



## ENVIRONMENTAL VULNERABILITY INDEX: APPLICATION TO THE WHITE BANDAMA BASSIN IN THE NORTHERN CÔTE D'IVOIRE

Yao Etienne KOUAKOU <sup>1,2\*</sup>, Brama KONE <sup>2,3</sup>, Guéladio CISSE <sup>4</sup>, Kouakou Bernard DJE <sup>5</sup>,  
Yao Alexis N'GO <sup>1</sup>, AbdourAhamane KONARE <sup>6</sup>, Issiaka SAVANE <sup>1</sup>

<sup>1</sup> Environmental Sciences and Management Unit, Nangui Abrogoua University

<sup>2</sup> Environment and Health Department, Centre Suisse de Recherches Scientifiques en Côte d'Ivoire (CSRS)

<sup>3</sup> University Peleforo Gon Coulibaly of Korhogo,

<sup>4</sup> Ecosystem Health Science Unit, Department of Public Health and Epidemiology, Swiss Tropical and Public Health Institute (SwissTPH)

<sup>5</sup> Society of Exploitation and Airport, Aviation and Meteorology Development (SODEXAM)

<sup>6</sup> Félix Houphouët Boigny University, Cocody, Abidjan

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### Abstract

*The White Bandama Basin (WBB) faces multiple changes that could undermine it. In order to analyze its sensitivity to those changes, the environmental Vulnerability Index (EVI), developed by the South Pacific Applied Geosciences Commission (SOPAC), as a global composite index that quantifies the vulnerability of an area's environment, was applied to the basin. The results revealed that the major vulnerability issues are from anthropogenic sources, country-characteristics and climate changes. The most important climate risk factor for the basin is drought. The overall risk factor in the basin is higher than the means of resistance, making it moderately sensitive to changes.*

**Keywords:** Anthropogenic; Bandama; Basin; Environmental; Indices; Vulnerability.

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### Introduction

Climate change is one of the most critical global challenges of our times. Adaptation to climate change is necessary, in addition to the mitigation of climate change, to avoid unacceptable impacts of anthropogenic climate change [1]. UNFCCC Article 4 requires developed countries to assist developing countries that are “particularly vulnerable” to climate change in meeting the costs of adaptation to its adverse effects. The word ‘vulnerability’ refers to the capacity to be wounded, i.e., the degree to which a system is likely to experience harm due to exposure to a hazard [2]. For the IPCC, vulnerability to climate change is: “... the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change,

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\* Corresponding author: [kyaotienne@yahoo.fr](mailto:kyaotienne@yahoo.fr)

including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and the variation to which a system is exposed, its sensitivity and its adaptive capacity” [1]. Several conceptual frameworks have been developed to categorize vulnerability factors and to describe different vulnerability concepts. In the current effort, vulnerability is treated as a phenomenon in convolution with hazard, as without a hazard, no system is vulnerable [3]. In other words, when a system loses resilience, it becomes vulnerable [4]. Most of the relevant publications indicated that ecological resilience refers to an ecosystem’s ability to absorb shocks while maintaining almost the same function or – expressed differently – remain within the same state [5, 6]. These terms usually exhibit a vague and confusing character, since they have been widely used with different meanings in a variety of disciplines and they are considered to be antonyms [3, 7]. They also present a dynamic character which is changing from one time scale to another and as such they can be used as valuable indicators of a region’s environmental state [6, 8, 9]. Measuring the environmental vulnerability of an ecosystem, a region or a country, is an extremely complex task since the ability of a particular system to cope with potential stresses or the pressure required for an ecological threshold to be crossed cannot be exactly determined in space and time [10(unpublished)]. Such knowledge could enhance the human ability to predict –within a margin of certainty – an ecosystem’s behavior under specific unsettling events and guide the environmental management options – at any level – towards a sustainable path for adaptation [6].

The White Bandama Basin (WBB) in Côte d’Ivoire is one of the most vulnerable areas to climate change in the country. Rainfall in the basin has declined since 1970s and the temperatures are higher and higher [11]. There is an important climate variability marked by the drought phenomenon which caused in 2005 the depletion of the main drinking water source (the dam) of Korhogo, affecting nearly 200,000 people. The same region known suddenly since 2006, numerous episodes of flooding in the towns of Korhogo, Bouna, Ferkéssédougou, Mbengué, Tengrela and Odienné, causing more than ten deaths and extensive damage (281 huts collapsed, trails and roads cut roofs of schools and health centers away ...) [12, 13]. Although drought phenomena and flooding seem incompatible, they can overlap in time in some areas. The superposition of these two climatic events on the same territory, combine with over risk undermining the environment and making it vulnerable, including communities. Thus, the challenge for researchers in such a context is to assess the vulnerability of such an ecosystem facing multiple hazards. In this context, some indicators and their synthesis offer clues into a much needed methodological approach [14]. Many authors have developed several approaches including: the Composite Human Vulnerability Index and the Global Vulnerability Mapping [15], the vulnerability-resilience indicators (VRI) [16], the Environmental Sustainability Index (ESI) [17], the dimensions of vulnerability [18], the country-level risk measures [19] and the Environmental Vulnerability Index (EVI) [20]. Among all those tools, the EVI is of particular interest because it focuses on capturing and quantifying the total environmental vulnerability of a country or a region [20]. The EVI does not focus on vulnerability to a single hazard (e.g. forest fires or climate change in general), but considers a cross-section of the major factors

interacting in complex systems. That is why in this study we apply the Environmental Vulnerability Index (EVI) in order to identify, firstly, the most important climate hazard in the basin and secondly, to better understand the various risks to which the basin is subjected. The EVI has been developed by the South Pacific Applied Geoscience Commission (SOPAC), the United Nations Environment Program (UNEP) and their partners. The EVI was developed as a global composite index that quantifies the vulnerability of an area's environment. Furthermore, unlike previously developed vulnerability indices [7], it is totally focused on impacts on the environment itself and not on human systems. The EVI has been tested and applied on a global scale and it produced the first vulnerability scores for 235 countries in 2004 [15].

## Methodology

### Study area

The White Bandama Basin (WBB) is located in the northern Côte d'Ivoire, between Latitude 9°22' and 10°26' north and Longitude 5°00 and 6°30 west (Fig. 1). The population of the basin is mainly agricultural. With a surface area of approximately 10.050 km<sup>2</sup>, it is drained by a significant hydrographical network of approximately 222 km. Several dams have been built on the river system to the needs of agricultural and domestic water. The altitude ranges from 200 to 300 meters.

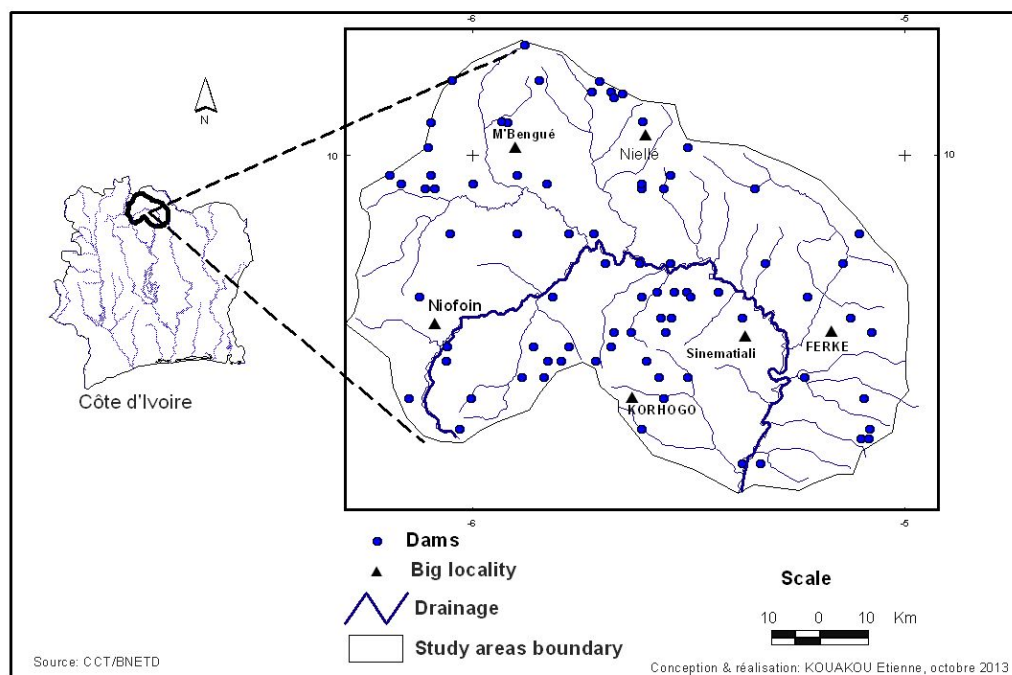


Fig. 1. White Bandama Bassin location

The vegetation consists primarily of clear forest and savanna. Annual rainfall ranges from 1,000 mm to 1,200 mm and the average annual temperature is 27°C. The WBB has two climatic seasons: a dry season from October to April, when rainfall is less than 100 mm, and a rainy season from May to September, with rainfall exceeding 100 mm. The months of December, January and February are the driest months, while July, August and September are the wettest, with an average monthly rainfall of over 200 mm.

### *Data sources*

Data were collected from a variety of sources: Ministries reports, the International Union for Conservation of Nature (UICN), SODEXAM (Society of Exploitation and Airport, Aviation and Meteorology Development), Felix Houphouët Boigny University, Nangui Abrogoua University, CIA (<https://www.cia.gov/library/publications/the-world-factbook/geos/iv.html>), ONG and Interviews.

### *Methods*

Our general methodology is based on the EVI approach as described by Pratt [7].

The calculation of the EVI is based on 40 indicators of environmental vulnerability. This list includes 26 indicators of risk (REI), 7 indicators of intrinsic resilience (IRI), and 7 indicators of environmental integrity or degradation (EDI). The indicators are also divided into five sub-indexes: climate change, geological, country characteristics, biological and anthropogenic events. The first three sub-indices (REI, IRI and EDI), describe the three aspects of vulnerability [7]:

- *Hazards*: measures anthropogenic and natural risk (REI).
- *Resistance*: gauges the inherent internal characteristics of a country which would tend to make it more/less able to cope with natural and anthropogenic hazards (IRI).
- *Damage*: Describes the ecological integrity or level of degradation of ecosystems (EDI).

The following definitions relating to indicators and indices were used [21]:

- An indicator was defined as any variable which characterizes the level of risk, resilience or environmental degradation in a region;
- A sub-indices (the REI, IRI and EDI) was defined as an aggregated average of the scores for indicators which related separately to risk, resilience or degradation; and
- An index (the EVI) was defined as an aggregated average of each of the three sub-indices (REI, IRI, EDI) to give an overall measure of the environmental vulnerability of a state, a region. The EVI is then, a composite of each of the three sub-indices.

The EVI indicators, use a scale of vulnerability that has been determined separately for each indicator [15] ranging from 1 (least vulnerable) to 7 (most vulnerable). The scale development was based on the ease of use avoiding many divisions (such as a 1–10 scale), on having a central point and not on sensitivity [22]. The final results/scores are produced based on the following equation:

$$EVI = 100 * \sum_{i=1}^n \frac{\text{indicators value}}{n} \tag{1}$$

n is the total number of indicators.

The resulting score (X) is classified into one of the five vulnerability categories (Kaly et al., 2004): (1) resilient  $X \leq 215$ ; (2) at risk  $215 < X \leq 265$ ; (3) vulnerable  $265 < X \leq 315$ ; (4) highly vulnerable  $315 < X \leq 365$ ; (5) extremely vulnerable  $X > 365$ .

After determination of the overall environmental vulnerability, we focus on the climate change indices to identify the most at risk climate indices for the basin, according the following definitions and equations.

**Calculation of the climate parameters**

To identify the most important climate risk in the basin, we analyzed, according to the available data, five (5) climate parameters of the EVI (high winds, dry periods, wet periods, hot periods, and cold periods). The definitions [21] and calculation of these parameters are as follows:

**High winds:** Average annual excess wind over the last five years (summing speeds on days during which the maximum recorded wind speed is greater than 20% higher than the 30 year average maximum wind speed for that month) averaged over all reference climate stations. This average is obtained by the following equations:

$$\bar{X}_{ym} = 1 / N_{\text{day } m} \sum_{d_m=1}^{N_{\text{day } m}} X_{y m d_m} \tag{2}$$

$$\bar{\bar{X}}_{ym} = 1 / N_{\text{year}} \sum_{y=1}^{N_{\text{year}}} \bar{X}_{y m} \tag{3}$$

$$PV_{y m d_m} = X_{y m d_m} / \bar{\bar{X}}_{ym} \quad N_{\text{year}} - 5 \leq y \leq N_{\text{year}} \tag{4}$$

With  $\bar{X}_{ym}$ , monthly average;  $\bar{\bar{X}}_{ym}$ , interannual average;  $X_{y m d_m}$ , the maximum daily observation; y is the year, m is the month and  $d_m$  refers to the day d of the month m and N is the number of days. PV is the percentage change over the past five years. We will focus

only on the day in which  $PV \geq 1.2 = 120\%$ , i.e. more than 20%. The final score of the index is given by:

$$\ln \overline{PV}_{y\ md_m} \tag{5}$$

**Dry periods:** Average annual rainfall deficit (mm) over the past 5 years for all months with more than 20% lower rainfall than the 30 year monthly average, averaged over all reference climate stations. It is calculated from equations 1, 2 and 3 except that here we will focus on PV values  $\leq 1.2 = 120\%$ , i.e. lower than -20% of the average. The final score is obtained by:

$$\ln \overline{PV}_{y\ md_m} \tag{6}$$

**Wet periods:** Average annual excess rainfall (mm) over the past 5 years for all months with more than 20% higher rainfall than the 30 year monthly average, averaged over all reference climate stations. The calculation of this indicator is the same as the speed of the wind but the final score is obtained by:

$$\sqrt{\overline{PV}_{y\ md_m}} \tag{7}$$

**Hot periods:** Average annual excess heat (degrees) over the past 5 years for all days more than 5°C (9°F) hotter than the 30 year mean monthly maximum, averaged over all reference climate stations. It is calculated from equations 1, 2 and 3 and the final score is obtained by:

$$\ln(\overline{PV}_{y\ md_m} + 1) \tag{8}$$

**Cold periods:** Average annual heat deficit (degrees) over the past 5 years for all days more than 5°C (9°F) cooler than the 30 year mean monthly minimum averaged over all reference climate stations. It is calculated the same way as the hot period’s indicator.

**Results**

Forty (82%) of the EVI indicators have been completed, which allows for a valid EVI. The overall EVI score for the WBB is 295. This suggests that the basin is, on a holistic level, vulnerable to effects from anthropogenic sources, country-characteristics and climate changes, but resilient to biological and geological risks (Fig. 2).

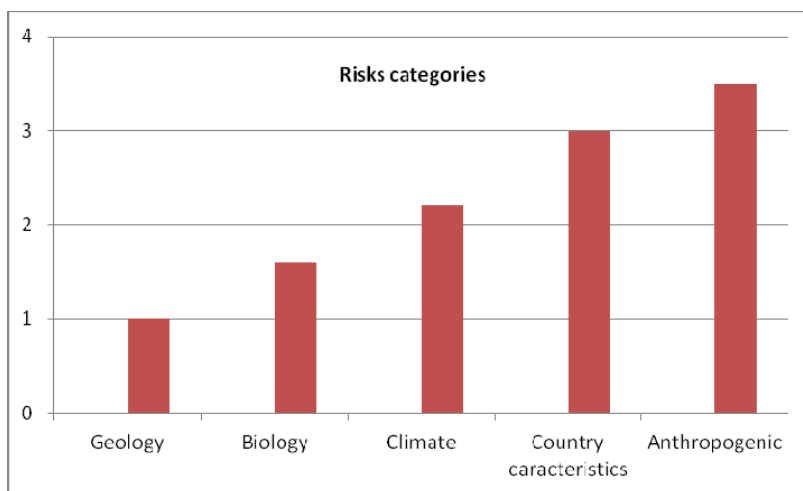


Fig. 2. EVI risk categories scores for the WBB

An analysis of the seven main sub-indices indicates that the most vulnerable issue of the WBB is related to the water resources, agriculture/Fisheries and biodiversity (Fig. 3). These sub-indices scores on the EVI scale are respectively 4.58, 3.8 and 3.43. After them, comes the human health index (3.2) and the climate change index (2.23). These results mean that water resources and agriculture/Fisheries and the biodiversity of the WBB are moderately vulnerable. Climate change, with a score of 2.23, is considered as a risk for the WBB, but the basin is resilient to the exposure to natural disasters (score of 1.89).

An analysis of the indices related to human activities (Fig. 4) shows a score of 7 for the population growth and resource conflicts. The waste management score was found to be 5. On the EVI scale this indicates that the basin is extremely vulnerable to effects of population growth and resource conflicts. Indicators such as density, waste treatment and waste production also affect the ecosystem services of the basin.

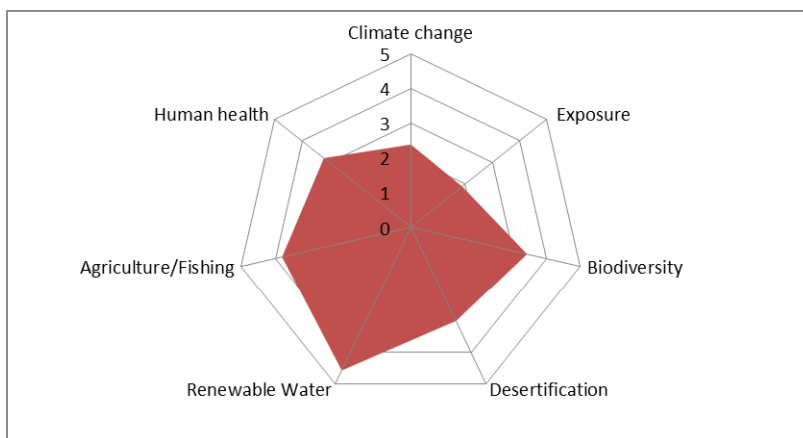
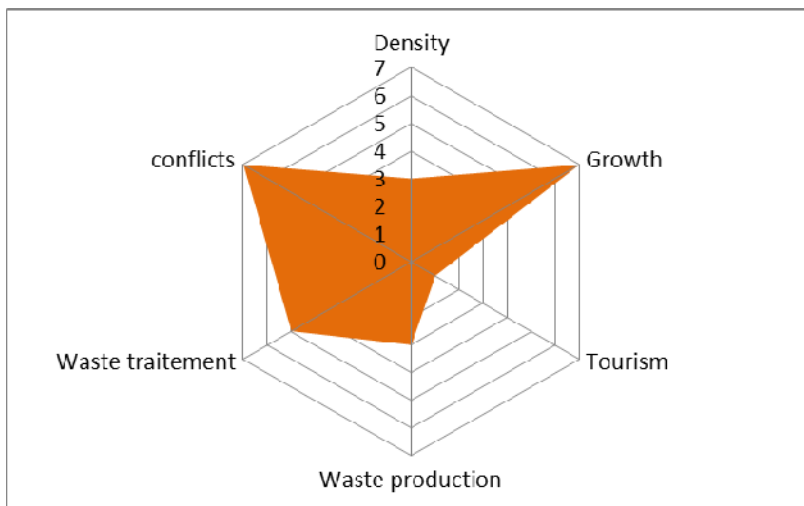
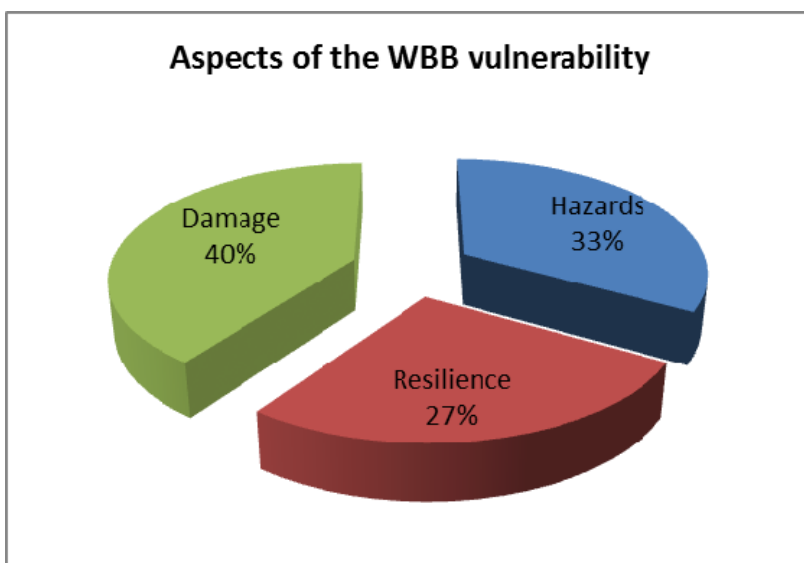


Fig. 3. Score of the seven main sub-indices of EVI



**Fig. 4.** EVI anthropogenic factors analysis

According to the three aspects of vulnerability, we obtained an overall risk score (REI) of 3.19 (33%) against a score of 2.57 (27%) for the resistance (IRI) and 3.86 (40%) for damages (EDI) (Fig. 5). These results show that if the risks came, it would be difficult for the ecosystem to cope with them. It is therefore apparent that, the basin does not have sufficient resources to cope with the potential risks that may occur in the basin.



**Fig. 5.** Analysis of the three aspects of vulnerability

The analysis of indicators related to climate change (Fig. 6) shows that the drought has a total score of 5 followed by the wet season with a score of 3. These results indicate that the



basin is highly vulnerable to drought and moderately vulnerable to flooding but is not exposed to high winds, hurricanes, heat waves and freshness.

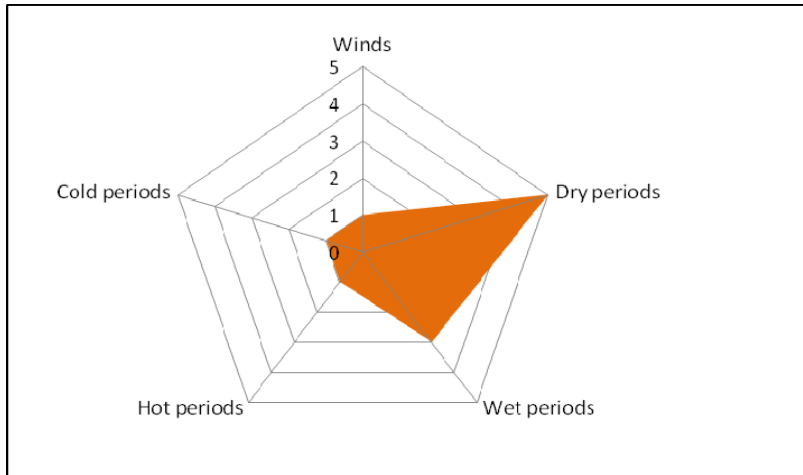


Fig. 6. EVI climate change indices analyses

The Fig. 7 shows the total Environmental Vulnerability Index (EVI) score of the White Bandama Basin. This figure clearly indicates that resources conflicts, population growth, vegetation loss, isolation and drought are the most important vulnerability issues of the basin. This confirmed precedent results.

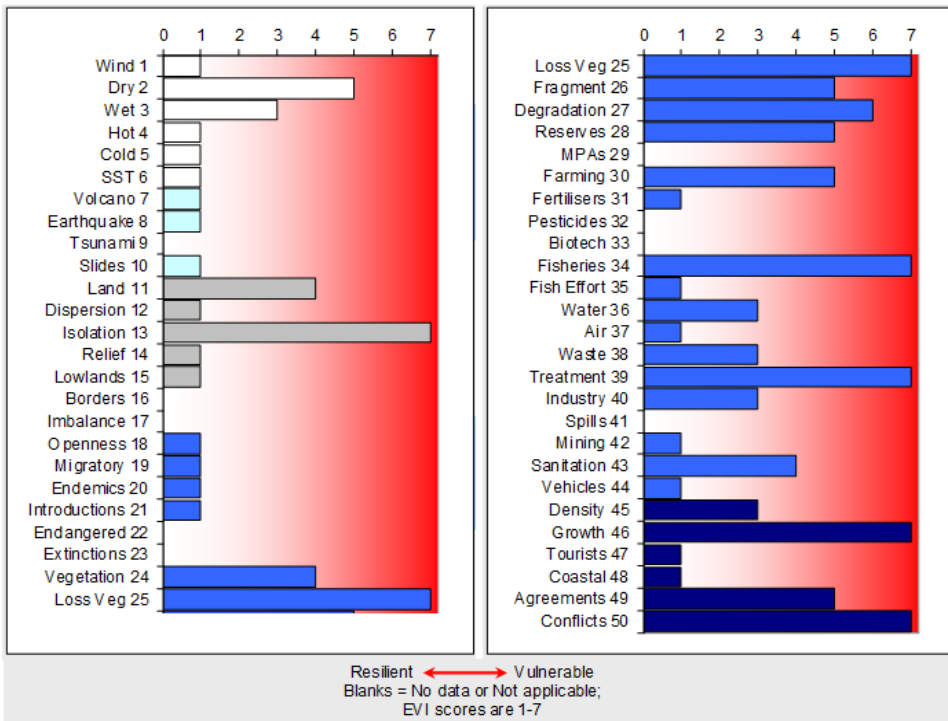


Fig. 7. Environmental Vulnerability Index of the White Bandama Basin

## Discussions

The WBB's EVI study indicates that the basin is moderately vulnerable. Outside the country's characteristics, risks affecting the basin are the anthropogenic actions and climate change. Our analysis according to the main sub-indices indicates that water resources and agriculture/Fisheries and biodiversity of the WBB are moderately vulnerable to these issues. This means that the indicators grouped into these sub-indices suffer more the effects of these problems. The main indicators of the sub-indices water resources are vegetation cover, loss of land degradation, water resources, use of pesticides and fertilizers, the waste treatment, population growth. The score of these indicators confirmed this fact. As we can see, most human activities affect the WBB. Studies, [23, 24] indicate the degradation of vegetation cover of the basin, the loss of fauna and flora outside of some protected areas and especially the use of unsuitable pesticides and fertilizers in agriculture. These results are comparable to those from previous studies [25, 26]. Studying the environmental vulnerability of the South Pacific islands of Fiji, Vanuatu, and Samoa, it was observed [25] that these islands are most vulnerable to issues involving land degradation, water resources, land area, and population density and the overall vulnerability score obtained makes them moderately vulnerable to natural and man-made disasters. Similar results were also obtained by other studies [26] in the island of Tobago which seems to be slightly vulnerable to effects from meteorological, biological, anthropogenic, country-related, and geological sources. The population growth, resource conflicts, waste management and density are the most important vulnerability issue related to anthropogenic aspect. Haiti [27] also showed environmental vulnerability, which has its roots in extreme poverty, rapid population growth and unplanned urbanization. Regarding the climate change aspect, we observe that climate change is a risk for the basin and drought is the most important climate risk for the basin. This result is in agreement with previous studies [11] (article in revision), which show that the basin went through a period of drought lasting since the 1970s. These results are in agreement with others [28] indicating that arid, semi-arid and dry African savannas and are particularly vulnerable to climate change. Contrary to the WBB situation, in the High-Atlas of Marrakech (Morocco), [29] (Poster presentation) shows that the cold period is the most important climate vulnerability issue. Combining all these effects, vulnerability aspects analyses in the WBB, indicate that the basin does not have sufficient resources to cope with the potential risks that may occur in the basin. The scores of 3.19 for risks (REI), 2.57 for resilience (IRI) and 3.86 for damage (EDI) were obtained for the WBB. These scores indicate the vulnerability of the basin and the need for an adaptation plan.

It is important to note that this EVI was obtained from various data sources and reflects the state of the environment at a given period. Hence, it can be subject to errors related to data. Because the environment is always in diverse and rapidly changing conditions, EVI scores may vary. Thus, it can change in the future to reflect changes in the environmental and man-made forces that influence it as already demonstrated by previous studies [29]. Comparing EVI scores

between 2004 and 2010 Nikolaos demonstrated that the basin has gone from a high vulnerability to an extremely vulnerability in six years.

## Conclusions

The application of the EVI in Bandama Basin allowed us to identify the most vulnerable issue of the basin. It showed that the basin is moderately vulnerable to anthropogenic sources, country-characteristics and climate change. The most important anthropogenic factors involved are: population growth, resources conflicts, waste treatment and density. All these factors have significantly disturbed the balance in the ecosystem of the basin. The water resources and agriculture/fisheries are the most vulnerable issues. Drought is the most important climate risk factor for the basin. The overall risk factor in the basin is higher than its means of resistance, making the basin moderately sensitive to changes.

This study provides potential trend impact risks, which will help develop mitigation or adaptation and better management of the ecosystem in the basin. It could, therefore, help decision makers in managing the environment in a context of changing climatic conditions.

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