Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

ISSN NO. 2320-5407

Article DOI:10.21474/IJAR01/19553
DOI URL: http://dx.doi.org/10.21474/IJAR01/19553

RESEARCH ARTICLE

CHARACTERIZATION OF RUNOFF ON AGRICULTURAL SOILS IN THE BANDAMA BLANC WATER-SHED, NORTHERN IVORY COAST, USING THE SCS-CN METHOD WITH GEOGRAPHIC INFOR-MATION SYSTEM (GIS) TOOLS

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Manuscript Info

Manuscript History
Received: 28 July 2024
Final Accepted: 30 August 2024
Published: September 2024

Key words:-
Runoff; Soil Conservation Service (SCS), Curve Numbers (CN), Geographic Infor-mation Systems (SIG); White Bandama

Abstract

This study focused on the characterization of runoff on agricultural soils in theBandama Blanc watershed in Badikaha, Northern Côte d'Ivoire. The objective was to highlight the influence of land use change on runoff. To achieve this, soil data and profiles were utilized, allowing for the analysis of the hydrological properties and characteristics of the soils in the study area using the SCS (U.S.D.A.) method. The study revealed a continuous increase in the proportions of built-up/bare soil and cultivated areas over three study periods. The respective proportions were 16%, 27%, and 48% for built-up/bare soil, and 11%, 17%, and 33% for cultivated areas in the years 1986, 2004, and 2023. Additionally, it showed that the soils in the watershed predominantly exhibit clayey texture. These findings, combined with curve numbers (CN), highlighted significant runoff occurring in the study area, with average CN values of 70.57, 57.14, and 66.67 for 1986, 2004, and 2023, respectively. It follows from these results that runoff is more pronounced in urban areas, bare soils, highly mechanized agricultural environments, and watercourses. This study demonstrated that GIS and remote sensing techniques enable large-scale determination of runoff using the SCS-CN method. Furthermore, it serves as a simple and cost-effective tool for modeling runoff.

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Introduction:-

The amount of water from precipitation that flows over the soil surface, escaping infil-tration and evapotranspiration, is referred to as runoff(Bhange, H. N. *andal*., 2014). According to these authors,Perrone (1998), Mirsha (2003) andFaregh and Benkhaled (2016), surface runoff depends on several factors, including the duration and intensity of precipitation, soil type, land use, vegetation cover, slope, and the density of the hydrographic network. Moreover, these factors are increasingly influenced by an-thropogenic activities. Many authors have identified various issues related to runoff in both urban and rural environments. Lhomme (2006) identified the major problem associated with rainfall runoff as water erosion and flooding. Kacem*andal*. (2017) and N'Goandal. (2018)

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[6] demonstrated that water erosion is a natural phenomenon and a major cause of soil degradation worldwide. This results in the loss of surface soil as water transports soil particles to deposit them elsewhere, leading to an estimated annual loss of 25 billion tons of soil. Furthermore, this soil transport has significant consequences for eroded and deposition areas. Water erosion accelerates sedimentation processes in low-lying areas and solid accumulation in watercourses, which reduces the storage capacity of water reservoirs and increases flood risks (Coulibaly*andal*., 2014). In eroded areas, a reduction in soil fertility and agricultural productivity has been observed(M'seffar, 2009). In Côte d'Ivoire, several authors, including (Coulibaly*andal*., 2014 ; Soroandal., 2013) have shown the vulnerability of soils in the Bandama Blanc watershed in Badikaha to water erosion due to the degradation of vegetation cover. Additionally, (Bamba *andal*., 2020)revealed the extent of soil degrada-tion in this watershed through a study on the dynamics of water erosion in agricultural soils. This watershed hosts over 71% of the agro-pastoral dams in Côte d'Ivoire, aimed at promoting agro-economic activities (Koffi, 2007). Given that the issues related to water erosion are direct consequences of rainfall runoff, it is crucial to characterize runoff on agricul-tural soils in the Bandama Blanc watershed in Badikaha, Northern Côte d'Ivoire. To this end, researchers (Xiao, 2011 ;Mirsha, 2012 ; Ji-Hong, 2014; Giridhar, 2014 and Koffi*andal*., 2020) have employed the SCS-CN method (U.S.D.A, 1986). This method, widely used in numerous studies worldwide due to its simplicity and the limited number of required parameters, considers the hydrologic soil group of the area, land use, and curve numbers (CN). However, in Côte d'Ivoire, few studies have been conducted on the characterization of rainfall runoff, particularly using the SCS-CN method. This method is integrated with Digital Elevation Models (DEM), remote sensing data, and Geographic Information Systems (GIS).

Materials and Methods:-

Study Area:-

The Bandama Blanc watershed in Northern Côte d'Ivoire is located between 9°22' and 10°26' N and between 5°00' and 6°30' W. It spans four regions: Bagoué, Hambol, Poro, and Tchologo**(Figure 1)**. The watershed includes Korhogo, the capital of the Poro region, and Ferkessedougou, the capital of the Tchologo region, covering an area of approximately 9,873.35 km². Topographically, the Bandama Blanc watershed is primarily composed of flat, monotonous plateaus with gentle undulations, interspersed with small hills, at elevations ranging from 200 to 650 meters. Pedologically, the watershed contains ferrallitic, tropical ferruginous, and occasionally lateritic soils. These soils have poor physical properties (shallow, hardened soils), presenting challenges for land use. In terms of vegetation, the area is predominantly savanna today, characterized by shrubs and gallery forests. The climate is Sudanian, with average annual precipitation ranging from 1,000 to 1,200 mm. The watershed is marked by two contrasting seasons: a very long dry season from October to April and a relatively short rainy season from May to September. Hydrologically, the watershed is drained by the Bandama Blanc River and its main tributaries, including the Yoré, Lorho, Seguétielé, Lohkoho, Lafigué, and Badenou. On one hand, the flow is very low or nonexistent from November to May, while on the other hand, the flood season occurs from August to September (Ouedraogo 2016).

Data and Material:-

Satellite:-

The satellite data consists of LANDSAT images: TM, ETM+, and OLI (Table 1). These images were utilized to classify land use types using color compositions of bands 4, 5, and 7. The time interval between these images is 18 years. Additionally, Digital Elevation Model (DEM) data sourced from STRM with a resolution of 30 meters were used to obtain topographic characteristics such as terrain slope, elevation, watershed boundaries, and the hydrographic network. This data is available for free on the following website: http://earthexplorer.usgs.gov/.

Table 1:- Landsat images used.

Satellites	**Sensors**	**Periods**	**Scenes**	**Resolution (m)**	**Source**
Landsat4-5	TM	06 November 1986	197-053	30	http://earthexplorer.usgs.gov
Landsat4-5	TM	06 November 1986	197-054	30	
Landsat 7	ETM+	21 December 2004	197-053	30	
Landsat 7	ETM+	21 December 2004	197-054	30	
Landsat8	OLI	20 December 2023	197-053	30	
Landsat8	OLI	20 December 2023	197-054	30	

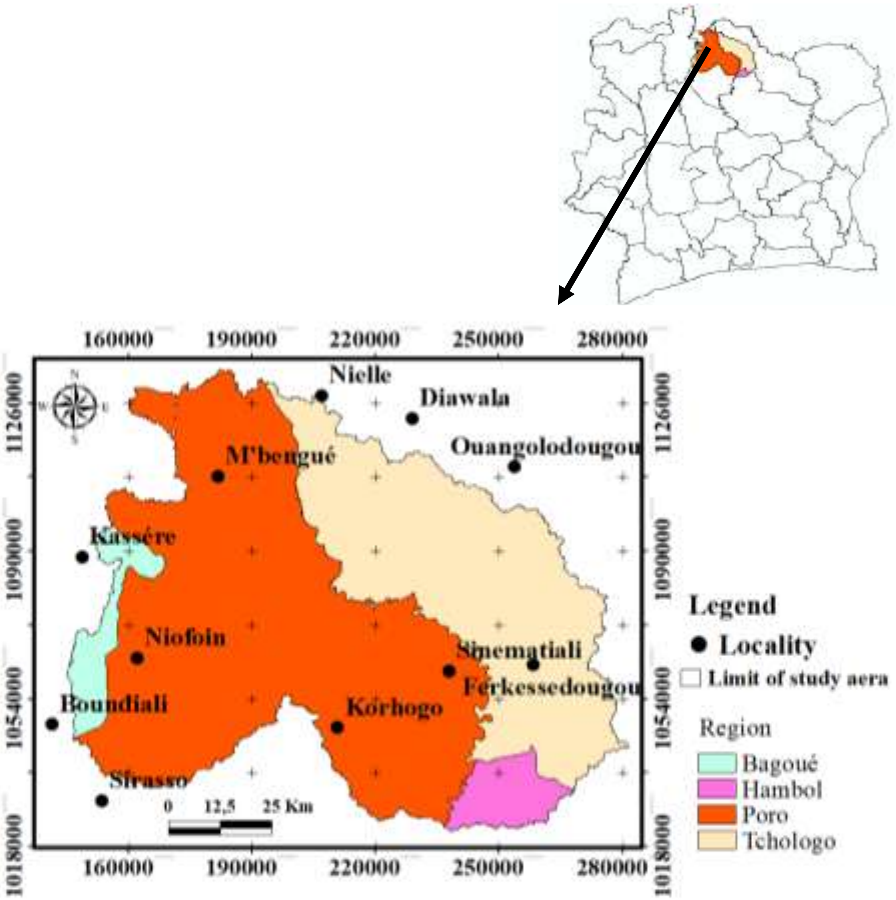

Figure 1:- Geographical location map of the study area.

Climate:-

The climatological data are essentially made up of daily rainfall data from SODEXAM (Sociétéd'Exploitationet de DéveloppementAéroportuaire, Aéronautique et Météorologique) stations in Korhogo, Sinématiali, Ferkessedougou, Ouangolodougou, Kasséré, Niellé, Niofion and M'Bengué between 1969 and 2023. These stations are located in and around the study area. The thematic maps were produced using QGis 2.18 software.

Pedological:-

The data from the Digital Soil Map of the World (DSMW) (FAO-UNESCO, 1976) and from 28 soil profiles with a depth of 100 cm, collected along transects (Figure 2) during a field visit, were utilized. This visit took place from March 8 to March 14, 2022, during which the hydraulic conductivity at each profile was measured using a single-ring infiltrometer and a stopwatch. These data were used to study the texture and structure of the soils in order to determine the hydrological soil groups of the study area. The 28 soil profiles, combined with the Digital Soil Map of the World, allowed for the validation of the texture and structure of the soils in the upper Bandama Blanc watershed.

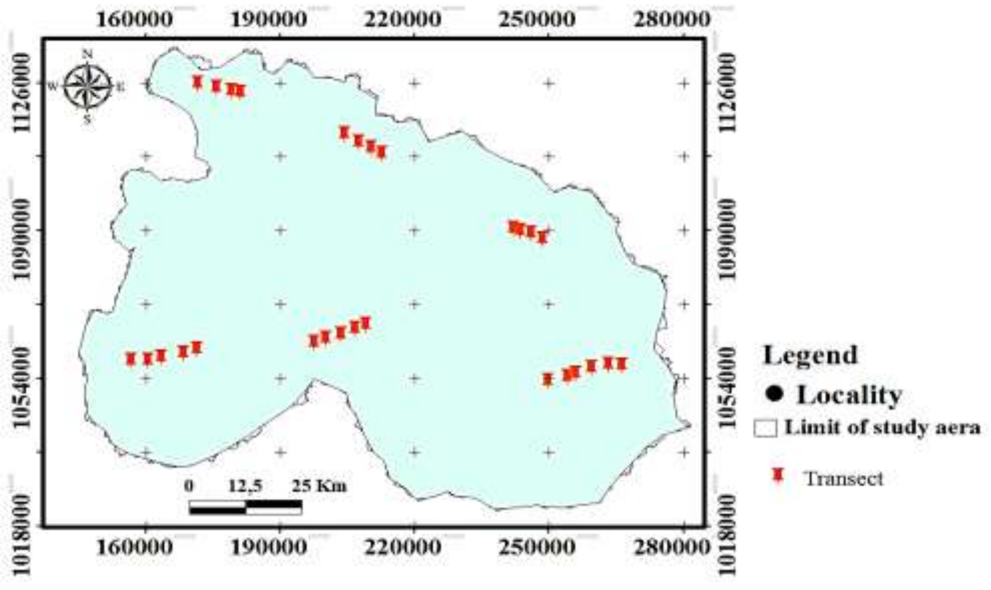

Figure 2:- Geographical map of transect the study area.

Methodology:-

Estimation of average surface rainfall on a spatial scale:-

The Thiessen polygon method was used to calculate the average area of influence for the 09 rain gauge stations (Equation 1) using GIS. One of the assumptions of this method is that there is a linear distribution of precipitation; therefore, many researchers recommend that its use be limited to relatively flat areas with linear precipitation distribution. However, arguments remain regarding the optimal density and spacing conditions for its application. According to Wiesner (1970), several authors have recommended the use of this method for areas characterized by a relatively dense and uniformly spaced rainfall network.

$$P_{average} = \frac{\sum A_i * P_i}{A_{Total}} \qquad (1)$$

With $P_{average}$: Average daily rainfall;

P_i :daily rainfall;

A_i : Area of a sub-basin within the study watershed;

A_{total} : Total area of the watershed.

Methodology for analysing land use and land cover data:-

The supervised maximum likelihood classification method was used to produce land use maps for the years 1986, 2004, and 2023, considering seven (7) classes: bare soil/habitat, open forests, gallery forests, wooded savannas, crops, fallow land, and water. These classes were classified using ENVI 5.3 software and validated through a field survey. Finally, the Kappa coefficient and overall accuracy were analyzed. According to Banko (1998), the Kappa coefficient (K) was calculated using Equation (2). This method is effective for extracting information from an image via the confusion matrix, and the interpretation of the Kappa coefficient (K) is summarized in Table 2. Furthermore, as noted by Akpoti *andal*. (2016)the overall accuracy related to accepted and rejected pixels based on the confusion matrix was determined using Equation (3).

$$K = \frac{N \sum_{i=1}^{r} x_{ij} - \sum_{i=1}^{r} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} * x_{+i})} \qquad (2)$$

Where r ;is the number of rows in the matrix**;**

x_{ij} :is the number of observations in row i and column i;

x_{i+} and x_{+i} are the marginal totals of row i and column i, respectively,

N is Number of rows and columns in the confusion matrix.

Table 2:- Kappa cofficient (Akpoti, *andal*., 2016).

Coefficient de Kappa	**Interpretation**
K> 0,80	good precision
K between 0,40 and 0,80	moderate accuracy
K <0,40	poor accuracy

$$\text{Overall accuracy} = \frac{\text{Number of orrected pixel}}{\text{Total number of elected pixel}} * 100 \qquad (3)$$

Estimation of surface runoff:-

Surface runoff (Q) was predicted using a hydrological model developed by the USDA (United States Department of Agriculture) for estimating surface runoff based on the SCS-CN (Soil Conservation Service Curve Number) method established in 1986. The model incorporates the following results and data: land use, hydrological soil groups (A, B, C, and D) based on soil infiltration capacity according to Darcy's law, which involves measuring the infiltration rate of gravitational water into the soil ($cm.s^{-1}$ or $cm.h^{-1}$) using Equation (4) (Table 3; Figure 2), as well as daily rainfall data related to antecedent moisture conditions (AMC) (Table 4). Furthermore, the empirical Equation (5) was used for estimation.

$$Q = K \times S \times \frac{\Delta h}{L} \qquad (4)$$

Where Q: Volumetric flow rate of the fluid, K: permeability coefficient (m/s), Δh: height of the water column, L: length of the soil sample (m).

$$Q = \begin{cases} 0, & \text{for } P < 0 \\ \dfrac{(p - I_a)^2}{(P - I_a + S)}, & \text{for } P > 0 \end{cases} \qquad (5)$$

Where, Q = runoff (mm) ;P = rainfall (mm).

In addition, the maximum retention potential S, and water retention by the soil Ia, (initial interception and infiltration quantity) are given by equations 6 and 7 respectively.”.

$$I_a = 0.2 * S \qquad (6)$$

$$S = \frac{25400}{CN} - 254 \qquad (7)$$

Where CN is a number between 0 and 100, which varied according to land use, soil type (hydrological soil groups) and moisture conditions prior to AMC.

Table 3:- Hydrological soil group and their characteristics (Chow andal., 1988).

Group	Infiltration rate (cm/hr)		Soil texture
A	High	>25	Sandy, sandy silt or Sandy loam
B	Moderate	12,5-25	Sandy clay loam
C	Low	2,5-12,5	Silt loam or loam
D	Very low	>2,5	Clay loam, silty clay loam, sandy clay, silty clay or clay

Table 4:- Classification of antecedent moisture conditions (U.S.D.A, 1972).

Classe AMC Group of antecedent conditions	Total 5 days antecedent rainfall (mm)	
	Dormant season	Growingseason
I	<12,7	<35,6
II	12,7-27,9	35,6-53,3
III	>27,9	>53,3

The CN values are functions AMC-I, II and III and obtained in this study using empirical equations 8, 9 and 10 below :

$$\mathrm{CN_{II}} = \frac{\sum A_i * \mathrm{CN}_i}{\sum_i^n A_T} \quad (8).$$

Where $\mathrm{CN_i}$: is the curve number ($\mathrm{CN_{II}}$) derived from the land use class and the hydrological soil group ;
A_i : is the area of the hydrological soil group type;
A_T : total catchment area.

$$\mathrm{CN_I} = \frac{4.2 * \mathrm{CN_{II}}}{10 - 0.058 * \mathrm{CN_{II}}} \quad (9)$$

$$\mathrm{CN_{III}} = \frac{23 * \mathrm{CN_{II}}}{10 + 0.13 * \mathrm{CN_{II}}} \quad (10)$$

Previous humidity conditions (AMC):-

Antecedent moisture conditions (AMC) (Table 4) are indicators of watershed moisture and the soil's capacity to store moisture before a storm. They have a significant effect on the volume of runoff during and after precipitation events. Recognizing their importance, the SCS developed guidelines to adjust the curve number (CN) based on AMC, using total precipitation over the five days preceding a storm. Three levels of AMC were employed in the CN method: AMC-I for dry conditions, AMC-II for normal conditions, and AMC-III for wet conditions. Table 4 provides precipitation thresholds for these three AMC levels. According to USDA-SCS (1986), CN values are guided by AMC-II. Ultimately, determining the CN serves as a potential estimate of runoff. Under similar precipitation conditions, lower CN values indicate a high potential for water retention on the surface, while higher values indicate low water retention, leading to increased surface runoff volume.

Catchment area sub-basin:-

The study watershed was subdivided into seven (7) sub-basins using GIS and 30 m STRM imagery. This approach was employed to better identify the areas of the watershed that are more influenced by runoff (Figure 3).

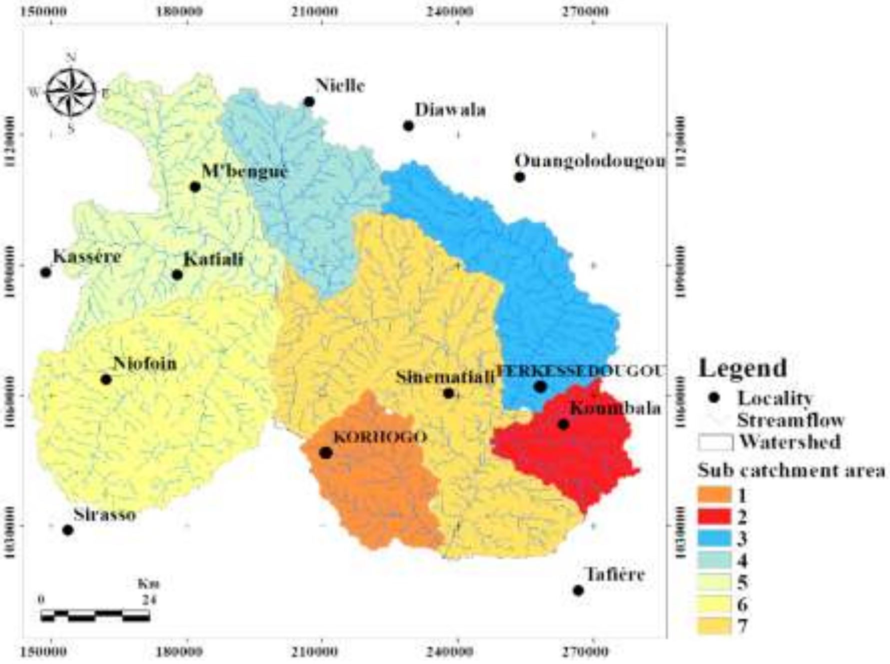

Figure 3:- Catchment area sub-basin of the study area.

Results:-

Assessing the accuracy of classifications:-

Figure 4 shows the land use change maps for the study area for the periods 1986, 2004, and 2023. The overall accuracies and Kappa indices of the classification are 99.40 % and 0.99 for the year 1986, 96.78 % and 0.96 for the year 2004, and 98.69 % and 0.97 for the year 2023. The statistical results of land use indicate that the proportion of water bodies, which was low at 3.5 % in 1986, increased to 8.1 % in 2004 before dropping to 5.3% in 2023. The proportion of gallery forests decreased from 8.1 % to 3.5 % between 1986 and 2004, continuing to decline to 1.7% in 2023. Similarly, the proportion of wooded savanna decreased from 28.4 % to 7.3 % between 1986 and 2023. Fallow land increased from 6.7 % to 14.3 % between 1986 and 2004, but then fell to 3.8% in 2023. The proportion of open forests gradually decreased from 28.4% to 7.2% between 1986 and 2023. However, the areas of habitat/bare soil and cultivated land increased during the study period. The proportions of habitat/bare soil rose from 16 % in 1986 to 41.2% in 2023, while cultivated land increased from 8.9 % to 33.5 % between 1986 and 2023.

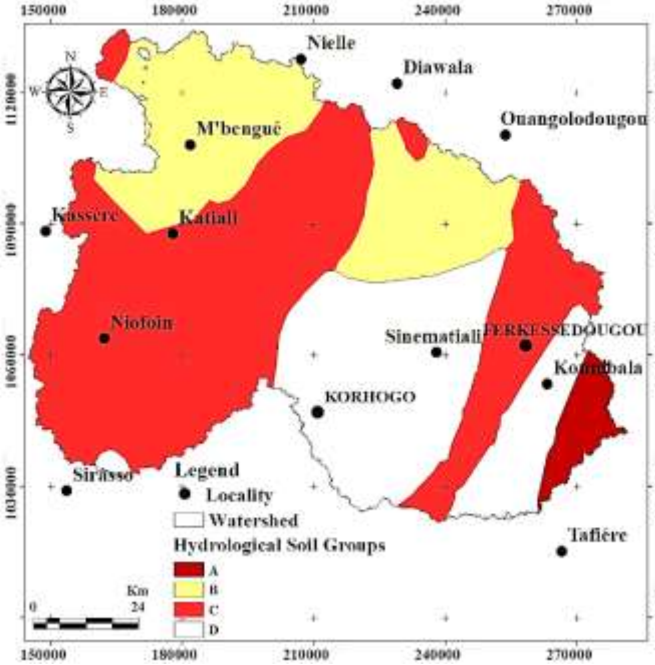

Figure 4:- Land use map of the Upper White Bandama Basin in 1986, 2004 and 2023.

Mapping of hydrological soil groups (HSG)

The proportions of the different hydrological soil groups are presentedin figure 5. It is evident that the most dominant soil type is clayey loam, which belongs to group C and occupies 47.26 % of the watershed. Following this, groups D, B, and A are in decreasing order, with respective proportions of 26.83 %, 23.05 %, and 2.84 % of the watershed. Thus, the watershed is predominantly comprised of clayey loam soils. This indicates a very low infiltration rate, consequently resulting in a very high runoff rate.

Estimation of runoff according to hydrological soil groups and land use:-

The twenty-four (24) curve numbers were calculated based on the four hydrological soil groups (HSG) and seven (7) land use classes. Additionally, the integration of these parameters into GIS allowed for the generation of the maps shown in figure 6. The calculated curve numbers range from 29 to 100. Furthermore, the distribution of these curve numbers across the maps for the years 1986, 2004, and 2023 indicates a significant runoff potential in 1986, with an average of 66.76, which decreased in 2005 to an average of 57.14. Finally, the runoff potential is very high in 2023, with an average of 70.57.

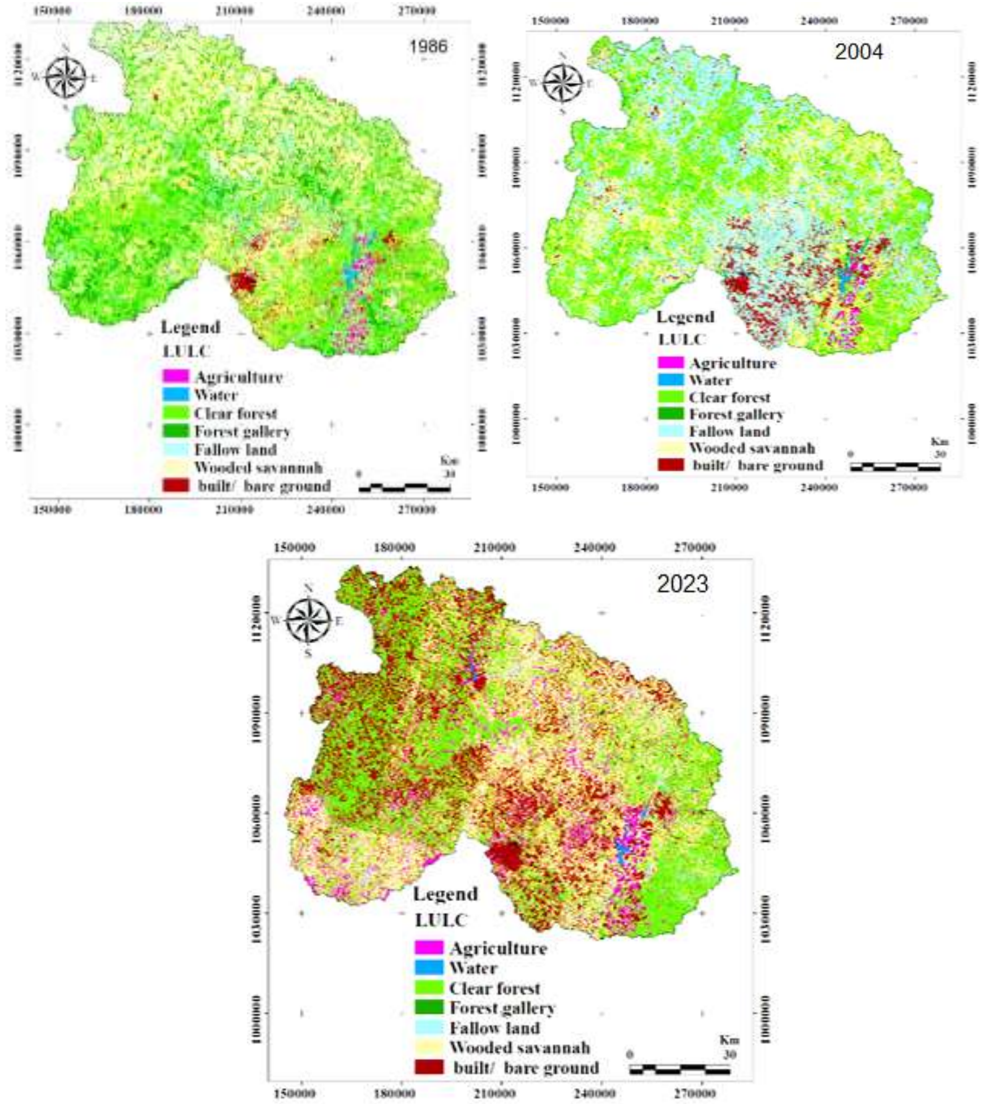

Figure 5:- Hydrological Soil Groups (HSG) of the Upper White Bandama Basin.

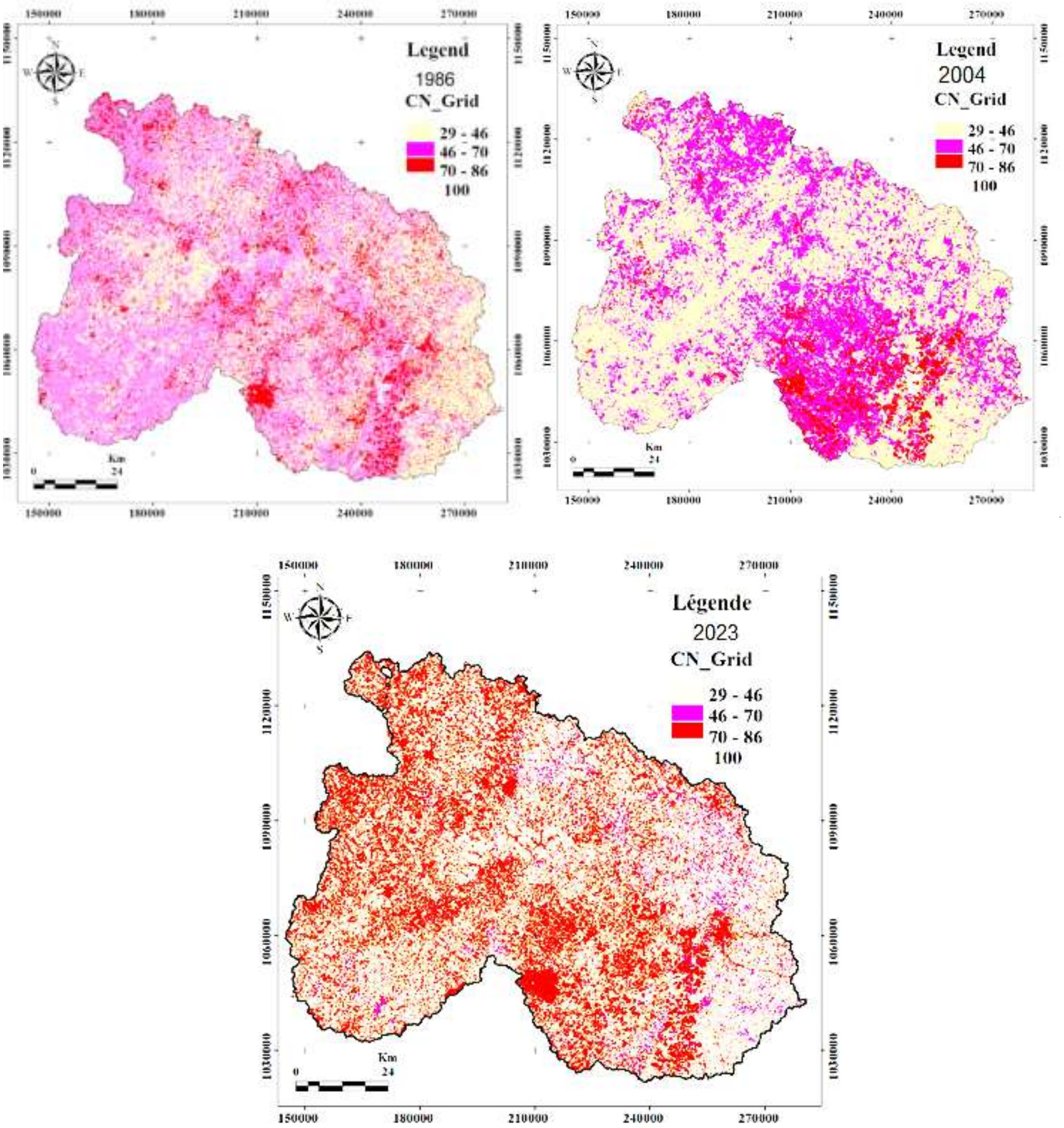

Figure 6:- Runoff potential as a function of curve number (CN) in 1986, 2004 and 2023.

Assessing the accuracy of classifications:-

Figure 7 illustrates a homogeneous and similar variation of runoff across the entire watershed during the three periods. The amounts of water runoff are greater during the periods 1969-1986 and 2005-2023compared to the period 1987-2004. Consequently, the sub-basins most influenced by runoff are primarily (1) and (7). In contrast, sub-basins (5) and (3) are less influenced throughout all study periods.

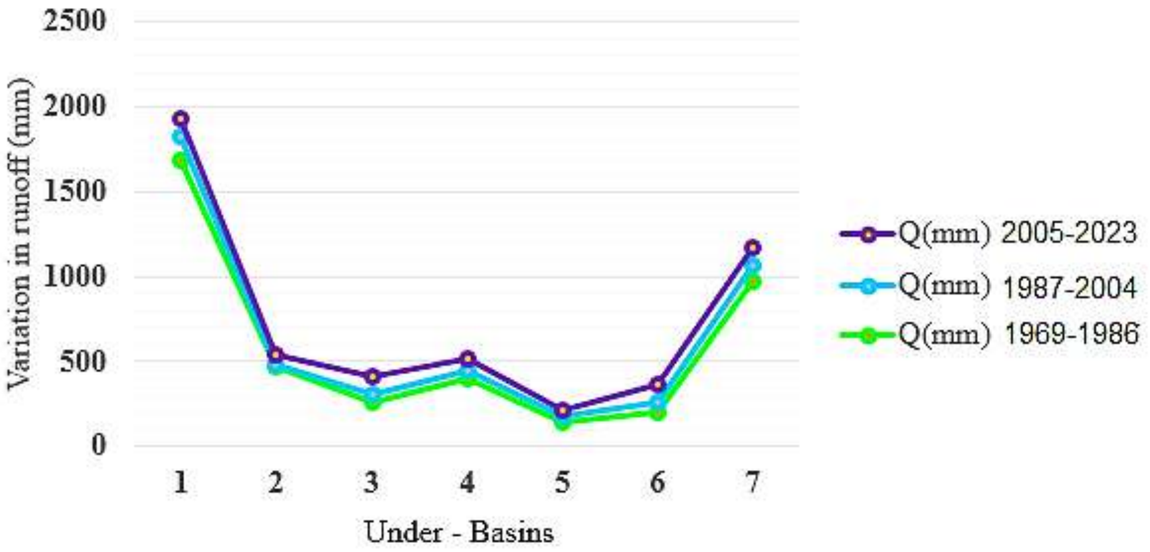

Figure 7:- Variation in runoff over the periods 1969-1986, 1987-2004 and 2005-2023.

Discussion:-

In this study, the spatio-temporal dynamics of land use were assessed based on the supervised classification of Landsat TM images from 1986, ETM+ from 2004, and OLI from 2023. The results indicate that habitats/bare soils and cultivated areas have rapidly increased during the study period. Their proportions rose from 16% in 1986 to 41.2% in 2023, with cultivated land increasing from 8.9% to 33.5% between 1986 and 2023. This increase in habitats/bare soils and agricultural land is attributed to urban expansion and the enlargement of cultivated areas due to population growth. Additionally, the rise of cashew cultivation over the past 20 years in Côte d'Ivoire is significant, as the study area is well-suited for cashew production. Furthermore, a decline in forested land, savannas, fallow land, and water bodies has been observed. This is linked to their conversion to agricultural spaces and tree felling for charcoal production. The reduction in water bodies is associated with climate change, which has caused variability in precipitation and decreased water surfaces due to significant evaporation resulting from rising temperatures. These results are corroborated by the works of Soroandal. (2013), Coulibalyandal. (2016), and Bamba andal. (2020). Moreover, according to Cheggour (2008), these effects are more pronounced in Guinean savannas, semi-arid, and arid regions. As a direct consequence of the degradation of vegetation cover, the soil in the watershed is exposed to the effects of rainwater runoff. This study showed that 74.09% of the watershed has a clayey texture, which promotes runoff due to a very low infiltration rate. Additionally, the reduction in vegetation cover highlighted by the land use study explains the significant average curve number (CN) values observed in Figure 6. The average CN values are 66.67, 57.14, and 70.57 for the years 1986, 2004, and 2023, respectively. According to Kimeli and Okumu (2017), a low curve number indicates low runoff and high infiltration, while a high curve number implies significant runoff and low infiltration. Finally, the significant runoff values calculated are particularly noticeable in sub-basins (1) and (7). In sub-basin (1), this can be attributed to intensive mechanized agriculture. This sub-basin hosts large agro-industrial plantations (SUCAF-CI) producing sugar. This cultivation necessitates tree felling for irrigation and regular soil tillage. According to Keller (2019), agricultural machinery increases the risk of soil compaction, which further raises the risk of surface runoff, erosion, and flooding in case of more intense precipitation. Sub-basin (7) contains the main river course of the watershed, the Bandama Blanc, where curve numbers can reach up to 100, indicating high runoff potential. However, in 2005, the average CN was slightly lower compared to 1986 and 2023, likely due to fluctuations in the rainfall series in the study area (Koffiandal., 2020).. These results align with those obtained by Bamba (2024). Ultimately, these findings demonstrate that the watershed is influenced by rainwater runoff and is consequently vulnerable to hydraulic erosion.

Conclusion and Recommendation:-

This study aims to highlight the influence of land use change on runoff in the Bandama Blanc watershed at Badikaha in northern Côte d’Ivoire. The findings reveal that the proportions of habitats/bare soil and cultivated areas have increased over the three study periods. Their proportions rose from 16% in 1986 to 41.2% in 2023, with cultivated land increasing from 8.9% to 33.5% between 1986 and 2023. The study also demonstrated that the soils in the watershed are predominantly clayey in texture. These results, combined with the curve numbers (CN), underscore the significant runoff occurring in the study area. The average CN values are 66.67, 57.14, and 70.57 for the years 1986, 2004, and 2023, respectively. It can be inferred that runoff is more pronounced in urban areas, on bare soils, in highly mechanized agricultural environments, and along river courses. This study has shown that GIS and remote sensing techniques effectively facilitate the determination of runoff using the SCS-CN method on a large scale. We recommend improved agricultural support for farmers to intensify the use of soil conservation systems based on agroforestry and anti-erosive practices.

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