MAPPING ANTHROPOGENIC PRESSURES IN THE BANDAMA RIVER BASIN (CÔTE D'IVOIRE): A MULTICRITERIA APPROACH INTEGRATED WITH GIS

Manuscript Info

……………………..

Manuscript History

Received: xxxxxxxxxxxxxxxx

Final Accepted: xxxxxxxxxxxx

Published: xxxxxxxxxxxxxxxx

Key words:-

Anthropogenic pressures, AHP, GIS, Bandama, Côte d'Ivoire, integrated water managemen.

Abstract

………………………………………………………………

Anthropogenic pressures are among the main drivers of disturbance in aquatic ecosystems and water resources in tropical basins. This study proposes an assessment and mapping of anthropogenic pressures in the Bandama River basin, the largest in Côte d'Ivoire. The methodology combines the Analytic Hierarchy Process (AHP) and Geographic Information Systems (GIS), integrating three key factors: hydraulic infrastructures, land use, and population density. The results show that hydraulic infrastructures represent the dominant factor (56%), followed by land use (32%) and population density (12%). The anthropogenic pressure map reveals a North–South gradient, with very high pressures in the regions of Korhogo, Ferkessédougou, Yamoussoukro, and Toumodi. These pressures induce major hydrological disturbances, including alterations of flow regimes, intensified runoff, and reservoir siltation. The results highlight the need for integrated water resources management to strengthen the basin's hydrological resilience in the face of increasing anthropogenic dynamics.

………………………………………………………………………………………………….....

Introduction:-

The increasing pressure on natural resources, driven by demographic, agricultural, and energy development, is profoundly transforming tropical river basins (Ellis et al., 2010). In West Africa, climate variability and human activities are the main drivers of modifications in the hydrological cycle (Hubert &Carbonnel, 1993; Savané et al., 2001; Goula et al., 2006). The droughts of the 1970s caused a 10–30% decrease in rainfall and a 20–60% reduction in river flows, thereby increasing water vulnerability for populations (Paturel et al., 1997). At the same time, agricultural expansion, deforestation, and the multiplication of dams have intensified pressures on aquatic ecosystems (Giertz et al., 2005).

The Bandama River basin, which covers 97,500 km², plays a vital role in water supply, irrigation, hydropower generation, and socio-economic development in Côte d'Ivoire. However, it is subject to strong anthropization: the construction of major hydroelectric dams (Kossou, Taabo, Buyo, Singrobo-Ahouaty), the development of hundreds of agro-pastoral reservoirs, and rapid agricultural expansion (FAO, 1996; Kouassi et al., 2017). These dynamics modify the regulation of flows, exacerbate erosion, and generate conflicts over water use.

In this context, mapping anthropogenic pressures is an essential tool for identifying and ranking vulnerable areas. The Analytic Hierarchy Process (AHP) coupled with Geographic Information Systems (GIS) provides a robust approach for spatializing multiple criteria and evaluating their relative importance (Saaty, 1980; Malczewski, 2006).

The objective of this study is to map relative anthropogenic pressures in the Bandama basin. More specifically, it aims to: (i) identify the main pressure factors, (ii) rank their importance, and (iii) produce a spatialized map.

Materials and Methods: -

Search area:

The Bandama River basin, the largest in Côte d’Ivoire, covers approximately 97,500 km² and extends from the North (Korhogo region) to the South, where it flows into the Atlantic Ocean near Grand-Lahou (Figure 1). The climate is of the Sudanian–Guinean tropical type, characterized by an alternation between a rainy season (May–October) and a dry season (November–April).The basin presents a diversity of landscapes: wooded savannas and open forests in the North, dense forests in the South, ferruginous and ferralitic soils, with altitudes ranging between 200 and 400 m. From a socio-economic perspective, the Bandama constitutes a strategic axis that supplies a large part of the Ivorian population with drinking water, irrigation, and hydroelectric power (FAO, 1996; Kouassi et al., 2017).

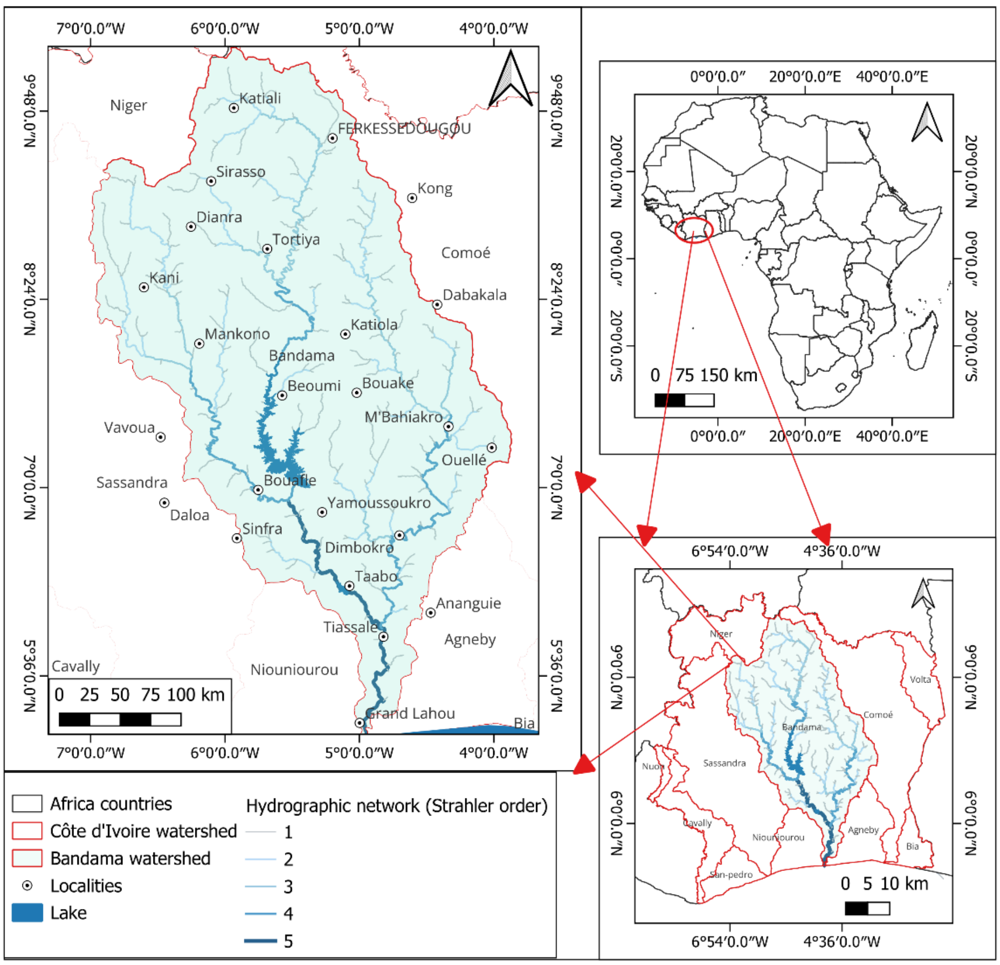

Figure 1: Geographical location of the Bandama River Basin

Data

The data used in this study were collected from several institutional, satellite, and bibliographic sources in order to cover all the parameters necessary for evaluating anthropogenic pressures in the Bandama basin.For land use, a Landsat satellite image from the year 2020, obtained via the USGS platform (https://earthexplorer.usgs.gov/.The data used in this study were drawn from multiple institutional, satellite, and bibliographic sources to cover all the parameters required for assessing anthropogenic pressures in the Bandama basin.For land use, Landsat satellite images (1990, 2000, 2010, and 2020) obtained via the USGS platform were employed. Demographic data were taken from the General Population and Housing Census (RGPH 2014). Regarding hydraulic infrastructures, an inventory was compiled from several sources, including FAO databases (1996), AGEROUTE reports, and other national documents. This inventory identified the main hydroelectric dams (Kossou, Taabo, Buyo, Singrobo-Ahouaty) as well as a multitude of smaller agro-pastoral reservoirs.Complementary data were used to further characterize the basin: soil maps from FAO (1998), digital elevation models (SRTM with 30 m resolution), and institutional documents related to water management plans and national inventories.

Methods

The methodology adopted in this study is based on the integration of Multi-Criteria Analysis (MCA) and Geographic Information Systems (GIS) for mapping relative anthropogenic pressures. This type of approach is recognized as robust for the spatialization of complex and multifactorial phenomena (Malczewski, 2006; Feizizadeh& Blaschke, 2013).

Development of a spatial database

All collected data were georeferenced and integrated into a GIS (ArcGIS and QGIS). The thematic layers (land use, population, hydraulic infrastructures) were standardized to a resolution of 1 km² to enable their comparison and overlay.

Prioritization of pressure criteria

The weighting of criteria was carried out using the Analytic Hierarchy Process (AHP) method developed by Saaty (1980). Three main factors were considered: hydraulic infrastructures (dams, weirs, reservoirs), land use (agriculture, urbanization, deforestation), and population density.

Construction of the pairwise comparison matrix

Each criterion was compared with the others using Saaty's scale (values from 1 to 9), which expresses the relative importance of pressures. The consistency of judgments was verified using the consistency index (CI) and the consistency ratio (CR), which must remain below 0.1 (Saaty, 2008).

Calculation of relative weights and integration into the GIS

The weights obtained were used to weight the normalized thematic layers. The weighted linear combination method generated a map of relative anthropogenic pressures, distinguishing areas of low, medium, high, and very high pressure.

Validation

The final map was cross-checked with field observations (local surveys, national hydraulic reports).

Results

Identified anthropogenic pressure factors

Hydraulic infrastructures

Hydraulic infrastructures represent the dominant factor, with an average weight of 56% in total pressure. This predominance is linked to the high density of recorded structures, including the major hydroelectric dams (Kossou, Taabo, Buyo, Singrobo-Ahouaty) and a multitude of agro-pastoral reservoirs and weirs. These infrastructures alter the natural regulation of flows and accentuate seasonal hydrological contrasts, particularly in the central part of the country (Figure 2).

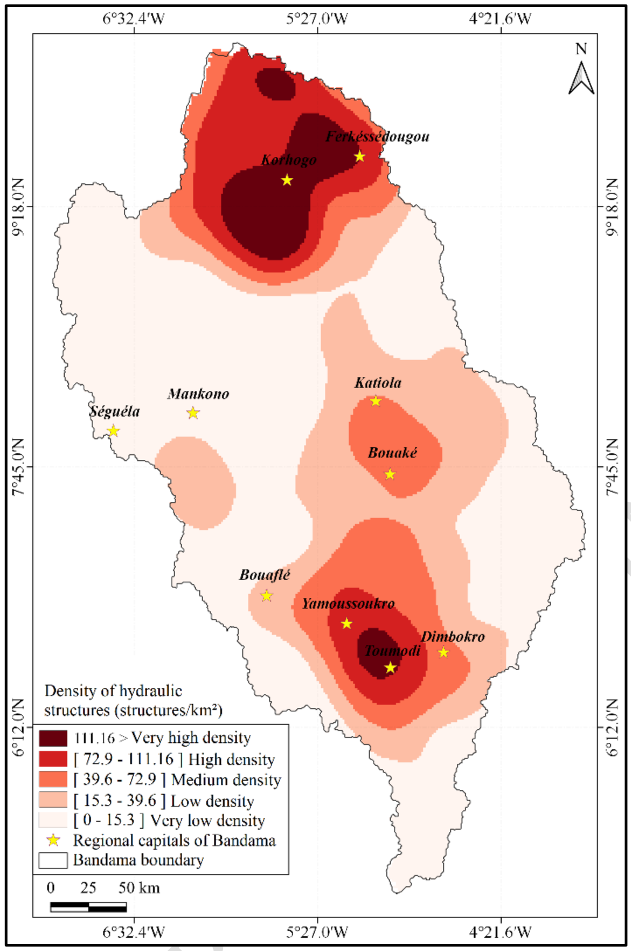

Figure 2: Density of hydraulic structures in the Bandama River basin

Land use

Land use accounts for 32% of the pressures. Agricultural expansion, deforestation, and urbanization contribute to soil impermeabilization and increased surface runoff. Figure 3 show's the loss of forest cover in the North (Korhogo, Ferkessédougou) and the rapid urbanization in the Yamoussoukro and Toumodi areas emerge as structuring factors.

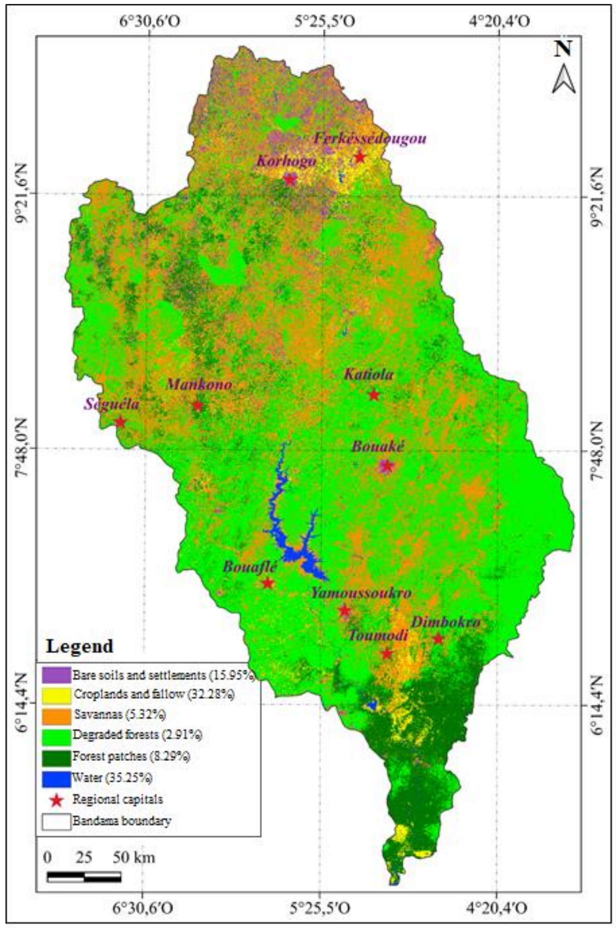

Figure 3: Land use map of the Bandama River basin

Population density

Figure 4 shows population density accounts for about 12% of the pressure hierarchy. Although its weighting is lower, it plays an indirect role by increasing the demand for drinking water, irrigation, and energy, which generates a multiplication of abstraction and storage facilities.

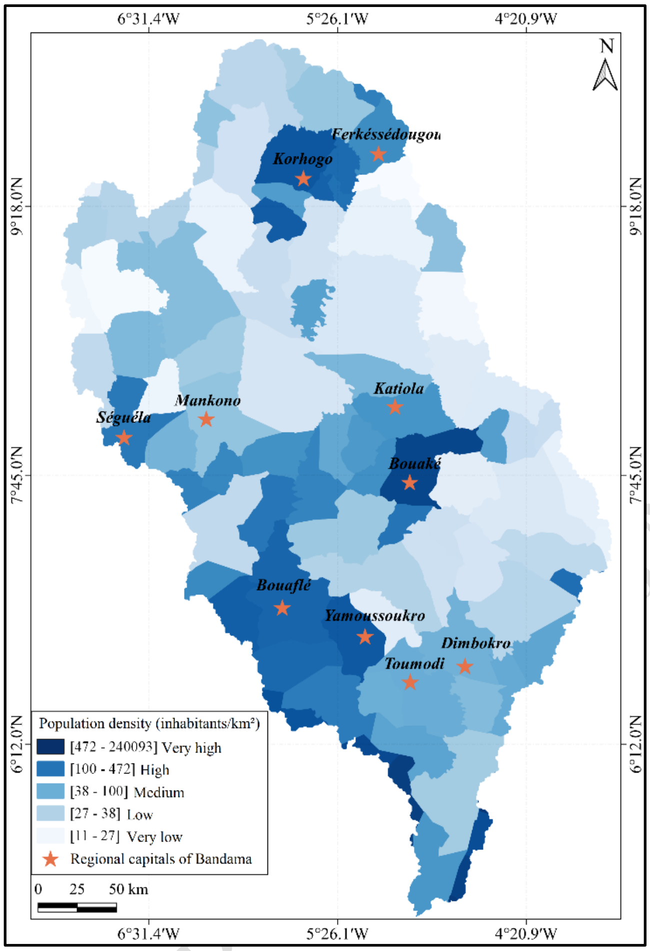

Figure 4: Population density in the Bandama River basin

Spatial distribution of anthropogenic pressures

The GIS-based mapping highlights a heterogeneous distribution of anthropogenic pressures across the basin (Figure5):

- **Very high-pressure zones:** Concentrated in the North (Korhogo, Ferkessédougou) and the Center (Yamoussoukro, Toumodi). These areas combine a high density of hydraulic infrastructures, extensive agriculture, and sustained demographic growth.
- **Medium to high-pressure zones:** Observed around the hydroelectric dams (Kossou, Taabo, Buyo), where flow regulation and adjacent agricultural activities exert significant influence.
- **Low-pressure zones:** Mainly located in the southern forested areas (around Grand-Lahou and the outskirts of Abidjan), where vegetation cover remains denser and the density of hydraulic infrastructures is lower.

The synthesis map reveals a clear North–South gradient, with intensification of pressures in the Sahelian and Sudanian zones, marked by agricultural dependence and climatic irregularities.

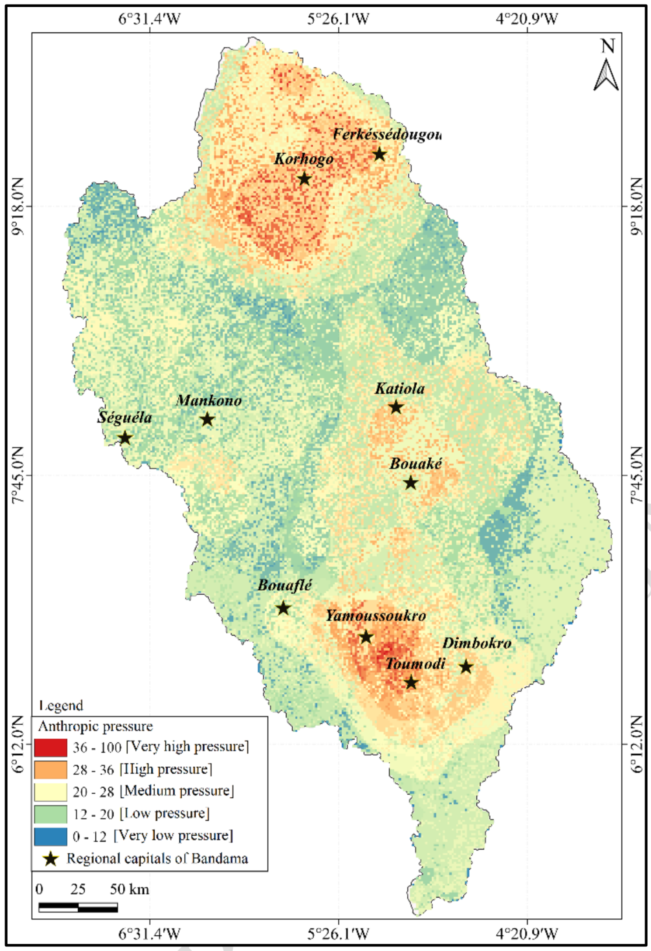

Figure 5: Relative anthropogenic pressure in the Bandama River watershed

Discussion

The results of this study clearly highlight the predominance of human activities in transforming the hydrological functioning of the Bandama basin. With a weighting of 56%, hydraulic infrastructures appear as the central pressure factor, confirming the importance of these structures in the artificial regulation of water flows. These findings are consistent with those of Belmar et al. (2010) and Eekhout et al. (2020), who emphasized the major impact of dams and reservoirs on hydrological regimes, often surpassing that of climatic variations. The high density of agro-pastoral reservoirs and weirs reinforces this dynamic by multiplying withdrawal and regulation points.

Land use constitutes the second most important pressure factor (32%), reflecting the extent of deforestation and agricultural expansion within the basin. This trend, also observed by Giertz et al. (2005) in West Africa, leads to reduced infiltration and increased surface runoff, aggravating erosion and reservoir siltation. Rapid urbanization, particularly around Yamoussoukro and Toumodi, accentuates soil impermeabilization and contributes to landscape fragmentation.

Population density, although less weighted (12%), remains an indirect but structuring factor. Indeed, the growing demand for drinking water, irrigation, and energy exerts increasing pressure on available resources, justifying the multiplication of hydraulic infrastructures. This dynamic is similar to that described by Ellis et al. (2010) regarding the anthropogenic transformation of biomes at the global scale.

The spatial analysis reveals a marked North–South gradient, with northern and central areas being the most exposed. These results reflect the combination of climatic constraints (irregular rainfall) and anthropogenic pressures (extensive agriculture, demographic growth). This finding is consistent with the analyses of Kouassi et al. (2017), who highlighted the persistence of droughts and their interaction with human activities as drivers of increased vulnerability.

These observations emphasize the urgent need for an integrated approach to water resources management. The use of the Analytic Hierarchy Process (Saaty, 1980; 2008) allowed for an objective ranking of pressures, but further refinement could include additional criteria such as water quality, agricultural practices (use of inputs), or climate change dynamics. Furthermore, validating the mapping with field surveys is essential to strengthen the robustness of the results and guide public policies. Ultimately, this study underlines the necessity of integrated and participatory management policies, combining infrastructure planning, ecosystem preservation, and regulation of water uses. The hydrological resilience of the Bandama basin will therefore depend on the ability to reconcile socio-economic development with the sustainability of water resources in the context of increasing anthropogenic pressures.

Conclusion

This study assessed and mapped the anthropogenic pressures exerted on the Bandama River basin through an approach combining the Analytic Hierarchy Process (AHP) and Geographic Information Systems (GIS). The results show that hydraulic infrastructures represent the major pressure factor (56%), followed by land use (32%) and population density (12%).

The spatial distribution of pressures reveals a North–South gradient, with very high-pressure zones identified around Korhogo, Ferkessédougou, Yamoussoukro, and Toumodi. These zones reflect the combination of demographic, agricultural, and hydro-agricultural development dynamics.

The findings confirm that human activities play a predominant role in disrupting the basin's hydrological processes, surpassing the influence of climatic variations alone. The consequences include altered flow regimes, intensified erosion and reservoir siltation, and the weakening of aquatic ecosystems.

In this context, the hydrological resilience of the Bandama basin will essentially depend on the capacity to regulate and plan resource exploitation. Effective management will require integrated and participatory water governance strategies, ensuring a balance between socio-economic development and the sustainability of water resources.

Références

1. Belmar, Ó., Velasco, J., Martínez-Capel, F., & Marín, A. A. (2010). Natural flow regime, degree of alteration and environmental flows in the Mula stream (Segura River basin, SE Spain). *Limnetica*, 29(2), pp. 353-368

2. Eekhout, J. P. C., Boix-Fayos, C., Pérez-Cutillas, P., & de Vente, J. (2020). The impact of reservoir construction and changes in land use and climate on ecosystem services in a large Mediterranean catchment. *Journal of Hydrology*, *590*, 125208

3. Ellis, E. C., Klein Goldewijk, K., Siebert, S., Lightman, D., &Ramankutty, N. (2010). *Anthropogenic transformation of the biomes, 1700 to 2000*. *Global Ecology and Biogeography*, 19(5), pp.589-606

4. FAO (1996). Etat des connaissances sur les pêcheries continentales ivoiriennes. Rapport de consultation, avril 1996. Rome : Organisation des Nations Unies pour l'alimentation et l'agriculture (FAO),52 p.

5. FAO (1998). World Reference Base for Soil Resources. World Soil Resources Reports No. Rome. 84, 91 p.

6. Feizizadeh, B., & Blaschke, T. (2013). GIS-multicriteria decision analysis for landslide susceptibility mapping. Environmental Earth Sciences, 66, pp. 97-112.

7. Giertz, S., Junge, B., &Diekkrüger, B. (2005). Assessing the effects of land use change on soil and hydrology in West Africa. Physics and Chemistry of the Earth, 30, pp. 485–496.

8. Goula Bi Tié, A., Savane, I., Konan, B., Fadika, V., & Kouadio, G. B. (2006). Impact de la variabilité climatique sur les ressources hydriques des bassins de N'Zo et N'Zi en Côte d'Ivoire (Afrique tropicale humide). VertigO - la revue électronique en sciences de l'environnement, 7(1). https://doi.org/10.4000/vertigo.2038

9. Hubert, P., &Carbonnel, J.-P. (1993). Segmentation des séries annuelles de débits des grands fleuves africains. Bulletin de Liaison du Comite Interafricain d'Etudes Hydrauliques, pp.3-10

11. Kouassi A. M., Assoko A. V. S., Djè K. B., Kouakou K. E., Kouamé K. F. et Biemi J. (2017). Analysis of the persistence of drought in West Africa: Characterization of the recent climate variability in Ivory Coast. *Environmental and Water Sciences, Public Health et Territorial Intelligence*, 2, pp. 47-59.

12. Malczewski, J. (2006). GIS-based multicriteria decision analysis: a survey of the literature. International Journal of Geographical Information Science, 20(7), pp. 703-726.

13. Saaty, T. L. (1980). The analytic hierarchy process: Planning, priority setting, resource allocation. New York: McGraw-Hill, 281 p.

14. Saaty, T. L. (2008). Decision making with the analytic hierarchy process. International Journal of Services Sciences, 1(1), pp. 83-98.

15. Savané I., Coulibaly K. M. et Gioan P. (2001). Variabilité climatique et ressources en eaux souterraines dans la région semi-montagneuse de Man. Revue Sciences et changement planétaire-sécheresse, 4 pp. 231-237.

16. Paturel J.E., Servat E., Kouamé B., Lubès-Niel H., Ouedraogo M., Masson J.M. (1997), "Climaticvariability in humidAfricaalong the Gulfe of Guinea. Part two: an integrated regional approach", *Journal de l' Hydrologie,* 191, pp. 16-36.