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CLIMATE DYNAMICS AND SPATIO-TEMPORAL DISTRIBUTION OF SEDIMENTS IN THE ZOU RIVER WATERSHED AT DOME IN BENIN (WEST AFRICA)

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ABSTRACT

Soil erosion is and remains one of the biggest environmental problems under current climatic conditions, threatening not only developed countries, but even more in developing countries. This study proposes to do modeling sediment production in the catchment of the River Zou in Benin related to the current climate. The methodological approach is based on rainfall statistics (empirical) monthly, seasonal and annual basin over the period from 1965 to 2010, and those projected for 2030. Similarly, the GIS tool and its coupling with agro-hydrological model SWAT have examined the effects of climate dynamics on sediment yield in the middle of study. It appears from the analysis of results obtained under the effect of climate fluctuations alone, the average annual sediment yield increased from 3.28 t / ha to 2.80 t / ha in the period 2025-2030 compared to 2000-2005 period, a decrease of 14.63%. Regarding the effect of the scenarios occupancy only soils the average annual sediment production has increased, compared to the occupation of reference soils (LU02) of 31.66%. As against the combined effects of climate fluctuations and dynamics of vegetation cover, it is observed a decrease in the average annual sediment yield of 4.20 t / ha to 3.17 t / ha between 2000-2005 and 2025-2030, a decrease of 24.52%.

Keywords: Watershed Zou River in Benin, climate dynamics, sediment production, agro-hydrological model SWAT.

INTRODUCTION

Water erosion is a complex and widespread phenomenon in semi-arid countries due to the nature of bare, compacted, and dried soils, which generate high peak flows and severe concentrated erosion (Megnounif and Ghenim, 2013).

Nowadays, the factors of erosion that influence erosive phenomena are now widely agreed upon and include the soil, its use, topography, and climate (Wischmeier and Smith, 1978 ; King and Le Bissonnais, 1992). However, the situation varies greatly from one location to another, and a comprehensive perspective necessary for planning advice to local communities requires mandatory consideration of this spatial disparity, with particular attention to scale transfers in the interpretation of erosive processes (Diallo *et al.,* 2000). The transport and deposition of sediments are of interest to hydrologists, as they overall affect the management of a watershed.

All terrestrial life depends on a thin layer of soil. The top meter of the Earth's surface nourishes more than six billion people, as well as an immeasurable number of insects, reptiles, birds, and animals. Even much of marine life depends on eroded or dissolved elements from the continents carried into aquatic environments. In recent decades, economic and demographic pressures have led to rapid and widespread degradation of cultivated soils around the world (Fox *et al.,* 2008).

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Today, soil degradation not only contributes to the impoverishment of ecosystems, but it also endangers the quality of life, and even the survival, of certain vulnerable populations. Indeed, the quantification and spatialization of soil erosion is an essential approach for understanding the ongoing processes in watersheds (Payet, 2009). The present study aims to relate sediment dynamics to current climatic conditions in the Zou River Watershed (BVRZ) in Benin.

STUDY AREA: THE ZOU RIVER WATERSHED (BVRZ)

Located straddling the Zou and Collines departments, the Zou basin (Figure 1) is entirely situated in the central-western part of Benin, with a slight extension into Togolese territory. It is precisely located between 7°15' and 8°33' north latitude and 1°35' and 2°14' east longitude, covering an area of approximately 8,920 km². Its geographical position gives it a somewhat unique climatic environment.

The upper part of the basin, like the central part of Benin, is characterized by a transitional climate (Boko, 1988; Afouda, 1990) intermediate between the subequatorial climate with two rainy seasons and the tropical Sudanian-type climate. Meanwhile, the lower part, particularly around the Domè station, experiences, depending on the year, a rainfall pattern that is sometimes unimodal and sometimes bimodal (Atchadé, 2014).

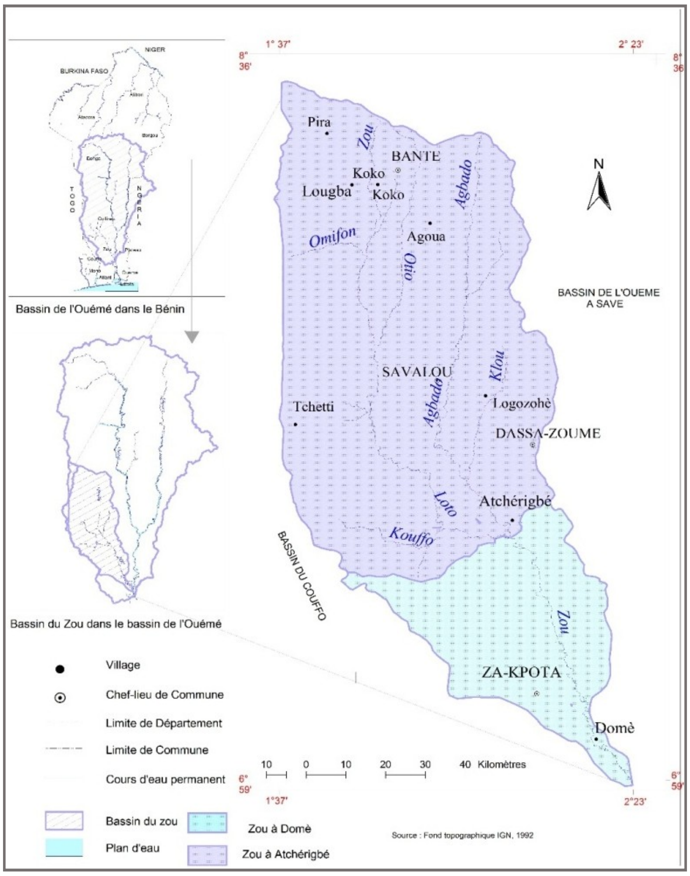

Figure 1 : Geographical location of the Zou watershed at the Domè outlet

The analysis of the year-to-year evolution of maximum and minimum temperatures in the area highlights a trend of warming in the basin for the period concerned. In general, the annual average temperatures fluctuated over the study period. They increased overall from 30.40 °C in 1970 to 34.17 °C in 2015, representing a rise of 3.77 °C for maximum temperatures, and from 21.79 °C to 23.47 °C, or 1.71 °C, for minimum temperatures at the Savè station. This increase in temperatures observed locally in the Commune of Bantè is higher than that reported by the IPCC (2007), which is 0.2 to 1 °C for Benin. This allows us to assert that beyond average values, specific characteristics can be observed when changing the spatial scale. This global warming, combined with increased precipitation variability and the rise of extreme events (droughts, floods), already has significant impacts on natural and human systems. The rise in ground temperatures can therefore have multiple effects on ecosystems (notably on plants). The upstream part of the basin generally aligns with the geology of the central Benin region, characterized by geomorphology closely linked to lithology and geological history (Berding and van Diepen, 1982): The terrain is a peneplain dominated by inselbergs, and the southern part rests on the series of sediments of the coastal sedimentary basin (Upper Cretaceous), marked by a recent sedimentary cover above the crystalline basement, which slopes approximately 2% towards the south. The vegetation throughout the commune of Savalou consists in some areas of forest galleries, dense dry forests, semi-deciduous forests, open forests, wooded savannas, shrubby and rocky savannas (Agoinon, 2012). This study environment, due to its geographical location, represents an important territorial issue for the economic activities of the local populations. Those that require the use of water resources from the Zou River watershed include agriculture (largely cotton production), artisanal fishing, cattle farming (practiced by the Fulani), etc. Indeed, the intensification of agricultural production can have significant medium- and long-term impacts on land use and fertility management, as cotton is a demanding crop. Already, on farms, plowing with a plow has become a common practice for soil preparation (Keita, 1997).

METHODS AND DATA

Several types of data were used in this study. These include climatological chronicles (rain, temperature), and land use chronicles. A catchment area of 8920 km2 is, a priori, far from being a homogeneous set from the hydrodynamic point of view and susceptibility of the soil to erosion. For this reason, a Digital Terrain Model (DTM) of the study area was first produced from topographic maps at 1:50000.

- The climatological data used concern: rainfall heights (daily, monthly, and annual) from rain gauge stations located in the Zou basin or its immediate surroundings. These are data from Agouna, Bantè, Pira, Gouka, Dassa, Tchètti, Savalou, Bohicon, Abomey, Zagnanado over the period 1965-2023. The potential evapotranspiration data (monthly) from the synoptic stations of Bohicon and Savè were collected from the National Meteorology Directorate (DMN). Finally, data on future climate scenarios (2015 to 2030) developed by the IMPETUS research program were used to estimate the effects of future climate changes on sediment production in the study area. These data are harmonized with outputs from climate models of the CORDEX program (Coordinated Regional Climate Downscaling Experiment). These are high-resolution data provided in grids of 0.44° * 0.44°, which is approximately 50 km * 50 (Giorgi *et al.,* 2009). A future aspect where simulations are carried out according to both RCP 4.5 and 8.5. The future period data extends from 2006 to 2100, and is therefore used for impact analysis of future climate changes.

Land use data are those provided by LANDSAT ETM 1998 and LANDSAT ETM 2010 images (with 30 m resolution) for the development of various thematic and land use maps in the Zou River watershed. Indeed, these are data provided on the types of land use, including: forests and forest galleries, open forests and wooded savannas, tree and shrub savannas, mosaics of crops and fallow land, water bodies, grasslands, and others. The area of each type of land cover was determined for the years 1998 and 2010.

Bossa's (2007) land use data on the Zou in Atchérigbé, supplemented by those used for the Ouémé basin, facilitated the performance of the various simulations. Finally, data from future scenarios on land use dynamics for the years 2017, 2022, and 2027, developed by the REVERTUWIN project in Benin, are used.

Data Processing

The study of climate variation at the scale of the Zou River watershed was carried out through its climatic parameters (Rainfall, Temperature, etc.). After collecting these data, they were converted into a dBASE file, representing the formats for these different types of inputs. The results obtained aim to estimate the solid load carried by the Zou River. They will be processed and presented in the form of maps.

To assess the effects of climate dynamics on the spatio-temporal distribution of sediment, the SWAT (Soil and Water Assessment Tool) model was used. This model was developed to predict the impact of land management practices on water, sediment, and agricultural chemical transport in large, complex watersheds with different soil types and land uses, over long periods. The model divides the entire Zou River basin into 13 sub-basins.

The simulations were carried out on a daily basis at the scale of hydrological response units, which represent a unique combination of land use and soil physical properties within each of the 13 sub-watersheds of the study area. In the aquatic phase of the model, exports, including water and sediment at the sub-watershed scale, were handled by the model routines that simulate deposition, resuspension, transformation, and erosion processes within the stream network. Land use for 1998 and 2010 was applied across the entire study area. It was reclassified by SWAT by matching each type of cover to the corresponding code in SWAT.

The future land use maps used in this study are those from 2017 (Lu17), 2022 (Lu22), and 2027 (Lu27). The land use maps are imported using the "Land Use and Soil Distribution" command, which is under another command called "AVSWAT," providing us with the distribution of HRUs (Hydrologic Response Units) across the basin. The HRU distribution command allowed the selection of the "Multiple Soil and Land Use" option, which had been chosen during the model calibration.

The DEM, after being projected, allowed SWAT to identify the hydrographic networks from which the watershed was delineated, as well as the lowest outlet located in Domè, so that it could direct the results of simulations carried out in the various sub-watersheds towards this outlet.

The work of text processing, image processing, and spatial analysis was carried out using software such as MS Excel, MS Word, and ArcGIS (ArcMAP) coupled with the SWAT software.

RESULTS AND DISCUSSION

- Sediment production in the Zou watershed at Domè

The set of scenario simulations carried out showed sediment production in a variety of ranges in the study area. The trends in sediment production obtained depend on the scenario used. Under the effect of climate fluctuations alone and with the 2002 land use map (figure 2), the average annual sediment production is 9.36 ± 2.80 t/ha.

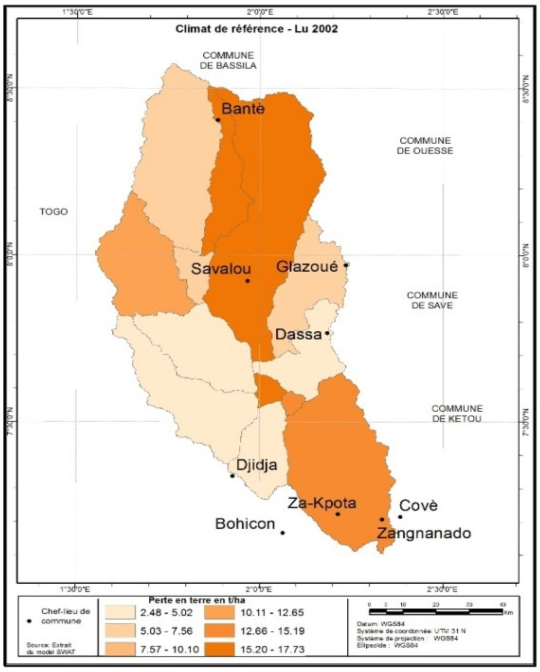

Figure 2: Spatio-temporal distribution of average sediment production according to land use in 2002 and climate data from 2000-2004.

The commune of Za-kpota concentrates the largest quantity of sediments at 17.76 t/ha, followed by the communes of Banté de Savalou (photo), Zagnando de Djidja and Dassa-Zoumè.

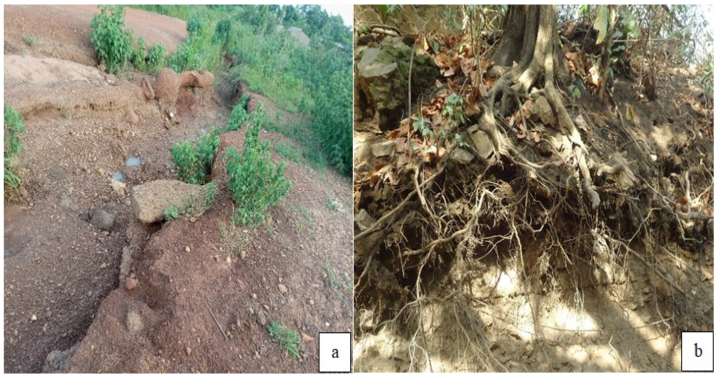

Photo 1: Erosion in the Zou River watershed (Savalou) and on the bank of the Klou River (b)

Shooting: *Atchadé, G., février 2020 et Janvier 2014*

Indeed, cotton production occupies vast areas and requires systematic deforestation and stump removal in the search for new plots. This already challenging situation is exacerbated by charcoal and timber production activities, which are more prominent in the upper part (Bantè, Pira, Tchèti) of the basin. The successive expansion of these charcoal sites contributes to the fragmentation of the forest. These areas cleared by charcoal production are more exposed to rain erosion (photo 1) and even wind erosion, leading to significant soil loss. In fact, in the Zou River watershed, it is the banks with relatively steep slopes, as well as the tracks, that are highly exposed to rain erosion.

On the other hand, under the combined effect of land use in 2002 and projected climate data for 2030, the average sediment production in the basin will drop to 4.78 t/ha. This reduction is explained by the decrease in surface runoff due to the reduction in precipitation and the increase in actual evapotranspiration (Kounou, 2009).

Regarding the effect of land use scenarios alone, the average annual sediment production increased by 31.66 % compared to that of the reference land use (Lu02). The positive trend is explained by the increase in surface runoff resulting from the reduction in vegetation density due to the expansion of agricultural areas (Dossou-yovo, 2011).

On the other hand, under the combined effect of climate fluctuations and vegetation cover dynamics, a decrease in the average annual sediment production from 4.20 t/ha to 3.17 t/ha is observed between the period 2000-2005 and 2025-2030 (figure 3), representing a reduction of 24.52 %.

Indeed, none of the sub-basins defined by the model are perfectly homogeneous, but each of them is clearly distinguished from the others by soil, topographic, and vegetation cover characteristics.

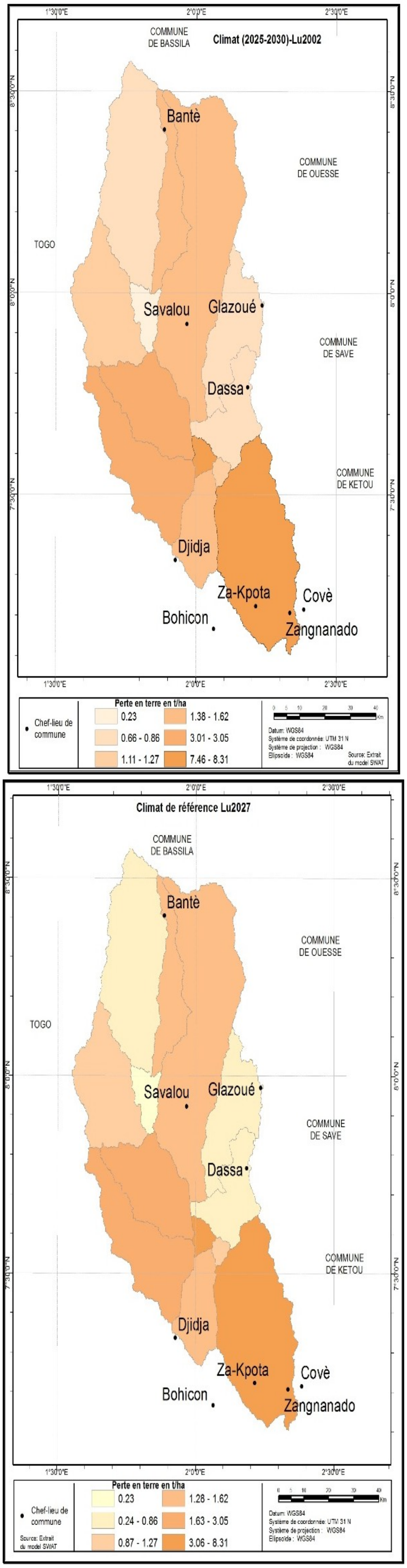

Figure 3 : Spatio-temporal distribution of average sediment production according to the scenarios : Climate 2025-2030 / Lu 2002, Climate 2025-2030 / Lu 2027

This negative trend is actually due to the dominant effects of climate variability compared to those of vegetation cover dynamics; effects that have led to a decrease in surface runoff and a decrease in sediment production.

These results seem to confirm those of Sintondji (2005), Hiepe (2008), and Dossou-yovo (2011), conducted respectively in the Térou-Igbomakoro basin, the upper Ouémé basin, and the Okpara in Kaboua, where these authors highlighted the effects of land use scenarios and climate change on sediment production. High soil losses will be observed in the areas of Bantè, Savalou, Covè, Zakpota, and Zagnanado. On the other hand, relatively low soil losses will be observed in other parts of the Zou River watershed in Domè, due to climate fluctuations and the effects of vegetation cover dynamics combined with the latter. Indeed, the prevention and control of erosion have become an important concern almost everywhere in the world. The terrain remains one of the fundamental conditions for the occurrence of erosion. The amounts of material moving from the top to the bottom of slopes vary depending on the topographic position, the nature of the rock, and the strength of the erosive agent. It plays a decisive role and influences soil removal through three essential characteristics: slope, length, and shape (Alla-Della, 2013). The steeper the slope, the greater the erosion. Erosion is also more intense on long slopes than on short ones. According to Bourrelier *et al.,* (2000), "the main feature of the environment's vulnerability lies in its direct relationship with the concentration of people, property, and infrastructure, which makes urban areas particularly susceptible to natural hazards. The treatments and analyses carried out using GIS provide spatialized information that can be used as a decision-support tool by allowing rapid identification of high-risk erosion areas in the Zou River watershed, which should be prioritized for control and protection.

CONCLUSION

Based on climate and land use scenarios, the combined or individual effects of these environmental parameters on sediment production have been highlighted. Thus, in the medium term, that is to say by 2030, climate variability will differently impact sediment production in the Zou River watershed in Benin. This situation will further worsen when this factor is combined with issues related to the degradation of vegetation cover.

The effects of forest resource degradation and climate change will lead to the highest erosion rates and soil losses in the municipalities of Bantè, Savalou, Covè, Zakpota, and Zagnanado. However, relatively low soil losses will be observed in the other municipalities of the Zou River watershed in Domè. Overall, the erosion risk in the Zou watershed remains moderate.

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