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Multivariate Analysis for Sustainable Water Management: Understanding and Managing Environmental Risks in the Ikopa Watershed, Madagascar

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Abstract: *This paper delves into environmental challenges in Madagascar's Ikopa Watershed, focusing on the impact of climate disruptions and human activities on terrestrial and aquatic ecosystems. Employing a multidisciplinary approach, the research is examining the intricate interplay of geological, climatic, and human-induced factors, exploring their implications for sustainable water resource management. The study has employed representative sampling, surveying 386 households, and has combined it with field data collection and an evaluation of local perspectives on environmental risks. The results have identified four main forms of environmental degradation: water and wind erosion, biological, and water degradation. These phenomena have significant implications for water availability and quality, as well as local agricultural activities. Additionally, the research has classified households into two groups based on their exposure to climate variability, emphasizing the need for tailored adaptation strategies to address specific environmental challenges. The findings underscore the importance of local adaptation initiatives, such as sustainable land management and community awareness, to enhance resilience against environmental risks. Conclusively, the paper emphasizes the importance of ongoing and customized water resource management in the Ikopa Watershed, taking into account local perspectives, adaptation strategies, and future environmental challenges.*

Keywords: *Water, management, risks; climate, adaptation, Ikopa's watershed*

I. Introduction

The Ikopa Watershed in Madagascar is facing a series of significant environmental challenges resulting from climatic disturbances and human activities. Current climate disruptions, characterized by their irregularity and increasing instability, exacerbate environmental risks, jeopardizing the health of terrestrial and aquatic ecosystems globally (Aziz et al., 2014; David et al., 2015). These environmental challenges are holding particular significance in Madagascar, an island located in the Indian Ocean, where the impacts of climate change are keenly felt. This phenomenon is affecting the availability of natural resources and the resilience of ecosystems in the region (MEDD, 2022; MEEF, 2017; Rabefarihy et al., 2020; Ranaivonasy, 2022).

The Ikopa Watershed is notably impacted by these environmental challenges owing to its unique geology, precipitation variations, and degradation of vegetation cover. In light of these challenges, a comprehensive understanding of the intricate interplay among geological, climatic, and anthropogenic factors in the Ikopa Watershed is crucial. This understanding is essential to grasp the implications for sustainable water resource management in the region (Harrod & Rolland, 2021; Veríssimo et al., 2014).

The main objective of this research is to comprehend the interactions among these factors and their influence on environmental risks in the Ikopa Watershed, as well as the implications of these interactions for sustainable water resource management in the region. To achieve this goal, the study employs a multidisciplinary approach, incorporating geographical, hydrological, and environmental analyses. Additionally, it explores the perceptions of local communities grappling with these environmental challenges. Highlighting the importance of local knowledge in identifying sustainable solutions, the study aims to provide effective practices for water resource management in the Ikopa Watershed. It takes into account the imperatives of environmental preservation and community resilience.

II. Materials and Method

2.1 Sampling Area

The study which is conducted in the Ikopa Watershed (Londe, 1989), Madagascar, engaged a representative sample of 386 households. The selection process utilized a classical stratified sampling method to ensure sufficient representation of the various zones within the watershed (Groves et al., 2009; Lohr, 2019).

This approach employed a proportional allocation strategy, wherein each sample stratum was composed of 55 households. The total sample size across the study area amounted to 386 households (Andriamparany et al., 2015; Razafindrabe et al., 2017). The choice of primary sampling units (PSUs) was executed through the utilization of cartographic and demographic data. Subsequently, spatial points in the various zones of the watershed were randomly selected (UNDP Madagascar, 2015).

To ensure comprehensive representation of the different zones within the watershed, it was categorized into three distinct zones. The upper zone includes the municipalities of Anosibe Trimoloharano in the Andramasina District and Ambalavao in the Antananarivo Atsimondrano District. The middle zone encompasses the municipalities of Fiadanana, Kiangara, and Marondry in the Ankazobe District. Finally, the lower zone comprises the municipalities of Antanimbary and Maevantanana II. In the field, household surveys were efficiently conducted using the mWater mobile data collection tool (Feighery et al., 2015). This platform facilitated accurate data collection and efficient management of the collected data, ensuring the reliability and quality of the analyzed data (Lohr, 2010)

2.2 Local Perception of Environmental Risks

a. Assessment of Environmental Risks

The approach employed for evaluating environmental risks in the Ikopa Watershed relies on the utilization of various statistical and analytical techniques. Firstly, the Kruskal-Wallis test (a) will be applied to evaluate significant differences among the identified risks in the different zones of the watershed (Kruskal & Wallis, 1952). This test will determine if the risks differ significantly between the studied zones (Gibbons & Chakraborti, 2011):

$$H = \frac{12}{N(N+1)}\left(\sum_{j=1}^{k}\frac{R_j^2}{n_j} - 3(N+1)\right) \qquad \text{(a)}$$

N : Total number of observations
k : Number of groups
R_j : Sum of ranks for group j
n_j : Size of group j

The results of the Kruskal-Wallis test will be interpreted based on the p-value. Low p-values will suggest significant differences among the risk groups, indicating notable variations in the perception of environmental risks within the watershed (Babbie, 2016). This interpretation will be essential for identifying risks that require particular attention from stakeholders and decision-makers (Agresti & Finlay, 2009).

In addition to the Kruskal-Wallis test, a frequency analysis will be conducted to determine the most commonly cited risks by participants (Everitt, 2005). This analysis involves counting the number of occurrences of each risk in the collected data (Siegel & Castellan, 1988). The most frequent risks will thus be identified, providing insights into the most widespread concerns within local communities (Zar, 2014).

Finally, to determine if there are correlations among the identified risks, a Spearman correlation will be performed (Conover & Iman, 1981). This analysis will assess if there is a monotonic linear relationship between the different risks (Basler, 1988; Held, 2010; Rouzic, 1979).

b. Exposure Levels to Risks

The methodology for assessing environmental risks was developed following several key steps for a thorough analysis of the collected data. First, Hierarchical Ascendant Classification (HAC) was used to group observations into homogeneous clusters based on their similarities (Hair et *al.*, 2019). This method allowed for the creation of distinct categories of data, thus facilitating further analysis of environmental risks.

Next, Discriminant Factor Analysis (DFA) was conducted to identify discriminant variables that contribute most to the differentiation between groups formed by HAC (Johnson & Wichern, 2007). DFA helped determine which variables are most important for distinguishing different groups based on their environmental characteristics. Additionally, this analysis validated the relevance of the groups defined by HAC, thus reinforcing the robustness of the results.

Subsequently, the Kruskal-Wallis test was applied to determine if the observed differences between groups were statistically significant (Conover & Iman, 1981). This non-parametric test was used to assess whether environmental risk levels varied significantly among the different groups identified by HAC and confirmed by DFA. Finally, the discriminant variables identified by DFA were further analyzed to understand their contribution to exposure to environmental risks (Zar, 2014).

c. Assessment of Potential Environmental Risk Impacts

The methodological approach chosen to assess the impacts of potential environmental risks in the Ikopa Watershed Basin in Madagascar relied on chi-square statistical analysis (Agresti & Finlay, 2009). Once the risks were identified through frequency analysis, the chi-square test (b) with the Cramer's V coefficient (c) was applied to evaluate the relationship between these potential risks and the observed environmental impacts (Zar, 2014) (Table 2).

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i} \quad \text{(b)}$$

O_i : Observed observation
E_i : Expected observation

$$V = \sqrt{\frac{\chi^2}{N(min(Nb.lignes, Nb.colonnes) - 1)}} \quad (c)$$

V : Cramer's V coefficient
χ^2 : Chi-square statistic, calculated from the contingency table
N : Total sample size
min(..) : Corresponds to the minimum number of categories in categorical variables

The chi-square test, complemented by Cramer's V coefficient, was employed to analyze the strength of the association between potential risks and environmental impacts. Cramer's V coefficient was interpreted to measure this association strength (Table 1), thereby providing insights into the relevance and significance of the risks identified concerning the observed environmental impacts.

Table 1. Reference Value of the Cramer's V Coefficient

Cramer's V	Value Relation
$V < 0.1$	Very weak or negligible relations
V between 0.1 and 0.2	Weak relations
V between 0.20 and 0.30	Moderate relations
$V \geq 0.3$	Strong relations

Sources : (Cohen, 2013; Cramér, 1999)

Table 2. Variables Related to Environmental Risk Analysis

Variables Code	Variables	Hazards
DegTyp	Main types of land resource degradation (including soil, water, vegetation, and animals)	Risks
ProdAgr	Agricultural Production (decreasing - increasing)	Impacts
QltCult	Crop Quality (decreasing - increasing)	Impacts
DispEP	Availability of Drinking Water (decreasing - increasing)	Impacts
QltEP	Quality of Drinking Water (decreasing - increasing)	Impacts
DispEI	Availability of Water for Irrigation (decreasing - increasing)	Impacts
QltEI	Quality of Irrigation Water (increasing - decreasing)	Impacts
CEQte	Water Cycle/Runoff: Water Quantity (decreasing - increasing)	Impacts
CEQlt	Water Cycle/Runoff: Water Quality (decreasing - increasing)	Impacts
CERuis	Water Cycle/Runoff: Surface Runoff (increasing - decreasing)	Impacts
CEDrain	Water Cycle/Runoff: Drainage of Excess Water (reduced - improved)	Impacts
CENap	Water Cycle/Runoff: Groundwater (reduced - improved)	Impacts
SCouvSol	Soils: Soil Cover (decreasing - improving)	Impacts
SPertSol	Soils: Soil Loss (increasing - decreasing)	Impacts
SAccutSol	Soils: Soil Accumulation (decreasing - increasing)	Impacts
SCompSol	Soils: Soil Compaction (increasing - decreasing)	Impacts
BCouvVeg	Biodiversity: Vegetation Cover (decreasing - increasing)	Impacts
BBiomas	Biodiversity: Biomass/Above-ground (decreasing - increasing)	Impacts

Variables Code	Variables	Hazards
RRCImpInd	Climate Change and Risk: Flood Impacts (increasing - decreasing)	Impacts
RRCImpGlis	Climate Change and Risk: Landslides/Debris Flows (increasing - decreasing)	Impacts
RRCImpSec	Climate Change and Risk: Drought Impacts (increasing - decreasing)	Impacts
RRCImpCyc	Climate Change and Risk: Impacts of Cyclones, Torrential Rains (increasing - decreasing)	Impacts

2.3 Adaptation strategies analysis

To analyze adaptation strategies, the Cochran's Q test (d) was initially utilized to identify any homogeneous groups within local adaptation practices. This method compared the variability of observations across different groups, providing insights into the diversity of strategies adopted by communities. Being a non-parametric test, the Cochran's Q test was employed to ascertain whether significant differences existed between basin areas concerning measures for mitigating environmental risks (Cochran, 1950).

$$Q = \sum \frac{(O_i - E_i)^2}{E_i} \quad \text{(d)}$$

Q	:	Value of Cochran's Q test
k	:	Number of groups
n_i	:	Sample size for group i
X_{ij}	:	Value of the measurement for individual j in group i
$\bar{X}$	:	Mean of all measured values in all groups
X_i	:	Mean of the measured values in group i

Then, the chi-square test was used to statistically evaluate the independence or dependence between perceptions of impacts and prevention measures adopted by local communities in the Ikopa Watershed Basin. This analysis aims to deepen the understanding of adaptation strategies and their relationship with the perception of climate risks, as well as to determine the perceived effectiveness of preventive strategies.

III. Results and Discussion

3.1 Evaluation of Potential Environmental Degradation Risks in the Ikopa Watershed

a. Identification of Potential Risks

The use of the Kruskal-Wallis test for assessing the homogeneity of different zones within the Ikopa Watershed regarding the studied variables has indicated the absence of significant differences. The detailed results show that the respective p-values exceed the critical threshold of 5%, thus confirming a similarity between these zones. Therefore, the non-significance of differences between zones, as demonstrated by the KW test results, highlights a homogeneity in the studied degradation processes.

The results of frequency analyses provided significant insights into comparing the means of different degradations in the Ikopa Watershed. The results identified several types of degradations that distinctly cluster, independently from each other, based on frequencies exceeding the mean.

Specifically, four types of degradations are prominent (Table 3), showing a marked association with frequencies exceeding the mean. Wind and biological erosions, each with a frequency of 51.55%, have illustrated similar trends, indicating a notable correlation between these two types of degradation. Similarly, water-related degradation and water erosion have displayed respective frequencies of 50.00% and 48.70%, also confirming a close and independent association between these two phenomena.

Table 3. Kruskal-Wallis Test and Frequency Analysis for Identifying Potential Risks

Variable\Test	Variables' name	K (Observed value)	K (critical Value)	DDL	Kruskal-Wallis (p-value)	alpha	Groups	Frequency (%)
DegTyp – 1	Water erosion	4,658	5,991	2	0,097	0,05	A	**48,71**
DegTyp – 2	Wind erosion	1,478	5,991	2	0,478	0,05	A	**51,55**
DegTyp – 3	Chemical degradation	2,246	5,991	2	0,325	0,05	A	46,11
DegTyp – 4	Physical degradation	2,016	5,991	2	0,365	0,05	A	43,26
DegTyp – 5	Biological degradation	4,907	5,991	2	0,086	0,05	A	**51,55**
DegTyp - 6	Water degradation	0,339	5,991	2	0,844	0,05	A	**50,00**
							Moyenne	***48.53***

b. Household Typology Based on Exposure to Potential Risks

The analysis utilizing Hierarchical Cluster Analysis (HCA) and Discriminant Factor Analysis (DFA) has classified observations into two distinct groups based on their exposure to climatic variability, accounting for a total inertia of 100% (Table 4).

The first group, comprising 27.6% of surveyed households, exhibits a moderate exposure to climatic variability. Significant negative impacts are observed in this group, particularly affecting agricultural production, crop quality, and access to clean water.

Conversely, the second group, encompassing 72.4% of surveyed households, experiences lower exposure to climatic variability. Negative impacts within this group are less pronounced, with relatively stable variations in agricultural production and access to clean water.

Table 4. Distribution of Households Exposed to Environmental Risks by Basin Watershed Zone

		Groups							
		Group 1				Group 2			
		Number	Nb. row (%)	Nb.columns (%)	Nb. tables (%)	Number	Nb. row (%)	Nb.columns (%)	Nb. tables (%)
Bassin Area	Upper	15	26,8	14,2	3,9	41	73,2	14,7	10,7
	Middle	55	25,1	51,9	14,3	164	74,9	59,0	42,7
	Lower	36	33,0	34,0	9,4	73	67,0	26,3	19,0
	Total	106	27,6	100,0	27,6	278	72,4	100,0	72,4

The Kruskal-Wallis test applied to various environmental variables in the Ikopa Watershed has revealed several significant findings:

1. Confirmed Negative Impacts: The results have significantly demonstrated negative impacts across various domains, including agricultural production, crop quality, access to clean water, excess water drainage, soil accumulation, vegetation cover, above-ground biomass, flood impacts, and landslide/debris flow impacts.
2. Stability in Certain Areas: However, some variables showed no significant variations between groups, indicating relative stability. These stable aspects include water quality related to the water cycle, groundwater levels, water availability for irrigation, soil loss, vegetation cover, and impacts of cyclones/heavy rains.

Table 5. Analysis of Kruskal-Wallis Tests for Evaluating Differences Between Groups 1 and 2 on Various Environmental Aspects

	Null hypothesis	Statistical Tests	Asymptotic Significance (two-tailed)	Decision	Group 1	Group 2
1	The distribution of Impact on Agricultural Production is identical across categories of Group 1 and 2.	Kruskal-Wallis test for independent samples	0,000	Reject the null hypothesis	1;2	5
2	The distribution of Impact on Crop Quality is identical across categories of Group 1 and 2.	Kruskal-Wallis test for independent samples	0,008	Reject the null hypothesis	1;4;5	
3	The distribution of Impact on Drinking Water Availability is identical across categories of Group 1 and 2.	Kruskal-Wallis test for independent samples	0,000	Reject the null hypothesis	5	3
4	The distribution of Impact on Drinking Water Quality is identical across categories of Group 1 and 2.	Kruskal-Wallis test for independent samples	0,004	Reject the null hypothesis		1
5	The distribution of Impact on Water Availability for Irrigation	Kruskal-Wallis test for independent samples	0,083	Retain the null hypothesis	4	2

	Null hypothesis	Statistical Tests	Asymptotic Significance (two-tailed)	Decision	Group 1	Group 2
	is identical across categories of Group 1 and 2.					
6	The distribution of Impact on Water Quality is identical across categories of Group 1 and 2.	Kruskal-Wallis test for independent samples	0,954	Retain the null hypothesis	2	
7	The distribution of Impact on Excess Water Drainage is identical across categories of Group 1 and 2.	Kruskal-Wallis test for independent samples	0,002	Reject the null hypothesis	1	
8	The distribution of Impact on Groundwater Table is identical across categories of Group 1 and 2.	Kruskal-Wallis test for independent samples	0,595	Retain the null hypothesis	1	
9	The distribution of Impact on Soil Coverage is identical across categories of Group 1 and 2.	Kruskal-Wallis test for independent samples	0,003	Reject the null hypothesis	1;2	3;5
10	The distribution of Impact on Soil Loss is	Kruskal-Wallis test for independent samples	0,145	Retain the null hypothesis	5	

	Null hypothesis	Statistical Tests	Asymptotic Significance (two-tailed)	Decision	Group 1	Group 2
	identical across categories of Group 1 and 2.					
11	The distribution of Impact on Soil Accumulation is identical across categories of Group 1 and 2.	Kruskal-Wallis test for independent samples	0,000	Reject the null hypothesis	1;3	2
12	The distribution of Impact on Vegetation Coverage is identical across categories of Group 1 and 2.	Kruskal-Wallis test for independent samples	0,683	Retain the null hypothesis	3	
13	The distribution of Impact on Above-Ground Biomass is identical across categories of Group 1 and 2.	Kruskal-Wallis test for independent samples	0,003	Reject the null hypothesis	5	1
14	The distribution of Impact on Floods is identical across categories of Group 1 and 2.	Kruskal-Wallis test for independent samples	0,000	Reject the null hypothesis		2
15	The distribution of Impact on Landslides	Kruskal-Wallis test for independent samples	0,000	Reject the null hypothesis	4	2

	Null hypothesis	Statistical Tests	Asymptotic Significance (two-tailed)	Decision	Group 1	Group 2
	and Debris Flows is identical across categories of Group 1 and 2.					
16	The distribution of Impact on Cyclones, Torrential Rains is identical across categories of Group 1 and 2.	Kruskal-Wallis test for independent samples	0,747	Retain the null hypothesis	2	

The asymptotic significances are displayed. The significance level is 0.05.

c. Environmental Risks and Their Impacts

Pearson's chi-squared tests, accompanied by Phi and Cramer's V values, were utilized to assess the relationship between different types of degradation (DegTyp) and environmental impacts (ImpRisk). The results revealed significant associations for certain variables (Figure 01):

1. Water Erosion (DegTyp - 1): Water erosion shows a significant but weak relationship with drinking water quality, soil cover, and landslide/debris flow impacts. These findings indicate diversity in the nature of the links between soil erosion and environmental risks, highlighting the complexity of interactions within the studied watershed.
2. Wind Erosion (DegTyp - 2): Wind erosion exhibits significant but weak relationships with several environmental aspects, including agricultural production, crop quality, drinking water availability, water quality, groundwater levels, impacts on above-ground biomass, flood impacts, and cyclones. These results underscore varied connections between wind degradation and environmental risks, shedding light on the complexity of interactions in the studied watershed.
3. Biological Degradation (DegTyp - 5): Biological degradation shows weak but significant relationships with water availability for irrigation. These results highlight specific links between soil biological degradation and certain aspects of environmental risks, providing relevant information for sustainable resource management in the studied watershed.
4. Water Degradation (DegTyp - 6): Water degradation demonstrates weak but significant relationships with several environmental aspects such as agricultural production, crop quality, water availability for irrigation, groundwater levels, soil cover, soil loss, landslide impacts, and cyclones.

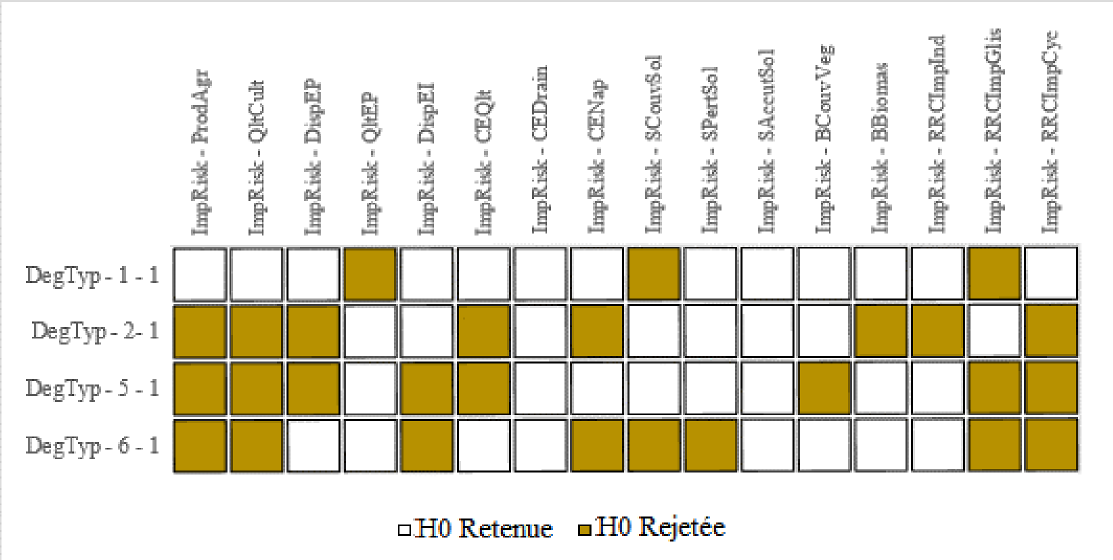

Figure 1. *Inter-Variable Relationships between Risk Types and Their Impacts*

3.2 Local Adaptation Strategies to Climate Variability in the Ikopa Watershed

a. Appraisal of Adaptation Strategies at the Watershed Level

The Cochran's Q test results revealed no significant differences among the identified groups within local adaptation practices in the Ikopa Watershed. The p-value (0.6868) exceeded the significance level of alpha=0.05, indicating that the null hypothesis H0, stating that the treatments (groups) were identical, was not rejected. In other words, the observed variability among the groups was not statistically significant, suggesting that local adaptation practices in different areas of the watershed did not differ significantly in terms of preventive measures against the effects of environmental risks.

b. Adaptation Strategies in Response to Negative Impacts of Environmental Risks

The Pearson's chi-squared test results revealed significant associations between risk reduction practices (PrevRedDegR) and local perception of risk impacts (ImpRisk). These results, with p-values ranging from 0.000 to 0.997 and weak to moderate but significant relationships (V of Cramer ranging from 0.041 to 0.236), underscore the importance of considering these links for a thorough understanding of local adaptation strategies.

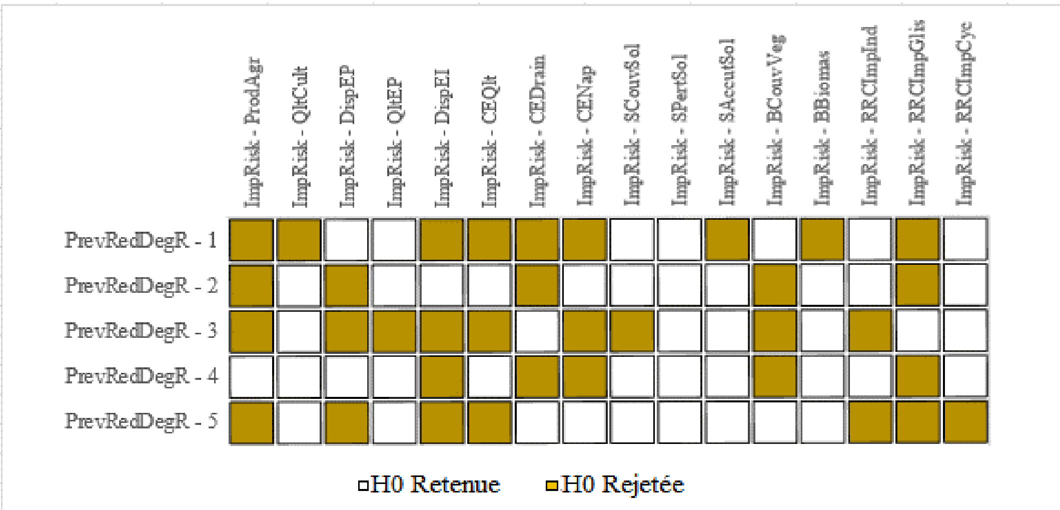

Figure 2. *Inter-Variable Relationship Map: Adaptation Measure and Risk Impact on Human Activities*

The results revealed significant links between local strategies for land degradation prevention and reduction and the perception of specific environmental impacts related to water erosion. Although land degradation prevention and reduction practices showed a non-significant positive correlation with certain environmental impacts, variations were observed in their relationship with specific impacts.

The analysis also revealed significant relationships between perceptions of environmental impacts and local adaptation strategies. Prevention and reduction practices for land degradation varied depending on different environmental risks. Furthermore, the results highlighted significant associations between environmental risk impacts and local adaptation measures, with specific patterns of adopting measures in response to different types of impacts.

3.3 Discussions

a. Impact of Fluctuations on Water Resource Availability in the Ikopa Watershed

Risk analysis in the Ikopa Watershed has identified four major forms of degradation, including water and wind erosion, biological degradation, and water degradation (Laborde, 2009; Villeneuve et *al*., 2016). These forms of degradation significantly contribute to the observed alterations in the watershed. Significant variations have been noted in perceived environmental impacts, particularly depending on exposure to climatic variability (Smith et *al*., 2018). These variations suggest a complex relationship between climatic phenomena and observed environmental consequences. Climate change influences precipitation patterns, directly impacting groundwater recharge and overall water availability (Laborde, 2009; Villeneuve et *al*., 2016).

Local perception of the impacts of climatic variabilities reflects diversity stemming from household vulnerability and local peculiarities (Hébert et *al*., 2020). The analysis distinguished two distinct groups, each significantly influenced by risks related to climatic variability (Smith et *al*., 2018). The results indicate that implementing specific mitigation and prevention measures, based on an analysis of potential risks, could potentially reduce the adverse effects of climatic variabilities on water resources in the Ikopa Watershed (Hébert et *al*., 2020).

Nevertheless, it is crucial to recognize that local community perceptions may be influenced by various factors, such as local media, political discourse, or individual experiences, which can introduce distortions in how environmental risks are perceived (Smith et *al*., 2018). Moreover, the methods used to collect and analyze data may have their biases, underscoring the importance of carefully examining these aspects to assess the reliability of conclusions drawn from local perceptions.

b. The Crucial Importance of Local Adaptation Initiatives in Resilience Against Environmental Hazards

Resilience to environmental risks largely depends on the implementation of local adaptation measures, such as sustainable land management, land use planning, and community awareness. These initiatives must be specific to the basin's characteristics and the needs of local communities, involving a participatory approach with local stakeholders (Haque et *al*., 2019). Promoting community resilience also relies on education, establishing appropriate infrastructure, and creating early warning mechanisms (Kelman, 2018). These local measures complement global actions and strengthen the basin's capacity to address environmental challenges (Smith et *al*., 2020).

The results indicate substantial differences in adaptation strategies between areas moderately exposed and less exposed to climatic variability, highlighting differentiated adaptation to specific environmental challenges encountered in each watershed area (Villeneuve et *al*., 2019). This in-depth understanding of the watershed, combined with a rigorous assessment of environmental risks and local adaptation strategies, provides a solid foundation for guiding policy and practices aimed at mitigating the impacts of environmental degradation (Haque et *al*., 2019). In alignment with national adaptation strategies, local empowerment and strengthening contribute to improving the water resource situation at the watershed scale (MEDD, 2021; MEAH, 2021).

Local initiatives for environmental risk management in the Ikopa Watershed seem to indicate local awareness, thus confirming the advanced hypothesis. These initiatives provide models of adaptation and prevention, offering valuable insights for developing effective community-level strategies (Boya, 2006; Fabien & Maman, 2006). However, some important variables may not have been included in the study, which could influence the results. Additionally, the study's conclusions may not be applicable to later periods due to changes in policies or agricultural practices (Verlynde, 2018).

IV. Conclusion

In conclusion, the study of the Ikopa watershed highlights the significant impact of various forms of environmental degradation, including water and wind erosion, biological degradation, and water degradation. These phenomena contribute significantly to the observed alterations in the region. Variations in perceived environmental impacts are observed depending on exposure to climatic variability, underscoring a complex relationship between climatic phenomena and environmental consequences.

Local adaptation strategies exhibit variations based on the extent of exposure to climatic variability, highlighting tailored adaptation to specific environmental challenges. The significance of wind erosion and biological degradation in the region is underscored, exerting notable impacts on vegetation cover and the availability of drinking water.

Local adaptation measures are aiming to raise awareness of the impacts of land degradation and to restore affected areas, ensuring an adequate supply of drinking water and maintaining water quality. However, sustained management and appropriate measures are crucial to consolidate these results over time and address future environmental challenges.

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