Categories**	**Sources**	**Direct linked module**
Age			
Household size		Field survey	Households
Household participating in flood training	Yes	Field survey	Households
	No		
Percentage of cultivated area affected		Field survey	Households
Agricultural plot elevation		GIS based calculation	Agricultural plot
Agricultural plot soil type	Chromic Vertisols	GIS based calculation	Agricultural plot
	Dystric Nitosols		
	Eutric Gleysols		
	Eutric Nitosols		
	Gleyic Luvisols		
Household incomes	No response	Field survey	Households
	Less than 100 000		
	>100 000 - 200 000		
	>200 000 - 300 000		
	Less than 300 000		
	More than 300 000		
Flood experience	≤ 10 years	Field survey	Households
	11-20 years		
	21-30 years		
	> 30 years		
Financial recovery	Financial recovery (Less than 5 months)	Field survey	Households
	Financial recovery (6 to 11 months)		
	Financial recovery (1 to 2 years)		
	Financial recovery (2 years)		
Water level	Water level value from 2010	Field survey	Households
	Less than one meter		
	More than one meter		
Flood duration	≤ 15 days	Field survey	Households
	16 - 30 days		
	31-45 days		
	> 45 days		

2.4.6. Modeling flood risk and structural measures

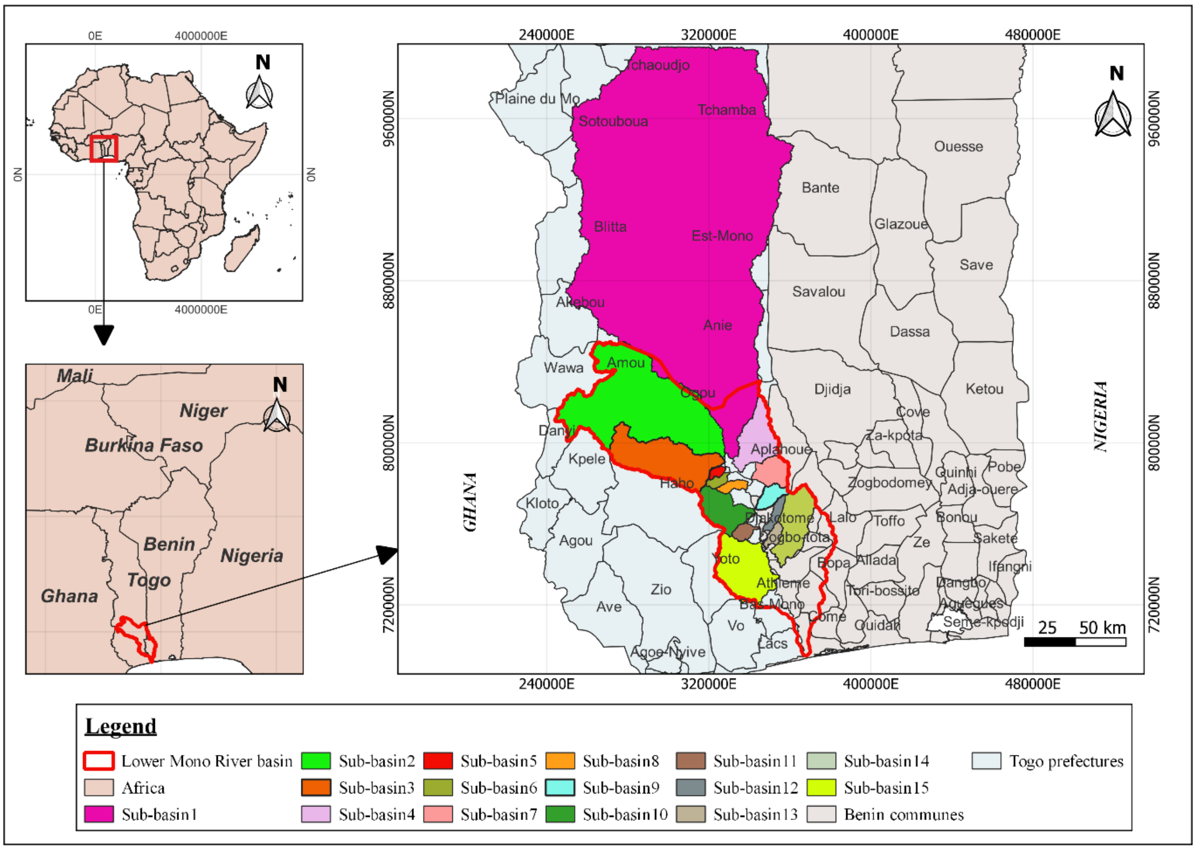
For modeling flood hazard maps and testing the utility of structural measures such as drainage systems and retention basins, different analysis methods were used.

➢ **Estimation of sub-basin flows and different return times**

Flood risk analysis was carried out for different discharge periods corresponding to 10- and 100-year return periods. For these 10- and 100-year chance events, HEC-RAS analysis is carried out to generate water surface profiles and other hydraulic details. The hydrological studies allowed us to determine and delimit the sub-basins within the Mono basin, identify their physical parameters, and then estimate the decennial and centennial floods. The estimation of these discharges was done for the following steps:

➢ **Sub-basin delineation of the study area**

The watershed delineation process is carried out to identify the stream location and basin in digital elevation by using GRASS GIS. Raster tools were used for all the steps involved in the watershed delineation process. These steps consist of computing the fill, flow accumulation, flow direction, basin, and converting the raster to a polygon file. The watershed delineation of the DEM is shown in Figure 20.



Source : http://earthexplorer.usgs.gov

Figure 20 :Sub-basins within the lower Mono River basin

Once the sub-basins were delineated, the hydro morphological parameters of the watershed were determined. The hydro morphological parameters of the watershed are a set of physiographic data obtained from physiographic features and field measurements that give a certain amount of information about the watersheds. The different parameters (Fao, 1997) of the delimited sub-basins are:

- **Surface and perimeter of the watershed**: these are obtained after the delineation of the watersheds by manipulating cartographic software (especially QGIS). The surface is expressed in km2 and the perimeter in km;
- **The Gravelius compactness coefficient**: is determined from the perimeter of the watershed and its surface. It is close to 1 for an almost circular watershed and greater than 1 when the basin is elongated. For its determination, the following formula is used:

$$K_G = \frac{P}{2\sqrt{\Pi \cdot A}} \approx 0,28\frac{P}{\sqrt{A}}$$

With: P (km) = Perimeter; A (km²) = Area

- **The global slope index:** is the index characterizing the relief of a basin;
- **The lengths of the generated watercourses:** This parameter is obtained after the characterization of the catchment area with cartographic software;
- **Runoff coefficient**: digital maps of the main soil types in the region were overlaid on the information layers in QGIS. This allows us to assess the infiltrability classes of each delineated basin and, thus, estimate their decadal runoff coefficient.

For the estimation of the runoff coefficient of the targeted watersheds, the method of evaluating the average annual runoff deficit (D) by the TURC formula (EPEL (École Polytechnique Fédérale de Lausanne), 2023) was used. Thus, the annual runoff coefficient (r) is obtained by the equation:

$$r\ (\%) = 100\ (\frac{P - D}{P})$$

D is obtained by the Turc equation as follow $D = \frac{P}{\sqrt{0.9 + \frac{P^2}{L^2}}}$s

With L = 300 + 25 T + 0.05 T3; P: average annual rainfall (mm); T: average annual temperature (°C).

- **Global slope index**: Indicator characterizing the relief of a basin. It is defined by the following formula:

$$I_g = \frac{D}{L}$$

Where, D represents the difference in elevation, expressed in meters, separating the altitudes having approximately 5% and 95% of the basin surface above them; these altitudes are determined on the hypsometric curve; L is the length of the equivalent rectangle, expressed in km; Ig is expressed as rn/km

- **Specific Differential Elevation (Ds):** The product of the overall slope index (Ig) and the square root of the basin area (S). It is expressed in meters and is independent, in theory, of the area of the basin. Different classes of relief can be distinguished according to Ds
- **P_{m10} average ten-year precipitation over the basin.**

The Table 8 shows the characteristics of the basins.

Table 8: Sub-basin characteristic

Basins	Area (Km2)	Perimeter (Km)	Icomp	L	D	Ig(m/km)	Ds(m)	PM (%)	P10	A	Pm10
Basin 1	14645.81	999.21	2.33	378.59	339.68	0.90	108.58	0.01	120	0.59	71.01
Basin 2	2478.67	504.63	2.86	202.53	650.36	3.21	159.87	0.04	120	0.67	80.08
Basin 3	926.05	274.51	2.54	106.82	178.15	1.67	50.75	0.06	120	0.71	85.11
Basin 4	444.48	109.74	1.47	33.79	92.23	2.73	57.55	0.09	120	0.74	88.86
Basin 5	35.05	42.55	2.03	15.36	63.05	4.11	24.31	0.38	120	0.85	101.83
Basin 6	51.30	37.35	1.47	11.52	76.43	6.64	47.54	0.30	150	0.83	124.86
Basin 7	207.63	101.44	1.99	36.31	92.98	2.56	36.90	0.14	150	0.77	115.94
Basin 8	66.03	40.05	1.39	11.90	77.56	6.52	52.98	0.26	150	0.82	123.25
Basin 9	115.13	80.02	2.10	29.28	141.05	4.82	51.69	0.19	150	0.80	119.70
Basin 10	363.85	150.89	2.23	56.37	81.19	1.44	27.47	0.10	150	0.75	112.35
Basin 11	70.81	61.17	2.05	22.17	79.61	3.59	30.21	0.25	150	0.82	122.80
Basin 12	75.23	80.46	2.62	31.56	161.17	5.11	44.30	0.25	150	0.82	122.42
Basin 13	69.03	40.15	1.36	11.77	115.55	9.82	81.59	0.26	150	0.82	122.97
Basin 14	474.73	109.61	1.42	33.02	181.17	5.49	119.56	0.09	150	0.74	110.66
Basin 15	734.47	131.45	1.37	38.62	95.76	2.48	67.19	0.07	150	0.72	107.87

- **Determination of the decennial and centennial return flow**

Conventional methods, ORSTOM (the French Institute of Scientific Research for Development in cooperation)) were used to determine the decennial and centennial return discharge project floods at the outlet of an ungauged sub-basin within the catchment of LMR (Fao, 1997). The updated and revised method, published in 1996, applies to catchments between the annual isohyets of 150–200 and 1,200 mm, with areas between 0.2 or 1-2 km^2 and 1,500 or 2,000 km^2(Fao, 1997). The peak flow corresponding to the surface runoff of the decennial flood is defined by the relation:

$$\boldsymbol{Qr_{10} = A.P_{10}.Kr_{10}.\alpha_{10}.S/Tb_{10}}$$

With: A: The coefficient of abatement: $\boldsymbol{P_{10}}$: **t**he daily 10-year rainfall; $\boldsymbol{Kr_{10}}$: the runoff coefficient corresponding to the ten-year flood; $\boldsymbol{\alpha_{10}}$: the peak coefficient corresponding to the 10-year flood; S: The area of the watershed; $\boldsymbol{Tb_{10}}$: The base time corresponds to the 10-year flood. These different parameters are determined using abacuses and formulas (FAO, 1997). The coefficient of passage from the 10-year flood to the 100-year flood is determined using the GRADEX method (Fao, 1997). The 100-year flow return period (**Q_{100}**) was obtained by the following formula:

$$Q_{100} = C \times Q_{10}$$

$$\text{With } C = 1 + \frac{P_{100} - P_{10}}{P_{10}} \times \frac{(T_b/24)^{0.12}}{K_{r10}}$$

P_{10}: is the daily precipitation corresponding to a return period of 10 years;

P_{100}: is the daily precipitation corresponding to a 100-year return period;

T_b: is the base time in hours;

K_{r10}: is the runoff coefficient for the 10-year flood (expressed as a fraction, not as a not a percentage);

C is a grossing up coefficient greater than 1.

The Table 9 presents the discharge of the sub-basins for 10 and 100 years return periods.

Table 9: Estimation of discharge for 10- and 100-year return period

Sub-basins	Kr10(%)	Vr10	Tb(heure)	Alpha	Qm10(m3/s)	Coeff	Q10	C	Q100
Basin 1	16.2	168550882.4	308.0	2.6	395.2	1.1	434.7	4.2	1819.3
Basin 2	20.5	36069630.4	93.0	2.6	280.1	1.1	308.1	3.2	980.2
Basin 3	17.9	11745996.5	80.1	2.6	105.9	1.1	116.5	3.5	403.0
Basin 4	17.1	6336701.3	55.7	2.6	82.1	1.1	90.4	3.5	312.8
Basin 5	23.2	578347.8	21.3	2.6	19.6	1.1	20.6	2.6	53.9
Basin 6	26.6	967935.9	14.8	2.6	47.1	1.1	49.4	2.3	116.2
Basin 7	18.5	2725913.3	44.6	2.6	44.2	1.1	48.6	3.2	156.2
Basin 8	26.0	1217089.3	16.5	2.6	53.4	1.1	56.1	2.4	134.5
Basin 9	22.5	1841089.8	27.1	2.6	49.1	1.1	54.0	2.7	146.5
Basin 10	16.4	4248831.0	60.4	2.6	50.8	1.1	55.9	3.6	200.1
Basin 11	21.3	1070965.5	28.1	2.6	27.5	1.1	28.9	2.8	81.5
Basin 12	23.6	1258607.1	22.7	2.6	40.1	1.1	42.1	2.6	109.6
Basin 13	28.6	1400707.0	5.5	2.6	182.9	1.1	192.1	2.1	406.3
Basin 14	22.4	7538491.4	37.8	2.6	144.0	1.1	158.3	2.8	442.5
Basin 15	17.7	9244872.4	67.7	2.6	98.7	1.1	108.5	3.4	372.0

- **Model development:**

In HEC-RAS, the geometry contains information related to the river network and its characteristics. So, for this study, hydraulic structures, including the river lines, river banks, river flow path, cross sections, and roughness coefficient, were created and defined. This is stored in a dedicated geometry file. The geometric features were obtained by the digital elevation model and the Google hybrid map (satellite image). Figure 21 shows the geometric file developed.

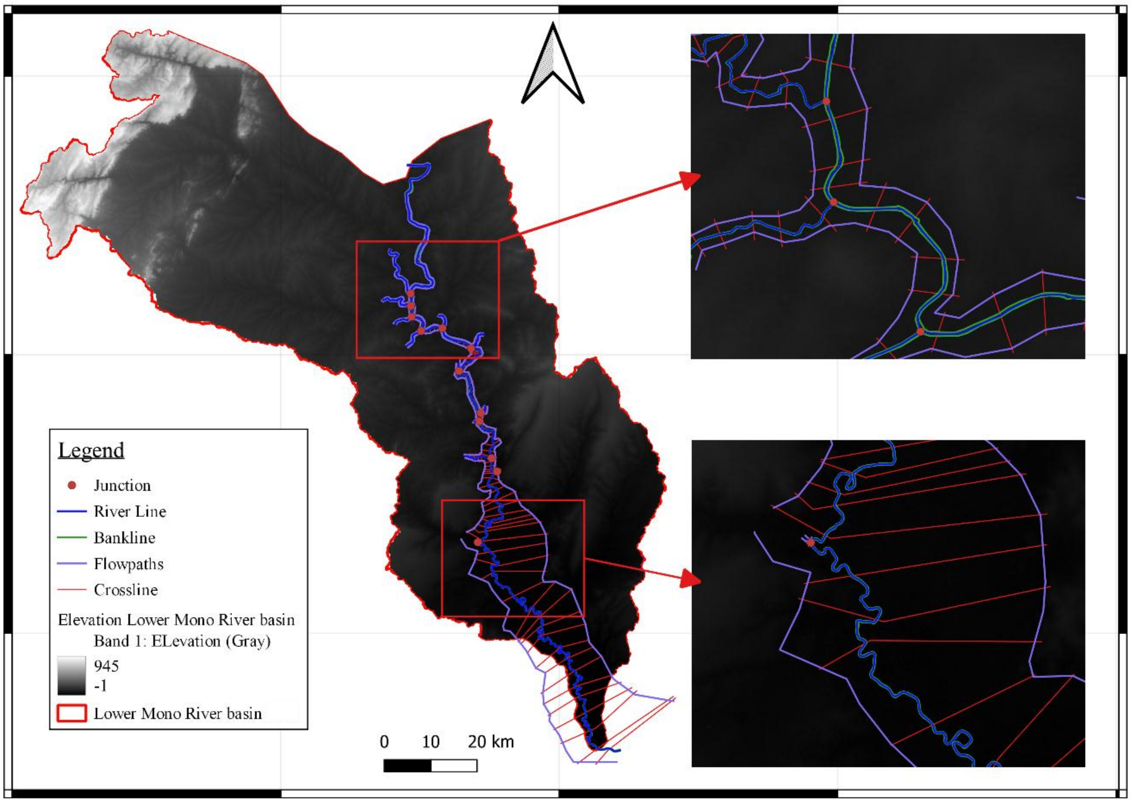


Figure 21: Geometric features

The HEC-RAS software was then used to simulate the steady-state flow analysis for different flow scenarios, such as various return periods (Q10, Q100), to generate flood hazard maps that show the extent and depth of flooding for each scenario. The estimated value of discharge for a 10- and 100-year return period was integrated into the HEC RAS for each affluent and the river. In steady-state analysis, constant boundary conditions are entered. In this study, steady-state analysis is used because it corresponds better with evaluating design flood conditions. Steady flow data, needed to perform a steady water surface profile calculation, consists of boundary conditions and peak discharge information. "*The boundary conditions are needed to determine the depth of the water both upstream and downstream.*" (AL-Hussein et al., 2022).

The model validates itself by comparing the simulated hydraulic conditions with an existing map of flood risk and field observations (a survey). The areas at risk and the flood depths and water surface for different flood scenarios (Q10 and Q100) were identified. The potential impact of floods on the study area was then analyzed. Figure 22 shows the flow chart of the model in HEC RAS.

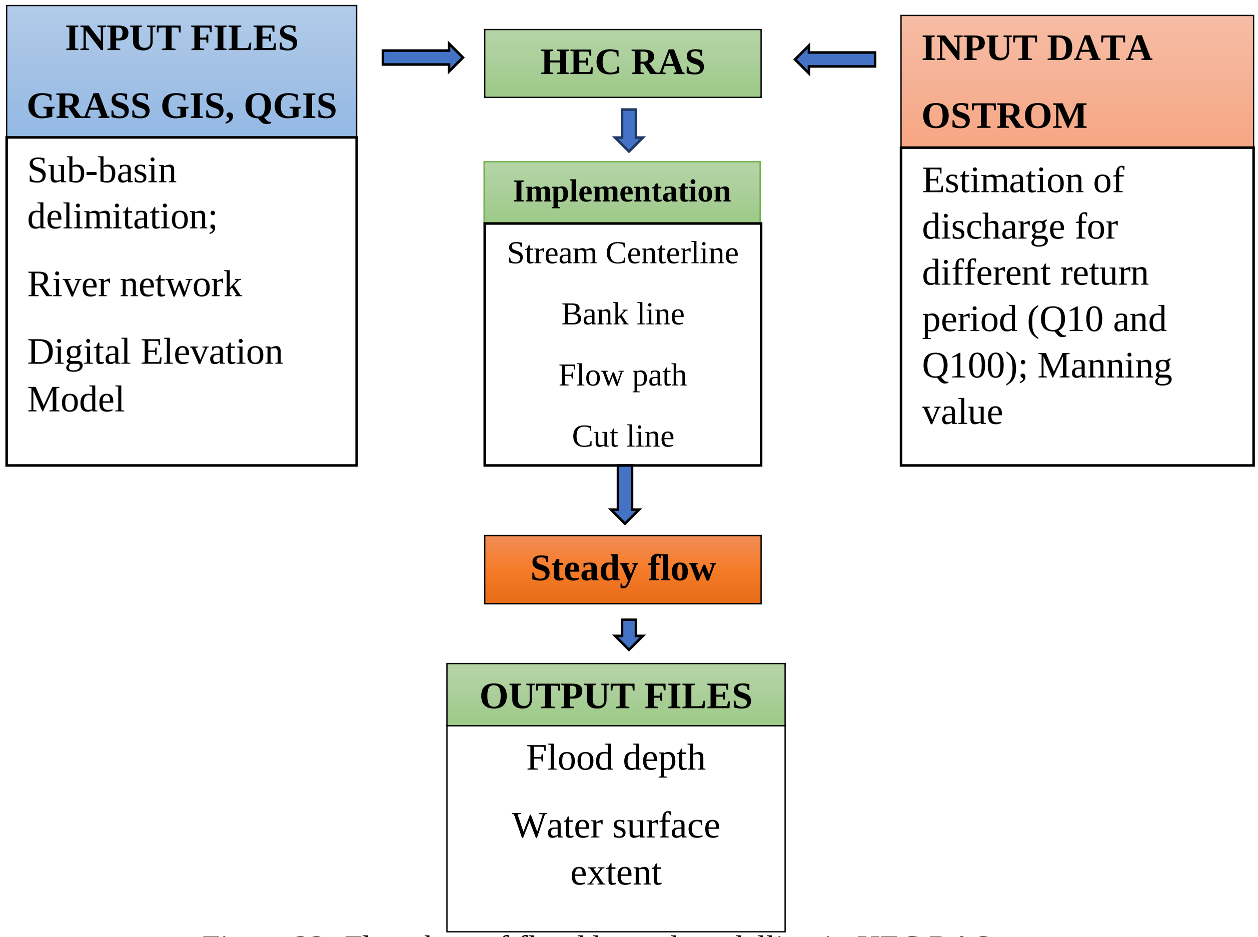


Figure 22**:** Flowchart of flood hazard modelling in HEC RAS

The model was also used to test the effectiveness of different structural measures, including drainage systems (bed clearing, embankments, and excavations) and retention basins in reducing flood risk. The effectiveness of the implementing measures was done by comparing the hydraulic conditions before and after implementing the measures. Future information regarding the modeling is provided in the appendix.

2.5. Partial conclusion

This chapter presented the study area. The Lower Mono River basin is shared between two West African countries with two types of climates, including Sudan's tropical and sub-equatorial. It is characterized by a tropical soil type. Land use and land cover are dominated by cropland and savannah. In the last year, it has been observed an increase in settlement and savannah land. This may represent the cause of the flood. In the next chapter, different concepts will be defined and presented to provide a better understanding of the flood-related topic.

The data obtained and the methodology to be employed for their analysis were provided in this chapter. Their application enables them to achieve results for each specific objective.

CHAPTER 3: Socio Hydrological Drivers and Vulnerability of Households to Flood Risk

CHAPTER 3: Socio Hydrological Drivers And Vulnerability Of Households To Flood Risk

3.1. Introduction

This chapter gives insight into the drivers of floods and takes into account the perception of households. It presents firstly the comparison of households' perception of flood hazard with historical climate and hydrological data to identify the hydrological drivers of flood. Secondly, it analyzes different socio-economic groups of households to identify social drivers which make households vulnerable to flood risk in the LMR.

3.2. Result

3.2.1. Comparison of annual historical rainfall data and household's perceptions

3.2.1.1. Historical annual rainfall

An analysis of rainfall records for the last 41 years showed obvious annual rainfall variability, particularly in the years 2019, 1979, and 2010 (Figure 23**).** The year 2019 recorded the maximum rainfall from 1360.8 to 1473.5 mm depending on the prefectures or communes, followed by the year 1979 (from 1295.5 to 1423 mm depending on the prefectures or communes), and the year 2010 (1268 to 1404.3 mm depending on the prefectures or communes).

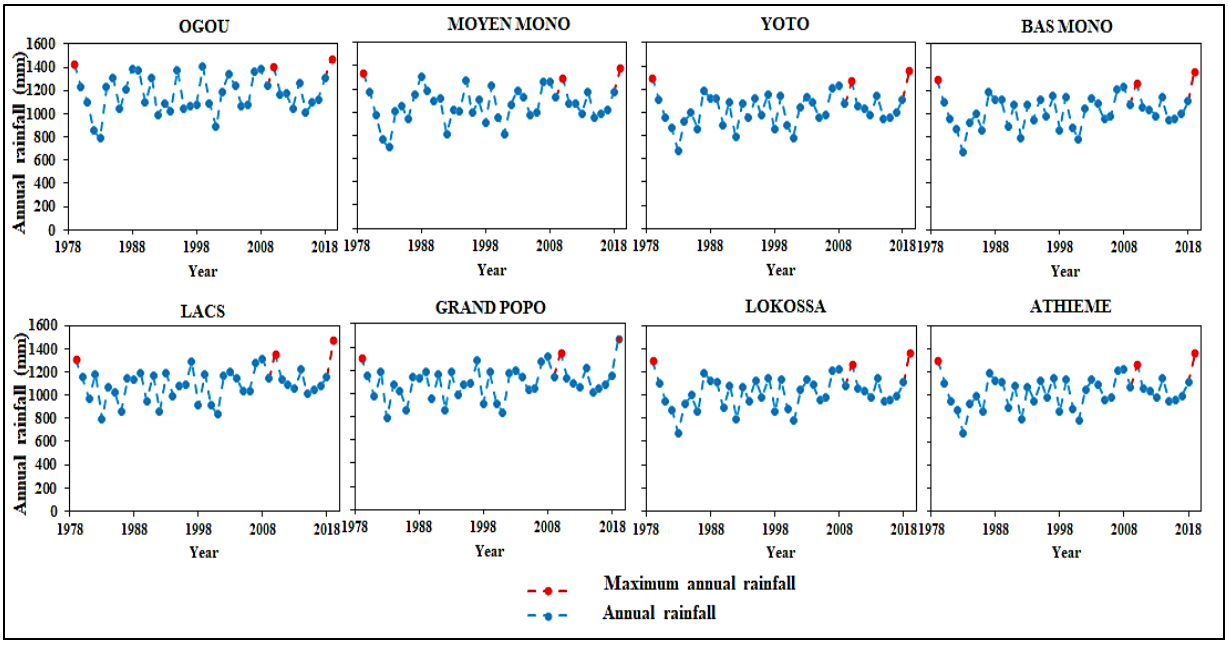


Figure 23: Annual rainfall in Lower Mono River basin (1979-2019)

The analysis of the annual rainfall anomaly reveals that the 41 years are characterized by different drought and flood classes. The majority of the wet years are classified in the categories of near-normal and mild floods in the study area. Three years, especially 1979 (1.40 to 1.80), 2010 (1.36 to 1.72), and 2019 (1.78 to 2.51) were found to have severe and extreme flooding (Figure). The high value of the anomaly was obtained in 2019 in the commune situated in the lower part of the basin. Lacs and Grand Popo recorded 2.51, while Athiémé and Yoto recorded 2.24 (Figure 24). The moving average for five years indicates variation in rainfall totals and also shows an upward trend in the last few years.

The annual rainfall analysis shows that the years 2010 and 2019 recorded high values of rainfall and are classified as severe and extreme flooding years.

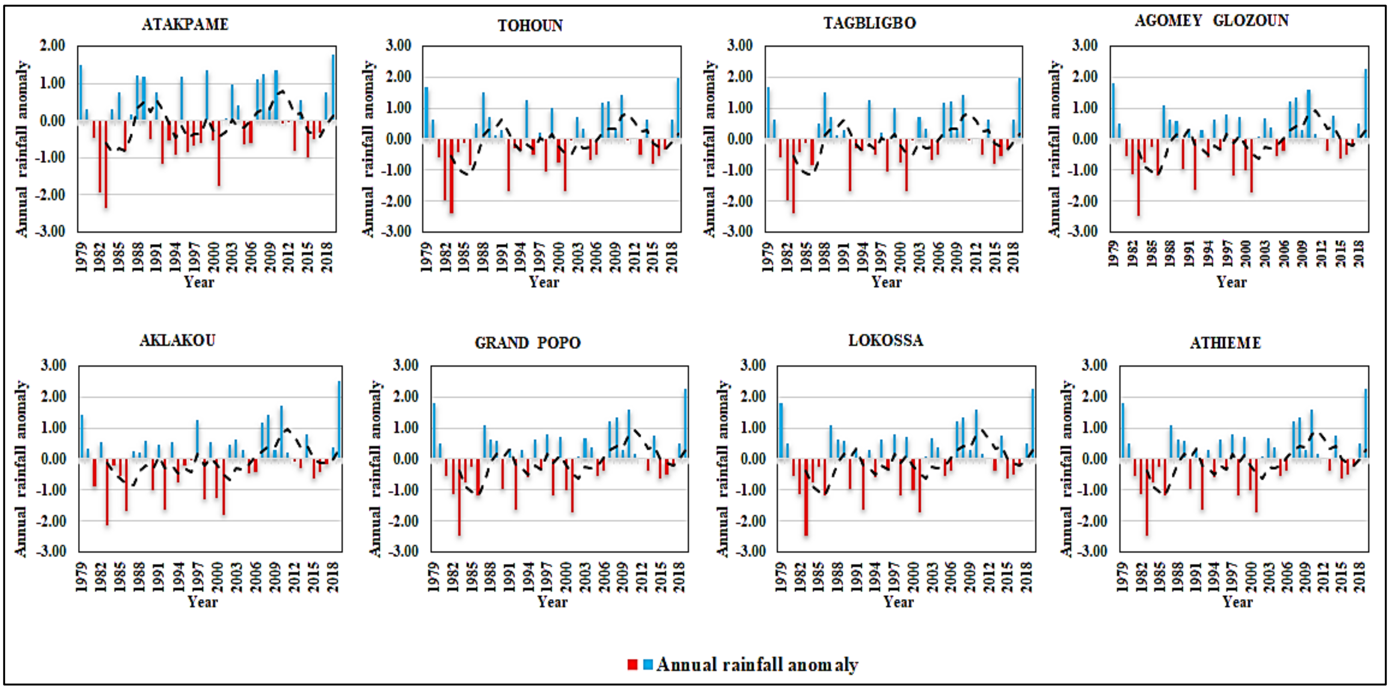


Figure 24: Annual rainfall anomaly (1979-2019)

3.2.1.2. Monthly rainfall and discharge variation

A comparison of the monthly rainfall pattern and discharge at the upper and lower regions of the basin reveals that the maximum discharge value is reached in September (Figure 25). September is the wettest month in the communes of Ogou and Moyen Mono in the upper section. In the lower section, September and October are the months with the most rainfall during the short rainy season. Rainfall may cause greater discharge, forcing the river to overflow and flood nearby homes. Yet, the month of June has the largest rainfall value of the year in the lower section.

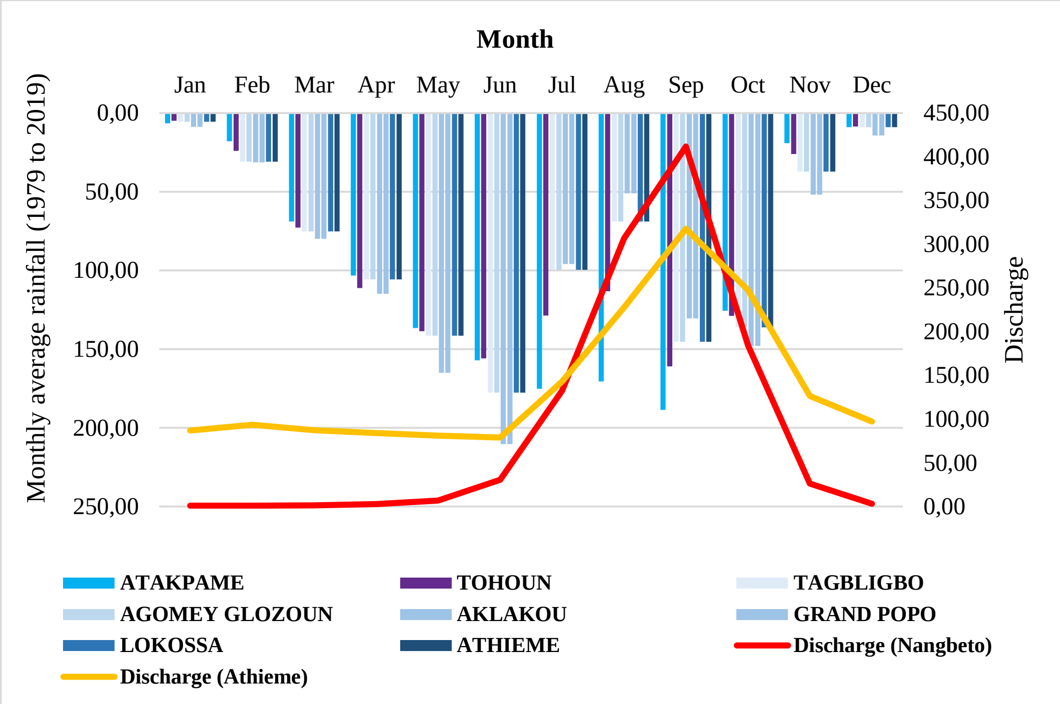
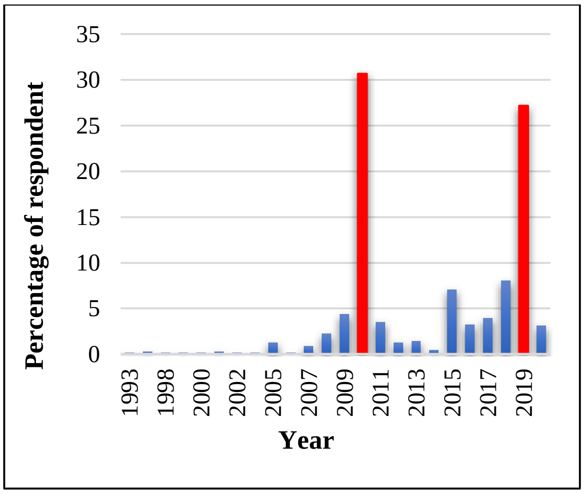


Figure 25: Monthly precipitation and discharge

The respondents considered 2010 and 2019 to be the most flood-prone years during the last 20 years. This was reported by 30% and 27% of the total respondents for 2010 and 2019, respectively (Figure 26). In terms of rainfall pattern, 85% of states reported having excess rainfall in the last 20 years (Figure 27). In contrast, 1% of respondents reported normal rainfall. Since the average age of the interviewers is between 25 and 50 years old, the 1979 extreme rainfall was not captured in the respondents' answers (Figure 26).



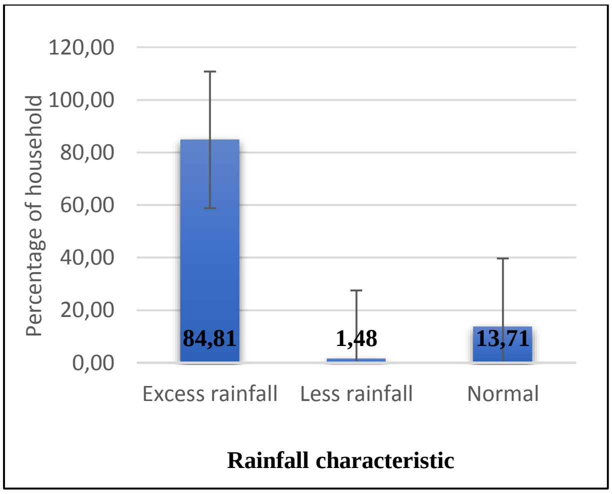


Figure 26 : Severe flood years

Figure 27: Perceived rainfall changes

The annual rainfall analysis shows that the years 2010 and 2019 recorded high values of rainfall and are classified as severe and extreme flooding years. These years corresponded to the ones characterized as the most flooded in the households' perceptions. Thus, rainfall may represent the causes of flooding in the Lower Mono River basins.

3.2.1.3. Trend of annual discharge at Athiémé and Nangbeto

Figure 28 presents the trend of annual discharge at Athiémé and Nangbeto. This figure shows that the discharge at the Athiémé outlet is greater than the one recorded at the Nangbeto outlet and they have the same trend of variation. It can be said that the communities in the Lower part of the basin may be more affected by floods than the ones in the upper part. The annual maximum discharges were recorded in 1987, 2003, 2008, and 1995, 2003, and 2009 respectively at the outlet of Athiémé and Nangbeto. These years also recorded maximum precipitation values.

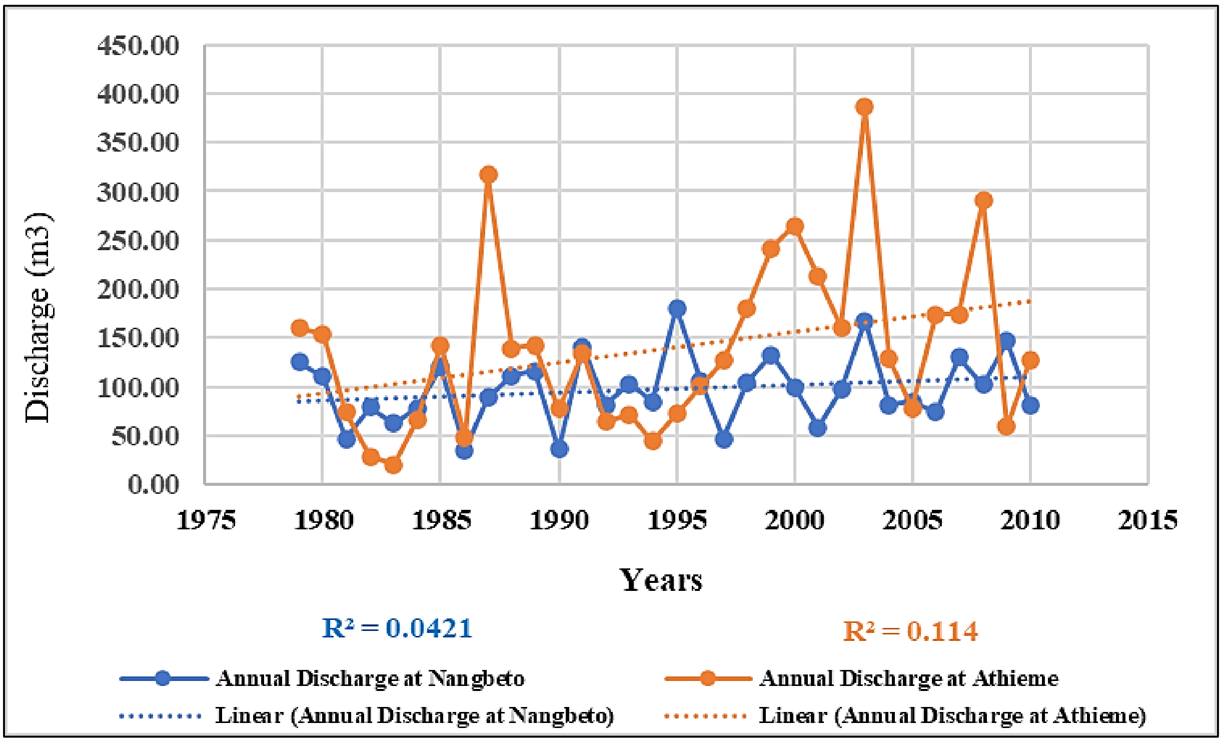


Figure 28: Evolution of annual discharge at Athiémé and Nangbeto

3.2.1.4. Relationship between monthly rainfall with the household perceptions on flooded months

The result of the correlation analysis shows a positive correlation between household perceptions of flooded months and the recorded rainfall data in specific prefectures (Ogou, Moyen Mono, and Yoto), which are located in the low part of the catchment (Figure 29). Indeed, even though there was a positive correlation between local knowledge and rainfall data in some areas, the relationship was not strongly significant (maximum R2 = 0.56). These findings indicate that rainfall induces an increase in water flow at the upper part of the catchment and represents one of the causes of flooding. However, in the lower part, rainfall seems not to be the main cause of flooding, according to the respondents' perception.

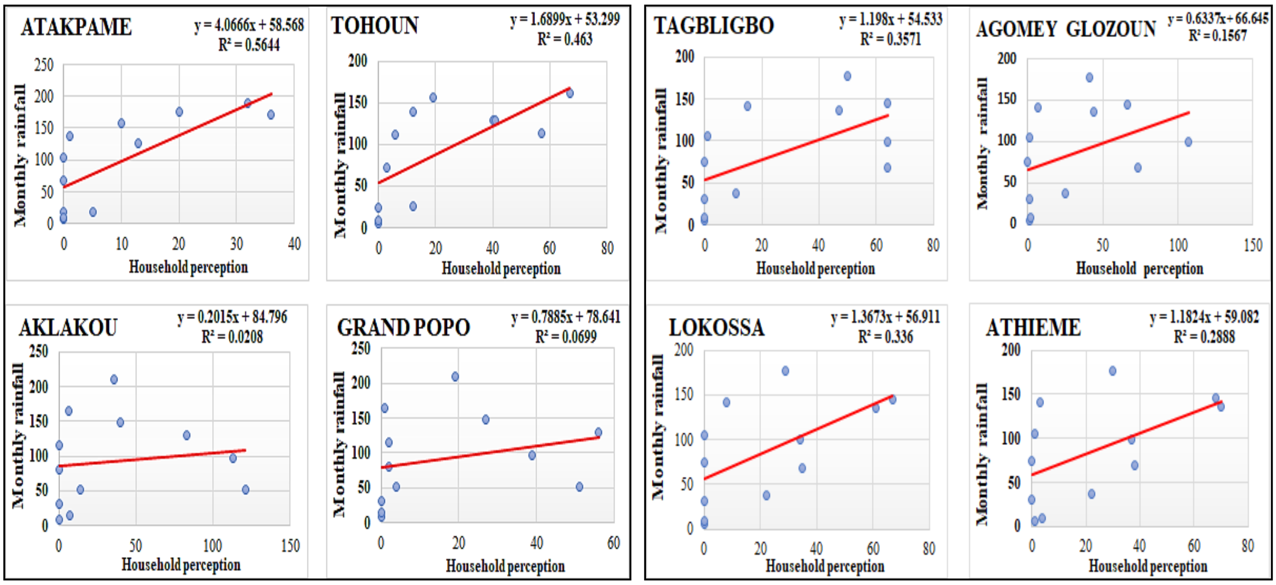


Figure 29: Correlation between monthly rainfall and household perceptions on flooded month

Tables 10 and 11 indicate the relationships between household views of flooded months, flows, and rainfall in Atakpame and Athiémé. The study of these statistics reveals that there is a positive association between the months of flooding, rainfall, and flows in the upstream of the basin. On the other side, towards the lower part of the basin, we see that the months with the most votes from households have a stronger link with the flows than the rain, which has a weaker correlation.

We can also see a high association between rainfall and outflow in the upper part the basin, although this correlation is minimal at the lower part. This confirms the findings of the previous analyses.

Table 10 : Correlation between flooded month, discharge and rainfall at the upper part of the basin

Correlations				
		ATAKPAME Perception of household on flooded month	Monthly rainfall at ATAKPAME	Discharge (Nangbeto/ ATAKPAME)
ATAKPAME Perception of households on flooded month	Pearson Correlation	1	.751**	.945**
	Sig. (2-tailed)		.005	.000
	N	12	12	12
Monthly rainfall at ATAKPAME	Pearson Correlation	.751**	1	.671*
	Sig. (2-tailed)	.005		.017
	N	12	12	12
Discharge (Nangbeto/ ATAKPAME)	Pearson Correlation	.945**	.671*	1
	Sig. (2-tailed)	.000	.017	
	N	12	12	12
**. Correlation is significant at the 0.01 level (2-tailed).				
*. Correlation is significant at the 0.05 level (2-tailed). Sig: significance				

Table 11: Correlation between flooded month, discharge and rainfall at the base valey of the basin

Correlations				
		Athieme perception of household on flooded month	Discharge (Athieme)	Monthly rainfall at ATHIEME
Athieme perception of household on flooded month	Pearson Correlation	1	.896**	.537
	Sig. (2-tailed)		.000	.072
	N	12	12	12
Discharge (Athieme)	Pearson Correlation	.896**	1	.314
	Sig. (2-tailed)	.000		.321
	N	12	12	12
Monthly rainfall at ATHIEME	Pearson Correlation	.537	.314	1
	Sig. (2-tailed)	.072	.321	
	N	12	12	12
**. Correlation is significant at the 0.01 level (2-tailed). Sig: significance				

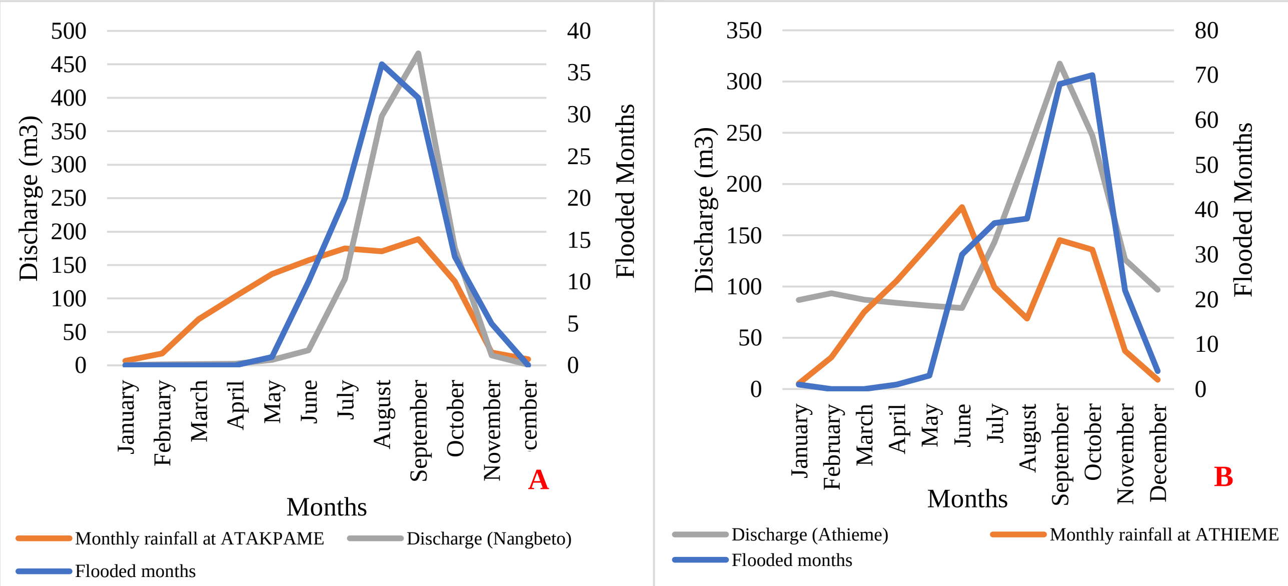


Figure 30 : Monthly dynamics of rainfall, discharge and flooded months

The analysis of the Figures 30-A et 30-B shows that rainfall provokes an increase in water flow and then floods, especially in the months of August and September in the upper part of the basin. In the lower part of the basin, it can be observed that rainfall leads to flooding in the month of June. From the months of July to August, floods are provoked by the discharge, and they increase in the months of September and October with the rainy season in this part. In the lower part of the basin, in addition to rainfall there is another factor that causes flood.

3.2.1.5. Perceived causes of floods in the LMR catchment

According to the respondents, several factors are causing flooding in their localities (Figure 31).

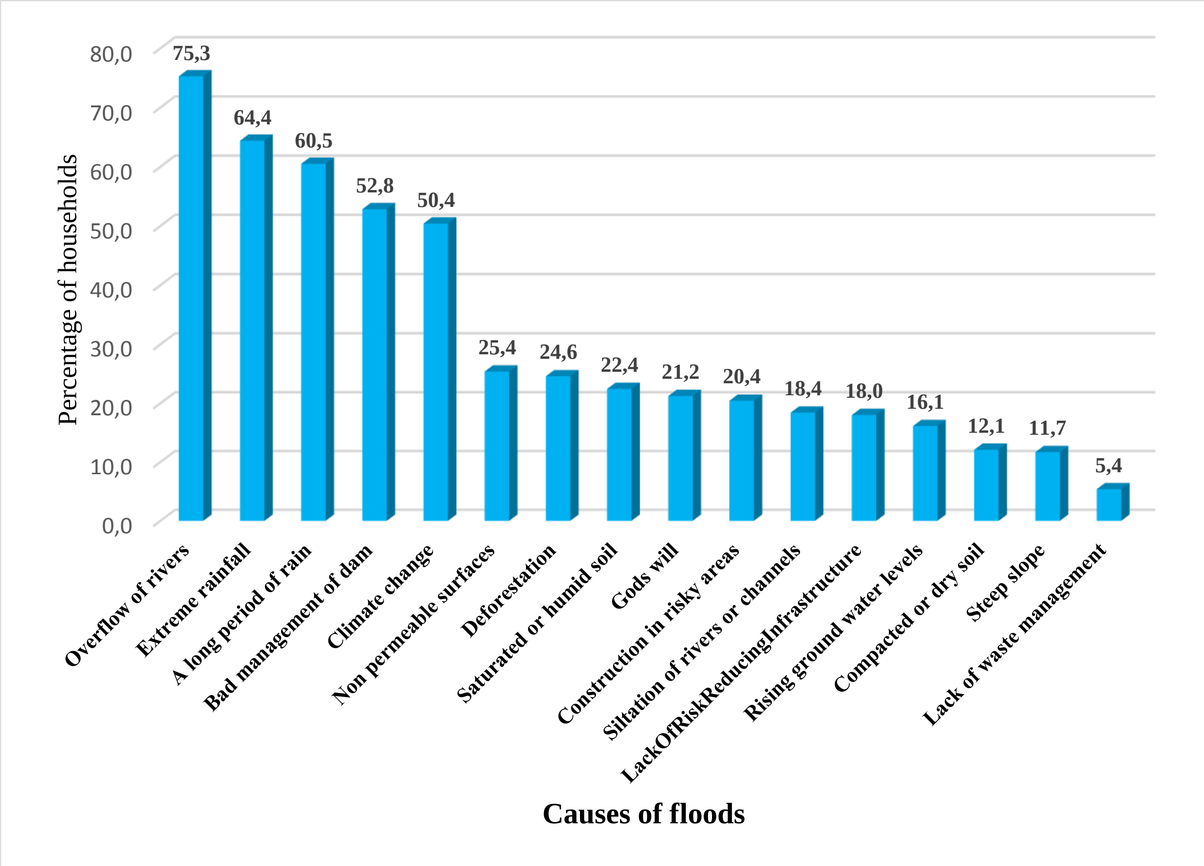


Figure 31: Household's perceptions on causes of floods in LMR catchment

Figure 31 shows that, apart from the change in rainfall, other factors were considered major causes of floods in the LMR catchment. Among the top three perceived causes are river overflow, extreme rainfall, and bad management of the dams, especially the release of water. Respondents believe that the installation of the Nangbeto dam has induced flood events in their villages every time it releases water. They feel that the Nangbeto dam construction causes floods in their villages every time it releases water. Indeed, the opening of the Nangbeto dam spillway, combined with extreme rainfall and a short rainy season, causes water to accumulate in the communes in the lower part of the basin, making them more vulnerable to this phenomenon.

3.2.2. Typological household agent groups

The principal component analysis (PCA) reveals seven (07) principal components. These components explained 65% of the independent variables' total variance (Table 12).

Table 12: Total variance explained by extracted components using Principal Component Analysis

Component	Initial Eigen values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	**3.208**	**18.869**	**18.869**	**3.208**	**18.869**	**18.869**	**2.778**	**16.342**	**16.342**
2	**2.113**	**12.429**	**31.298**	**2.113**	**12.429**	**31.298**	**1.659**	**9.761**	**26.103**
3	**1.376**	**8.096**	**39.394**	**1.376**	**8.096**	**39.394**	**1.606**	**9.444**	**35.547**
4	**1.199**	**7.054**	**46.448**	**1.199**	**7.054**	**46.448**	**1.276**	**7.508**	**43.056**
5	**1.083**	**6.369**	**52.817**	**1.083**	**6.369**	**52.817**	**1.276**	**7.507**	**50.562**
6	1.044	6.141	58.958	1.044	6.141	58.958	1.260	7.410	57.972
7	1.016	5.979	64.937	1.016	5.979	64.937	1.184	6.964	64.937
8	.930	5.468	70.405						
9	.857	5.039	75.444						
10	.789	4.640	80.084						
11	.726	4.271	84.355						
12	.617	3.630	87.984						
13	.565	3.322	91.306						
14	.517	3.041	94.347						
15	.460	2.708	97.056						
16	.375	2.206	99.261						
17	.126	.739	100.000						

Kaiser-Meyer-Olkin Measure of Sampling Adequacy = .718; Bartlett's Test of Sphericity Approx. (Chi-Square=1935.779; df=136; Sig.=.000)

The analysis of Table 12 reveals that the principal component 1 (PC1) is strongly related to the labor variable of households, the so-called labor factor, due to the variables it includes. It is determined by household size (loading = 0.913), household labor (loading = 0.886), and household dependents (loading = 0.770). This component accounts for 16.34% of the total variance of the original dataset. Capacity building and exposure factors are explained by the PC2 because they are constituted by households' membership in disaster risk management (0.822), their participation in flood training (0.677), and their plot distance to a river (-0.476). This factor accounts for 9.76% of the total variance of the original dataset. The PC3 takes into account the plot characteristics of the household. The components of this factor are plot location (0.829), perceived probability of being affected (-0.818), and plot elevation (0.370). This factor accounts for 9.44% of the total variance of the original dataset. The PC4 is referred to as "farming practices," and it accounts for 7.51 percent of the total variance. It is determined by the principal crop (0.801) and the fact that households practice multiple cropping on the plot (0.512). The education factor of households is well explained on the PC5, and it explains 7.51% of the total variance. The house characteristic of the household is taken into account by the PC3 (household exposure factor).

The PC6 and PC7 related respectively to the human capital (gender (0.749), household incomes (0.414), and risk attitude factors (risk attitude (0.769) and household risk perception (.562). The rotated component matrix was used to determine specific components that categorized the household agents (Table 13).

Table 13: Rotated component matrix (i.e., loadings) using Varimax with Kaiser Normalization method

	Principal Components						
	1 Labour factor (16.34%)	2 Capacity building and exposure (9.76%)	3 Plot character istic (9.44%)	4 Farming practicing (7.51 %)	5 Education (7.51 %)	6 Human capital (7.41%)	7 Risk attitude (6.96%)
Household size	**.913**	-.095	.118	-.096	-.020	.049	-.030
Household labor	**.886**	-.093	.113	-.130	.082	.047	-.016
Household dependents	**.770**	.080	.020	.089	-.005	-.011	-.033
Number of literate persons	.622	.090	.024	-.014	**.484**	.030	.048
Membership in disaster risk management	-.067	**.822**	-.012	.052	.045	.042	.034
Participation in flood training	.026	**.677**	-.047	.065	.099	-.065	.079
Plot distance to river	-.051	**-.476**	.127	.467	.257	-.287	.039
Plot location	.032	.000	**.829**	-.064	.015	.067	.002
Perceived probability of being affected	-.151	.076	**-.818**	.026	.082	.013	.025
Plot elevation	.333	-.345	**.370**	-.288	-.328	.007	-.308
Practicing multiple cropping on the plot	-.060	.095	-.091	**.801**	-.024	-.039	.011
Household education level	.102	.081	-.091	-.031	**.839**	.105	.030
Gender	.031	-.080	.074	-.142	.147	**.749**	.071
Principal crop in rainy season	-.008	.095	-.109	**.512**	-.173	.572	.055
Household incomes	.133	.248	.169	.027	.263	**.414**	-.397
Risk attitude (risk taker)	.043	-.043	-.039	.048	-.039	.261	**.769**
Household risk perception	-.043	.220	.037	-.001	.124	-.142	**.562**
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a. Rotation converged in 8 iterations							

3.2.3. Household typology and characteristics

The results from PCA and cluster (K-means) analysis generated two types of households, including their distinct characteristics (Table 14).

Table 14: Descriptive statistics for key categorizing variables of each classified household type

Key Variables	Household type	N	Minimum	Maximum	Mean	Std. Deviation
Household size	1	621	0	16	6.17	2.630
	2	123	5	53	15.40	7.525
	Total	744	0	53	7.70	5.179
Household labor	1	621	0	13	3.75	2.194
	2	123	1	30	9.74	5.152
	Total	744	0	30	4.74	3.651
Household dependents	1	621	0	15	4.93	2.457
	2	123	0	34	9.60	5.511
	Total	744	0	34	5.71	3.610
Number of literate persons	1	621	0	15	3.07	2.057
	2	123	0	20	4.77	4.150
	Total	744	0	20	3.35	2.601
Membership in disaster risk management (0= No; 1= Yes)	1	621	0	1	.50	.500
	2	123	0	1	.18	.385
	Total	744	0	1	.44	.497
Participation in flood training (0= No; 1= Yes)	1	621	0	1	.33	.472
	2	123	0	1	.13	.338
	Total	744	0	1	.30	.458
Plot distance to river	1	579	3	11681	1955.11	2670.937
	2	115	5	11773	2183.59	3044.250
	Total					
Plot location (1=Lowland; 2= Middle; 3= Upland)	1	448	1	3	1.12	.337
	2	93	1	3	1.54	.700
	Total	694	3	11773	1992.97	2735.290
Practicing multiple cropping on the plot (1= Intercropping; 2= Overlapping; 3= None)	1	588	1	3	2.34	.877
	2	119	1	3	1.89	.928
	Total	707	1	3	2.26	.901
Household education level (1= No education; 2= Primary; 3= Secondary; 4= University; 5= Won't say)	1	621	1	5	2.72	.750
	2	123	1	4	2.55	.851
	Total	744	1	5	2.69	.769
Gender (0= Female; 1= Male)	1	621	0	1	.59	.491
	2	123	0	1	.64	.481
	Total	744	0	1	.60	.490
Principal crop in rainy season (1= Yam; 2= Maize; 3= Cassava; 4= Rice; 5= Other)	1	586	1	5	2.46	1.049
	2	119	2	5	2.15	.633
	Total	705	1	5	2.41	.997
Household incomes (1= No response; 2= Less than 100 000; 3= > 100 000 to 200 000; 4= >200 000 to 300 000; 5= More than 300 000.)	1	621	1	5	3.57	1.157
	2	123	1	5	3.86	1.244
	Total	744	1	5	3.61	1.176
Risk attitude (risk taker) (0= No; 1= Yes; 2= Don't know)	1	621	0	2	.84	.468
	2	123	0	2	.58	.587
	Total	744	0	2	.80	.499
Household risk perception (0= No; 1= Yes)	1	621	0	1	.96	.189
	2	123	0	1	.86	.347
	Total	744	0	1	.95	.226
Perceived probability of being affected (1=Low; 2= Medium; 3=High)	1	448	1	3	2.80	.410
	2	93	1	3	2.09	.732
	Total	541	1	3	2.68	.551
Plot elevation	1	588	-8	160	18.88	25.195
	2	121	1	159	76.75	46.730
	Total	709	-8	160	28.75	37.029

N: group size, Min: minimal value of the variables and max= maximal value of variables.

Figure 32 illustrates the characteristics of each home type depending on the various variables. Household type 1 has a reduced labor factor and plot features (distance to river, location, main crop, numerous crop techniques), a high-capacity building, flood exposure, and a risk-taking attitude. Figures 33–35 are the results of a cluster (KCA) study. Each cluster type is defined by a specific value for each variable. The higher the values of the given variables, the more they are positively influenced by it, and vice versa.

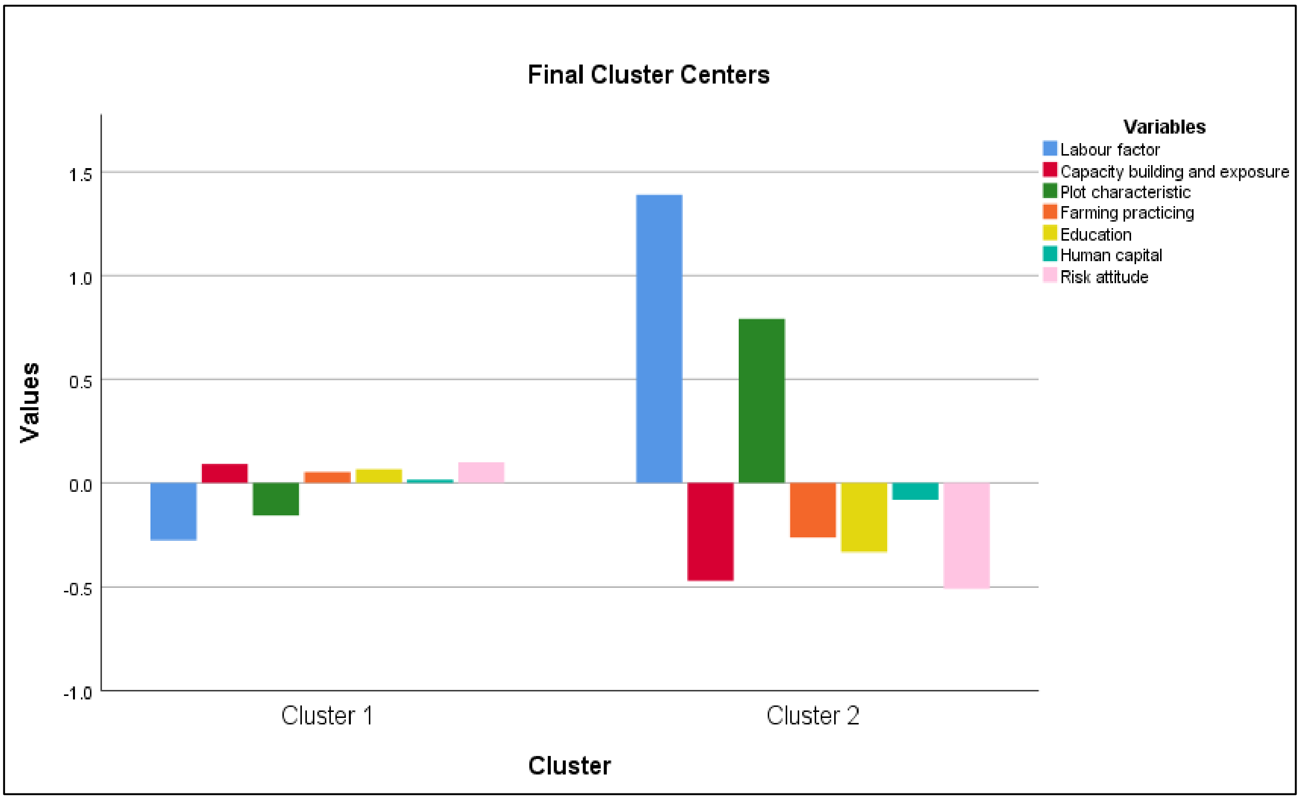


Figure 32: Characteristic of household type based on different factor

3.2.4. Household vulnerability

The vulnerability of households is described using spider diagrams, which differentiate the groups based on plot elevation, income, labor, risk awareness, and risk perception. Figures 33 and 34 describe the main characteristics of household type 1 based on plot location (mainly on lowland), low household incomes, low labor availability, and a less literate person. This type of household is more involved in disaster risk management in the community and in flood management training compared to household type 2 (H_type = 2). Household Type 1's plot is closer to the river than those of Household Type 2. In addition, their plots are located in the lowlands, making them more exposed to flooding than those of household type 2.

In contrast, household type 2 is characterized by high labor availability and income, with plots mostly located or situated in the uplands. They also have a high level of literacy but are less involved in flood preparedness activities.

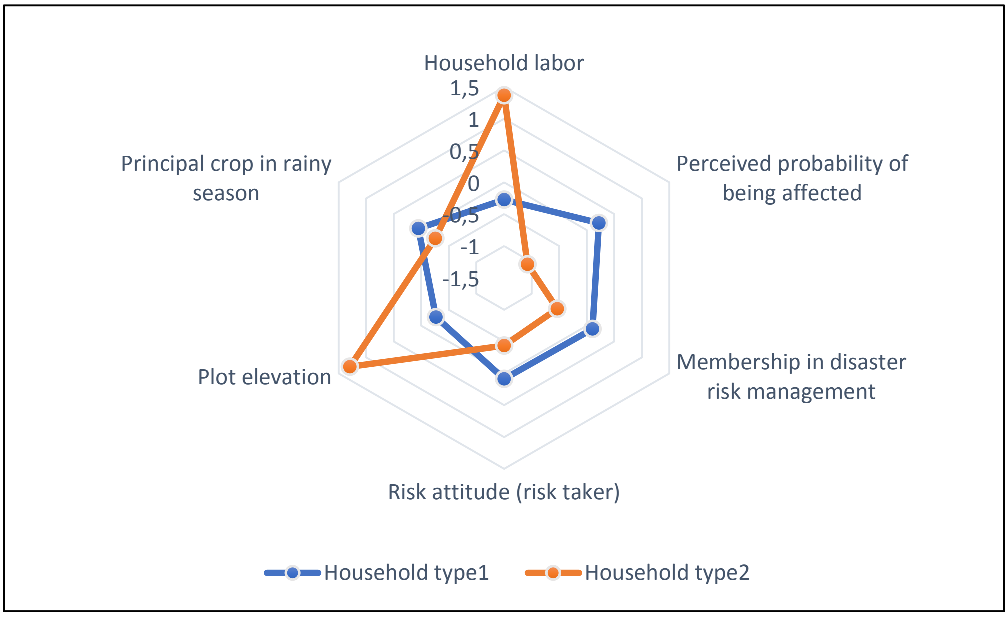


Figure 33: Differences between household types 1 and 2 in terms of labor availability, plot elevation, and perceived flood risk, membership in disaster risk management, risk attitude of household heads, and main crop during the rainy season.

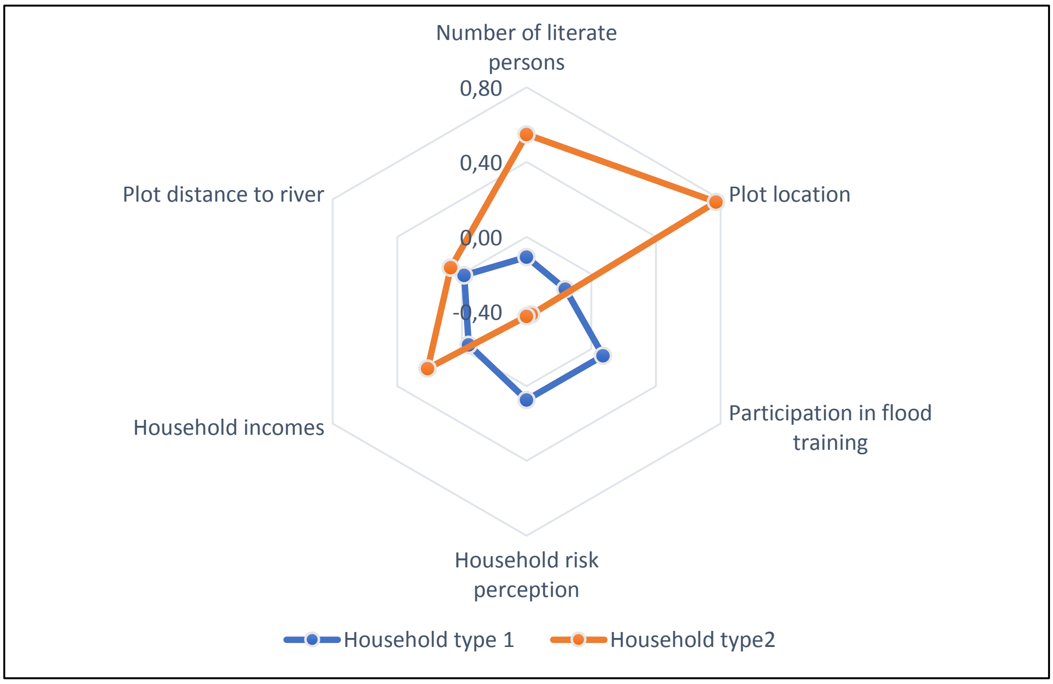


Figure 34: Difference between household types 1 and 2 in terms of literate people, household incomes, plot location, household member participation in flood training, and their assessment of flood risk.

Further, Figure 35 distinguishes household types in terms of flood and agriculture practice experience.

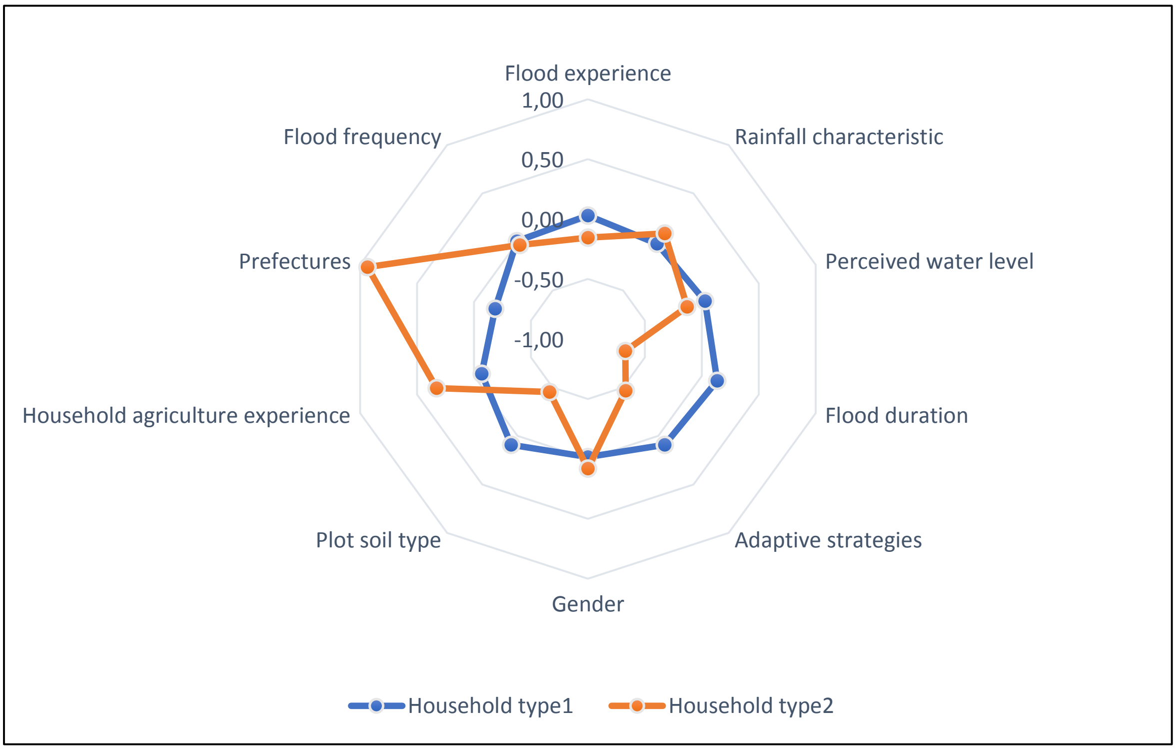


Figure 35: Differences between household types 1 and 2 in terms of prefecture flood experience, flood year rainfall characteristics, perception of their village's flood risk, agricultural experience, gender, plot soil type, prefecture, flood frequency and duration, implementation of adaptive strategies, plot level of water, and plot distance to the river.

In fact, households of type 1 have more experience with flood management than households of type 2. On the contrary, household type 2 has more experience in practicing agriculture than household type 1. In addition, Household 1 implemented more adaptive strategies than Household 2. This may also be explained by the fact that they are most affected by floods and are at higher flood risk than household type 2. Household 1 is governed by the commune or prefecture at the lower part of the basin (Athieme, Bas-Mono, Grand Popo, Lacs), and type 2 is governed more by the commune at the upper part of the basin. For this reason, household type 2 characterizes the rainfall of a flood year as extreme in contrast to household type 1. This may mean that flood causes in the prefecture at the upper part of the basin are related to rainfall and are less impacted by floods, while other factors may contribute to flooding in the lower part of the LMR basin. Also, from the point of view of household type 1, the flood duration in their village is higher than type 2. Thus, all the results in Figures 10, 11, and 12 show that household type 1 is the most vulnerable and is more likely to be most affected by floods compared to household 2.

Taking all the households' differences into account, household type 1 is renamed to "flood-prone households" due to their location mostly at the lowland, and household type 2 is renamed "better-off households".

3.2.5. Factors associated with flood

The Table 15 presents the factors associated with flood in the perception of households.

Table 15: Factors associated with flood in the perception of households

Water level on plot		B	Std. Error	Sig.	95% Confidence Interval for Exp(B)	
					Lower Bound	Upper Bound
0 to 0,5 meter	Intercept	-4.589	1.148	.000***		
	Household header age	.044	.016	.006***	1.013	1.079
	Plot distance to river (m)	.000	.000	.000***	1.000	1.000
	Plot elevation	.023	.012	.051*	1.000	1.048
	Household incomes (less than 100 000 FCFA)	-1.541	.665	.020**	.058	.788
	Household incomes (100 000-200 000 FCFA)	-.061	.537	.909	.328	2.695
	Household incomes (200 000- 300 000 FCFA)	.052	.562	.926	.350	3.169
	Household flood experience (≤ 10 year)	1.791	.833	.032**	1.171	30.699
	Household flood experience (11-20 years)	.704	.569	.217	.662	6.169
	Household flood experience (21-30 years)	.639	.546	.241	.650	5.520
	Plot soil type (Chromic Vertisols)	-2.675	1.476	.070*	.004	1.244
	Plot soil type (Dystric Nitosols)	.490	.646	.448	.460	5.791
	Plot soil type (Eutric Gleysols)	.333	.716	.642	.343	5.677
0,5 to 1 meter	Intercept	-1.990	.824	.016**		
	Household header age	.028	.012	.023**	1.004	1.054
	Plot distance to river (m)	.000	.000	.000***	1.000	1.000
	Plot elevation	.001	.012	.905	.979	1.024
	Household incomes (less than 100 000 FCFA)	-.877	.456	.054*	.170	1.016
	Household incomes (100 000-200 000 FCFA)	-.369	.424	.384	.301	1.588
	Household incomes (200 000- 300 000 FCFA)	.204	.425	.632	.533	2.818
	Household flood experience (≤ 10 year)	.849	.658	.197	.644	8.485
	Household flood experience (11-20 years)	.414	.402	.304	.688	3.327
	Household flood experience (21-30 years)	.123	.402	.759	.514	2.487
	Plot soil type (Chromic Vertisols)	-1.106	1.280	.387	.027	4.062
	Plot soil type (Dystric Nitosols)	.069	.451	.879	.443	2.593
	Plot soil type (Eutric Gleysols)	.654	.494	.185	.731	5.062
1 to 2 meters	Intercept	.435	.733	.553		
	Household header age	.000	.011	.970	.979	1.023
	Plot distance to river (m)	.000	.000	.031**	1.000	1.000
	Plot elevation	-.035	.013	.007***	.942	.991
	Household incomes (less than 100 000 FCFA)	-.666	.382	.081*	.243	1.087
	Household incomes (100 000-200 000 FCFA)	-.648	.372	.081*	.253	1.084
	Household incomes (200 000- 300 000 FCFA)	-.006	.379	.988	.473	2.088
	Household flood experience (≤ 10 year)	.617	.575	.283	.601	5.722
	Household flood experience (11-20 years)	.047	.350	.894	.528	2.080
	Household flood experience (21-30 years)	-.015	.347	.966	.500	1.944
	Plot soil type (Chromic Vertisols)	2.243	1.309	.087*	.724	122.601
	Plot soil type (Dystric Nitosols)	.836	.411	.042**	1.031	5.165
	Plot soil type (Eutric Gleysols)	1.055	.459	.022**	1.168	7.065
	Reference: water level more than 2 meters; -2 Log Likelihood: 1076.603; pvalue: .000; Nagelkerke: .223					

The multilinear regression (Table 15) reveals that household header age, plot distance to a river, plot elevation, household incomes, household flood experience, and plot soil type represent the social and biophysical factors that influenced water level in case of flooding for the flood-prone household. In fact, in the perception of households, the water level of 0 to 1 meter is found in households characterized by older headers with less experience in flood events and having their plot distant to the river and at higher altitudes than the ones with water levels higher than 2. Households with less income and who have Chromic Vertisol as their soil type are more affected by flood with higher water levels than 0 to 0.5 meters.

The households that selected 1 to 2 as the water level in case of flooding on their plot are the ones in lowland areas and have Chromic Vertisols, Dystric Nitosols, and Eutric Gleysols as soil types. Households with incomes less than 200, 000 FCFA are less affected by the range of water levels less than 2 meters than the one affected by the water level higher than 2 meters. From this analysis, a flood occurs in households that have their plot in lowland areas and is characterized by Chromic Vertisols, Dystric Nitosols, and Eutric Gleysols.

The increase of water level on households’ plots is favored by the Vertisols, Nitosols, and Gleysols and low elevation. Younger household header is more affected by higher water levels in the event of flooding. Households with less income are affected by the flood. This confirms the characteristics of flood-prone households.

3.3. Discussion

This study compares firstly household perception of flood to climate (rainfall) with hydrological data in the Mono River basin and secondly, identify the different group of socio-economic characteristics of household to identify drivers and factors that make household vulnerable to flood risk in the LMR. The comparison of households ‘perceptions flood risk to hydrological and rainfall data revealed that rainfall is the principal cause of flooding in the region. A similar finding was reported by Hannah Reid et al. (2009) in Bangladesh. Also, it appears that rainfall is the principal cause of flooding in the region, shown both by the empirical data and the household perceptions. This result corroborates with many studies and reports conducted in the study area, which have also shown how hydro metrological events, especially floods, have caused huge damage to the local population (Badou et al. 2021; IUCN/PACO, 2016; Lawin et al. 2019; Dieye, 2011). In the view of household, in the upper part, rainfall is linked to flood while in the lower part, flooding is less associated towith rainfall and other factors such as dam management contributes to flooding. In addition to extreme rainfall, other major causes of flooding such as the Nangbeto dam management was also reported by respondents. This was also mentioned by, the official press agency of the government of Benin (Agence Bénin Presse (ABP)) that "*the flooding was exacerbated by dam releases at Nangbéto and Anié in the Plateaux Region of Togo. Several small tributaries of the Mono have also flooded*" (Floodlist, 2019). Ago, et al (2005) noted in their study a significant flow in the river basin in June, with a peak in September, and maximum flows are centered in September. However, they realized that after the construction of the dam, a true onset of flow was still observed in June upstream. These flows became more significant (5% increase) in August and September and permanent at the outlet of the basin (Athiémé). In addition, Ntajal et al. (2017) reported that communities at higher elevations are less at risk than the ones at low altitudes and concluded the causes of flood risk in the lower part of the catchment do not only come from the extreme rainfall but also the result of the bad regulation of Nangbeto dam. Our study corroborates with the study of Parkoo et al. (2022), which indicated that the population in the lower part of the catchment ranked the "release of water by the Nangbeto dam" as the main cause of flooding in the target study communities. Moreover, Wetzel et al. (2022) showed that stakeholders perceived that, the flood duration, depth, velocity, and spatial extent in the LMR catchment are associated with the discharge at Nangbeto. This has been observed in a Transboundary River Basin in the Korean Peninsula showed that the release of water from the dam constructed on the river represents the principal cause of flood in the downstream part (Thu Ha, Kim, and Bae 2020). The same feeling was expressed by the households in Pakistan (Nawaz 2002). It was also reported by IFRC (2022) recently, that in 2022 river Mono overflew it bank. The sudden increase in water levels occurred when the waters in the Nagbéto dam in Togo were released and intense rains fell, leaving four (4) people dead from drowning, thirty-five (35) from water-related accidents and three (3) others went missing.

Furthermore, two categories of households were identified including the flood-prone households and the better off one. Flood-prone households are characterized by less labor factor and plot characteristics, high-capacity building, exposure to flood, and risk attitude. The flood-prone households are more involved in disaster risk management in the community and flood management training. They have their plot closer to the river, located in the lowland, which makes them more exposed to flood than those of better-off households. Also, the flood-prone households are located in the lower part and the area with high vulnerability while the better-off households are mostly in the upper part and area with lower vulnerability. The flood-prone households are more exposed and vulnerable because they are located in a low-prone area, close to the river, and characterized by low literacy person and low incomes. This result corroborated the result of Silva and Kawasaki (2020) who concluded that floods increase the economic gap between households with less (poor) and high incomes (non-poor).

3.4. Partial conclusion

Floods are one of the disasters that occur more frequently in the transboundary basin shared between Benin and Togo. Despite the plan set up by the governments of each country to cope with that phenomenon, the risk is still high, and the projections predict the situation to worsen even further. Adaptation strategies are therefore necessary to reduce the risk of flooding and improve the living conditions of communities. To identify an efficient and sustainable strategy, it is important to understand the drivers. From this chapter, climate change and bad management of Nangbeto dams represent the hydrological drivers of flooding, and the presence of households in low-lying areas and close to the river, having less income and a lower education level, are the social drivers of flooding. Adaptive strategies need to pay more attention to combining structural and non-structural measures to reduce the impact of flooding in the Lower Mono River catchment. From the findings, the perception of the local communities is important for having more insight into the real drivers of the flood. The local perception can also guide decision-makers in taking the best measures to tackle flood risk in the Mono River catchment. Therefore, the proposition of efficient adaptive strategies needs to pay more attention to local communities' participation to reduce the impact of flooding in the Lower Mono River catchment. For an efficient and effective adaptive measure, it is important to consider the most vulnerable group. In addition, a good drainage system or channel diversion for other usage can allow the best circulation of water and reduce the affected area by flood in the study area.

CHAPTER 4: RISK PERCEPTION, ADAPTATION STRATEGIES AND DECISIONS OF HOUSEHOLDS TOWARD THE NEGATIVES IMPACTS OF FLOOD

CHAPTER 4: Risk Perception, Adaptation Strategies And Decisions Of Households Toward The Negatives Impacts Of Flood

4.1. Introduction

It lacks knowledge and the ability to identify existing adaptive strategies developed by local populations to cope with flooding, as well as what motivates their choices, in the Lower Mono River. Understanding the preferences of households or communities in terms of adaptation methods to cope with floods may aid in selecting an effective one and leading stakeholders in a proactive flood response attitude. Adaptation to climatic variability and change is critical for both impact assessment (estimating likely adaptations) and policy development (to advise on or prescribe adaptations).

4.2. Result

4.2.1. Climate change-related hazards in the Lower Mono River basin

Figure 36 shows the household's perception of climate-related hazards.

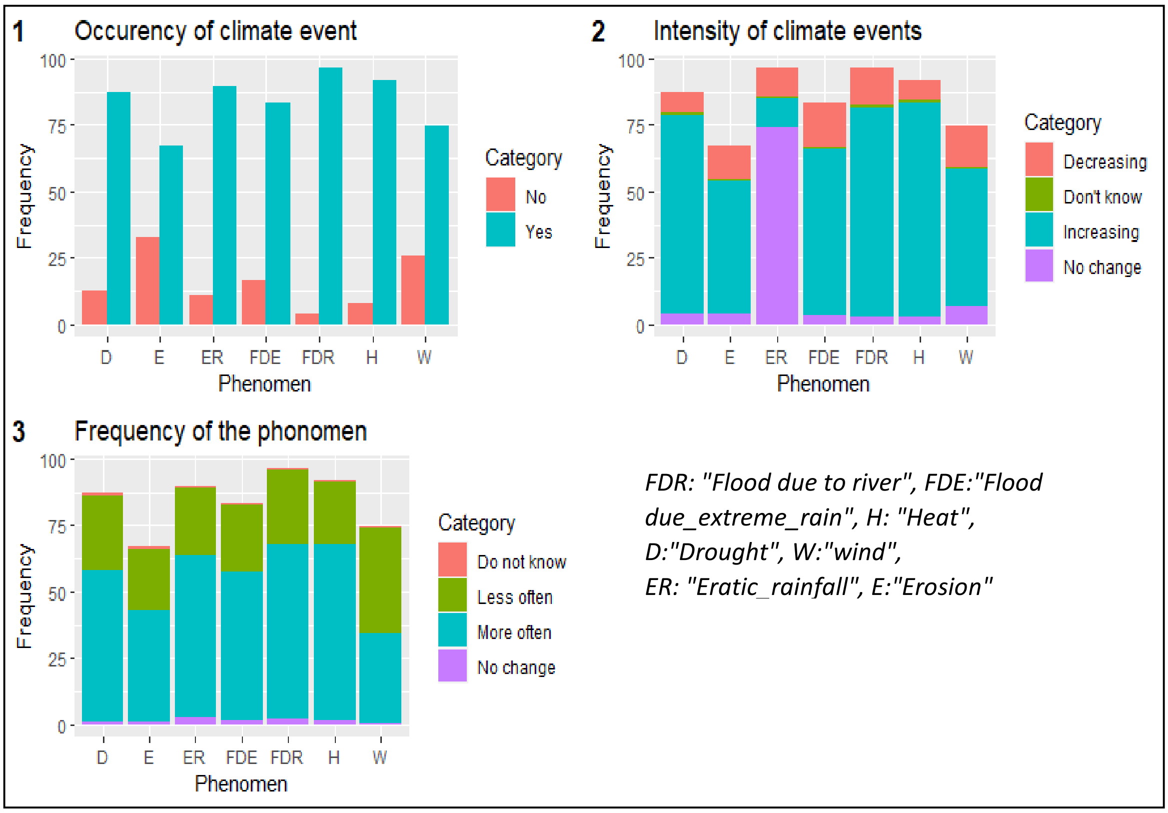


Figure 36: Climate change-related hazards in the communities

From this figure, it can be seen that, according to the respondent, all the climate-related hazards occur in the study area, especially drought, flooding (flash flooding or river flooding), erratic rainfall, and heat waves. This demonstrates that climate-related impacts occur widely in the area and people perceive major changes in them. However, a deep analysis of the different phenomena can give more insight into how they manifest in the area. So, from the point of view of the respondent, flooding (flash flooding or river flooding) represents one of the phenomena that occur more frequently, have increased in intensity, and are more frequent in the Mono River basin.

4.2.2. Flood impact on households

In the view of households, floods cause a lot of damage and have a negative impact mainly on different aspects of their lives, including agriculture, material (houses), health, and commerce. Agriculture is the domain of activity that is most impacted by flooding, followed by health, commerce, and material damage. In fact, 98.92% of the respondents affirm that the activity group that is most affected by flooding is farmers. Also, respectively, 95.70% claimed that their fields are impacted by floods; 83.20% of the interviewers responded that floods negatively impact their health; 72.98% suffered the negative impact of floods on their commerce activities; and 66.94% affirmed that they have suffered material damage due to the flood occurrence, as shown on Figure 37. The frequency of the flood impact on the household is mostly once a year, and the severity of that event is strong mostly for agriculture and material (house damage).

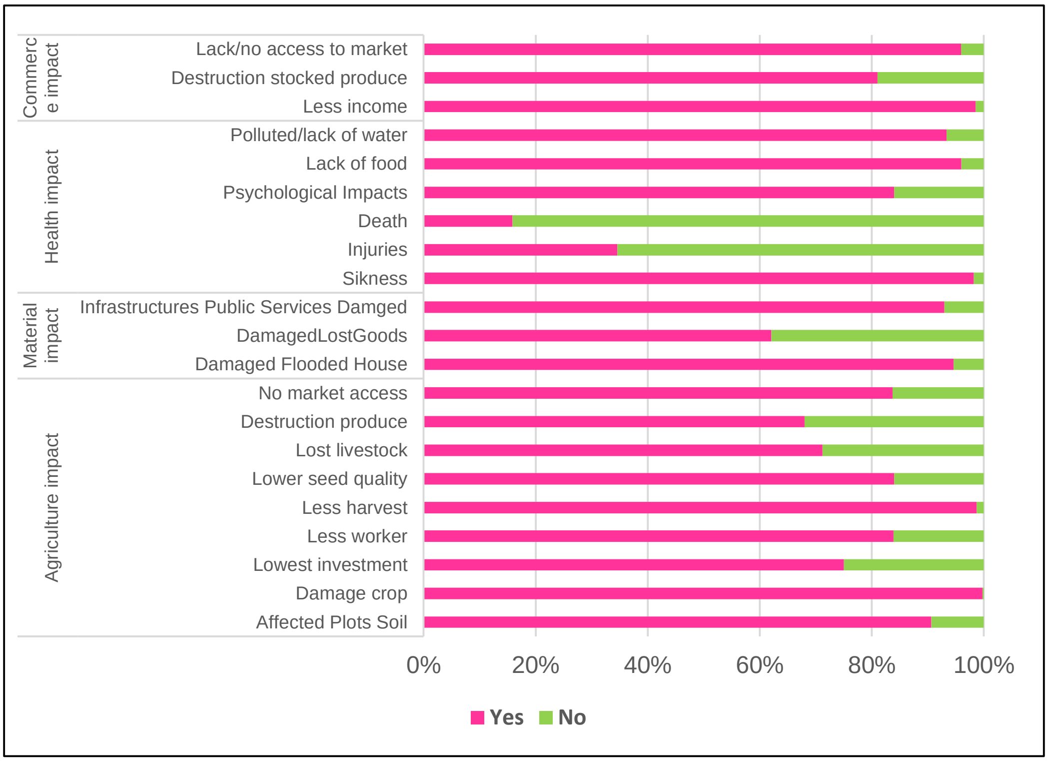


Figure 37: Flood impact on households

The principal impacts of flooding are crop damage, less harvest, less income, sickness, soil damage, lack of food, no access to markets, and damaged flooded houses (Figure 38).

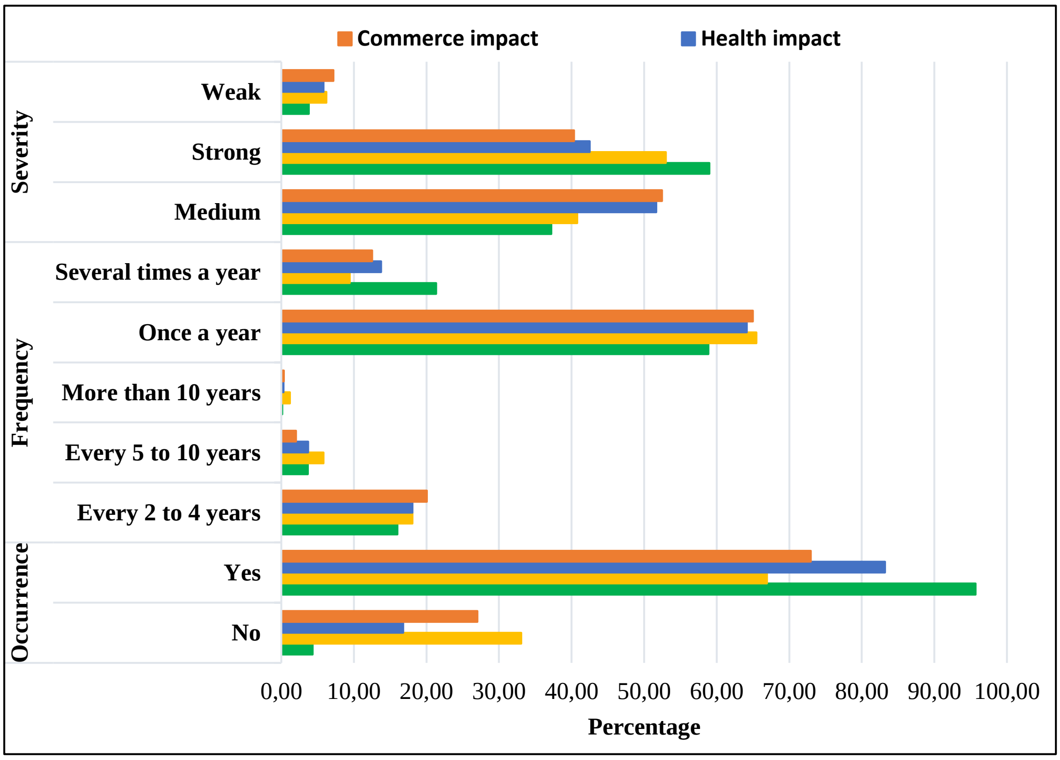


Figure 38: Effect of flood on households

Regarding the precedent result, agriculture is the principal sector impacted by flooding, with huge damage to crops (Figure 38). This can be explained by the fact that the principal activity of the household is agriculture. All those negative impacts on agriculture, including crop damage and soil affected, implicate a lower harvest, as shown in Figure 39.

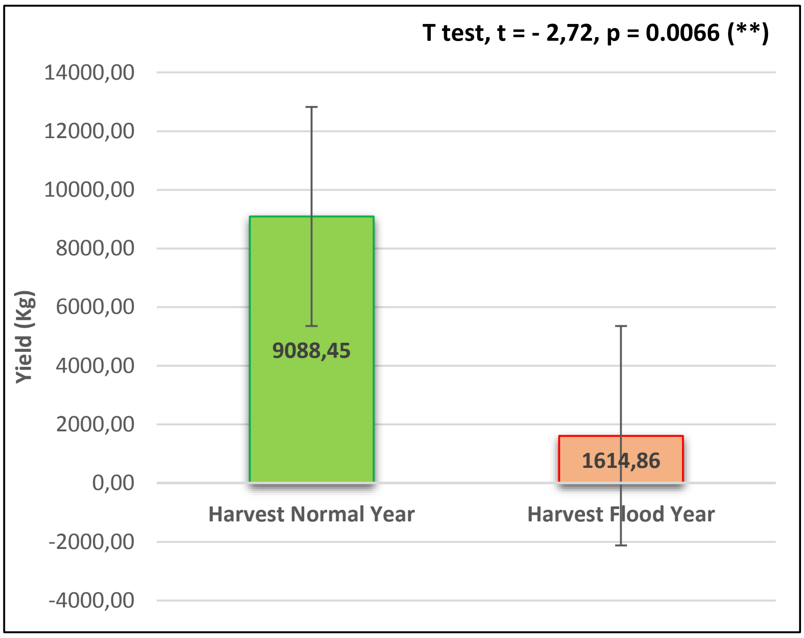


Figure 39: Comparison of crop yield in normal compare to flood year

4.2.3. Perception of household on future flood

As presented in Table 16, most of the respondents (65.86%) observed that flooding occurs once a year, and it occurs twice or less than once a year for respectively 16 % and 13% of the interviewers. As reported, 56.9% of the respondents believe that flooding in the future will increase, while 7.4% think the contrary. Also, 33.9% and 32.7% affirmed, respectively, that the impact of flooding on their households will be strong and very strong, and only 17.6% and 4% believed that it will be respectively medium and weak.

Table 16: Characteristic of future flood

		n	**Percentage (%)**
Actual frequency of flood impact	Don't know		3.22
	Less than once a year		12.63
	More often		2.15
	Once a year		65.86
	Twice a year		16.12
	Extremely severe	107	14.4

Future severity of flood on households	Not severe	37	5.0
	Severe	314	42.2
	Very severe	286	38.4
Future flooding	Decreasing	55	7.4
	Don't know	237	31.9
	Increasing	423	56.9
	No change	29	3.9
Probability household property affect in future	Don't know	76	10.2
	Medium (40 - <60%)	131	17.6
	Strong (60 - <80%)	252	33.9
	Very strong (80 - 100%)	243	32.7
	Very weak (0 - <20%)	12	1.6
	Weak (20 - <40%)	30	4.0

The impact of flooding in different sectors has led households to implement or develop different strategies to reduce the effects.

4.2.4. Adaptive Strategies implement by the type of households to cope with agriculture and material damage

To cope with flood impacts on agriculture, households implement different measures to reduce the impact of floods on agriculture. The most important adaptive strategies developed by flood-prone households (household type 1) include other commercial activities (93%), modification of the agricultural calendar (84%), crop diversification (84%), evacuation of livestock before floods (65%), and crop substitution (58%).

Regarding the better-off households (household type 2), the most adopted adaptive strategies are other commercial activities (90%), modification of the agricultural calendar (87%), crop diversification (75%), crop substitution (63%), and evacuation of livestock. It can be underlined that the measures mostly implemented by the household do not require a lot of financial means (Figure 40).

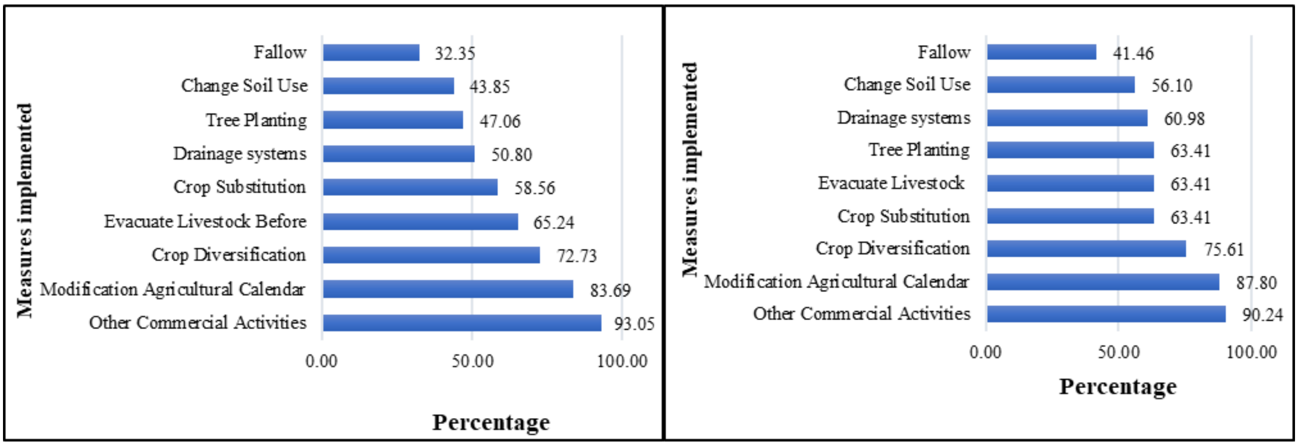


Figure 40: Strategies developed by the household type 1(A) and type 2 (B)

When asked for the most efficient adaptive strategies to cope with flood impact on agriculture, the flood-prone household identified other activities (38%), drainage systems (18%), earth dike (7%) and modification of the agricultural calendar (7%) as the most efficient, while 17% of them thought that none of the measures they implemented were efficient (Figure 41-A). The better-off households identify other commercial activities (20%), drainage systems (17%), changes in soil use (12), crop diversification (10), and modification of the agricultural calendar (10), as the most efficient adaptive strategies (Figure 41-B).

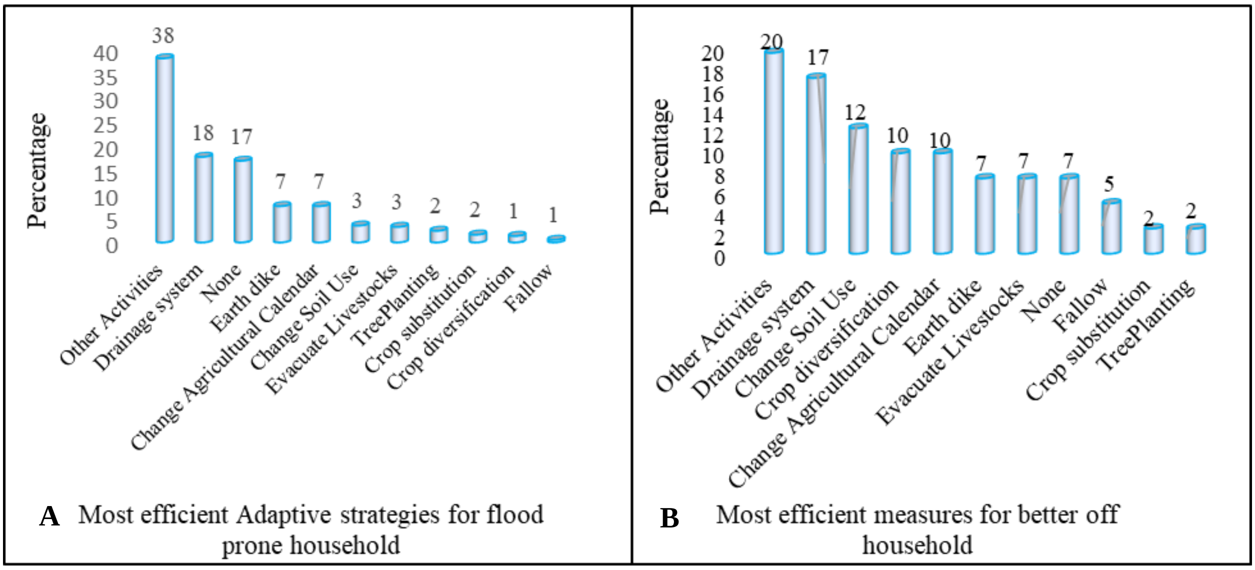


Figure 41: Most efficient adaptive strategies in the view of household

4.2.5. Household decision to adapt and select a particular adaptive measure

Households' decisions were analyzed through two models: the binary and multinominal regression, respectively, for *the decision to adapt to flooding* and the *adaptive strategies choice* sub-model. The decision to adapt to the flood sub-model calculated stochastically the probability of the households deciding to adapt or not to cope with flood impact on their agricultural plot. These preference coefficients were obtained from the results of binary regression. Tables 17 and 18 present the variables that influence the decision of households **to adapt** (yes) or **not to adapt** (no) to flood impact on their agricultural plot, respectively, for household types 1 and 2. This analysis was performed by household type. From this table, 63% of flood-prone households (i.e., 374 households) had adopted an adaptive measure to cope with flood impacts on agriculture, while 37% (i.e., 223 households) did not. Concerning better-off households, less of them had decided to adopt, 35% (i.e., 41 households), while 65% (i.e., 76 households) did not. Similarly, the adaptive measure choice sub-model represents the probability of households (whether they are better off or flood-prone) choosing a particular type of adaptive measure by using the multinominal or M-logit model. Table 19 shows the factors that influence households' decisions to implement a specific measure, such as having other activities, implementing a drainage system, protecting earth dikes, and modifying the agricultural calendar for flood-prone households. The chi-square test reveals that the empirical M-logit model is significant (p = 0.000).

Twelve and thirteen variables were used to run, respectively, *the decision to adapt to the flooding* sub-model and *adaptive strategies choice* sub-model. Concerning the first model, among the variables, six and five were found significantly related to the choice to adopt in each type of household (p 0.05 and p 0.01, respectively) as follows: household size (-), household participating in flood training (-), household farming experience (-), household flood experience (+), flood duration (-), agricultural plot elevation (-), and percentage of cultivated area affected (+) for flood-prone households; household income (+), household participating in flood training (-), water level on the plot (-), and plot soil type (-) for better-off households.

Regarding the flood-prone household, the negative significant coefficient of the household size shows that households with more members adapt less than those with fewer members. Participating in flood training influenced negatively their choice to adapt. This means that without this training, households are aware and conscious of the occurrence of floods, but a lack of financial means can cause them to not act regarding flood risk. Households with less farming experience (less than 10 years) adapt less to reduce flood impact, while those with less flood experience (less than 10 years) adapt more. A short duration of flooding (> 15 days) and a long duration (31 to 45 days) influenced negatively the adaptation of households. This suggests that households do not adapt when flooding occurs, and water already reaches a certain level on their plots. The coefficient of agricultural plot elevation was negatively significant, which implies that the lower the plot is in the elevation, the higher the probability of flood-prone households adopting adaptive measure. Furthermore, the higher the percentage of their crop lost due to flooding, the more motivated they are to adapt. The same observation is made for the better-off household regarding household participation in flood training and plot elevation. In addition, for the better-off household, the positively significant coefficient of household incomes (less than 100,000) with the option of adopting an adaptive measure shows its positive influence on households to adapt. This means that better-off households with less income are the most impacted by flooding. The coefficient of agricultural plot elevation was negatively significant, which implies that the lower the plots' elevation is, the higher the probability of flood-prone households adapting. Also, the agricultural soil type Chromic vertisol positively influenced the household choice to adapt. The more the water level on the plot increases, the less they adapt. This means that when the water level is higher on a given plot, the household deos not install a measure on it. Better-off households with lower incomes are experiencing more flooding. From this analysis, the exposure of households combined with the impact of previous flood events on flood-prone households is the principal factor that influences households' decisions to adopt.

Table 17: Factors influencing flood prone households to adapt

Variables	B	S.E.	Wald	Sig.	Exp(B)
Age	-.024	.018	1.689	.194	.976
HH size	-.152	.070	4.730	.030**	.859
HH participating in flood training (Yes)	-.600	.355	2.860	.091*	.549
HH incomes (Less than 100 000)	.108	.488	.049	.825	1.114
HH incomes (>100 000 – 200 000)	.036	.458	.006	.938	1.036
HH incomes ((>200 000 – 300 000)	-.401	.411	.951	.329	.670
HH farming experience (≤ 10 years)	-1.675	.716	5.479	.019**	.187
HH farming experience (11-20)	-.815	.530	2.363	.124	.443
HH farming experience (21-30)	.443	.518	.732	.392	1.558
HH flood experience (≤ 10 years)	1.229	.674	3.320	.068*	3.417
HH flood experience (11-20)	-.043	.456	.009	.924	.958
HH flood experience (21-30)	.529	.443	1.422	.233	1.697
Flood duration (≤15 days)	-1.548	.518	8.932	.003***	.213
Flood duration (16-30 days)	-.151	.447	.114	.735	.860
Flood duration (31-45 days)	-.816	.474	2.966	.085*	.442
Plot elevation	-.021	.008	6.487	.011**	.980
Water level on plot during flood event in 2010	.181	.124	2.132	.144	1.198
Plot soil type =Dystric Nitosols	-.349	.336	1.079	.299	.705
Percentage of cultivated area affected	.012	.004	9.414	.002***	1.012
Financial recovery (Less than 5 months)	.109	.487	.050	.823	1.115
Financial recovery (6 to 11 months)	.137	.464	.088	.767	1.147
Financial recovery (1 to 2 years)	-.947	.636	2.216	.137	.388
Financial recovery (2 years)	.019	1.510	.000	.990	1.019
Constant	3.560	1.418	6.304	.012**	35.177

-2 Log likelihood= 268.431; Nagelkerke R Square= .331; pvalue= .000; Df=1; Yes (N= 374 households) 63% and No (N= 223 households) 37%.

Table 18: Factors influencing better off households to adapt

	B	S.E.	Wald	Sig.	Exp(B)
HH income (Less than 100 000)	4.127	1.562	6.977	.008***	61.975
HH income (>100 000 – 200 000)	.208	.957	.047	.828	1.231
HH income ((>200 000 – 300 000)	-.226	.780	.084	.772	.798
HH participating in flood training (Yes)	-2.277	1.239	3.379	.066*	.103
Plot elevation	-.044	.019	5.472	.019**	.957
Water level on plot	-.739	.252	8.577	.003***	.478
Plot soil type =Chromic Vertisols	3.499	1.849	3.584	.058*	33.092
Constant	3.976	1.561	6.491	.011**	53.301
-2 Log likelihood= 58.691; Nagelkerke R Square= .474; pvalue= .000; Df=1; Yes (N=41 households) 35%; No (N=76 households) 65%					

On the other hand, eight variables, including household size (+), agricultural plot elevation (-), participating in flood training (+), household income (-), financial recovery (+), percentage of crop affected (+), plot soil type (-), and water level (+), were found significant when computing the probability of households choosing a particular adaptive measure concerning the flood-prone households, as shown by Table 19. The household size, financial recovery (less than 1 year), and water level influenced positively flood-prone households to have other commercial activity, while plot elevation influenced negatively households with high incomes (>200 000–300 000 FCFA) and who did not participate in flood training. Flood-prone households involved in flood training who recover financially from flood and have a water level of less than 1 meter on their agricultural plot in the lowland are more likely to implement a drainage system than those who did not participate in flood training and have Eutric Gleysol soil type on their agricultural plot.

Modification of the agricultural calendar is selected by households in flood-prone areas with high levels of water and high percentage losses of cultivated area from floods. Also, as the flood duration increases with the water level (up to less than 1 meter), more households modify their agricultural calendar. Households with high incomes (>200 000–300 000 FCFA) do not choose this measure to cope with flooding.

None of the variables was found to be significant in the decision-making of better-off households to choose an adaptive measure.

Table 19: Factors influencing households to choose the most effective measure

Adaptation most effective		B	Std. Error	Sig.	95% Confidence Interval for Exp(B)	
					Lower Bound	Upper Bound
Other Commercial Activities	Intercept	.944	2.813	.737		
	Household header age	-.006	.030	.854	.938	1.055
	Household size	.291	.127	.022**	1.043	1.717
	Plot elevation	-.072	.030	.016**	.877	.987
	Plot distance to river (m)	.000	.000	.351	1.000	1.000
	Percentage of crop area affected	.013	.013	.293	.988	1.039
	Yield in flooded year	.000	.000	.822	1.000	1.000
	HH income (Less than 100 000)	.406	1.019	.690	.204	11.064
	HH income (>100 000 – 200 000)	-.536	.676	.428	.156	2.200
	HH income ((>200 000 – 300 000)	-1.276	.697	.067*	.071	1.095
	Participating in flood training (No)	-2.024	.643	.002***	.037	.465
	Header literacy (No)	-.339	.535	.526	.249	2.035
	HH farming experience (≤ 10 years)	-.896	1.056	.396	.052	3.232
	HH farming experience (11-20)	.184	.884	.835	.213	6.803
	HH farming experience (21-30)	.487	.738	.510	.383	6.913
	Flood duration (≤15 days)	1.585	1.157	.171	.505	47.097
	Flood duration (16-30 days)	.361	.684	.597	.376	5.479
	Flood duration (31-45 days)	1.134	.801	.157	.647	14.919
	Financial recovery (Less than 5 months)	1.776	.757	.019**	1.338	26.068
	Financial recovery (6 to 11 months)	1.208	.673	.072*	.896	12.514
	Financial recovery (1 to 2 years)	-.326	1.287	.800	.058	9.001
	Financial recovery (2 years)	-16.044	5296.098	.998	.000	.[c]
	Plot soil type (Chromic vertisols)	21.437	1850.382	.991	.000	.[c]
	Plot soil type (Dystric Nitosols)	-1.622	1.336	.225	.014	2.709
	Plot soil type (Eutric Gleysols)	-2.156	1.373	.116	.008	1.708
	Plot water level (less than 1 meter)	3.690	1.160	.001***	4.121	388.901
Drainage system	Intercept	-2.967	3.324	.372		
	Household header age	.032	.034	.342	.966	1.104
	Household size	.054	.146	.711	.793	1.404
	Plot elevation	-.060	.032	.056*	.885	1.002
	Plot distance to river (m)	.000	.000	.974	1.000	1.000
	Percentage of crop area affected	.012	.015	.408	.984	1.041
	Yield in flooded year	.000	.000	.406	1.000	1.000
	HH income (Less than 100 000)	1.385	1.096	.206	.467	34.198
	HH income (>100 000 – 200 000)	-.557	.829	.501	.113	2.907
	HH income ((>200 000 – 300 000)	-1.283	.875	.142	.050	1.538
	Participating in flood training (No)	-2.283	.757	.003***	.023	.450
	Header literacy (No)	-.111	.637	.862	.257	3.121
	HH farming experience (≤ 10 years)	-.142	1.387	.918	.057	13.145
	HH farming experience (11-20)	.844	1.085	.437	.277	19.501
	HH farming experience (21-30)	.956	.917	.297	.431	15.703
	Flood duration (≤15 days)	2.027	1.310	.122	.583	98.871
	Flood duration (16-30 days)	.025	.858	.977	.191	5.511
	Flood duration (31-45 days)	1.286	.944	.173	.569	22.989
	Financial recovery (Less than 5 months)	4.722	1.279	.000***	9.160	1380.259
	Financial recovery (6 to 11 months)	2.148	1.277	.092*	.702	104.626
	Financial recovery (1 to 2 years)	3.760	1.558	.016**	2.025	911.063
	Financial recovery (2 years)	-13.063	8264.054	.999	.000	.[c]
	Plot soil type (Chromic vertisols)	3.830	2916.007	.999	.000	.[c]
	Plot soil type (Dystric Nitosols)	-1.580	1.531	.302	.010	4.138
	Plot soil type (Eutric Gleysols)	-3.010	1.599	.060*	.002	1.132
	Plot water level (more than 1 meter)	4.093	1.267	.001***	4.999	718.246

Modification of Agricultural Calendar	Intercept	-26.207	1218.384	.983		
	Household header age	.001	.039	.977	.927	1.081
	Household size	.221	.174	.203	.887	1.755
	Plot elevation	-.070	.034	.039**	.873	.997
	Plot distance to river (m)	.000	.000	.864	1.000	1.000
	Percentage of crop area affected	.064	.034	.057*	.998	1.139
	Yield in flooded year	.000	.000	.549	1.000	1.000
	HH income (Less than 100 000)	.497	1.321	.707	.123	21.890
	HH income (>100 000 – 200 000)	-.970	1.056	.358	.048	3.003
	HH income ((>200 000 – 300 000)	-1.701	1.027	.098*	.024	1.366
	Participating in flood training (No)	.397	1.026	.699	.199	11.103
	Header literacy (No)	.416	.744	.576	.353	6.522
	HH farming experience (≤ 10 years)	-.473	1.502	.753	.033	11.829
	HH farming experience (11-20)	.035	1.182	.976	.102	10.500
	HH farming experience (21-30)	-.543	1.051	.606	.074	4.562
	Flood duration (≤15 days)	4.135	1.511	.006***	3.233	1208.301
	Flood duration (16-30 days)	2.491	1.088	.022**	1.430	101.869
	Flood duration (31-45 days)	3.302	1.215	.007***	2.509	294.223
	Financial recovery (Less than 5 months)	1.707	1.182	.149	.543	55.924
	Financial recovery (6 to 11 months)	1.629	1.037	.116	.668	38.893
	Financial recovery (1 to 2 years)	.989	1.733	.568	.090	80.323
	Plot soil type (Chromic vertisols)	36.726	2215.480	.987	.000	.[c]
	Plot soil type (Dystric Nitosols)	15.379	1218.376	.990	.000	.[c]
	Plot soil type (Eutric Gleysols)	13.636	1218.376	.991	.000	.[c]
	Plot water level (more than 1 meter)	5.224	1.269	.000***	15.443	2234.459
	Likelihood Ratio Tests: 208.441; Nagelkerke: .660; pvalue= .000; Df=1; Other Commercial Activities (106): 47.3%; Drainage system (44): 19.6%; None (49): 21.9%; Modification of agricultural calendar (25):11.2%					

Table 20: Factors affecting the percentage of agricultural loss

Water levels influence positively agricultural loss while agricultural plot elevation influences it negatively.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	76.413	4.609		16.579	.000***
	Agricultural plot elevation	-.099	.049	-.105	-2.018	.044**
	Plot distance to river	.038	.033	.057	1.129	.259
	Plot water level (0,5 to 1 meter)	10.675	4.723	.192	2.260	.024**
	Plot water level (More than one meter)	14.315	4.304	.283	3.326	.001***
	Agricultural plot soil type (Dystric Nitosols)	4.789	2.466	.100	1.942	.053
Dependent Variable: Percentage of agricultural loss Sig.: .000; Sum of Squares: 13599.416; F: 5.035						

4.2.6. Government actions within the LMR basin in the perception of households

The governments in both countries are taking various measures to assist homes in dealing with flooding. Figure 42 shows that 50% of respondents believed the government has taken both proactive and reactive actions to decrease the impact of flooding. Figure 42 depicts the various government initiatives and their utility from the perspective of households.

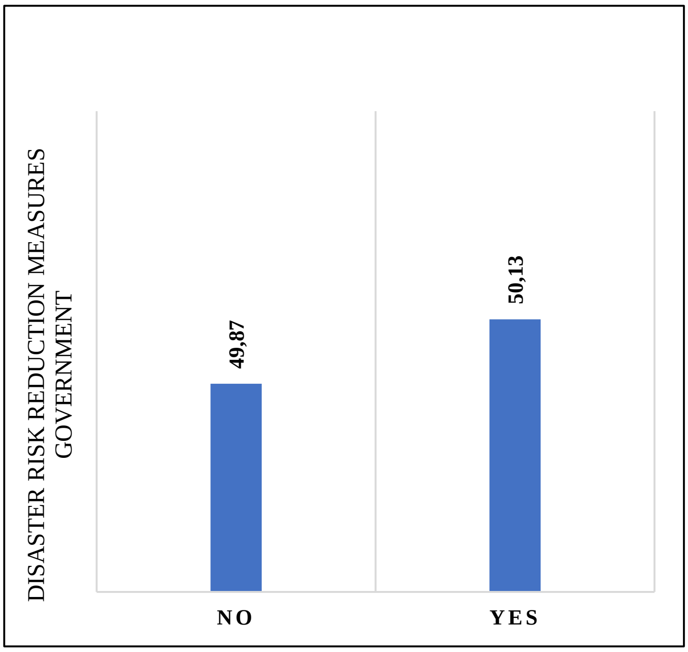


Figure 42 : Government action in the LMR basin

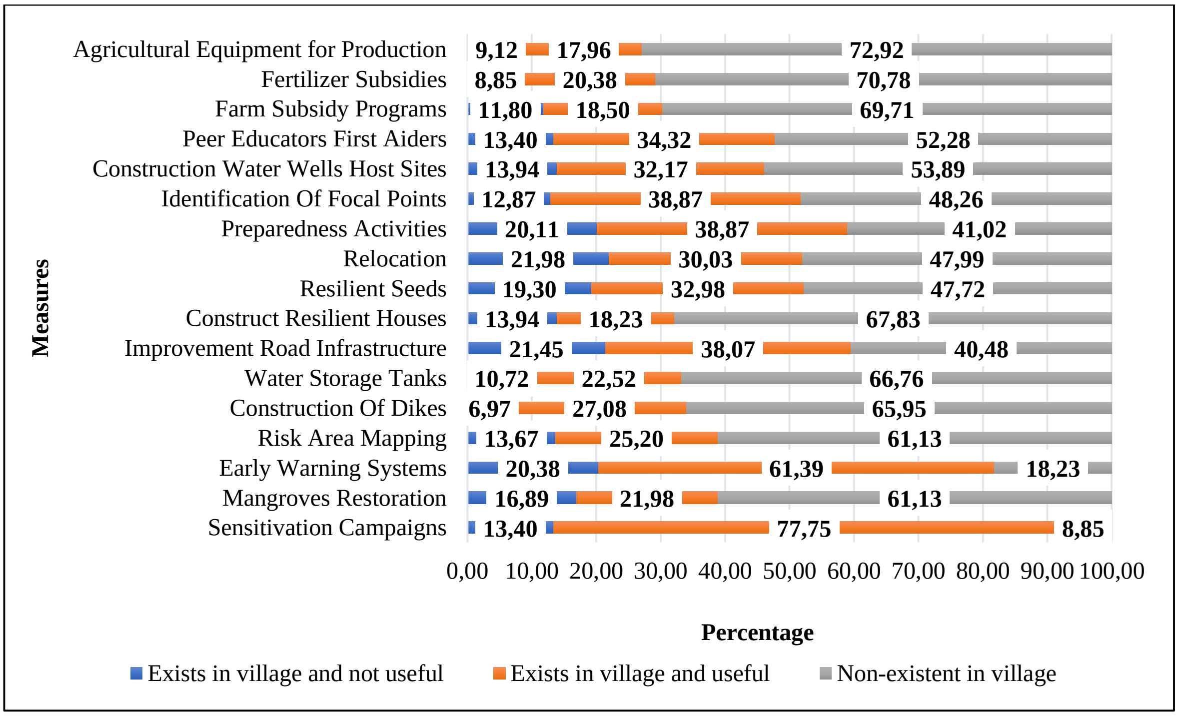


Figure 43 : Measure implemented by governments in the view of households

According to Figure 43, proactive measures such as early warning systems, sensitization campaigns, road infrastructure improvement, preparedness activities, and peer educators as first aiders are the most implemented, but according to the surveys, this alone is insufficient and does not truly reduce the impact of flooding on their households. We see that agricultural production strategies such as agricultural equipment, fertilizer subsidies, a farm subsidy program, and hardy seeds are rare. Techniques for hydro-agricultural development are extremely rare. In the case of flooding, households relocate to safer areas while the flood waters recede. However, few households find this measure useful in villages where it exists. These analyses show that both proactive and reactive measures must be genuinely enhanced and strengthened to improve household resilience to flood hazards in the basin. Similarly, hydro-agricultural development should be taken into account.

4.3. Discussion

4.3.1. Household perception of flood impact and existed adaptive strategies

Flood-impacted households are in different sectors of activities and living, including agriculture, commerce, material (houses), and health. Other reports and studies have come across this result (Ago et al., 2005; United Nations Office for Disaster Risk Reduction, 2021; Olivier Ballo, 2022). Agriculture is the principal sector impacted by flooding, with huge damage to crops (The Government of Togo et al., 2010). Agriculture damage occurs more frequently and with greater severity than other types of damage. The effect of flooding on agriculture includes crop damage, less harvest, lower incomes, sickness, soil damage, a lack of food, and no access to markets. This can be explained by the fact that the principal activity of the household is agriculture. According to the review made based on the post-disaster assessments by FAO, (2015), it was reported that the total damage and losses to the crop subsector amount to about USD 13 billion, and almost 60 percent of these damage and losses were caused by floods. It was also reported that from 2006 to 2016, almost two-thirds of all damage and loss to crops was caused by floods (Food and Agriculture Organization of the United Nations, 2017), which were responsible for a total of USD 21 billion in crop and livestock production losses from 2008–201, accounting for 19 percent of the total loss (Food and Agriculture Organization of the United Nations, 2017).

The most important adaptive strategies developed by both households (the better-off and flood-prone households) to cope with floods in agriculture include other commercial activities, modification of the agricultural calendar, crop diversification, evacuation of livestock before floods, and crop substitution. Similarly, Nguimalet (2018), in their studies, identified temporary relocation and having others participate in activities as the adaptive measures implemented by communities to cope with both drought and flood risk. They explained the seeking of other activities as a future shift from one activity to another if extreme climate events affect activities over the long term. In this way, activities that do not depend on natural resources or are not impacted by pressures coming from climate change are a possible adaptation measure for communities. Furthermore, communities in the LMR basin are aware of the flood risk, but they choose not to relocate for a variety of reasons. From the point of view of the respondents, flood risk represents a risk in their villages, as 95% agree with that statement (Figure 44). They are still in the region for different reasons. The word cloud made by the figure presents the different reasons why they are still in these risky areas.

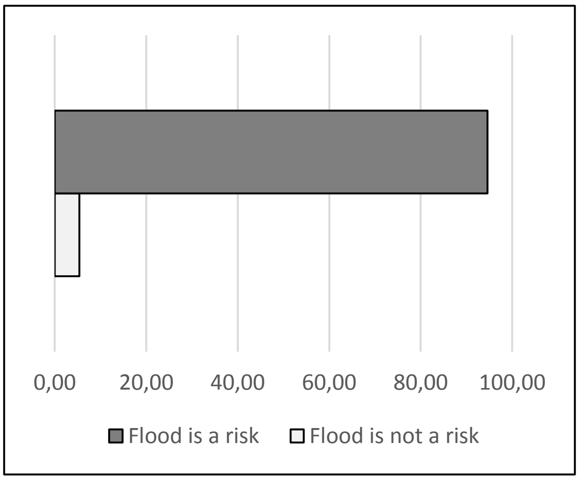


Figure 45:Flood risk

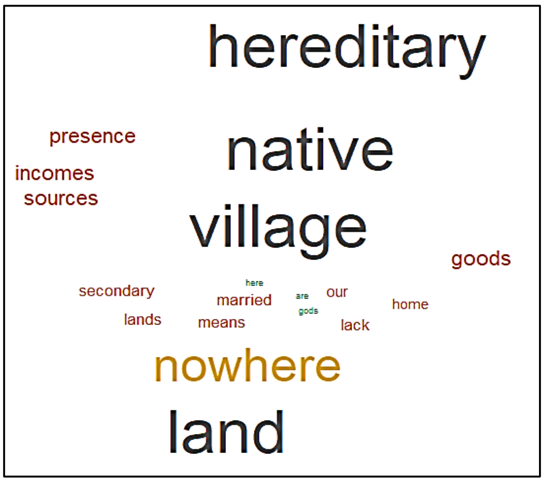


Figure 44: Reason why households are still living in a risky area

As shown by Figure 45, the main reasons that keep households in flood-prone areas are those in the main character presented by the word cloud. The majority of the respondents considered their villages to be the place where they were born and grew up (their native village), and they didn't have a reason to leave it. Also, they have all their land and heritage from their parents and relatives and therefore cannot abandon it. Furthermore, they do not have anywhere else to go as all their income and goods are coming from that area. Another reason is the lack of means and the fact that some women are married in the area, so they cannot abandon their families and have to be with their husbands. This may imply the fact that women do not always have the right to give their opinion on decision-making in the household.

Based on that, local communities preferred to stay in the basin despite the flood risk. When combining the adaptive strategies most commonly implemented in the LMR basin, other activities can be considered temporary or secondary. Then, in times of flooding, communities could develop other activities, such as fishing. With respect to their agricultural activities, changing the agricultural calendars and diversifying the crops of production are the measures implemented in order to avoid the impact of flooding. For this reason, it would be important to set up a system for preparing households. Therefore, it will be necessary to set up a system of capacity-building both for preparedness and also for mitigation by households through the diversification of their activities and new agricultural practices so that they are informed in real-time of the climatic forecasts. Also, it was reported by Nguimalet (2018) that floods are generally recognized as something that cannot be entirely prevented and that measures can be taken to lessen their impact and speed up recovery. He added that such a shift in thinking may inspire donor agencies, which provide aid or rehabilitation post-flooding, to consider using the same amounts of money to fund flood adaptation initiatives as well.

It can be underlined that the measures mostly implemented by the household do not require a lot of financial means. It was mentioned by Abbas et al. (2015) that in developing countries, rural populations are more vulnerable to floods because of poor flood mitigation adaptive infrastructure and limited resources. Also, they implemented more or less proactive measures to cope with the flood impact. For instance, they installed a drainage system, modified their agricultural calendar, and relocated their livestock before the flood event. This corresponds to the findings of Mashi et al., (2020), in which they identified households that implemented proactive measures.

4.3.2. Household decision making regarding flood risk

Flood-prone households' flood experience and their plot in lowlands with a high area of their agricultural plot affected by flood decided to adapt to flood while the ones with a large size, having less farming experience, participating in flood training, and having their plot characterized by the presence of water (short or long duration) due to flood were not. This is not in line with the result of Mashi et al., (2020), who found that the larger households are, the more they adapt (Alhassan, 2020). When water is present and has a certain duration on an agricultural plot, households do not adapt. Better-off households with lower incomes are the ones that experience more flooding. From this analysis, the exposure of households combined with the impact of previous flood events on flood-prone households is the principal factor that influences households' decisions to adapt. In the same vein, Alhassan, (2020) found that information on flood occurrence drove the farmer's decision to adopt. Eberechukwu et al., (2018) concluded in their study that having previous experience of flooding increases the chances of households adopting flood defense measures. In addition, Wutzler & Hudson, (2021) and Cao et al., (2020) added that high experience with previous flood events and lowly perceived response costs could strengthen proactive adaptation behavior. Similarly, the choice of specific adaptive strategies or measures by households is positively influenced by their experiences with past flood events (water level, high percentage loss of cultivated area, flood duration) and the exposure of their agricultural plot (in lowland). The awareness of floods and the exposure influenced the decision-making of households on how to cope with floods. Other commercial activities and drainage systems permit the financial recovery of households from the flood risk, while the modification of the agricultural calendar does not. This can be explained by the fact that these measures can be implemented before and during the flood event. In addition, households with lower incomes are likely to choose other commercial activities and the modification of the agricultural calendar over drainage systems.

4.4. Partial conclusion

This chapter discussed the impact of flooding on households in general, the existing adaptive strategies implemented by them to face or reduce the impact of flooding, and the factors that influenced them to adapt and choose a particular type of adaptive measure. The results show that the principal sector of activities impacted by households in the LMR basin is agriculture. To reduce this impact, different adaptive measures which were the most implemented included having other commercial activities, modification of the agricultural calendar, drainage system, crop diversification, and substitution. These measures require less investment, and some of them are proactive.

The choice of households to adapt and choose a specific adaptive measure is positively influenced by their experiences with past flood events (water level, high percentage loss of cultivated area, flood duration, flood experience) and the exposure of their agricultural plot (in lowland). The awareness of floods and the exposure influenced the decision-making of households on how to cope with floods. Other commercial activities and drainage systems permit the financial recovery of households from the flood risk, while the modification of the agricultural calendar does not. This can be explained by the fact that these measures can be implemented before and during the flood event. In addition, households with lower incomes are likely to choose other commercial activities and the modification of the agricultural calendar over drainage systems. Households implement the measures mostly before (proactively) and during the flood event, and structural measures like a drainage system are implemented by households with high incomes. We recommend greater preparedness, capacity building, and the diversification of livelihoods as means of enhancing adaptation.

Chapter 5 Modeling flood hazard for exploring future impacts of different discharge scenarios and decision-making (structural measures) from households on flood extent

Chapter 5: Modeling flood hazard for exploring future impacts of different discharge scenarios and decision-making (structural measures) from households on flood extent

5.1. Introduction

In light of all the foregoing, the major research question raising is: Which adaptive strategies can be implemented to cope with flood risk in the Lower Mono River Basin?

HEC-RAS is a powerful decision-making tool in flood management. HEC-RAS is software that allows users to determine one-dimensional steady flow, one- and two-dimensional unsteady flow, sediment transport and mobile bed calculations, water temperature, and water quality modeling (CEIWR-HEC, 2023)

In this Chapter, the effectiveness of structural measures was tested for different scenarios of flood based on two different discharge return periods. The HEC-RAS model was used to this end.

5.2. Results

5.2.1. Household capacity to cope with flood risk

The most implemented adaptive strategies by the households are having other commercial activities, modifying the agricultural calendar, and improving the drainage system. Despite these strategies, the communities along the Lower Mono River are each year impacted by flood risk. Optimizing these adaptive strategies could help them cope with the flood risk. For instance, having other commercial activities could allow them to have some income and cope with their needs during the disaster while waiting for the water to leave. The activities can include, for instance, fishing and selling palm nuts. The installed mitigation methods, such as the drainage systems, are manual and not based on technique qualification for evacuating the excess water from a flood. These structural measures can be technically implemented to reduce the impact of flooding on households.

When asking households if they have the capacity to cope with flood risk and their perception of whether flood risk reduction is costly or not, 90 and 85 percent responded, respectively, that they do not have the capacity to reduce the flood risk and that the risk reduction is costly (Figure 46)

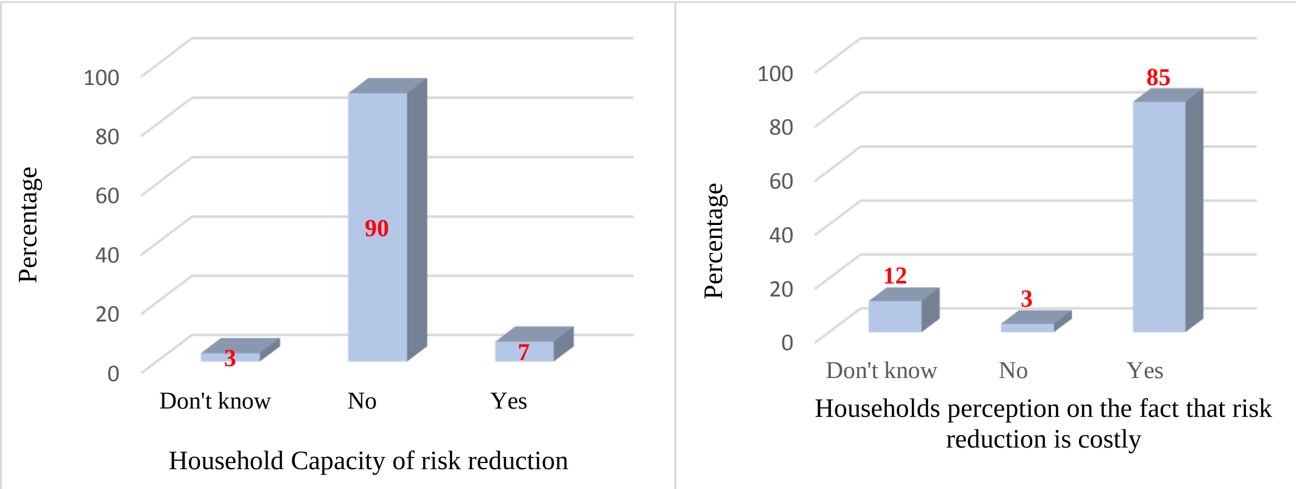
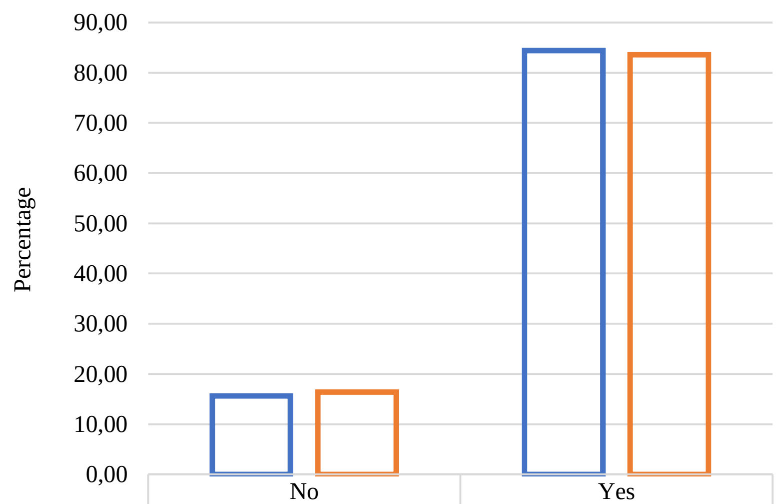


Figure 46: Capacity of household to cope with flood risk

Also, their perception was asked about the implementation of some structural methods (Will you agree if the government decided to install hydro agricultural or engineering scheme?). Figure 47 shows their responses to accepting these mitigation methods. The hydraulic model HEC-RAS was then used for testing these different mitigation systems, including the drainage system, levee, and retention basin.



	No	Yes
Engineering (levee)	15,59	84,41
Hydro agricultural planning (drainage system and retention basin)	16,40	83,60

Figure 47: Perception of households on implementing structural measures

5.2.2. Modeling of flood hazard map

Figure 48 shows the flood hazard map in the Lower Mono River basin for the 10- and 100-year discharge return periods. From this figure, the flood water level varies from 0 to 1.12 m for the 10-year return period, while it varies from 0 to 1.39 m for the 100-year return period. In addition, most of the households' houses with their agricultural plots that claimed to be affected by flood are within the flooded area. In addition, the analysis of this figure shows that the lower part of the basin, as shown in the Chapter 4, is more affected by flooding than the upper part. The floods caused by the 10- and 100-year discharge return periods affect an area of 184.22 km^2 and 307.01 km^2 in the basin, respectively. This shows that the 100-year discharge return period affected more than the 10-year discharge period. The same remarks were made in the lower part of the study area.

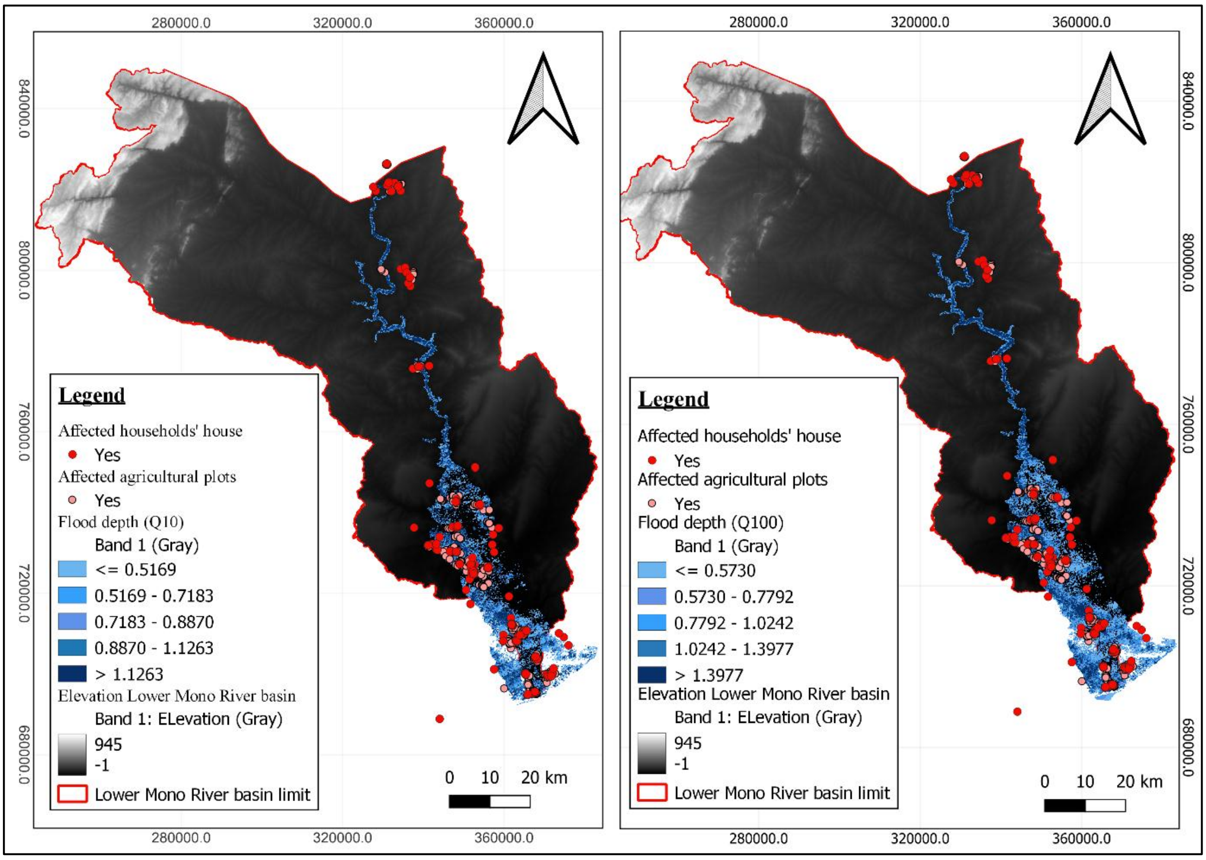


Figure 48: Flood hazard map in the Lower Mono River basin

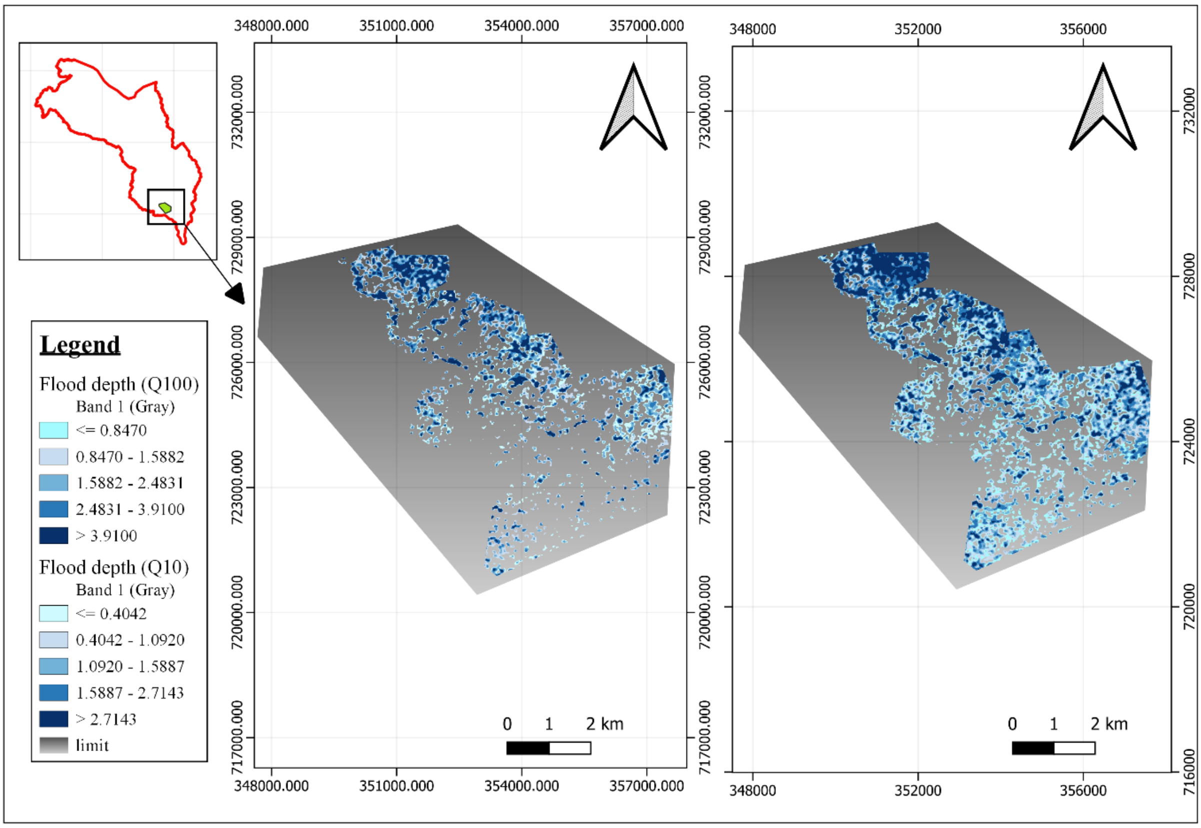


Figure 49 Flood hazard map in the base valey of the Lower Mono River basin

Figure 49 displays the details in terms of flood depth and flood coverage in the lower part of the study area.

Figures 50 and 51 show the water level within the river bank in both situations, respectively, at the upper and lower parts of the basin. It can be noted that water from the river rises and goes over the river bank. In addition, the elevations at the banks of the river have smaller values.

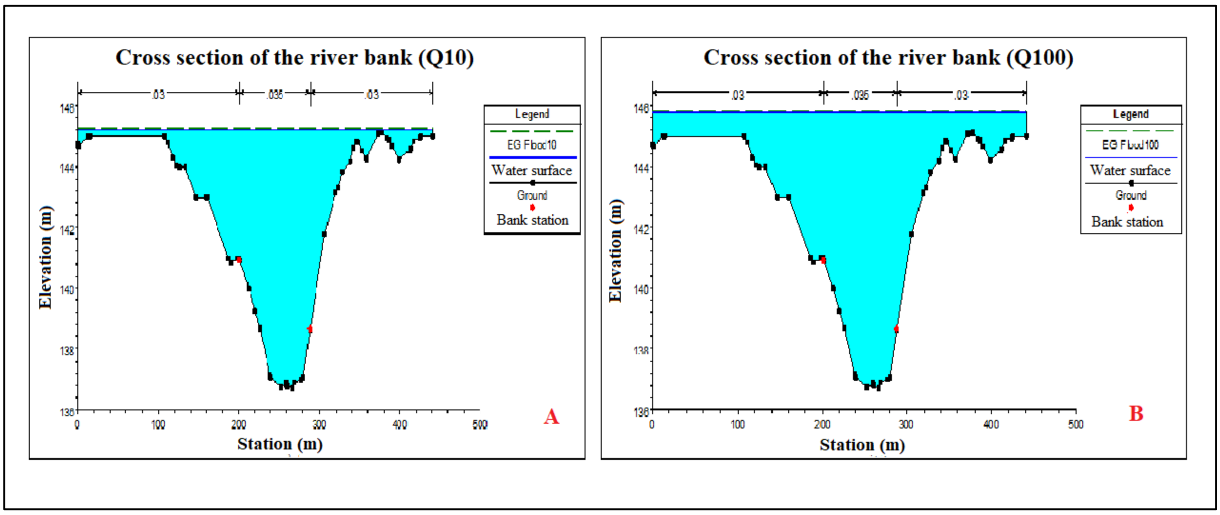


Figure 50: Cross section of the river bank (Q10 (A) and Q100 (B)) at the upper part

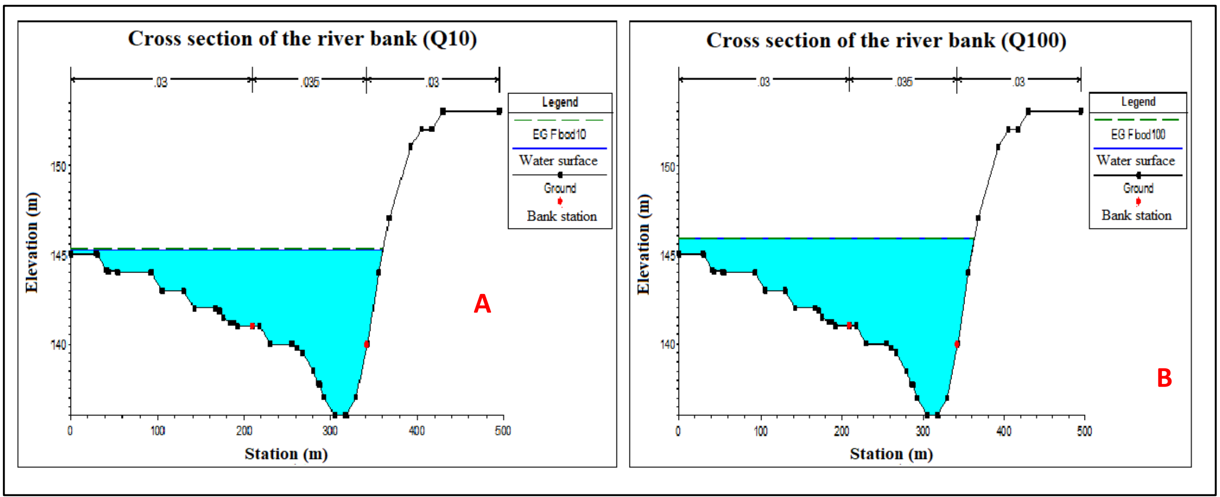


Figure 51: Cross section of the river bank (Q10 (A) and Q100 (B)) at the base valey of the basin

Since agriculture is the main activity in the study area, the flooding and its duration will have a negative effect on it. The main crop grown by the communities is maize (Figure 52).

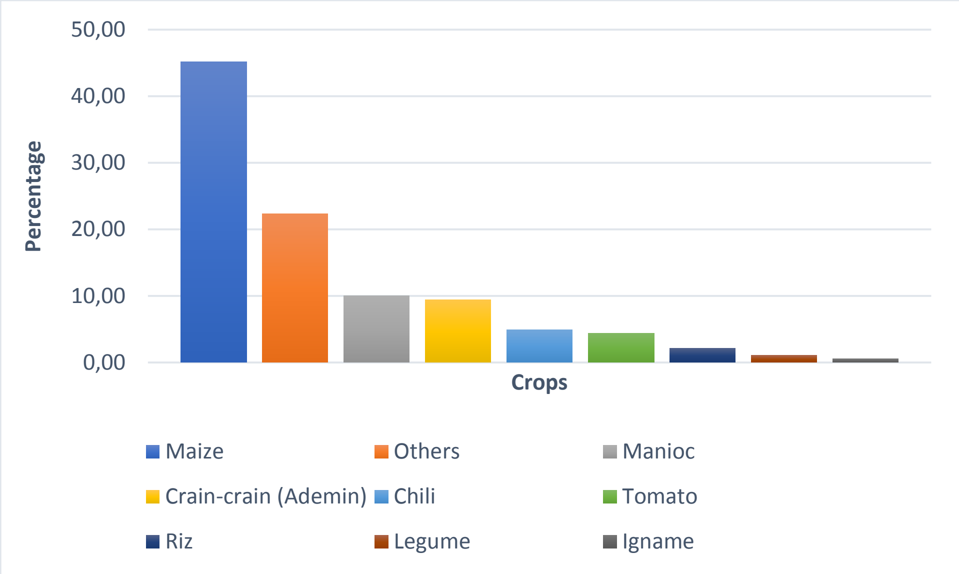


Figure 52: Different cultures practiced in the basin

Figure 53 shows the impact of flooding on the maize yield in the perception of the households affected by flood. From this figure, flooding significantly reduces maize yield.

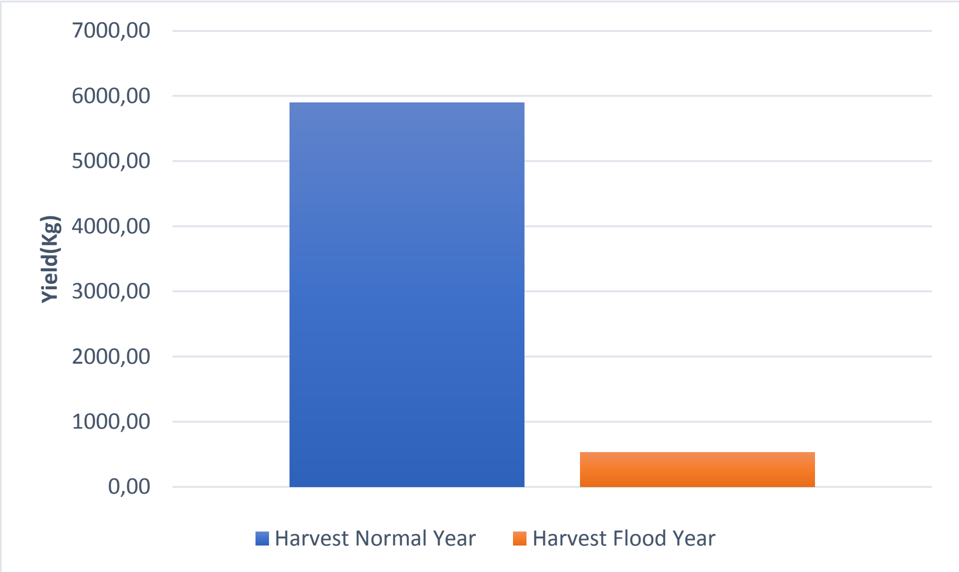


Figure 53 : Maize Yield in Normal Year versus Flood Year

Daku et al. (2022) worked on this in their study by looking at the maize response to temporary floods under ambient on-farm conditions in the West African Sahel. Their results showed that three days and six days of flooding with a water depth of 8 centimeters, reduced grain yield by at least 35% when they occurred at the tasseling stage. Only 4–6 days of flooding reduced grain yield by 21% at the six-leaf stage. Figures 54 and 55 show respectively based on the duration of the flood, the impact of the flood on the grain yield in the Lower Mono River basin when considering the flood occurrence at the sis-leaf stage and tasseling stage. The analysis of these figures reveals that in both situations, there is a progressive decrease in maize yield as the duration of flooded water in the household fields increases. This reduction reaches zero when the duration of water is more than thirty days at the stage of six leaves and three leaves. From these figures, it can be said that the increase in the flood duration causes a reduction in the yield. To increase productivity, it is crucial to put in place a system that can minimize or eliminate the flooding of agricultural plots.

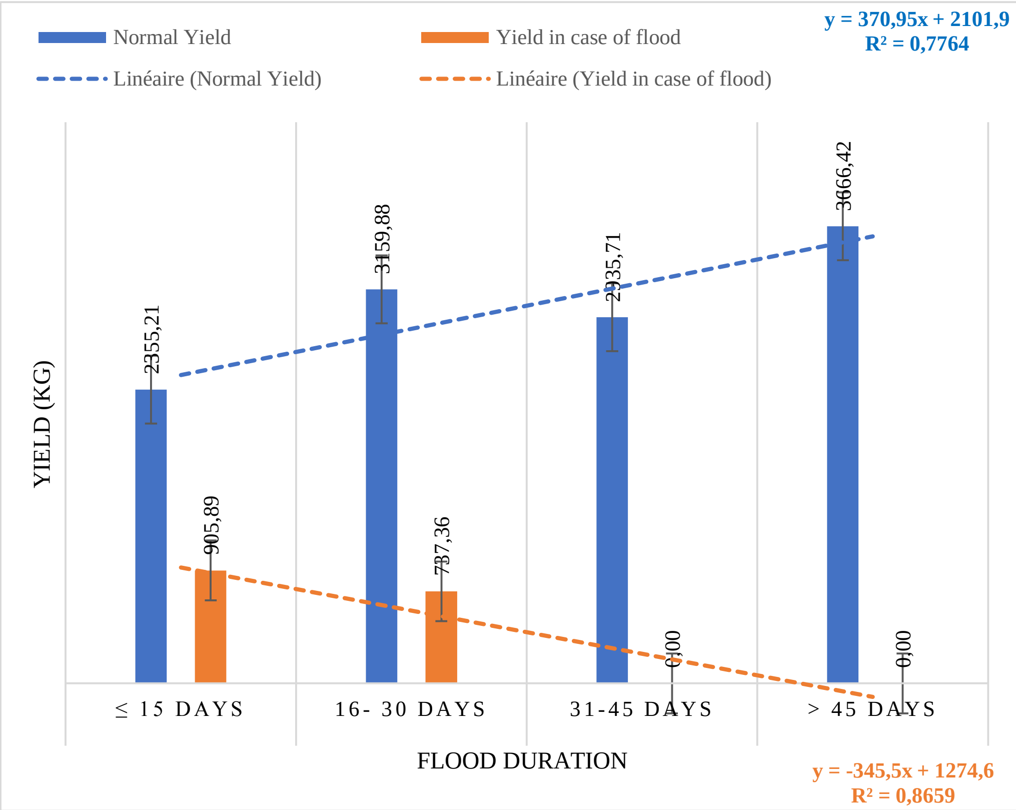


Figure 54 : Impact of flood duration on maize yield at the six-leaf stage

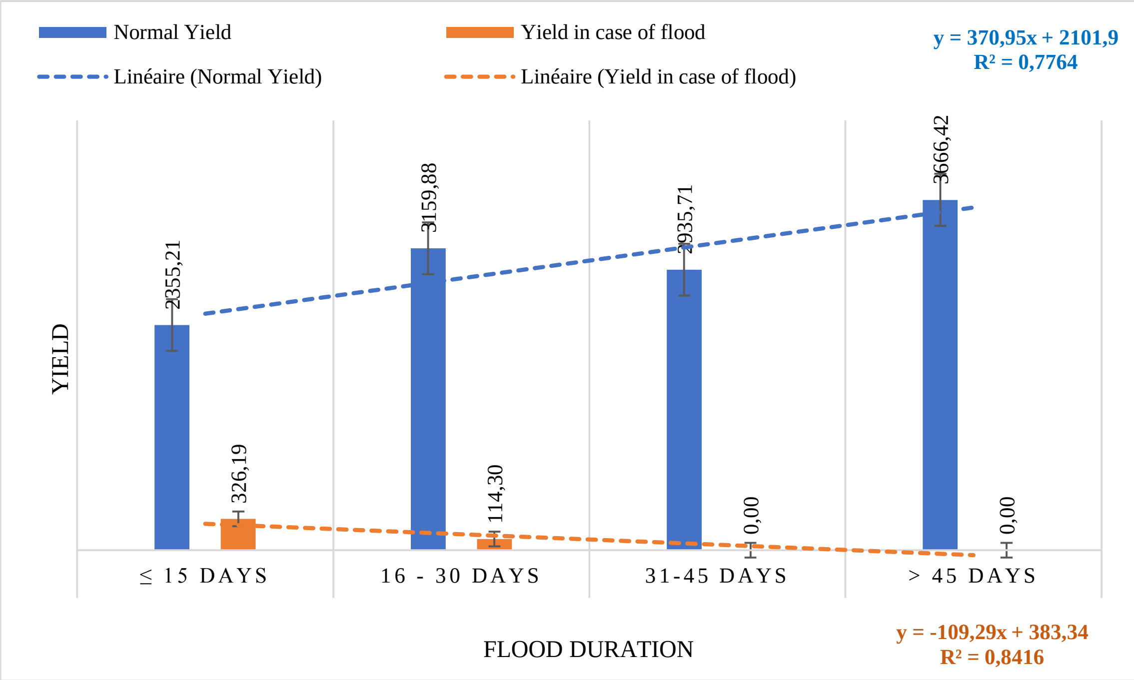


Figure 55 : Impact of flood duration on maize yield at the six-leaf stage

5.2.3. Influence of drainage system in flood risk reduction

In order to canalize the water within the river bank, the drainage system of the river was ameliorated by modifying the ground surface by increasing the elevation (embankments) of the river bank for a maximum of 2 m and reducing (excavations) it to a maximum of 4 m where needed (Figure 56).

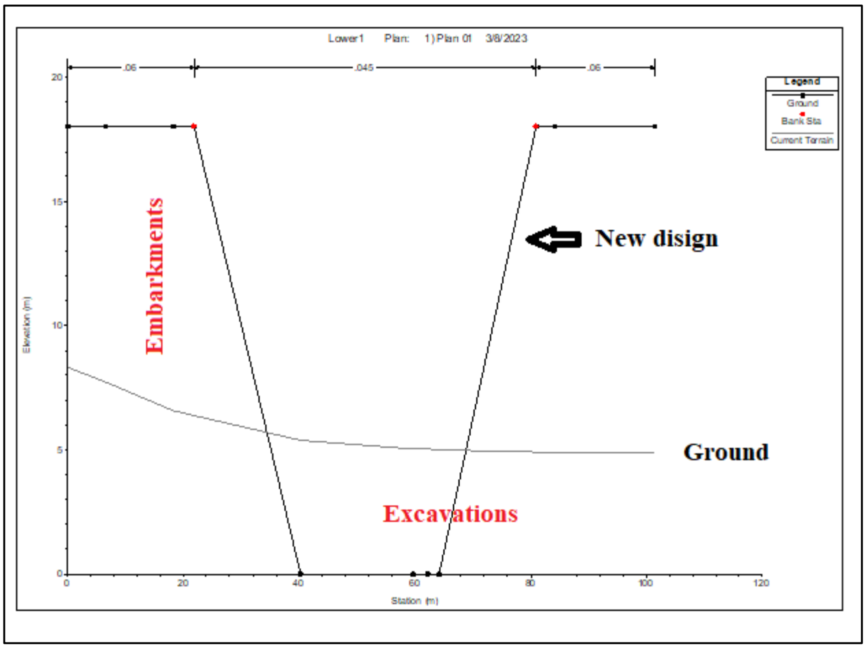


Figure 56: Design develop for flood risk reduction

In addition, the retention basin combined with the drainage system was tested in the lower part of the basin to get more insight into the efficiency of the structural measure. Figure 57 shows the modification of the ground elevation, respectively, for the drainage system and retention basin.

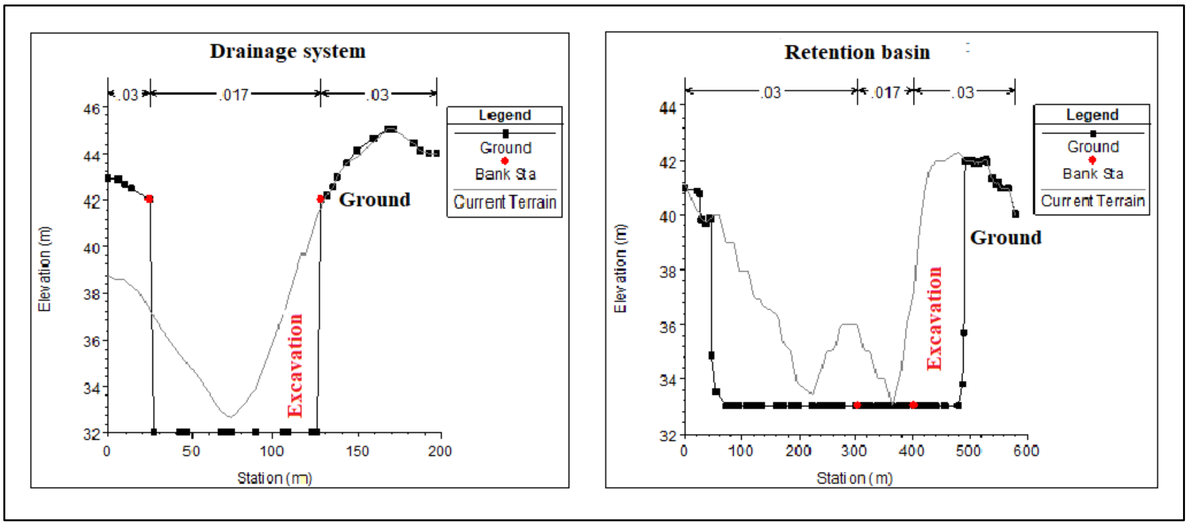


Figure 57: Design develop for flood risk reduction

Figures 58 and 59 show the result of structural measures in reducing the flood risk in the study area. The analysis of Figure 58 shows that the flood caused by the 10- and 100-year discharge return periods affected an area respectively of 122.16 km^2 and 147.76 km^2. Compared with the case without measures, the areas affected by flooding were reduced by 62.06 and 159.25, respectively, for the flood caused by the 10- and 100-year discharge return periods.

In addition, the households' houses and agricultural plots were less affected by the flood. Structural measures can reduce the flood risk in the study area. Figure 58 also shows the result of the hydrological model with the different discharges for the 10 and 100-year return periods with the implementation of drainage systems and retention basins in the lower part.

Furthermore, Figure 60 illustrates the difference between the areas affected by flooding before and after the measures for the different return periods. According to this figure, the area impacted by flooding has decreased significantly by 50% in the event of flooding induced by a flow with a 10-year return period and by 64% in the case of flooding with a flow of a 100-year return period. The canalization of the water in the river bank and the retention basins can stock water and contribute to the reduction of flood risk in the Lower Mono River basin.

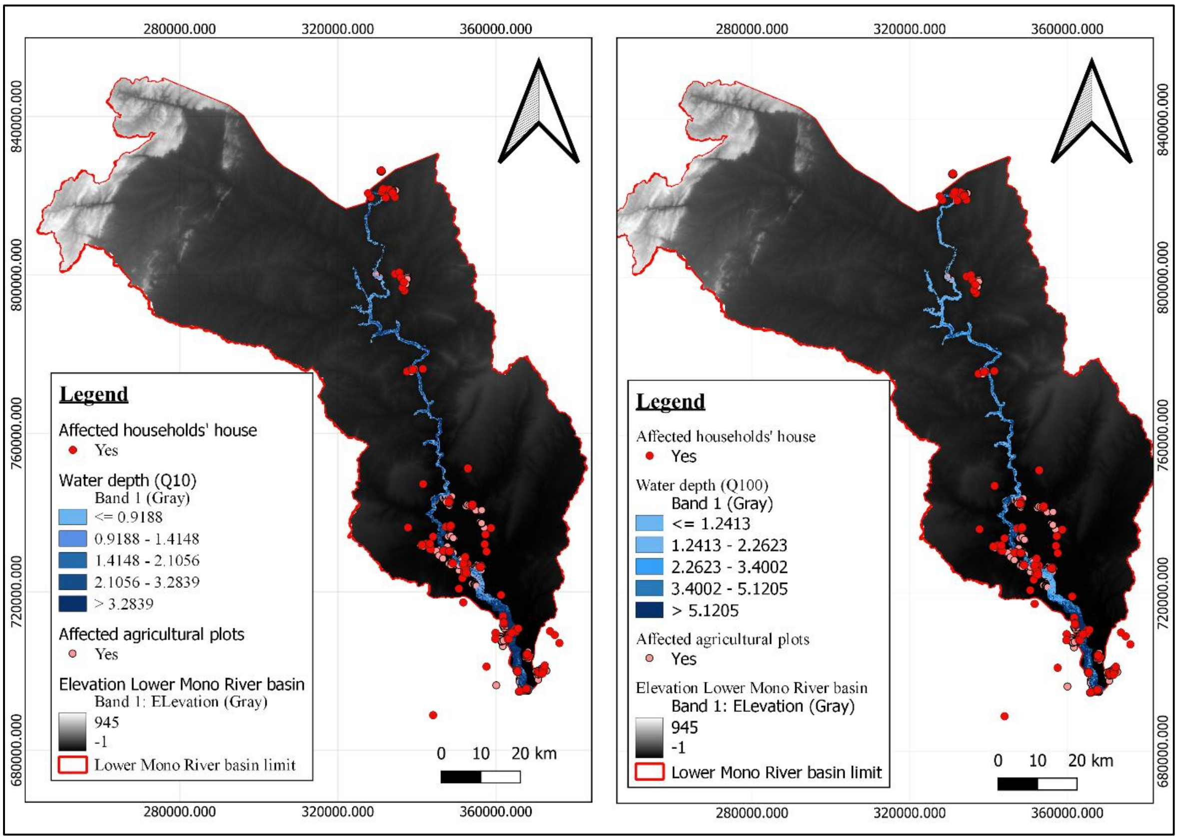


Figure 58: Flood water level for different scenarios (Q10 and Q100)

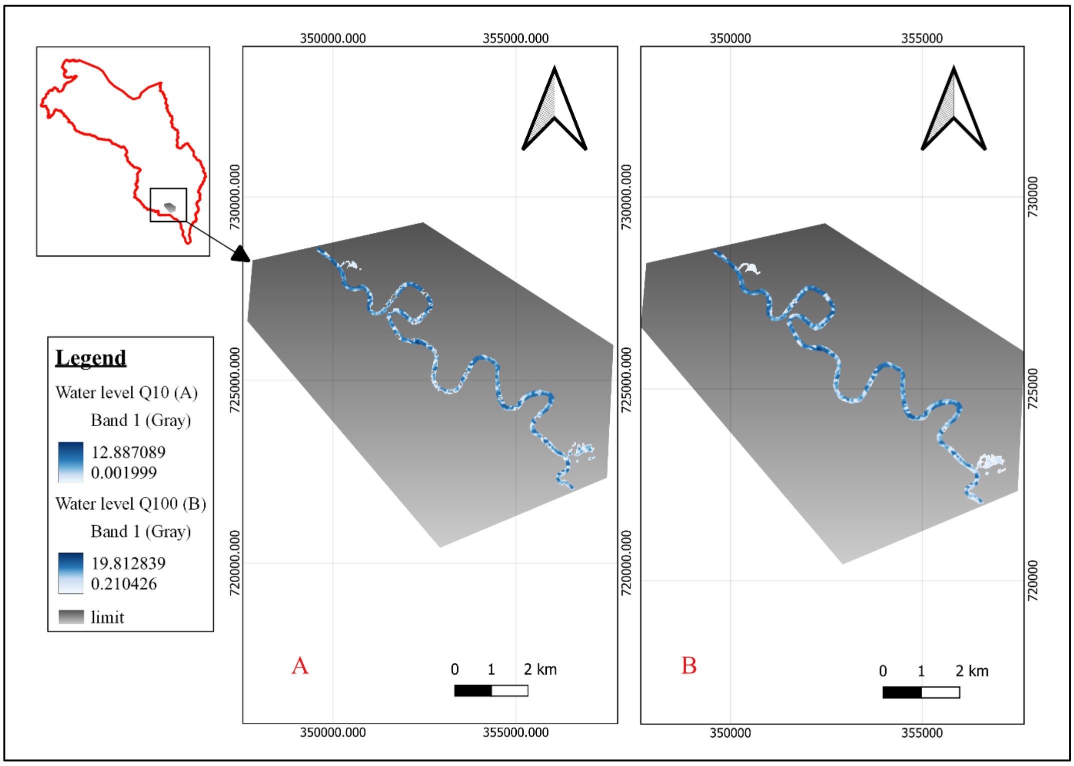


Figure 59: Flood water level for different scenarios (Q10 and Q100) with structural measure

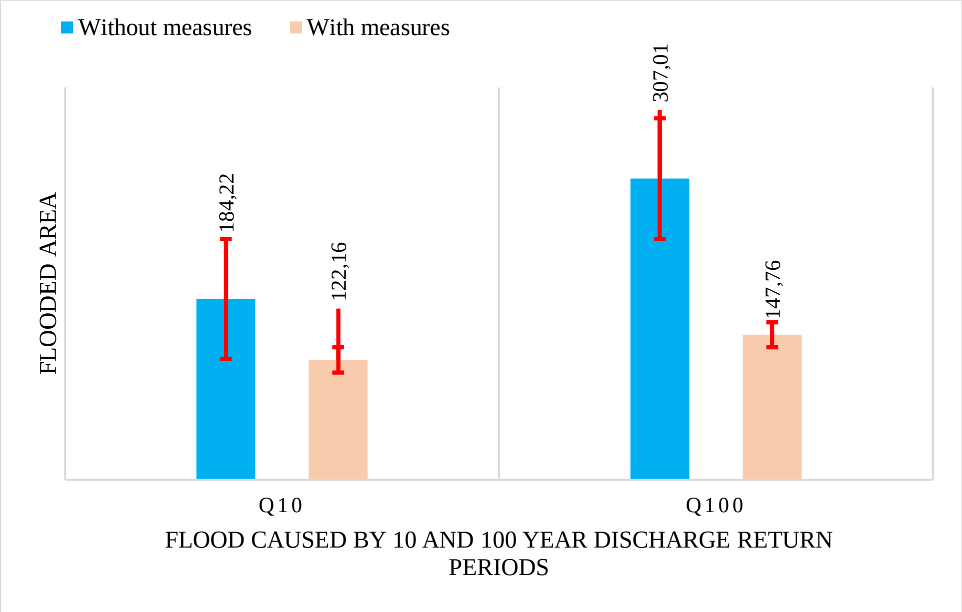


Figure 60: Difference between areas affected without and with measures

The Figures 61 and 62 show the water level after flooding and illustrating how the water is retained in the channels and the retention basins. These results indicate that a better drainage system combined with the retention basins can reduce the risk of flooding in the study area.

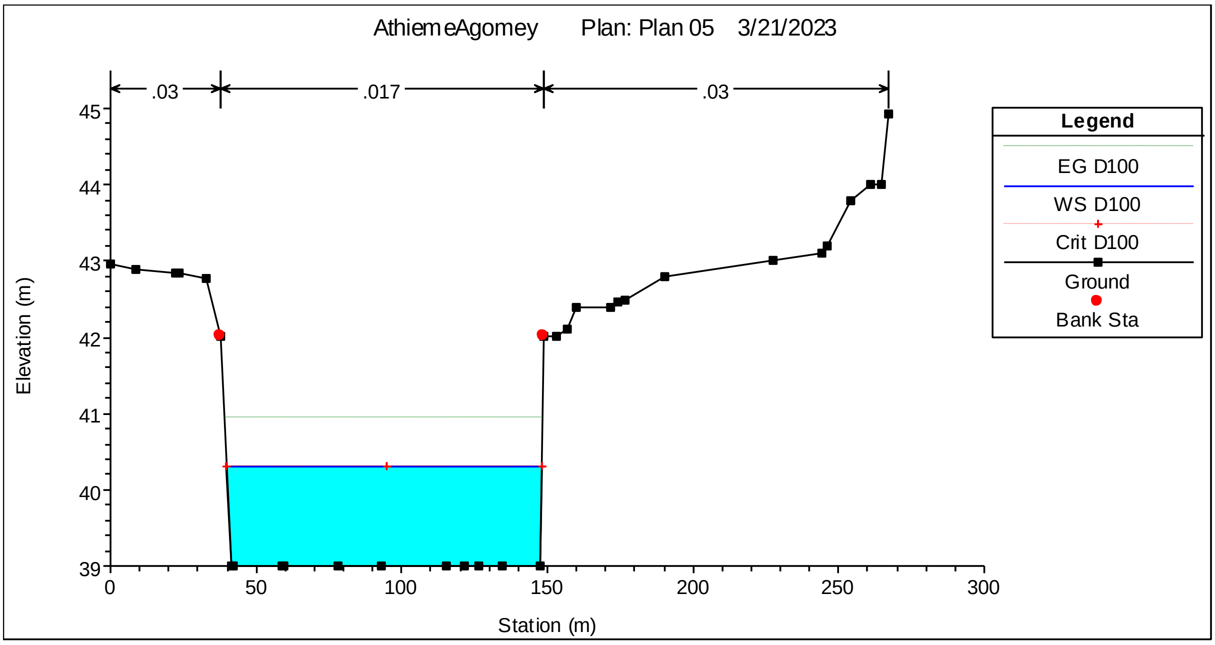


Figure 61 : Cross section of diversion channel (Q100)

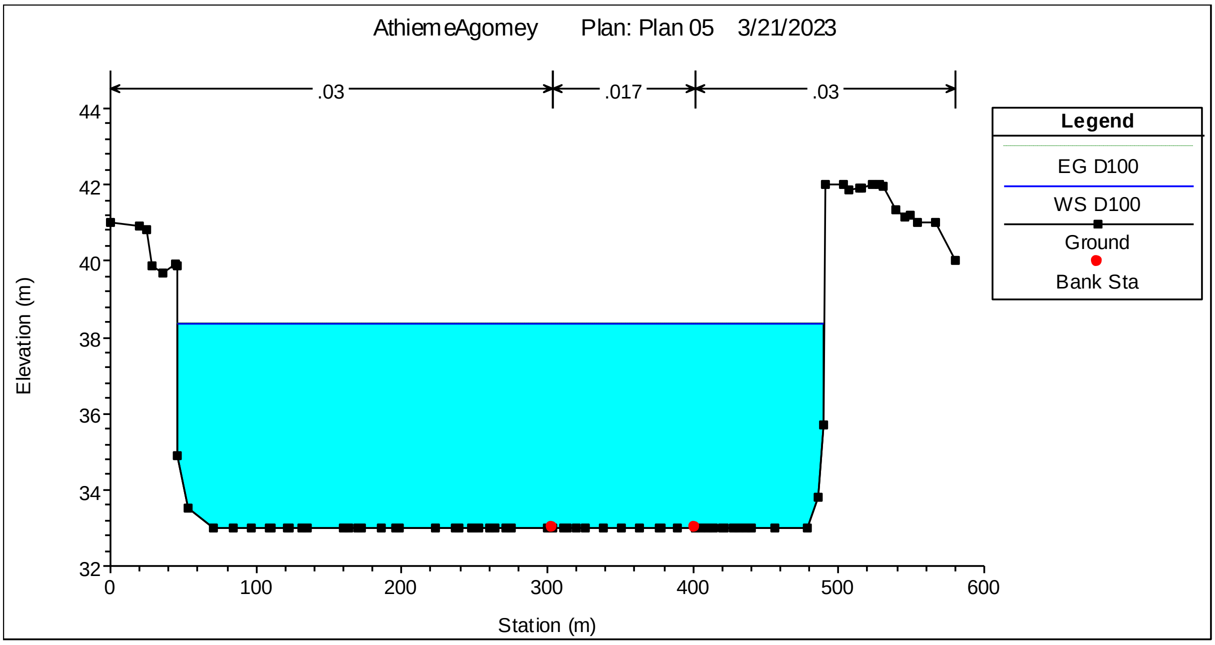


Figure 62 : Cross section of retention basin (Q100)

In this study, two retention basins with different sizes were tested depending on the elevation model of the ground obtained from the DEM. These basins can evacuate and stock, respectively, 53264 liters and 13816 liters of water and can occupy, respectively, 1381.6 m2 and 345.4 m2 of area.

5.3. Discussion

HEC-RAS was used to map flood hazards in the Lower Mono River basin for different return periods and evaluate some structural measures including drainage system and retention basin. From the results, most of the households 'houses and plots that were claimed during the survey to be affected by the flood were found in the area affected by the flood. Also, the longer the duration of the flood within the households' fields, the more it reduced the yield of the principal crop in the study area. Many studies were also conducted using HEC-RAS to map flood hazards and risks for different return periods. Flow depths were simulated for different return periods and the areas with high risk of inundation were also identified using HEC-RAS (Al-Zahrani et al. 2016). HEC-RAS and HEC-GeoRas were used by Sholichin et al. (2019) for flood mapping and classification of risk areas. Basnet & Acharya (2019) conducted a study using HEC-RAS for modeling floods for different return periods in the Seti River (Ramghat area of Pokhara, Nepal). They found that 100-year peak flood was found more vulnerable to population. Basnet & Acharya (2019) used HEC-RAS to model flood situations in different return periods for determining the water surface profile and to map the floodplain. Communities in the lower part of the basin are more affected than those in the upper part. This result is in line with the study of AL-Hussein et al. (2022) which indicated that floods were more severe in villages closest to the river's mouth than in those further downstream. The same observation was made by Jagadeesh & Veni (2021). They justify this matter of thing by the effect of the existence of a dam with the river catchment.

In addition, different structural measures, including levees, drainage systems, and retention basins, were tested and found useful in reducing flood risk. Regulation and improvement of the drainage system combined with retention basins can reduce the risk of flooding in households, allow them to practice their agricultural activities, and also allow households to develop other activities such as fishing. It was demonstrated by Mahmoud et al. (2021) in their study on the effectiveness of drainage systems on maize yield, that a controlled drainage system increases the average relative yield of maize crop by 6%. Sholichin et al., (2019) in their study analyzed the effectiveness of diversion channels in reducing flood risks in the Ciliwung River located in Kalibata, Kebon Baru, and Kampung Melayu respectively found that there is a reduction in inundation area and a decrease in water level by testing different diversion channels in reducing flood risk. Yerramilli (2012) used HEC-RAS to estimate the flood depth, extent, and the vulnerability of different facilities including material plants, potable water waste, water facilities, transportation, hospitals, and schools. It is important to indicate that, the resolution of the DEM used in this study for the hydrological model did not give more details on the ground reality. DEM with low resolution gives major variation in relief while the problem of flooding requires more precision (Sholichin et al., 2019). The result from HEC RAS is more accurate with high-resolution DEM which was not accessible. Psomiadis et al. (2021) in their study compare the detailed digital surface model (DSM) and DEM in flood hazard modeling and indicate that DSM may give more accurate information regarding surface relief. They have also highlighted that those existing natural obstacles such as vegetation, buildings, and greenhouses, enable more realistic hydraulic simulation results.

As structural measures are implemented as solutions to flood reduction, they can also have unplanned opposite effects. For example, a river embankment can break and affect more people. The construction of dams to protect communities from the risks of flooding due to the river can lead households to settle not too far from the river, and when an exceptional flood arrives, the number of people affected would be enormous. In addition, the drainage system can become clogged over time, and the same consequences remain if it is not properly maintained. It is therefore important to consider the anthropogenic effect on these different infrastructures to ensure their sustainability. HEC-RAS combines with Agent-Based Models (ABM) that can enable taking into account the participation and behavior of communities in connection to the development of amenities. Agent-based models are presently the preferred way to assist with such preparedness by addressing the system as a whole and incorporating dynamics of various types: hydrology, population behavior, evacuation, crisis management, and so on. This study can also integrate the feedback of households regarding the maintenance or the controversial effect of these structural measures and vice versa. This can allow to have more insight into the flood risk evolvement within the catchment and reduce its impact. Other studies used the ABM model to this end (El Bilali et al., 2021; Chapuis et al., 2021).

5.4. Partial Conclusion:

In this chapter, flood hazard was modeled for different return periods of river discharge, using HEC RAS, and the effectiveness of some structural measures were tested using the same hydrological model. To this end, discharge data for the sub-basin within the LMR basin for 10 and 100 return periods were estimated using the OSTROM methodology for the ungauged basin. These data combined with the DEM were then used to model flood hazards and design structural measures in HEC-RAS. The results show that, for different return periods, structural measures including drainage systems, levees, and retention basins can reduce the flood risk in the study area. Flood hazard was mapped using the result from HEC-RAS in QGIS. In addition, the surface affected by flooding within the basin was significantly reduced after the implementation of structural measures (drainage system, levee, and retention basin). This result shows that implementing a drainage system combined with a drainage system can reduce flood risk in the Lower Mono River basin. These measures, combined with the installation of pumps, can also help communities to do agricultural activities during dry seasons and the retention basin can be used for fisheries and pumping water. It is important to notice that the structural measure takes longer and is costly to implement. Participation and acceptance by communities are then important for the sustainable management of these measures. Furthermore, Farooq et al. (2019) considered non-structural measures are methods implemented to support effective flood mitigation measures. Therefore, in order to considerably lower the risk of flooding in the study region, it is crucial to include non-structural methods in addition to structural ones, such as mapping potential flood zones, raising awareness, and reinforcing the capacity of households.

GENERAL CONCLUSION

General Conclusion

This study was conducted for the following purposes: firstly, to provide more insight into the impact of the flood in the Lower Mono River on the communities, the causes of this hazard in the context of climate change, and the point of view of the communities. Secondly, the existing adaptive systems were analyzed, and the flood risk was modeled by considering the most effective from the point of view of households using the model HEC-RAS. This chapter presents a summary of the key findings, conclusions, and recommendations regarding each specific objective.

6.1. General conclusion

The aim of this study was to investigate the impacts of climate change and the decisions made by households on flood risk using the HEC-RAS model. To this end, three specific objectives were defined including: assessing the socio-hydrological drivers and vulnerability of households to flood risk; assessing adaptation strategies and decision-making processes of households regarding the negative impacts of floods; modeling flood hazards for exploring future impacts of different discharge scenarios, and decision-making (structural measures) from households on flood extent. To achieve them, primary (survey on households within the basin) and secondary (climatic, hydrologic, biophysical, etc.) data were used following some specific analytic methods.

As a result, it can be summarized that, from the first objective, climate change and management of Nangbeto dams represent the hydrological drivers of flooding, and the presence of households in low-lying areas and close to the river, having less income and a lower education level, are the social drivers of flooding. Regarding the second objective, floods impact many sectors of activities in the study area, especially agriculture. To cope with this impact, households implemented different adaptive strategies that are more proactive and do not require a lot of resources to be installed. In addition, the awareness of floods and the exposure influenced the decision-making of households on how to cope with floods. Finally, from the third objective, flood hazard was mapped for a 10- and 100-year return period, and structural measures developed by the households were tested. The more the discharge increases, the more the surface affected by the flood is high and the probability of households being affected will increase. The implementation of a drainage system combined with a retention basin reduces the affected area by the flood. The structural measure represents a potential measure that can reduce flood risk in the LMR basin.

6.2. Recommendations

6.2.1. Recommendations for further research

This study shows that DEM through HEC-RAS can be effectively used for modeling flood hazards and also testing the efficacy of some structural measures. However, using high-resolution DEM may improve the work, and give better results on flood impact (agriculture, buildings, etc. affected by flood), and allow for a better choice of structural measures to be set up. In addition, only two return periods were used for this study. Without predetermined ground data connected to the cross-section, this study was conducted. Thus, topography information can be gathered for cross-sections in future research to increase accuracy. Different return periods or estimated discharges from different climatic scenarios can be used to explore flood risk using the same model. Other studies could combine all the potential measures to have more insight (into excavation (dredging) to a certain water depth; embankment of the river; and excavation + embankment. Adaptive strategies most effectively implemented by the households were presented in this study. Nevertheless, further study could identify from the point of view of households the effectiveness of these measures. For instance, what could be the consequences or impact of these measures in reducing flood risk? Flood risk can be then modeled by integrating the household decision and behavior over time by using an Agent-Based Model.

The HEC-RAS model set an entry point to contribute to understanding flood hazards and utility of structural measures in coping with flood risk with discharge data. Other climate factors such as sea level rise and rainfall for a better understanding and insight into climate change implications on flood risk can be explored. Also, this modeling approach can therefore be repeated in other areas.

6.2.2. Recommendations for decision making (Government, ANPC, Red cross, etc)

Flood has a huge impact on communities within the Lower Mono River especially on agriculture each year and farmers' livelihoods require more attention and efficient management from decision-makers. The funding of this study gives more insight into the drivers of this phenomenon, the vulnerability of households, their decision-making to this hazard and tests the effectiveness of some structural measures to reduce the flood risk.

I. GENERAL CONCLUSION

From this study, it was noticed that different groups are found and can be impacted differently by floods. Climate change and management of Nangbeto dams represent the hydrological drivers of flooding, and the presence of households in low-lying areas and close to the river, having less income and a lower education level, are the social drivers of flooding. The awareness of floods and the exposure influenced the decision-making of households on how to cope with floods. We recommend the reinforcement of the alert system by ANPC and Red Cross through informing communities within the catchment especially the ones at the base valey of the basin. The populations in the lower part of the basin are more vulnerable to floods, it is important to strengthen the information and early warning system to allow them to prepare in time before the release of the waters of the Nangbeto dam and then inform them about climate forecasts in real time. With the advancement of technologies, set up a mobile application that can inform focal points and at least village chiefs or households' headers about climate forecasts as well as the consequences of these on their various activities and the precautions to be taken. To do this, it is necessary to improve the level of education and literacy in these villages. Similarly, capacity building of agents responsible for climate forecasts (meteorologists from National Meteorological Agencies) and an increase in field agents are required. Households when experiencing flood choose to have other activities, it is important to support alternative financial activities (e.g., non-farm activities) to increase income and reduce poverty. Also, the promotion of capacity building and reinforcement of community awareness through training (agricultural technique for crop diversification, new crop varieties, tolerant to flood, fishing technic, etc.) and donation of needed materials such as pirogue, tolerant seed to flood, etc. is needed. In the current context, where most communities do not want to leave their villages for other places, it would be important to think about the reinforcement or construction of flood-resilient houses and the installation of hydro-agricultural facilities to considerably reduce future impacts of flooding.

The banks of the Mono River benefit from the hills in some locations, and the development of their banks would provide an important tourism attraction for the two countries. These operations can begin or start in the lower portion of the basin by constructing dykes and basins of retention, as well as establishing intake sites for drainage and irrigation systems in the fields. It will also be necessary to train farmers in agricultural diversification practices, flood-tolerant crops, the maintenance of hydro-agricultural development works, as well as to support and promote other activities in the basin, such as fishing, trade, and so on. This was developed in the village of EDOH-WOWUIKOKPE (BAS-MONO) whereby the communities were mobilized to build a water reservoir and related infrastructure that made it possible to drain the flooded areas and clean up the environment (World Bank, 2016). In this project, as explained above, communities were mobilized to participate in the building of a water reservoir or retention basin to reduce the flood risk in their village and develop new activities that could increase their income. Here is some feedback from the implementation of this project (World Bank, 2016):

"*They all mobilized to support the initiative. It is a real source of local labor, which has helped to speed up the work. The environment is now cleansed, and the large quantities of water that invaded the houses are drained towards the basin and will be used for crops during the off-season*," explained Yao Alex Hoegnikou, director of the NGO Organization of Volunteer Development Actors. -Action plus (OVAD-AP) which supervised the population during the execution of the works.

"*We have now forgotten about the floods, and our agricultural activities are resuming. Before, women went to other localities to work in the fields of others; now they can cultivate their own fields. We have also decided to embark on fish farming, an economic activity that we have so desired in this village*," says Yawovi Zomatsi, village chief.

It is a good example of a project that can be improved and developed in the other villages with the hydro-agricole system to reduce the flood risk in the Lower Mono River basin.

These initiatives can be carried out by each country's agriculture, livestock, and fisheries ministries as well as the tourism one, in partnership with the ANPC, international organizations such as the FAO, the UNDP, the World Bank, and other non-governmental organizations (NGOs) such as Caritas, the Red Cross, and others. It is also critical to include the scientific community.

This will make it easier for communities to carry out their varied activities and will considerably reduce poverty and hunger. Similarly, their health will be protected. It is also critical that the government, based on the mapping of potential flood zones, prohibits the settlement of homes in these zones by applying sanctions. To ensure that this restriction is followed, it would be important to enhance awareness and information among communities and local governments upstream. All these actions will contribute to the achievement of certain sustainable development goals, such as poverty and hunger reduction, health preservation, quality education, and climate change mitigation measures.

6.2.3. Recommendations for the local population:

To the local communities we recommend:

- Develop open and frank collaboration with stakeholders involved in flood risk management;
- Change their way of thinking, join forces, and decide that the situation must change for their well-being and for future generations;
- Respect the recommendations and instructions of local authorities or decision-makers in flood risk management frameworks;
- Efficiently manage the support systems or infrastructures made available to them;
- Join forces and help each other to implement perceived more efficient measures;
- Develop risk prevention rather than reactivity skills by keeping abreast of climate forecasts and combining this with their knowledge of local warning indicators to take appropriate measures so as not to be surprised by flooding, which happens every year.

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APPENDICES

7.1.APPENDICE I: Questionnaire

Questionnaire No.____________

Country of residence: (a) Togo (b) Benin

Name of the prefecture/commune____________

Name of the district/Township: ____________

Name of the village ______________________________________

Coordinates of the village: latitude ____________ longitude ____________

Coordinates of the house: latitude _____________ longitude ______________

Name of Interviewer: ____________________________

Name of Interviewee: ____________________________

Date of interview: ____________

Questionnaire contents:

1. **Household characteristics**
2. **Household members and house conditions**
3. **Household land (Plots characteristics): natural conditions, tenure, inputs and use**
4. **Climate change impacts and vulnerability**
5. **Flood risks patterns, impacts, coping and adaptation strategies**
6. **Government action against floods**
7. **Insurance**

Evaluation of Interview Quality: **1-Poor** **2- Fairly good** **3- Good** **4- Excellent**

1. HOUSEHOLD CHARACTERISTICS

1.1. Sex: **Male** ☐ **Female** ☐ **Other** ☐

1.2. Age (years): ________ (Interviewer: Please write down the exact age in years)

1.3. Marital Status: ________
a. Single b. Married c. Divorced/Separated d. Widow/Widower

1.4. Ethnicity: _____________
(Codes of ethnic group: 1 Adja, 2 Fon, 3 Kotafon, 4 Ewé , 5 Mina , 6 Ouatchi, 7 others:________)

1.5. Education level of the respondent: _____________
a. no education; b. primary; c. secondary; d. university

1.6. Years of education of respondent: ____________

1.7. Are you able to read and write?: _____________
a. Yes b. No c. Won't say

1.8. What is the highest level of education in the household: _____________
a. no education; b. primary; c. secondary; d. university

1.9. How many person in your household can read and write?: _________________ persons

1.10. Relationship to the head of household
a. I am the head of our household
b. I am the spouse of the head of household
c. I am the Son/Daughter of the head of household
d. I am the parent of the head of household
e. Other (please specify): ____

1.11. Which religion(s) is primarily practiced in your household (Multiple response possible)?
a. Christianity; b. Traditional (Vodoo); c. Islam; e. None d. Other to be specified:

1.12. Do you practice farming?: _____________ (a. Yes; b. No; If No, the respondent drops out of the survey)
If yes,

1.13. Since how many years do you practice farming?: _______________________________________
1) Less than 10 years 2) 11-20 years 3) 21-30 years 4) more than 30 years

1.14. To what extent is your household income dependent on agricultural activities?: _____________
a. Low dependency (< 25%)
b. Medium dependency (25% - <50%)
c. High dependency (50% - <75%)
d. Very high dependency (75% - 100%)
e. Can't tell/do not want to say

1.15. Does your household practice other activities or have other sources of income aside from agricultural activities? If yes, please name them? (multiple responses possible):

____

a. Livestock
b. Fisheries
c. Hunting
d. Local industries (loggers, processing of local products etc)
e. Building and Public Works
f. Commerce, Catering and Lodging
g. Transport and communication
h. Banks and Insurance
i. Other (to specify): ____

2. HOUSEHOLD MEMBERS AND HOUSE CONDITIONS

2.1. How many people does your household have? (including respondent):____________ (total)

___Male; ___female; ___Child (under 15 years of age); _____ Old Persons (above 60)

2.2. What is the number of dependents? (including respondent) ___________________
Note: *Include explanation for interviewer on the term of dependants*

2.3. Is your house affected by flood? **Yes** ☐ **No** ☐

2.4. If yes, what is the approximate depth of water in your home when there is flooding? : _____________

a) 0 to 0.5m; **b)** 0.5 to 1m; c) >1 to 2m; **d)** > 2m

2.5. House conditions (directly observed by interviewer):

Floor:	Walls:	Roof:
1 Compressed soil	1 Clay	1 thatch/ Straw
2 Cement concrete	2 wooden planks	2 iron/cement sheet
3 Patterned tile	3 cement/brick	3 cement concrete

2.6. House with a high foundation (directly observed by the interviewer)? : __________

(a.Yes; b.No).

3. HOUSEHOLD LAND: NATURAL CONDITIONS, TENURE, INPUTS AND USE

3.1. Tenure on landholdings and Farming characterization of landholding plots:

Plot ID	**3.1.1. -How did you acquire your land** 1- newly and freely cleared 2- inherited/Shared 3- use right given by local leaders 4. Per purchase; 5. Borrowing 6- other______	**3.1.2. -In general, your use rights to the plot are secured by what?** 0- none 1- your crops or trees on it 2- certified map/ sale receipt 3- customary regulation	**3.1.3. What main annual crops have you grown on this plot during the last cropping season?**	**3.1.4. What kind of soil-water conservation measure have you applied for this plot during the last cropping season?** 0- None 1- Rock bunds 2- Soil bunds 3- Terraces 4-Grass lines	**3.1.5. Did you apply fertilizers (Such as green or animal manure)?** 0- None 1- Green manure 2- Animal Manure 3 – Inorganic	**3.1.6. Did you apply any multiple cropping methods?** 0- None 1- Intercropping 2- Overlapping (If 1 or 2, then ask which crops intercropped)

	(multiple choices are possible)	4- other_____ (multiple choices are possible)					5-Stone line 6-Mulching 7-Cover crop 8-Other_____	4-others	
			Dry Season		**Wet Season**				
			Crop 1	**Crop 2**	**Crop 1**	**Crop 2**			
	1& 3	2 & 3	Vegetable	Maize	Maize	Cassava	3	1	0
1									
2									
3									
4									

CROP PRODUCTIVITY, LIVESTOCK PRODUCTION & INPUTS

3.2. Yield of each crop on the land (according to own perception in general and percent estimation of product sold).

Note: For the unit, they may give other, take it and ask about the equivalence in Kg.

Crops	Total Area	Cropping Season (applicable for annual crops only)		Estimation crop yield			Products sold			
							Normal year		Flooded year	
		Dry	Wet	Unit	Normal year	Flooded year	% yield for household consumption?	Price Sold per kg? (FCFA)	% yield for household consumption?	Price Sold per kg? (FCFA)
rice	2 ha		X	kg	50	30	50%	300	20%	400

3.2.1. How much do you invest for the agricultural activities?: ___________________________________

3.2.2. For future investments, what type of land-use/landscape do you prefer ?____________________

3.2.3. Why do you like such land use? ____

3.2.4. Do you have any plan to open new land/convert your lands/plot? Y/N: _____

3.2.5. What type of land use do you plan to convert your plot to? ____

3.2.6. Of all the land uses you have, which do you think is the most suitable for flooding risk management? ______________________________

3.3. Livestock production

Main livestock of the household	3.3.1. Number of animals?		3.3.2. Product sold to the market				3.3.3. Cost of feeding (per month)	
			Normal year		Flooded year		Normal year	Flooded year
	Normal year	Flooded year	% product sold	Price Sold per kg? (FCFA)	% product sold	Price Sold per kg? (FCFA		
Poultry								
Sheep/Goat								
Cattles								
Chicken								
Pig								
Other:								
Other:								

4. CLIMATE CHANGE IMPACTS AND VULNERABILITY

4.1. Please fill the table below about climate change-related hazards in the communities.

Climate change-related hazards	4.1.1. Were you **affected** by the hazard in the past? (Yes or No)	4.1.2. Over the last 20 years, was there a change in **how often** the hazard occurs? (1. More often, 2. Less often, 3. No change)	4.1.3. Over the last 20 years, was there a change in the hazard's **intensity**? (1. Increased, 2. Decreased, 3. No change)	4.1.4. In case there are changes, are you already **adapting** to them? (1. Yes, 2. No)
River Floods				
Flooding from rain				
Heat				
Drought				
Windstorm				
Erratic rainfall				
Soil erosion				
Other to specify:				

4.2. Have you heard about the concept of climate change? __________ (1. Yes, 2. No, 3. I don't know)

5. FLOOD RISKS PERCEPTIONS: PATTERNS, EFFECTS AND ADAPTATION STRATEGIES

➢ Experience and knowledge about floods

5.1. For how long have you noticed floods in the village?

≤ 10 y ☐ **11 -20 y** ☐ **21- 30 y** ☐ **> 30 y** ☐

5.2. In which period (s) have you noticed the severes flooding pattern?

≤ 10 y ☐ **11 -20 y** ☐ **21- 30 y** ☐ **> 30 y** ☐

5.3. In which years have you noticed the most severe flooding pattern? (Please write down the years)

____

5.4. What were the characteristics of those years in terms of rainfall?
1) Normal 2) Surplus in rainfall 3) Deficit in rainfall

5.5. Looking back on past flood events you experience, in what year was your household **most affected** by a flood event? (name the year)
Year: __________

5.6. Which year was the **most recent year** in which your household was affected by a flood event?
Year: ____________

5.7. How severe was flood in the last 20 years to your household?: ____________

1) No longer severe 2) Decreasing severeness 3) No change 4) Increasingly severe 5) Extremely severe 6) Don't know

5.8. How long does the water stay on average in the village during flooding?
≤ 15 days ☐ **16 - 30 days** ☐ **31-45 days** ☐ **> 45 days** ☐

5.9. Please state how often floods occur **IN ONE YEAR** in the village **NOWADAYS**?: ____________

a) Once a year **b)** Twice a year **c)** More often **d)** Don't know

5.10. Please indicate in which months floods usually occur **NOWADAYS** (indicate the time period(s))
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

5.11. Please state **AFTER HOW MANY YEARS** floods usually occur **NOWADAYS** (period of reoccurrence in years):
a) One year **b)** Every 2-4 years **c)** Every 5-10 years **f)** More than 10 years **g)** Don't know

5.12. Please state how often floods occured **IN ONE YEAR** in the village **20 YEARS AGO**?: ____________

a) once a year **b)** twice a year **c)** More often **d)** Don't know

5.13. Please indicate in which months floods usually used to occur **20 YEARS AGO** (indicate the time period(s))

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

5.14. Please state **AFTER HOW MANY YEARS** floods usually occured **20 YEARS AGO** (period of reoccurrence in years):

a) One year **b)** Every 2-4 years **c)** Every 5-10 years **f)** More than 10 years **g)** Don't know

➢ Patterns and Causes of flooding

a. What do you think are the causes of flooding over the last 20 years? (ask the respondent the question and note all that reasons that are given in their explanation; read answers if they have difficulties responding): _________________

1. Extreme rainfall in a short time
2. Long period of rain
3. Changing climate
4. Dam management
5. Impermeable surfaces
6. Over flowing of rivers
7. Steep slope
8. Presence of compacted or dry soil
9. Rising groundwater levels
10. Presence of saturated or wet soil
11. Lack of risk-reducing infrastructure (e.g. drainages, dams, …)
12. Deforestation
13. People building houses in low-lying areas/areas close to the river
14. Siltation of rivers/channels
15. God's will
16. Lack of waste management
17. Don't know
18. Other (specify): ________________________

b. What are the changes you observed with regards to rainy seasons in the past 20 years? (mention all that apply)

1. Shorter rainy seasons 2. Longer rainy seasons 3. Later rainy seasons 4. Earlier rainy seasons 5. More rain in total 6. Less rain in total 7. More intense rain 8. Less intense rain 9. No changes 8. Don't know

Note: To facilitate respondents 'response, interviewers should first explain the different concepts used.

➢ Flood impacts assessment

5.15. According to the impacts, what is the group most affected by flooding in this village?

a) Farmers b) Pastoralists c) Fishermen d) Others (state) ………………………………………………………………………………

Why?………

5.16. Which crop is the most affected by flooding?

a) Rice b) Maize c) Sorghum d) Millet e) Cassava f) Other (state)

Why?……

5.17. Did your household ever experience agricultural damage/damage to your farms due to floods?

a) Yes b) No (if no, go directly to 5.19.)

5.17.1. Which adverse effects with regards to farming did your household experience because of flood events?

	a. Yes; b. No
Loss of farmland	
Crop damage	
Decrease in farm investment	
Scarcity of labor	
Decrease in yield	
Reduction of seed quality	
Loss of livestock	
Destruction of stored processed goods/produce	
Loss of /decreased access to markets	
Others to specify:	

5.17.2. On average (over the last 20 years), how often does your household experience agricultural damage/damage to your farms due to floods?

a) Several times a year; b) Once a year; c) Twice a year; d) Every 2-4 years; e) Every 5-10 years f) More than 10 years

5.17.3. How severe is the agricultural damage/damage to your farms on average per flood event?

a) Low b) Moderate c) High

5.17.4. Does your household have strategies to reduce the **RISK OF AGRICULTURAL DAMAGES** from floods?

a. Yes b. No (go to 5.18.9. if "No")

5.17.5. What are usually your strategies to reduce the risk of **AGRICULTURAL DAMAGE/DAMAGE TO FARMS** from floods? Please **RANK** them in terms of satisfaction after mentioning them? (Instruction for the interviewer: Please rank the measure with highest satisfaction with 1.)

Strategies	*a. Yes; b. No*	**Rank them with:** 1= high satisfaction, 2= satisfaction and 3= least satisfaction
Create drainage systems		
Focus on other activities (Ex: Palm nuts selling; fisheries, livestock, etc.)		
Diversification of crop varieties		
Crop substitution		
Changing cropping calendar		
Evacuate livestock before the flood		
Tree planting (e.g., mangroves)/Grass, Tree line		
Fallowing		
Convert to a new land use		
Do not do anything		

Other		
Other		

5.17.6. Will ________________ (first adaptation strategy/measure) reduce flood risks?
I don't believe it: ___; I believe ____; I don't know ____

5.17.7. What is the least costly adaptation strategy/measure (in terms of time and work)? ___________________________

5.17.8. Which of the adaptation measures is the most effective but most costly?
Answer : ___________________________...

5.17.9. How much time does your household need on average to recover **FINANCIALLY** from the damage to your **AGRICULTURAL/FARMS**?
a) 0 – 5 months b) 6 months - 11 months c) 1 – 2 years d) > 2 years d) Usually no recovery from the impacts

5.17.10. Please provide information on the damaged plots (Instructions: Inquire about a flooded area (flooded plot)

Plot ID	Coordinates of the plot	Total affected area (in ha)	Plot location **a**. Lowland **b.** Middle **c**. Upland	What is the Probability of the area being inundated? **1.** Low **2.** Middle **3.** High	What is approximattly the water depth of the plot when flooded **(m)** **1.** 0 to 0.5 **2.** 0.5 to 1 **3.** 1 to 2 **4.** > 2	What is the actual use of the farm a. still cultivated b. Under fallow c. abandoned
1						
2						
3						
4						

(If the plot is still cultivated, skip 5.18.11 and 5.18.12)

5.17.11. If under fallow, please specify for how long it has been fallowed: ____________Years

5.17.12. If abandoned, why? (Multiple answers are possible)

1 low crop yield
2 flooding event
3 lack of labor
4 for soil recovering
5 too far from home
6 other reasons: _____________

5.18. Did your household ever experience material damages (to your house or personal material belongings) due to floods?

a) Yes b) No (if no, go to 5.20.)

5.18.1. Which of the following material damages did your household experience due to floods? (MULTIPLE responses possible)

Material damage	*a. Yes; b. No*
Damaged/flooded house of residence	
Damaged/lost properties & goods (e.g., furniture, clothes, motorbike, mobile phone/tablet, etc.)	
Damaged infrastructure and public facilities (roads, electricity, water, sanitation, telecommunication, public/religious buildings etc.)	
Others :	

5.18.2. On average (over the last 20 years), how often does your household experience material damage due to floods?

a) Several times a year b) Once a year c) Every 2-4 years d) Every 5-10 years e) More than 10 years

5.18.3. How severe is the material damage to your household on average per flood event?

a) Low b) Moderate c) High

5.18.4. Does your household have strategies to reduce the **RISK OF MATERIAL DAMAGE** from floods?

a. Yes b. No (go to 5.19.9. if "No")

5.18.5. What are usually your strategies to reduce the risk of **MATERIAL DAMAGE** from floods? Please **RANK** them in terms of satisfaction after mentioning them? (Instruction for the interviewer: Please rank the measure with highest satisfaction with 1.)

Strategies	***a. Yes; b. No***	**Rank them with:** 1= high satisfaction, 2= satisfaction and 3= least satisfaction
Having canoes/ Sandbag track/pneu track		
Temporarily moving all household members to a safe place		
Having a temporary house in a safe zone		
Do other activities to subside the household needs		
Hanging items in the house to a high place		
Clearing drainage infrastructure or Building drainage infrastructure		
Strengthen house/ Raising foundation of house		
Raising entrance		
Attending flood preparedness training		
Building an embankment/embankments/dikes close to the river		
Saving money in anticipation of the flood		
Ceremonies or sacrifices of invocations of the protective gods		
Do not do anything		
Other:		
Other:		
Other:		

5.18.6. Will __________________ (first adaptation strategy/measure) reduce flood risks?

I don't believe it: ___; I believe ____; I don't know ____

5.18.7. What is the least costly adaptation strategy/measure (in terms of time and work)? ____________________________

5.18.8. Which of the adaptation measures is the most effective but most costly?

Answer : ____________________________

5.18.9. How much time does your household need on average to recover **FINANCIALLY** from the **MATERIAL DAMAGE**?: ____________

a) 0 – 5 months b) 6 months - 11 months c) 1 – 2 years d) > 2 years d) Usually no recovery from the impacts

5.19. Did your household ever experience health impacts due to floods?

a) Yes b) No (if no, go to 5.21.)

5.19.1. Which of the following health impacts did your household experience due to floods? (MULTIPLE responses possible)

Health impact	*a. Yes; b. No*
Sickness of a household members	
Injury of a household member	
Death of a household member	
Psychological impacts (Fear, trauma, depression, etc.)	
No food/reducing the consumption of food	
Polluted/no drinking water	
Others :	

5.19.2. On average (over the last 20 years), how often does your household experience health impacts due to floods?

a) Several times a year b) Once a year c) Every 2-4 years d) Every 5-10 years e) More than 10 years

5.19.3. How severe are the health impacts on average per flood event?

a) Low b) Moderate c) High

5.19.4. Does your household have strategies to reduce the **RISK OF HEALTH IMPACTS** from floods?

a. Yes b. No (go to 5.20.9 if "No")

5.19.5. What are usually your strategies to reduce the risk of **HEALTH IMPACTS** from floods? Please **RANK** them in terms of satisfaction after mentioning them? (Instruction for the interviewer: Please rank the measure with highest satisfaction with 1.)

Strategies	***a. Yes; b. No***	**Rank them with:** 1= high satisfaction, 2= satisfaction and 3= least satisfaction
Storing food reserves and medication in safe places		
Sending kids away to relatives at a safe place		
Temporarily move away from flooded area		
Permanently move away from flooded area		
Traditional medicine		
Going to a hospital/clinic/community health care worker		
Other:		
Other		
Other		

5.19.6. Will _________________ (first adaptation strategy/measure) reduce flood risks?

I don't believe it: ___; I believe ____; I don't know ____

5.19.7. What is the least costly adaptation strategy/measure (in terms of time and work)? __________________________

5.19.8. Which of the adaptation measures is the most effective but most costly?

Answer : __________________________

How much time does your household need on average to recover **FINANCIALLY** from the **HEALTH IMPACTS**? : ____________

a) 0 – 5 months b) 6 months - 11 months c) 1 – 2 years d) > 2 years d) Usually no recovery from the impacts

Did your household ever experience impacts on its commerce due to floods?: ____________

a) Yes b) No (if no, go to 5.22.)

Which of the following impacts on its commerce did your household experience due to floods? (MULTIPLE responses possible)

Impacts on household's commerce	*a. Yes; b. No*
No/less income	
Destruction of stored processed goods/produce	
Loss of /decreased access to markets	
Others:	
Others:	
Others:	

On average (over the last 20 years), how often does your household experience impacts on its commerce due to floods?

a) Several times a year b) Once a year c) Every 2-5 years d) Every 5-10 years e) More than 10 years

5.19.9. How severe are the impacts on your households' commerce on average per flood event?

a) Low b) Moderate c) High

Does your household have strategies to reduce the **RISK OF HEALTH IMPACTS** from floods?

a. Yes b. No (go to 5.21.9 if "No")

5.19.10. What are usually your strategies to reduce the risk of impacts on your **HOUSEHOLD'S COMMERCE** from floods? Please **RANK** them in terms of satisfaction after mentioning them? (Instruction for the interviewer: Please rank the measure with highest satisfaction with 1.)

Strategies	***a. Yes; b. No***	**Rank them with:** 1= high satisfaction, 2= satisfaction and 3= least satisfaction
Storing commercial goods/produce in safe places		
Having alternative ways of making money		
Keeping savings		
Others:		
Others:		
Others:		

5.19.11. Will __________________ (first adaptation strategy/measure) reduce flood risks?

I don't believe it: ___; I believe ____; I don't know ____

5.19.12. What is the least costly adaptation strategy/measure (in terms of time and work)? ____________________________

5.19.13. Which of the adaptation measures is the most effective but most costly?

Answer : ____________________________

5.19.14. How much time does your household need on average to recover **FINANCIALLY** from the impact on its **COMMERCE**?: : ______________________________

a) 0 – 5 months b) 6 months - 11 months c) 1 – 2 years d) > 2 years d) Usually no recovery from the impacts

Which if the following additional impacts did your household experience due to floods? (MULTIPLE responses possible): : ____________________________

a) Culturally important places were destroyed (e.g. cemetery) b) Household members had to leave the houses temporarily c) Household members moved away from the village permanently d) Interruption of education/schools were closed e) Social life was disturbed f) Movement was difficult g) Others: ________________

Do you personally have the capacity to reduce flood risk: Yes: ___ No: ___ I don't know: ____

5.20. Flood risk reduction is very costly. Yes: ___; No: ____; I don't know: ___

Risk of future flooding :

5.21. Do you think floods will in the future: Increase___ ; Decrease___ ; No change___ ; I don't know___ . : __________________________

5.22. How likely do you think it is that your property (house and farm) will be flooded in the future? ___%

5.23. To what degree will you feel the negative consequences of the floods? __________________________

1 = not severe; 2 = severe 3 = very severe 4 = extremely severe

5.24. Are you generally willing to take risks? Yes: __ No: __ I don't know: ___ : __________________________

Financial coping strategies to deal with damage from floods

5.25. Are you or someone of your household member of a savings group?: ____________________________

a) Yes b) No c) Won't say/Don't know

5.26. In case of experiencing those flood impacts mentioned before, to which of those options **DO YOU HAVE ACCESS TO** cover your **FINANCIAL NEEDS** from those impacts (MULTIPLE answers possible)?: ____________________________

- Cooperatives
- Support from the government
- Support from NGOs
- Community solidarity fund
- Insurance
- Credit from savings group(s)
- Remittances from family member or friends
- Credits from a private money lender
- Credits from banks
- Dealing with it on my own (for example by spending savings, spending less or selling possessions)
- Others: ____
- None of the options mentioned above

5.27. (Skip this question if remittances was not selected before) Where do the remittances from household members, relatives or friends to cover the financial needs arising from flood impacts?: ____________________________

1. From within the country 2. From outside the country 3. Both 4. Won't say

How satisfied are you with the options you have access to to cope with the financial impacts of floods? 1) Very unsatisfied 2) Unsatisfied 3) Indifferent 4) Satisfied 5) Very satisfied

Why?

____

_____

5.28. Which of the options **WOULD YOU PREFER TO ACCESS IN FUTURE** for covering the **FINANCIAL NEEDS** arising from flood impacts mentioned before? (Instruction for the interviewer: Please rank the measure with highest satisfaction with 1.)

Option	**Yes or No**	**Ranking (**1= high satisfaction, 2= satisfaction and 3= least satisfaction**)**
Cooperatives		
Support from NGOs		
Support from the government		
Insurance		
Community solidarity fund		
Credit from savings group(s)		
Credits from a private money lender		
Credits from banks		
Remittances from family members or friends		
Dealing with it on my own (for example by spending savings, spending less or selling possessions)		
Others:_______________		
None of the options mentioned above		

➢ Land management and adaptation strategies to flood

5.29. Do you anticipate the arrival of floods? Yes ☐ No ☐
If yes, which preparedness actions do you take?
……………………...
....

5.30. What flood warning signals or indicators are needed for you to take an action? :
____

1. Rainfall duration
2. Current water depth (balise)
3. Flood forcasting (radio, tv, meteo)
4. Rainfall
5. Communities information
6. Alarm (call, message)
7. Early warning system
8. Proximity to the river
9. House conditions
9. Other to specify.

5.31. Is there other traditional flood signals or indicators for you take action?
____

5.32. How does in your view each of these indicators contribute to reduce flood-related impacts?

Indicators	**Degree of contribution** **1**.High **2.** Medium **3**.Low
Rainfall duration	
Current water level (balise)	
Flood forcasting (radio, tv, meteo)	
Communities information	
Alarm	
Early warning system	
Proximity to the river	
House conditions	
Other to specify	

5.33. Do you think flooding is a risk in your village? Yes ☐ No ☐
If yes, why do you live in such an area?:…………………………………………………….

5.34. Is there a flood management committee in your community? Yes ☐ No (go ☐ 5.43.)

5.35. Are you a member of the committee? Yes ☐ ☐
a) What are the actions implement by the committee?:………………………………………
……..
…………………………………………………………………………………………………

5.36. Did anyone in your household ever attend an orientation, training or sensibilization about floods in particular? : ____ (a. Yes, b. No)
If yes, who gave the orientation/training/sensibilization ?
____
What is the type of orientation/training/sensibilization ?
____

5.37. Do you think awareness raising and/or training is useful? Yes ☐ No ☐
Why?
………

5.38. In the event of flooding, do you think it is not necessary to act, because it will not change anything
Yes ☐ No ☐

6. GOVERNMENT ACTION AGAINST FLOODS

6.1. Is there any prevention and protection measures or actions implemented by the government against floods in the village? Yes___ / No____ (if no, skip 6.1.2.)

6.1.1. If yes, please cite them (Check the respondent's answers and ask how they are useful in relation to risk management by filling the table below)

Actions taken by the government	**Are these actions implemented? (Yes/ No)**	**Are they useful? (Yes/No)**
Awareness-raising campaigns (on the culture of risk) / capacity building of communities		
The establishment of an (early) warning system		
Reforestation (mangroves) as a way to limit the effects		
Community mapping of risk areas		
Construction of protective dikes		
Engineering plan		
Tanks for water storage		
Construction of a bridge over the Mono River (Athieme)		
Improvement of road infrastructure		
Building Resilient Homes		
Selection of varieties/seeds with high resilience to climate change		
Resettlement/displacement of the population		
Flood preparedness activity		
Identification and training of focal points		
Construction of boreholes for drinking water in the host sites		
Soil remediation works and periodic dredging		
Extension of seasonal forecasts		
Training of peer educators and rescue workers		
Subsidy programs of farms		
Subsidie fertilizers		
Equipment (e.g. machine) of Agricultural production		
Other to specify :		

6.1.2. How do you appreciate the government's ability to anticipate and prepare for floods?
1. *Very good; 2. Good; 3.Indifferent 4. Bad; 5. Very Bad; 6 None*

6.2. Is there any prevention and protection measures or actions implemented by a NGOs against floods in the village? Yes___ / No____

6.2.1. If yes, please cite them :……..……………………………………………………………

Were those actions useful?
a) very useful b) useful c) indifferent d) not really useful e) not useful at all

6.3. Do you get help from the government during and after floods? Yes ☐ No ☐

6.4. If yes, what kind of assistance do you get?..

Actions taken by the government	**Are these actions implemented? (Yes/ No)**	**Are they useful? (Yes/No)**
Donation of mosquito nets and medicines		
Displacement of populations in places on		
Gift of tent and living		
Financial allowance to compensate for losses (agricultural, material, etc.) due to flooding		
Other		
Other		

How do you rate the government's response during and after the floods?:…………………………….
(1. Very good; 2. Good; 3.Indifferent 4. Bad; 5. Very Bad; 6 None)

6.5. Do you get help from any NGOs/structures during and after floods? Yes ☐ No ☐

6.6. If yes, what kind of assistance do you get?...
……………………………………………………………………………………………………
…………

6.7. How do you rate the NGO's response during and after the floods?
(1. Very good; 2. Good; 3.Indifferent 4. Bad; 5. Very Bad; 6 None)

6.8. What do you think should be done by the community to address the risk of flooding?...

Measures	Will you agree and participate to this kind of project? (Yes or No)
Engineering *(Such as a levee, dyke, drain, bridge, etc....)*	
Agricultural development plan (drainage sytem, irrigation, etc)	
Grant for buildings resilient houses	
Donation of land in another locality (permanent relocation of the village)	
Other:	
Other:	

6.9. . What are your expectations of the government?...
……………………………………………………………………………………………………
………………...

6.10. What do you think the community needs to do to adapt to future floods?
……………………………………………………………………………………………………
………………..…………………………………………………………………………………
……………………

7. Household income

7.1. What is your household income **PER YEAR**? (in CFA)

1) Less than 100.000 2) 100.001- 200.000 3) 200.001- 300.000 4) More than 300.000 5) No response

7.2. Income by month

Indicate relevant months with a circle around the relevant month number	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
1. In which months do you experience your highest level of income?	1	2	3	4	5	6	7	8	9	10	11	12
2. In which months do you experience your lowest level of income?	1	2	3	4	5	6	7	8	9	10	11	12

Insurance

7.3. Perception of insurance

On a range from 1 to 5- state to which extent you agree with the statements from a. to d.?	*1. I disagree* *2. I rather disagree* *3. Indifferent* *4. I rather agree* *5. I agree*
a. I understand how insurance works	
b. I trust that insurance companies will cover the damages they promised to cover	
c. Insurance is only there for rich people	
d. If I am purchasing insurance, my household is lacking money to cover immideate and essential needs	

7.4. Do you or any member of your household have some form of insurance at the moment?

a. Yes b. No (go directly to question 7.6)

7.5. What type of insurance is this? (name ALL types you have) (go to 7.9 afterwards)

1. Medical Insurance 2. Vehicle Insurance 3. Contents Insurance 4. House Insurance 5. Personal Accident Insurance

6. Life Insurance 7. Crop/Livestock Insurance 8. Flood insurance 9. Other:______________________

Did you or any member of your household ever have insurance before?

a. Yes b. No (go directly to question 7.8)

7.6. Which type(s) of insurance did your household have before? (name ALL types you had) (Skip next)

1. Medical Insurance 2. Vehicle Insurance 3. Contents Insurance 4. House Insurance 5. Personal Accident Insurance

6. Life Insurance 7. Crop/Livestock Insurance 8. Flood insurance 9. Other:______________________

7.7. Why does your household NOT have any type of insurance? (Please write down all points mentioned by the respondent)

____

____

____

____

7.8. Explain: Imagine that there is an insurance policy for floods under consideration to be implemented in your country:

- The policy expects you to pay an annual premium to the insurance company for the case that your household might be affected by a severe flood event.

- The payout stated in the policy will be made when a damaging flood occurs

In your opinion, which is the most important flood impact to be covered in such a flood insurance product? (Only **ONE** response possible)

1) Material damage (House and other personal belongings) 2) Agricultural damage/Damage to farms

3) Health impacts 4) Impact on household's commerce 5) None of those impacts 6) Don't know

7.9. How likely is it that your household will purchase such flood insurance covering this impact selected before if it would be available? (if the answer is Likely or Rather likely skip next question and go to 7.12. directly)

1. Likely 2. Rather likely 3. Indifferent 4. Rather unlikely 5. Unlikely

7.10. Why will you probably not like to buy flood insurance products or why don't you know? (Please write down all points mentioned by the respondent) (if this question was answered end interview here)

____
____
____
____
____

7.11. What would be your preferred way for paying yearly premiums for the insurance product? (Name ONE option only)

a. Credit Union b. Shop c. Bank d. Mobile payment service (for example Flooz, T-Money) e. Post Office

f. By hand/in chash g) Don't know h). Other (please state): ____

7.12. What would be your preferred way for receiving the payout of an insurance product? (Name ONE option only)

a. Credit Union b. Shop c. Bank d. Mobile payment service (for example Flooz, T-Money) e. Post Office

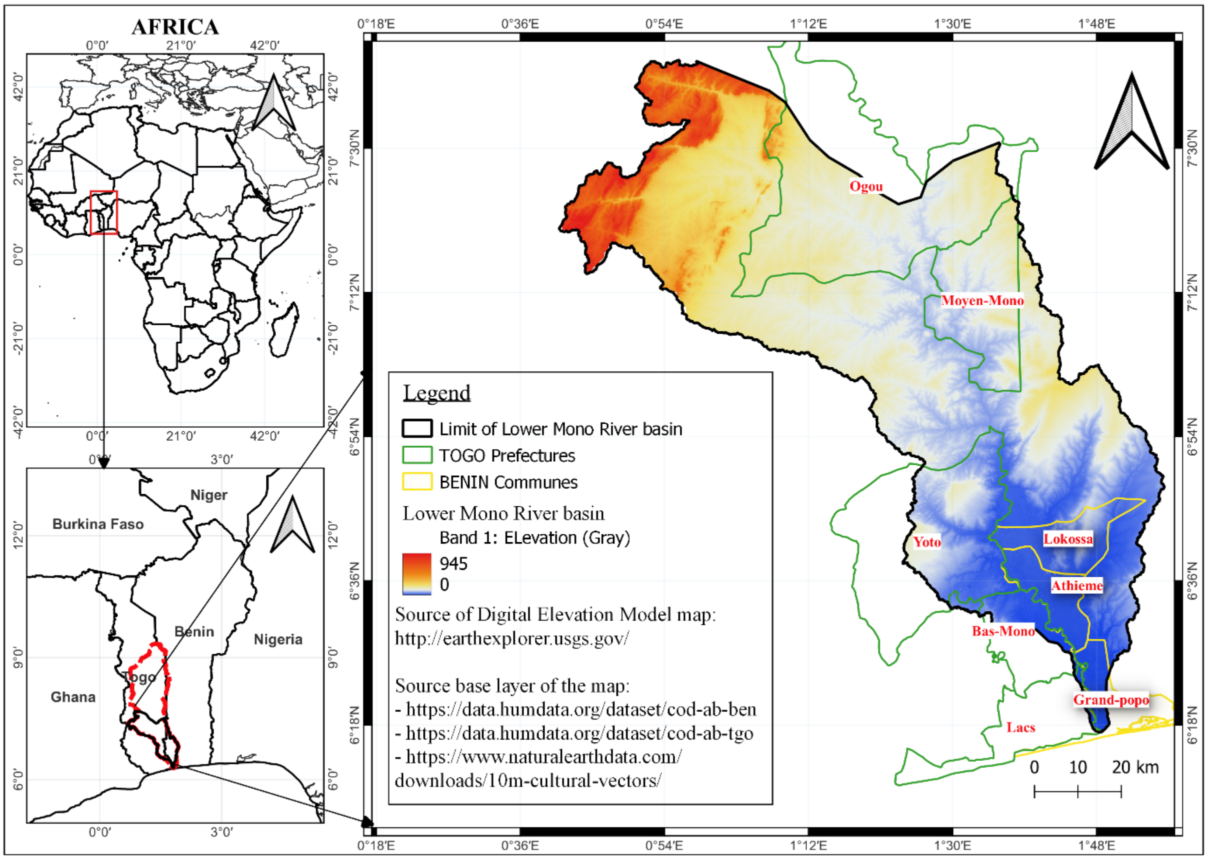
f. By hand/in chash g. Don't know h) Other (please state): ______________________________________

7.13. What is the longest time you could wait to receive a flood insurance payout in case of a flood event to cover for the losses you incurr, mentioned before (Material damage; Agricultural damage/Damage to farms; Health impacts or Impacts on commerce)?

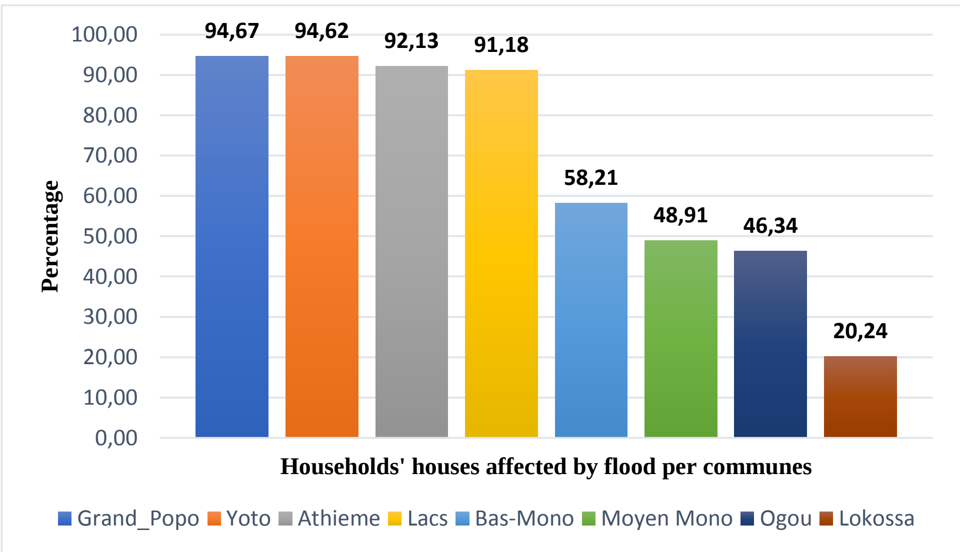
a. Not longer than 3 days b. From 3 to 7 days c. From 1 to 2 weeks d. Longer than 2 weeks

7.2.APPENDICE II: Topographic map Climatic data

➢ **Topographic map**



➢ **Households' houses affected by flood per communes in the perception of households surveyed**



- **Annual Climatic Research Unit (CRU) rainfall data**

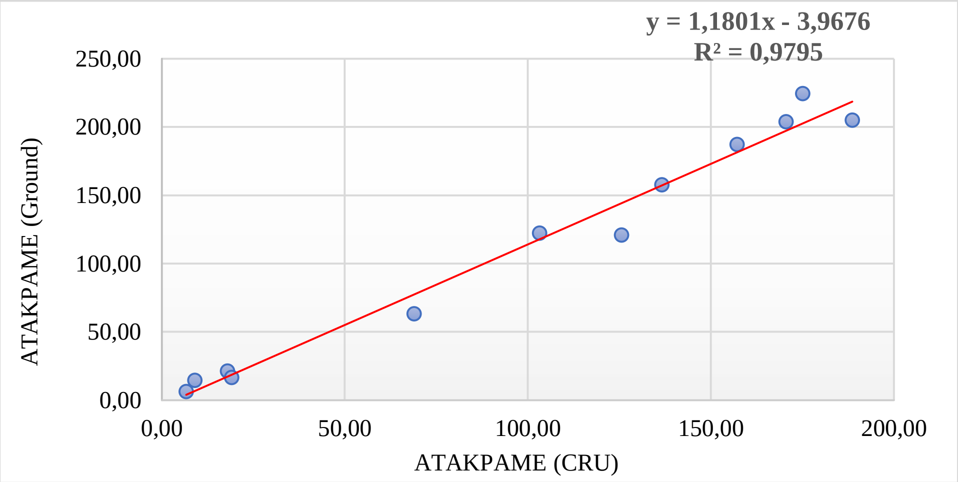
Years	OGOU	MOYEN MONO	YOTO	BAS MONO	LACS	GRAND POPO	LOKOSSA	ATHIEME
1979	1423.6	1335.5	1295.5	1295.5	1308.2	1308.2	1295.5	1295.5
1980	1227.5	1168.1	1103.7	1103.7	1151	1151.0	1103.7	1103.7
1981	1098.9	979.9	950.3	950.3	972.7	972.7	950.3	950.3
1982	855.9	765	866.8	866.8	1182.4	1182.4	866.8	866.8
1983	787.4	699.2	671.3	671.3	789.5	789.5	671.3	671.3
1984	1227.8	1004.6	921.9	921.9	1072.6	1072.6	921.9	921.9
1985	1304.1	1050.4	997.1	997.1	1023.7	1023.7	997.1	997.1
1986	1042.2	939	857.8	857.8	856.5	856.5	857.8	857.8
1987	1207.7	1150.3	1189.7	1189.7	1140.8	1140.8	1189.7	1189.7
1988	1378.4	1307.5	1123.9	1123.9	1131.7	1131.7	1123.9	1123.9
1989	1372.9	1182.1	1115.5	1115.5	1185.8	1185.8	1115.5	1115.5
1990	1094.3	1095.3	890.8	890.8	951.2	951.2	890.8	890.8
1991	1304.9	1120.3	1081.9	1081.9	1167.3	1167.3	1081.9	1081.9
1992	984.0	813.2	793.1	793.1	861	861.0	793.1	793.1
1993	1090.8	1024.5	1072.6	1072.6	1184.3	1184.3	1072.6	1072.6
1994	1024.6	1013.6	948.9	948.9	992.5	992.5	948.9	948.9
1995	1373.3	1269.2	1122.7	1122.7	1073	1073.0	1122.7	1122.7
1996	1038.8	994.5	980.8	980.8	1092.3	1092.3	980.8	980.8
1997	1068.7	1104.8	1148.2	1148.2	1284.4	1284.4	1148.2	1148.2
1998	1079.5	907.6	859.7	859.7	909.8	909.8	859.7	859.7
1999	1401.3	1231.4	1138.7	1138.7	1181.7	1181.7	1138.7	1138.7
2000	1089.0	955.4	883.8	883.8	914.2	914.2	883.8	883.8
2001	888.2	811.2	782.7	782.7	835.5	835.5	782.7	782.7
2002	1190.5	1065.9	1047.1	1047.1	1170.3	1170.3	1047.1	1047.1
2003	1336.8	1187.2	1131.9	1131.9	1197.1	1197.1	1131.9	1131.9
2004	1244.7	1124.6	1086.3	1086.3	1143.7	1143.7	1086.3	1086.3
2005	1068.8	970.1	953.9	953.9	1031.8	1031.8	953.9	953.9
2006	1079.1	997.8	978.0	978.0	1039.8	1039.8	978	978
2007	1360.9	1259	1211.3	1211.3	1273.9	1273.9	1211.3	1211.3
2008	1382.5	1262.9	1225.5	1225.5	1314	1314.0	1225.5	1225.5
2009	1237.9	1124.2	1073.2	1073.2	1142.6	1142.6	1073.2	1073.2
2010	1404.3	1295.5	1268.0	1268.0	1355.7	1355.7	1268	1268
2011	1164.7	1072.5	1055.9	1055.9	1135	1135.0	1055.9	1055.9
2012	1169.1	1076.4	1035.9	1035.9	1090.9	1090.9	1035.9	1035.9
2013	1043.9	991.5	978.3	978.3	1058.4	1058.4	978.3	978.3
2014	1266.9	1168.4	1141.9	1141.9	1218.3	1218.3	1141.9	1141.9
2015	1011.3	950.3	942.7	942.7	1008.2	1008.2	942.7	942.7
2016	1094.9	985	959.8	959.8	1041.9	1041.9	959.8	959.8
2017	1123.8	1023.6	994.7	994.7	1078	1078.0	994.7	994.7
2018	1305.2	1173	1108.6	1108.6	1156.5	1156.5	1108.6	1108.6
2019	1473.5	1378.5	1360.8	1360.8	1471.5	1471.5	1360.8	1360.8

➢ Annual rainfall anomaly

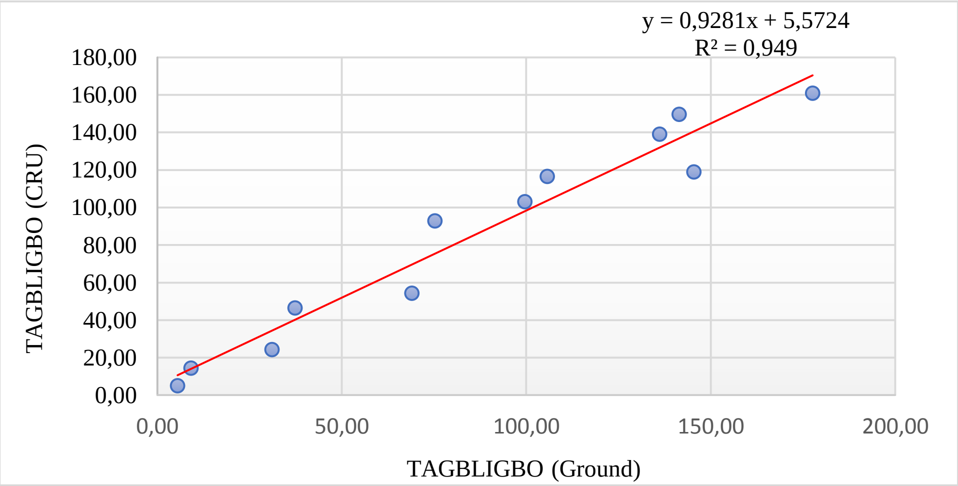
Years	Annual rainfall anomaly OGOU	Annual rainfall anomaly MOYEN MONO	Annual rainfall anomaly YOTO	Annual rainfall anomaly BAS MONO	Annual rainfall anomaly LACS	Annual rainfall anomaly GRAND POPO	Annual rainfall anomaly LOKOSSA	Annual rainfall anomaly ATHIEME
1979	1.48	1.68	1.80	1.80	1.40	1.40	1.80	1.797
1980	0.29	0.60	0.48	0.48	0.33	0.33	0.48	0.484
1981	-0.48	-0.60	-0.57	-0.57	-0.88	-0.88	-0.57	-0.566
1982	-1.94	-1.98	-1.14	-1.14	0.55	0.55	-1.14	-1.138
1983	-2.36	-2.40	-2.48	-2.48	-2.13	-2.13	-2.48	-2.476
1984	0.30	-0.44	-0.76	-0.76	-0.20	-0.20	-0.76	-0.760
1985	0.76	-0.15	-0.25	-0.25	-0.53	-0.53	-0.25	-0.245
1986	-0.82	-0.86	-1.20	-1.20	-1.67	-1.67	-1.20	-1.199
1987	0.18	0.49	1.07	1.07	0.26	0.26	1.07	1.073
1988	1.20	1.50	0.62	0.62	0.20	0.20	0.62	0.623
1989	1.17	0.69	0.57	0.57	0.57	0.57	0.57	0.565
1990	-0.51	0.14	-0.97	-0.97	-1.03	-1.03	-0.97	-0.973
1991	0.76	0.30	0.34	0.34	0.44	0.44	0.34	0.335
1992	-1.17	-1.67	-1.64	-1.64	-1.64	-1.64	-1.64	-1.642
1993	-0.53	-0.32	0.27	0.27	0.56	0.56	0.27	0.271
1994	-0.93	-0.39	-0.58	-0.58	-0.75	-0.75	-0.58	-0.575
1995	1.17	1.25	0.61	0.61	-0.20	-0.20	0.61	0.614
1996	-0.84	-0.51	-0.36	-0.36	-0.07	-0.07	-0.36	-0.357
1997	-0.66	0.20	0.79	0.79	1.24	1.24	0.79	0.789
1998	-0.60	-1.07	-1.19	-1.19	-1.31	-1.31	-1.19	-1.186
1999	1.34	1.01	0.72	0.72	0.54	0.54	0.72	0.724
2000	-0.54	-0.76	-1.02	-1.02	-1.28	-1.28	-1.02	-1.021
2001	-1.75	-1.68	-1.71	-1.71	-1.81	-1.81	-1.71	-1.713
2002	0.07	-0.05	0.10	0.10	0.46	0.46	0.10	0.097
2003	0.95	0.73	0.68	0.68	0.65	0.65	0.68	0.677
2004	0.40	0.33	0.37	0.37	0.28	0.28	0.37	0.365
2005	-0.66	-0.67	-0.54	-0.54	-0.48	-0.48	-0.54	-0.541
2006	-0.60	-0.49	-0.38	-0.38	-0.42	-0.42	-0.38	-0.376
2007	1.10	1.19	1.22	1.22	1.17	1.17	1.22	1.221
2008	1.23	1.21	1.32	1.32	1.44	1.44	1.32	1.318
2009	0.36	0.32	0.28	0.28	0.27	0.27	0.28	0.276
2010	1.36	1.42	1.61	1.61	1.72	1.72	1.61	1.609
2011	-0.08	-0.01	0.16	0.16	0.22	0.22	0.16	0.157
2012	-0.06	0.02	0.02	0.02	-0.08	-0.08	0.02	0.020
2013	-0.81	-0.53	-0.37	-0.37	-0.30	-0.30	-0.37	-0.374
2014	0.53	0.61	0.75	0.75	0.79	0.79	0.75	0.746
2015	-1.01	-0.79	-0.62	-0.62	-0.64	-0.64	-0.62	-0.618

2016	-0.50	-0.57	-0.50	-0.50	-0.41	-0.41	-0.50	-0.501
2017	-0.33	-0.32	-0.26	-0.26	-0.16	-0.16	-0.26	-0.262
2018	0.76	0.64	0.52	0.52	0.37	0.37	0.52	0.518
2019	1.78	1.95	2.24	2.24	2.51	2.51	2.24	2.244

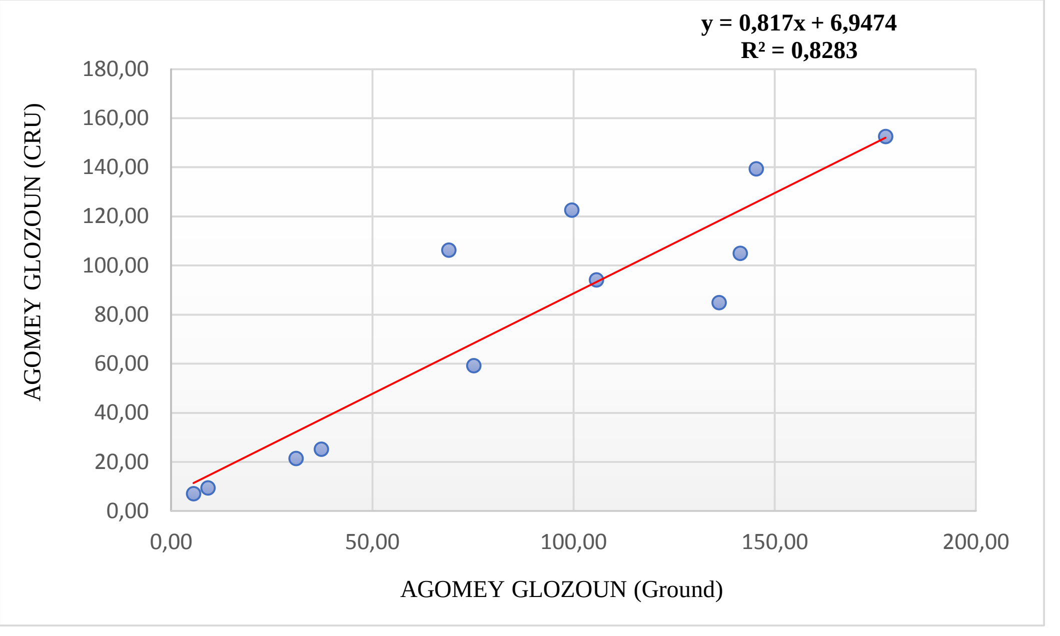
➢ **Correlation between CRU rainfall data and ground rainfall data**



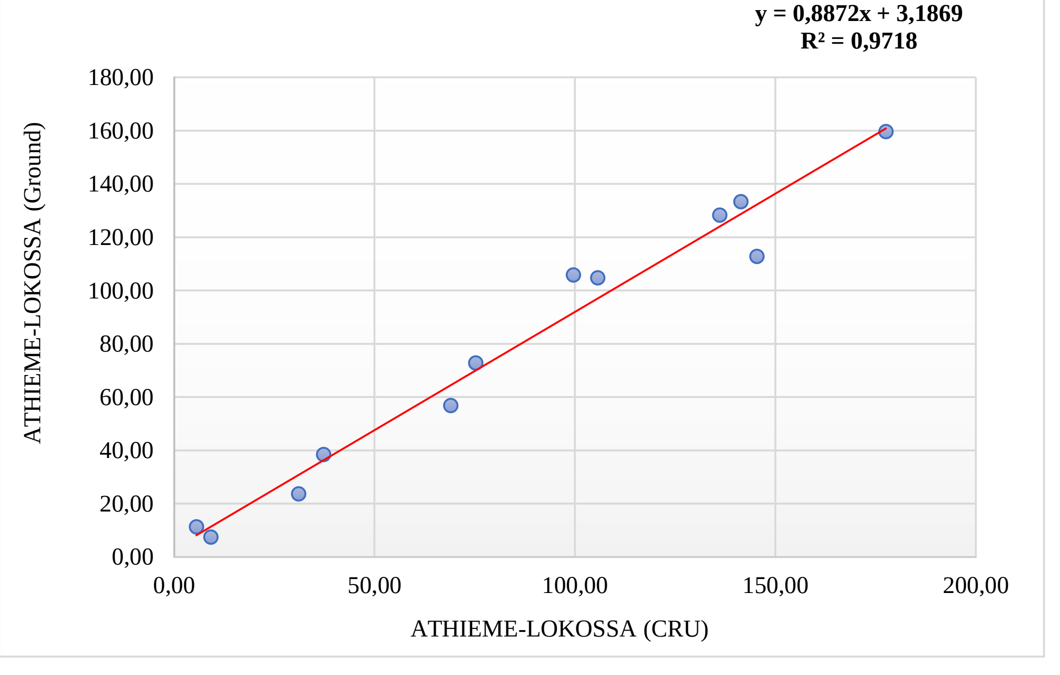
Correlation between CRU rainfall data and ground data (ATAKPAME)



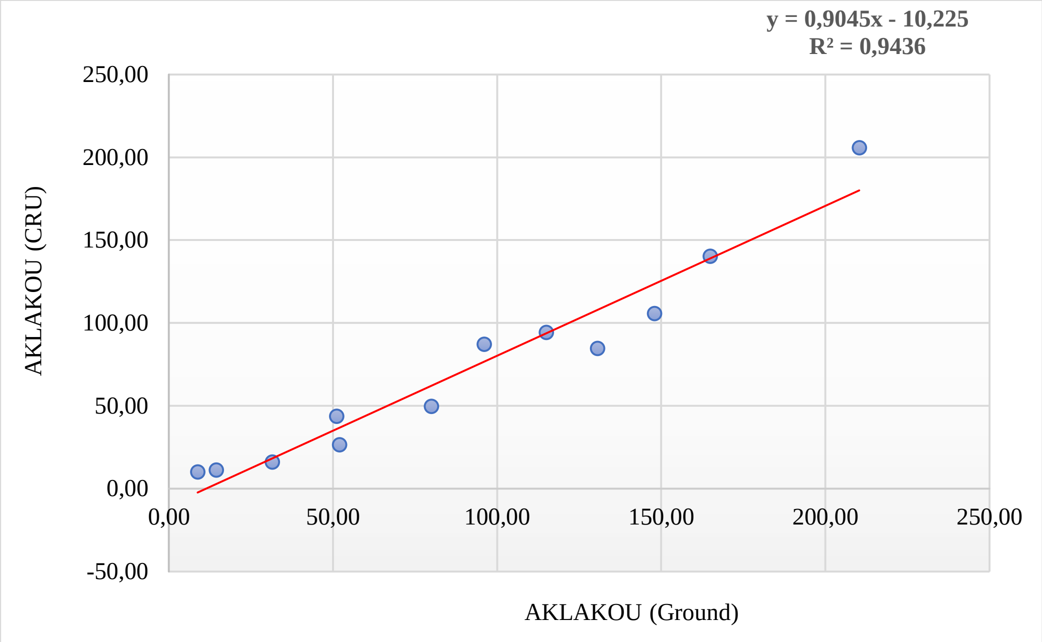
Correlation between CRU rainfall data and ground data (TAGBLIGBO)



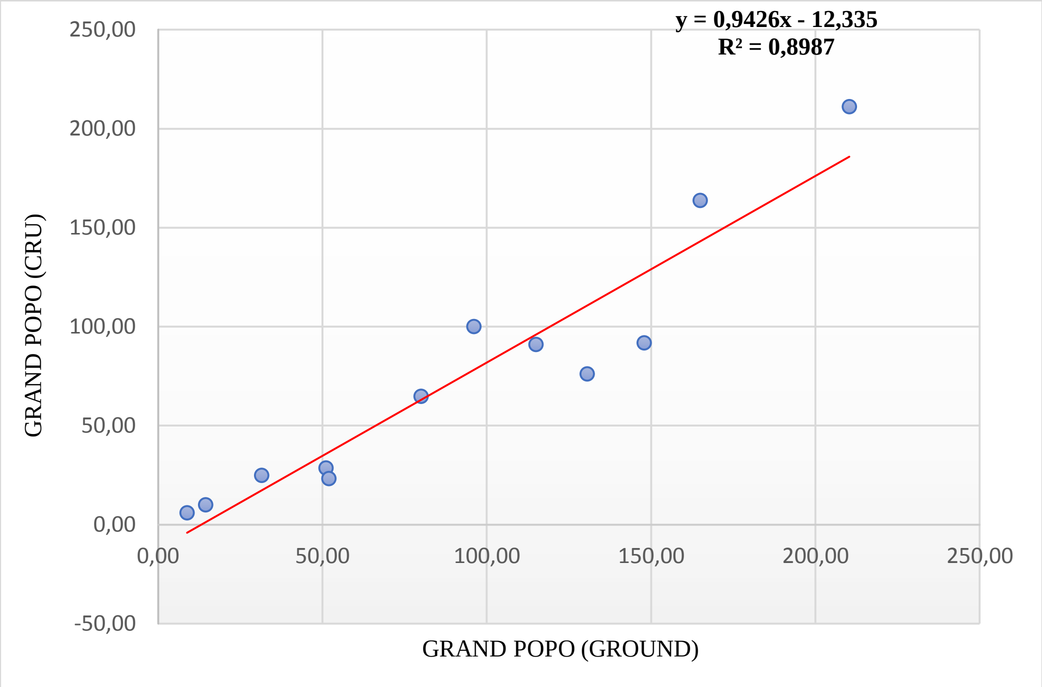
Correlation between CRU rainfall data and ground data (AGOMEY GLOZOUN)



Correlation between CRU rainfall data and ground data (ATHIEME LOKOSSA)



Correlation between CRU rainfall data and ground data (AKLAKOU)



Correlation between CRU rainfall data and ground data (GRAND POPO)

7.3.APPENDICE III: Household data analysis

- **Difference between the different households**

	Household labor	Perceived probability of being affected	Membership in disaster risk management	Risk attitude (risk taker)	Plot elevation	Principal crop in rainy season
Household type1	-0.2712	0.22	0.11	0.09	-0.27	0.05
Household type2	1.369219	-1.07	-0.53	-0.44	1.30	-0.26

	Number of literate persons	Plot location	Participation in flood training	Household risk perception	Household incomes	Plot distance to river
Household type 1	-0.11	-0.16	0.07	0.07	-0.04	-0.01
Household type2	0.55	0.77	-0.37	-0.37	0.21	0.07

	Flood experience	Rainfall characteristic	Perceived water level	Flood duration	Adaptive strategies	Gender	Plot soil type	Household agriculture experience	Prefectures	Flood frequency	Capacity of risk reduction	Risk reduction is costly
Household type1	0.03	-0.02	0.03	0.13	0.09	-0.02	0.09	-0.06523	-0.19	0.01	0.00	-0.07
Household type2	-0.16	0.09	-0.13	-0.67	-0.46	0.08	-0.45	0.328769	0.94	-0.03	-0.02	0.36

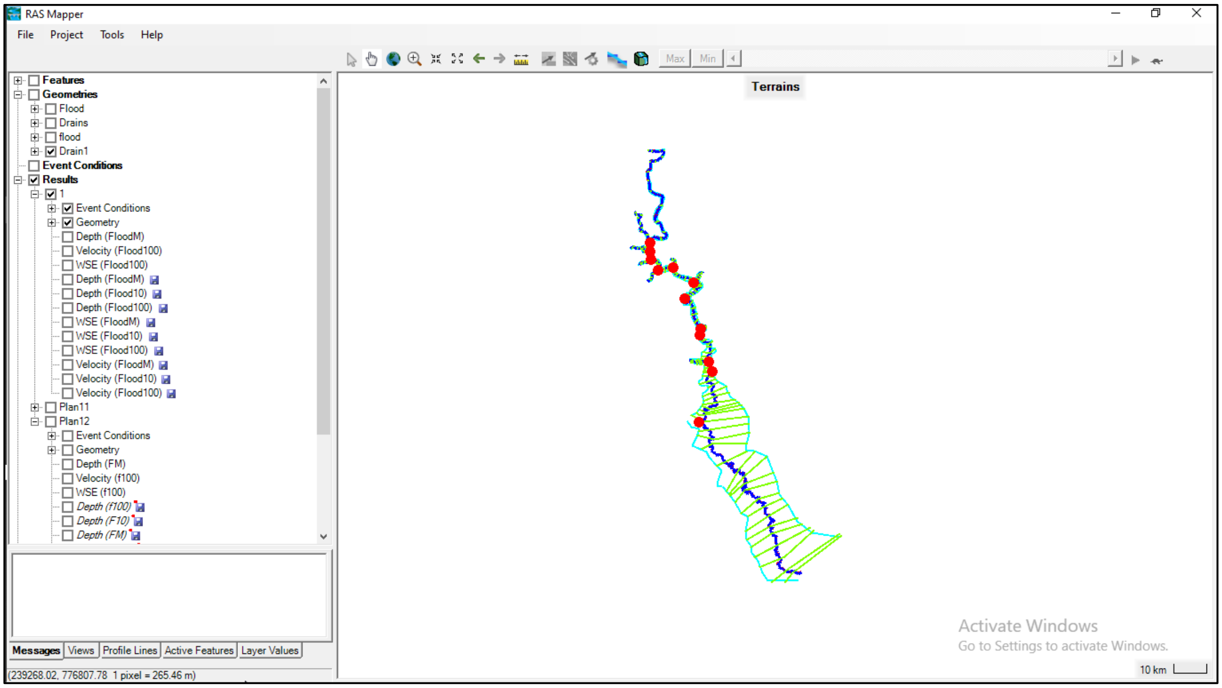
7.4.APPENDICE IV: Discharge estimation

Basins	Area (Kilometer square)	Perimeter (Kilometer)	Icomp	L	D	Ig(m/km)	Ds(m)	Pt(%)	PL(%)	PM (%)	Igcor	P10	LH	Pan	A	Pm10	Kr10(%)	Kr10	Vr10	Tb(min)
Basin 1	14645.81	999.21	2.33	378.59	339.68	0.90	108.58	0.02	0.01	0.01	0.60	120	17114.80	1500	0.59	71.01	16.21	0.16	168550882.40	18480.72
Basin 2	2478.67	504.63	2.86	202.53	650.36	3.21	159.87	0.04	0.03	0.04	2.14	120	7040.84	1500	0.67	80.08	20.49	0.20	36069630.37	5580.85
Basin 3	926.05	274.51	2.54	106.82	178.15	1.67	50.75	0.07	0.06	0.06	1.11	120	4303.61	1500	0.71	85.11	17.86	0.18	11745996.53	4804.43
Basin 4	444.48	109.74	1.47	33.79	92.23	2.73	57.55	0.09	0.09	0.09	1.82	120	2981.53	1500	0.74	88.86	17.08	0.17	6336701.27	3343.06
Basin 5	35.05	42.55	2.03	15.36	63.05	4.11	24.31	0.34	0.41	0.38	2.74	120	837.25	1500	0.85	101.83	23.24	0.23	578347.84	1275.41
Basin 6	51.30	37.35	1.47	11.52	76.43	6.64	47.54	0.28	0.33	0.30	4.43	150	1012.88	1500	0.83	124.86	26.57	0.27	967935.94	890.93
Basin 7	207.63	101.44	1.99	36.31	92.98	2.56	36.90	0.14	0.14	0.14	1.71	150	2037.79	1500	0.77	115.94	18.49	0.18	2725913.30	2674.19
Basin 8	66.03	40.05	1.39	11.90	77.56	6.52	52.98	0.25	0.28	0.26	4.35	150	1149.18	1500	0.82	123.25	25.96	0.26	1217089.30	987.50
Basin 9	115.13	80.02	2.10	29.28	141.05	4.82	51.69	0.19	0.20	0.19	3.21	150	1517.45	1500	0.80	119.70	22.52	0.23	1841089.81	1624.42
Basin 10	363.85	150.89	2.23	56.37	81.19	1.44	27.47	0.10	0.10	0.10	0.96	150	2697.60	1500	0.75	112.35	16.44	0.16	4248831.03	3625.54
Basin 11	70.81	61.17	2.05	22.17	79.61	3.59	30.21	0.24	0.27	0.25	2.39	150	1190.03	1500	0.82	122.80	21.30	0.21	1070965.50	1684.90
Basin 12	75.23	80.46	2.62	31.56	161.17	5.11	44.30	0.23	0.26	0.25	3.41	150	1226.64	1500	0.82	122.42	23.56	0.24	1258607.14	1359.01
Basin 13	69.03	40.15	1.36	11.77	115.55	9.82	81.59	0.24	0.28	0.26	6.55	150	1174.99	1500	0.82	122.97	28.57	0.29	1400707.04	331.78
Basin 14	474.73	109.61	1.42	33.02	181.17	5.49	119.56	0.09	0.09	0.09	3.66	150	3081.32	1500	0.74	110.66	22.36	0.22	7538491.44	2269.31
Basin 15	734.47	131.45	1.37	38.62	95.76	2.48	67.19	0.07	0.07	0.07	1.65	150	3832.68	1500	0.72	107.87	17.73	0.18	9244872.40	4060.92

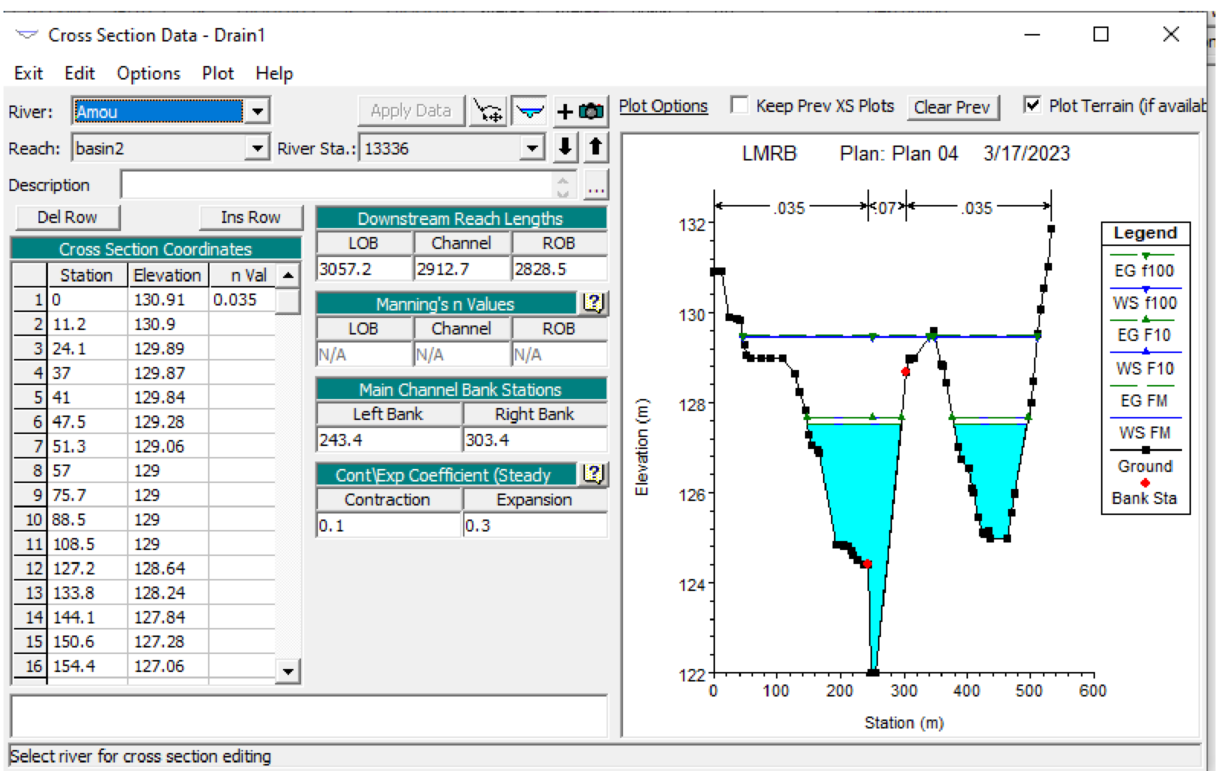
Tb(min)	Tb(heure)	Tb(s)	Qmr10(m3/s)	Alpha	Qm10(m3/s)	Coeff	Q10	C	Q100
18480.72	308.01	1108842.91	152.01	2.6	395.22	1.1	434.74	4.18	1819.33
5580.85	93.01	334851.03	107.72	2.6	280.07	1.1	308.07	3.18	980.19
4804.43	80.07	288266.08	40.75	2.6	105.94	1.1	116.54	3.46	403.03
3343.06	55.72	200583.38	31.59	2.6	82.14	1.1	90.35	3.46	312.77
1275.41	21.26	76524.42	7.56	2.6	19.65	1.05	20.63	2.61	53.89
890.93	14.85	53455.88	18.11	2.6	47.08	1.05	49.43	2.35	116.17

2674.19	44.57	160451.28	16.99	2.6	44.17	1.1	48.59	3.21	156.16
987.50	16.46	59250.08	20.54	2.6	53.41	1.05	56.08	2.40	134.54
1624.42	27.07	97465.34	18.89	2.6	49.11	1.1	54.02	2.71	146.52
3625.54	60.43	217532.53	19.53	2.6	50.78	1.1	55.86	3.58	200.07
1684.90	28.08	101094.03	10.59	2.6	27.54	1.05	28.92	2.82	81.50
1359.01	22.65	81540.38	15.44	2.6	40.13	1.05	42.14	2.60	109.64
331.78	5.53	19906.62	70.36	2.6	182.95	1.05	192.09	2.12	406.29
2269.31	37.82	136158.79	55.37	2.6	143.95	1.1	158.35	2.79	442.51
4060.92	67.68	243655.27	37.94	2.6	98.65	1.1	108.52	3.43	371.97
4268.77	71.15	256126.11	26.32	2.6	68.44	1.1	75.28	3.68	277.18
2342.88	39.05	140572.54	9.26	2.6	24.07	1.1	26.48	3.23	85.66
2350.07	39.17	141004.23	10.23	2.6	26.59	1.1	29.25	3.57	104.49
15290.31	254.84	917418.39	290.87	2.6	756.27	1.1	831.90	4.22	3511.24

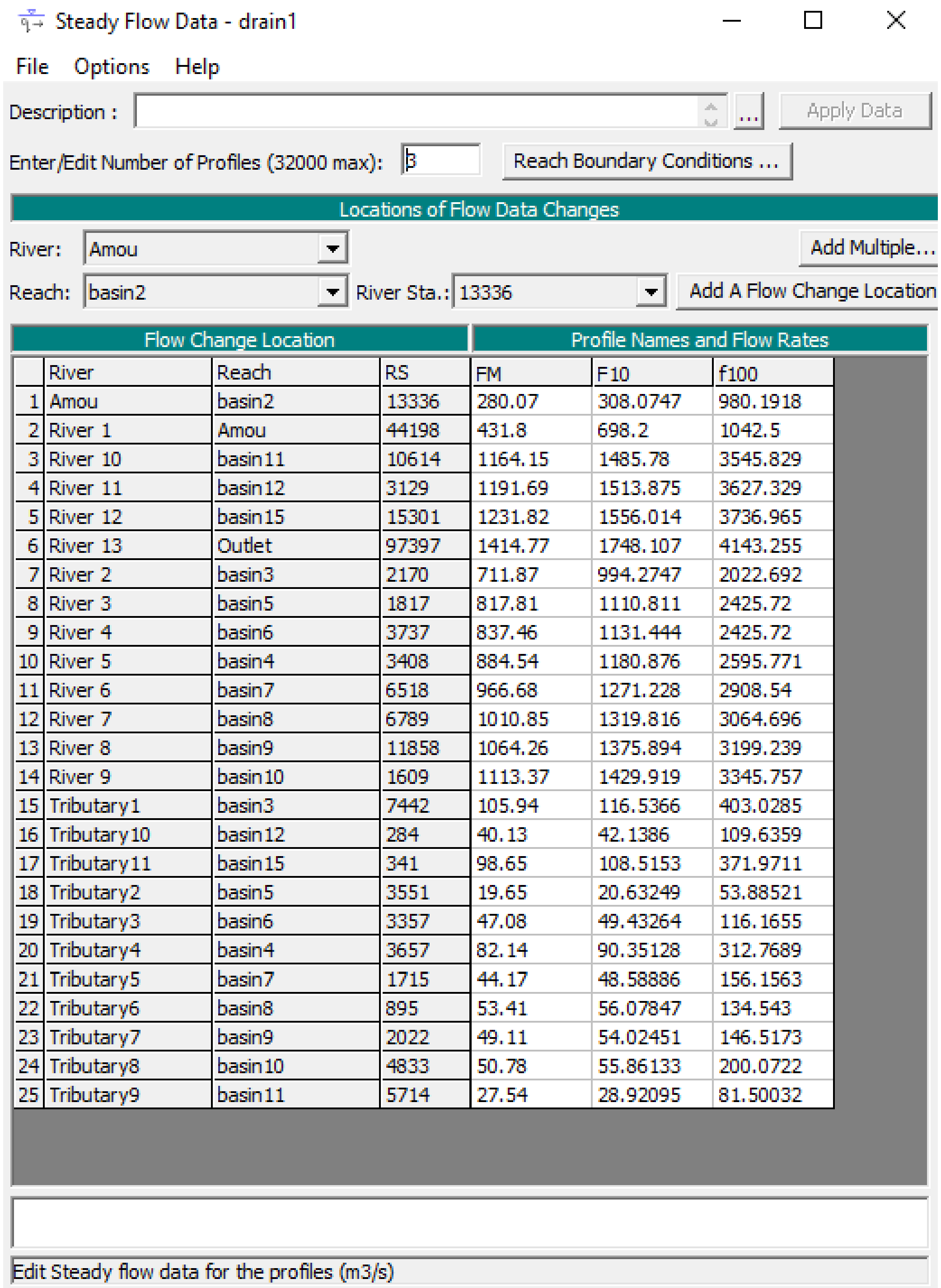
7.5.APPENDICES V: HEC RAS Model



Interface of the RAS MAPPER (HEC RAS)

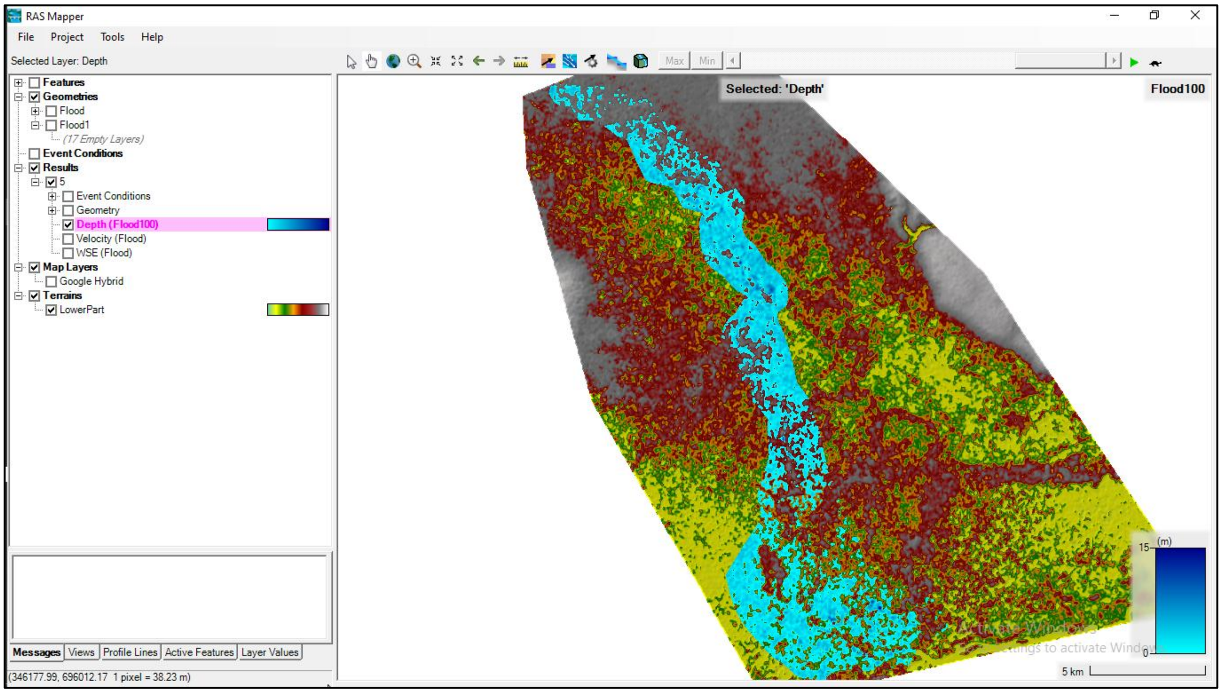


Cross section data modification interface



	River	Reach	RS	FM	F10	f100
1	Amou	basin2	13336	280.07	308.0747	980.1918
2	River 1	Amou	44198	431.8	698.2	1042.5
3	River 10	basin11	10614	1164.15	1485.78	3545.829
4	River 11	basin12	3129	1191.69	1513.875	3627.329
5	River 12	basin15	15301	1231.82	1556.014	3736.965
6	River 13	Outlet	97397	1414.77	1748.107	4143.255
7	River 2	basin3	2170	711.87	994.2747	2022.692
8	River 3	basin5	1817	817.81	1110.811	2425.72
9	River 4	basin6	3737	837.46	1131.444	2425.72
10	River 5	basin4	3408	884.54	1180.876	2595.771
11	River 6	basin7	6518	966.68	1271.228	2908.54
12	River 7	basin8	6789	1010.85	1319.816	3064.696
13	River 8	basin9	11858	1064.26	1375.894	3199.239
14	River 9	basin10	1609	1113.37	1429.919	3345.757
15	Tributary1	basin3	7442	105.94	116.5366	403.0285
16	Tributary10	basin12	284	40.13	42.1386	109.6359
17	Tributary11	basin15	341	98.65	108.5153	371.9711
18	Tributary2	basin5	3551	19.65	20.63249	53.88521
19	Tributary3	basin6	3357	47.08	49.43264	116.1655
20	Tributary4	basin4	3657	82.14	90.35128	312.7689
21	Tributary5	basin7	1715	44.17	48.58886	156.1563
22	Tributary6	basin8	895	53.41	56.07847	134.543
23	Tributary7	basin9	2022	49.11	54.02451	146.5173
24	Tributary8	basin10	4833	50.78	55.86133	200.0722
25	Tributary9	basin11	5714	27.54	28.92095	81.50032

Discharge data entry for simulation



Visualizing simulation result in the RAS Mapper

7.6.APPENDICE VI: Pictures of survey

Method of households' house construction in the village of KPODJI (Yoto)

Field close to the Mono River in the village of KODJO COPE in YOTO

Population practicing different activities in the Mono River (the village of TOTSANGNI in OGOU)

Warning system install near the Mono river in the village of TOSANGNI (OGOU) and AGOMEY GLOZOUN (BAS-MONO)

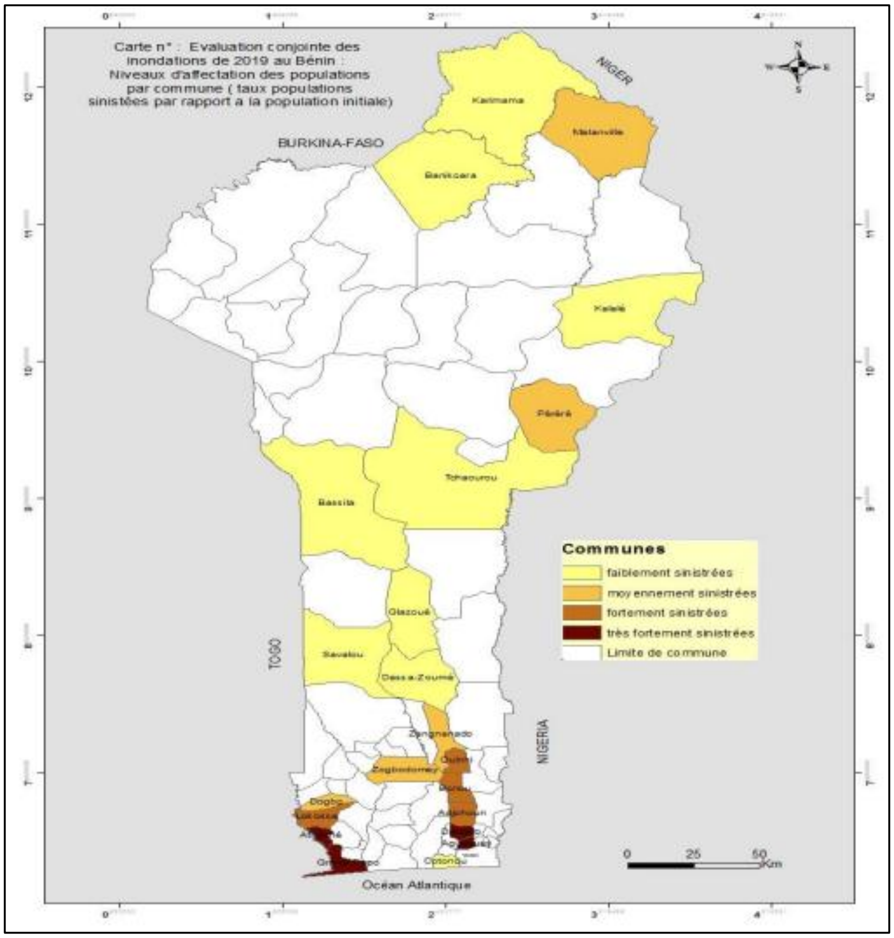
Drainage system at AGBANAKIN (Lacs)

Retention basin in field at AGBANAKIN (Lacs)

Manual irrigation of vegetable crop in dry season

Cultivation of vegetables in earthen dyke in the village of Agomey Glozoun

Irrigation system in AGBANAKIN (LACS)



Flood impact assessment in Benin (ANPC-TOGO, 2022)

Water reservoir build in the village of EDOH -WOWUIKOKPE; Koffi Hounkpe (World Bank, 2016)

7.7.APPENDICE VII: Article published

PLOS CLIMATE

RESEARCH ARTICLE

Comparing households' perception of floodhazard with historical climate and hydrological data in the Lower Mono Rivercatchment (West Africa), Benin and Togo

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Citation: Dossoumou NIP, Gnazou MDT, Villamor GB, Agbossou EK, Thiam S, Wagner S, et al. (2023) Comparing households' perception of floodhazard with historical climate and hydrological datain the Lower Mono River catchment (West Africa),Benin and Togo. PLOS Clim 2(4): e0000123. https://doi.org/10.1371/journal.pclm.0000123

Editor: Bharath Haridas Aithal, Indian Institute of Technology Kharagpur, INDIA

Received: September 3, 2022

Accepted: March 20, 2023

Published: April 24, 2023

Data Availability Statement: The data is availableon the repository DRYAD. The citation is as follows: NADEGE, DOSSOUMOU (2022), Comparing households' perception of flood hazard with historical climate and hydrological data in the Lower Mono River catchment (West Africa), Benin and Togo, Dryad, Dataset, https://doi.org/10.5061/dryad.6m905qg2v.

Funding: This research was funded by the German Federal Ministry of Education and Research

Abstract

The comparison of local perception of flood hazards, with hydrological and climate parameters, can give more insight and understanding on the causes of flood, its impacts and the strategies to effectively address the problem. This study examines whether households' perception of rainfall and flood occurrence are consistent with observed variation in climate parameter (rainfall) and hydrological (discharge) data in the Lower Mono River catchment (Togo-Benin, West Africa). Perceptions of the 744 households from the catchment were collected and compared to historical climatic and hydrological data using correlation analysis. The Standardized Precipitation Index was utilized to identify the extreme years in terms of precipitation. Chi-test and binary regression analyses were performed to identify the most affected communes within the catchment, and the factors that influence household perceptions on rainfall change, respectively. Findings reveal that 85% of the respondents per- ceived an excess in rainfall during the last 20 years and identify two particular years as the most affected by flood, which correspond to the climate data analysis. Households' percep- tions on flooded months are correlated with the monthly precipitation and discharge at the upper part of the catchment while the ones at down part are not correlated. Furthermore, thechi-test analysis shows that in the perception of households, the communes at the down part are more affected by flood than those at the upper part of the catchment. It is then important for decision maker to consider local communities' perception for having insight regarding climate parameters, the causes of flood and in the decision making for implement-ing measures to cope with this phenomenon.

Contents