Impact Of Land Use On Soils Quality And Erosion-Sedimentation Balance In The Malian Cotton Zone (Case Of Bélékoni Watershed)

Drissa DIALLO[1,2] Aboubacar BENGALY[2], Gaiba DIARRA[2] Philippe BONTE[3] Bruno RAPIDEL[4], Gil MAHE[5]

1 Faculté des Sciences et Techniques, USTTB, Bamako, Mali
2 Institut Polytechnique Rural de Formation et de Recherche Appliquée (IPR/IFRA)
3 Laboratoire des Sciences du Climat et de l'Envoronnement (LSCE)
4 Centre International de Recherche Agronomique pour le Developpement, UMR SYSTEM (CIRAD-INRA-SupAgro) Montpellier, France
5 Maison des Sciences de l'Eau, Université Montpellier II

Abstract

Bélékoni watershed (120km^2) is located in the upper basin of Niger River in Mali. The climate context (Sudanian zone) justify cotton production program. Analysis of last decades agricultural evolution impacts is the objective of the present study. Research methods include in situ observations and measurements and laboratory analysis. According French soil classification of 1967, three main soil types are distinguished in the watershed: Lithosol (soil1), Ferruginous Tropical Soil (soil2) and Mineral Hydromorphic Soil (soil3). Sol1 is marginal for cropping and wood development and the two others soils are indicated for actual agricultural intensification. Concerning land use, there are mainly cropland and land under natural vegetation, subjected to vainly grazing. The general trend is the soil degradation whereas land use. Carbon stock is low (20.2 t.ha^{-1} in the first 30 cm of soil profile). Soil 1 and 2 are affected by erosion, respectively 2.7 and 5.7 t.ha^{-1}.yr^{-1} or 0.4 and 0.2 cm.yr^{-1}; Soil3, located in the depression along river system is a sedimentation site: 10.1t.ha^{-1}.yr^{-1} or 0.7 cm.yr^{-1}. Major process currently affecting Bélékoni watershed are land use change, soil degradation and sedimentation in the river.

Keywords: erosion-sedimentation balance; land use; Mali; Sudanian zone; rotation cotton-cereal

1. Introduction

Land use and land cover are an important factor impacting the earth system dynamics at global and local levels [1, 2] (Lambin and al, 2001; Lepers and al, 2005). Their current rapidly change at global scale, due to many factors (tropical deforestation, rangelands modifications, agricultural intensification, and urbanization) is largely recognized. All the identified factors of this change are complex with multiple pathways. Their incidences are also various and concern the different components of our environment (soil, water and atmosphere). Concerning soil and water cycle, many studies over the world have shown that land use and cover influences soil quality and the occurrence and intensity of processes as runoff and erosion[3, 4] (Wei and al, 2007; Odunze et al, 2012). About soil quality, in relation with land use and land cover, carbon sequestration is an important concern which is largely discuss since decades [5, 6, 7](Masse, 1987; Post and Kwon, 2000; Ostle and al, 2009). It is known that, the conversion of forest lands in agricultural ones is responsible of the decrease of soil organic carbon content (SOC) [6]. Precisely, agricultural practices such conventional tillage increase soil erosion rate and consequently soil carbon loss, in opposition with no-tillage and minimum tillage [8](Diallo and al, 2007). In water availability evaluation, land use is considered as a pertinent input of hydrological models [9](Wijesekara and al, 2010), but identifying and quantifying the hydrological consequences of land use change are not trivial exercises [10](DeFries and Eshleman, 2004). Land use and land cover study in different ecosystems and farming situations, ie at local scale can permit the development of tools to support the decision for agriculture and water resources management at the concern scales. Concerning small agricultural watershed, a previous study in Malian Sudanese zone highlights the influence of soil types and land use and cover on erosion and carbon loss [11, 8] (Diallo et al, 2004; Diallo and al, 2007). The present study, related to Belekoni watershed, aimed at the understanding of the impact of agricultural practices on soil properties, carbon storage and the erosion-sedimentation balance [12](Bengaly, 2009).

It was conducted as part of a project CORUS (*Cooperation de Recherche Universitaire et Scientifique*) funded by the French Cooperation.

2. Material and methods

2.1 Study area

The study have been conducted in the watershed of Bélékoni, which is a small agricultural one (120 km^2), located in the upper basin of the Niger River in Mali (Figure 1) and in the cotton zone. Its physical characteristics are summarized in Table1.

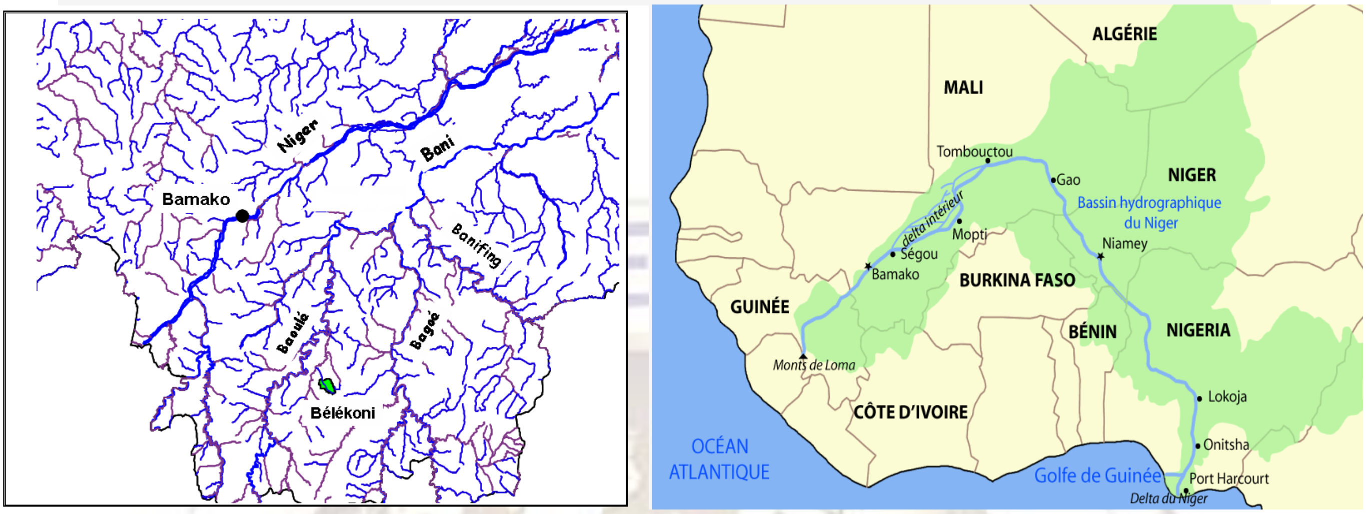


Figure 1 : Location of Bélékoni watershed

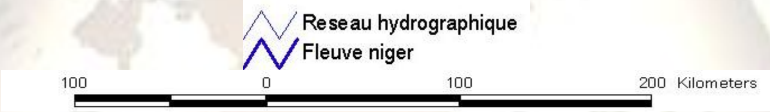


Table1: Physical characteristics of Belekoni **watershed [13]**

Outlet coordinats	11°21 N – 7°29W
S (km²)	120
P(km)	50
Maximum altitude (m)	400
Outlet altitude (m)	330
Kc	1,28
L (km)	18,60
l (km)	6,50
Ig (m.km-1)	3,00

S: surface; P: perimeter; Kc : coefficient form of Gravélius ;
L : longer of equivalent rectangle ; l : larger of equivalent rectangle ;
lg : global slope index

The climate context of Bélékoni watershed is the Sudanian zone where the interannual variability of rainfall is displayed. At Bougouni station (……….), the reference one for the watershed, the average annual rainfall recorded between 1978 and 2007 was 1133 mm. The highest monthly amount of rain is recorded in July and August (Figure 2). High values of the ETP (1685.5 mm.yr^{-1}) accentuate the water deficit for crops and generally negatively impact the hydrological balance in the concern ecosystems.

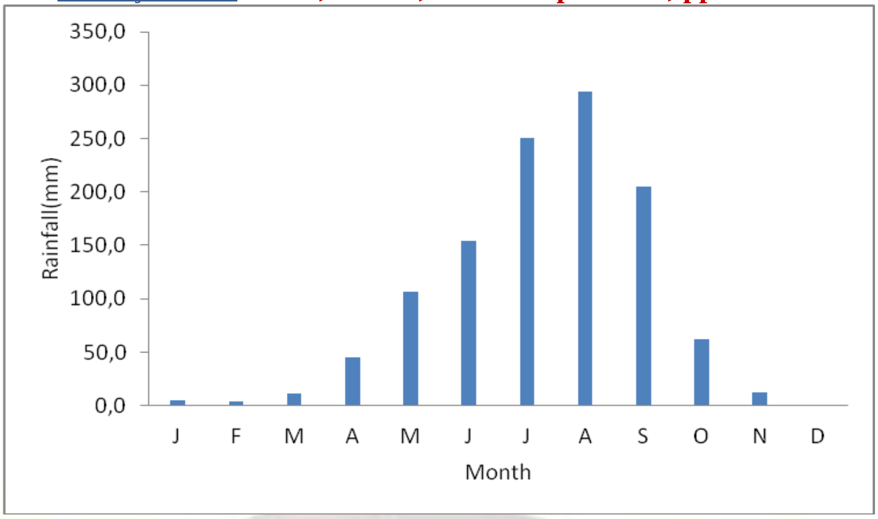


Figure 2: Monthly average rainfall (mm) from 1978 to 2007 at Bougouni station

Concerning the geological context, Bélékoni watershed is located on the West African Craton dominate by Birimian formations, consisting mainly of granite. This rock is generally covered by pedological materials and is rarely observed at surface. The main components of the relief are glacis with different altitudes and depression along the river system.

2.2 Methods Soil characterisation

Soil morphological description concerning 25 profiles was made with the following criteria: soil thickness, horizons color after the code Munshell, gravel presence in top soil, indicators of water table fluctuations in the profile. All the soil description points were chosen according geomorphologic criteria and land use categories. Bulk density was measured with the cylindrical core method [14] (Houston et al, 2002). In the laboratory, soil samples were subjected to some classic analysis with classic methods : particle size distribution according to the international method, the cation exchange capacity (CEC) by the method of ammonium acetate. The total carbon was measured according to Anne method (norm AFNOR X 31 - 109), the nitrogen by the Kjeldahl method. The pH was measured with the potentiometric method in a suspension with a soil / solution ratio of 1g / 2.5 ml.

Assesment of carbon stock in the top soil

In this study, the assessment of soil carbon stock concerned the first 30 cm of the profile. Actually soil carbon stock can be evaluated with direct method or indirect ones (pedotransfer function, satellite image interpretation). Direct method is generally considered more reliable [15] (Arrouays et al, 2003), and estimations are generally based on punctual measurements. In this method there is debate about the advantages and disadvantages of sampling pedogenic horizon or layer of fixed thickness. In the present study, the points of carbon stock assessment were chosen according to both soil type and land use. For soil sampling, layer of fixed thickness (0-10 cm; 10-20 cm; 20-30 cm) were considered in 17 profiles from Sol2 (10 profiles) and Soil 3 (7 profiles). It should be noted that the actual agriculture intensification in the Bélékoni watershed concern Soil 2 and 3. Soil1, recognized marginal for cropping, is less and less used for this function.

According classic practice, carbon stock was calculated in every layer (0-10 cm; 10-20 cm; 20-30 cm) from its characteristics (bulk density, carbon concentration, and thickness) then the different values were added. Subsequently, the carbon stocks per hectare in the first 30 cm were evaluated.

Evaluation of erosion-sedimentation balance with Cs-137 method

The utilization of radio isotope elements (such Cs-137) in soil erosion and sedimentation investigations has benefits widely recognized today [16, 17, 18]. In this method, gamma spectrometry detection in laboratory allows to know soil sample content in a given radionuclide (Cs-137 in the present study). To calculate the amount of soil loss or deposit by site, the proportional model was used; it simply assumes that soil loss or deposit in a sampling site is directly proportional to the loss or the accumulation of Cs-137 [19] (Martz et De Jong 1987):$E = (A * D * L) / t$

E: average loss or gain of soil ($kg.m^{-2}.an^{-1}$); A: Cs- 137 loss or gain of a sampling point (percentage of reference value); D: soil bulky density ($kg.m^{-3}$); L: depth of plowing horizon (m); t: the number of years since the peak of fallout Cs- 137 (1963).

In the present study, 34 soil samples were collected from 24 points which were selected according soil type and land use.

3. Results and discussions

3.1 Some basic characteristics of soils and land use

Three main soil types (noted soil1, soil2 and soil3) are distinguished in Bélekoni watershed: respectively Lithosol, Ferruginous Tropical Soil and Mineral Hydromorphic Soil, according French Soil Classification of 1967 [20]. In the landscape, these soils are arranged in sequence: soil1 occupies the highest topographic position and soil3 the lowest. The particle size distribution of these soils is presented in Table2. Soil1 is shallow (less than 40 cm depth) and contains ferruginous gravel (about 300g.kg^{-1} soil). Its content in clay is 8%. The other two soil types are thick (over 100 cm). Their gravel contents are negligible (71g.kg^{-1} and 15g.kg^{-1}, respectively for soil1 and soil 3). The means of clay content is 18% for soil2 and 22% for soil3.

In the watershed there are cropland and land under natural vegetation which are subject to vainly grazing (Table3). Soil1 is currently little cultivated (mainly millet and peanut), contrary to the practice of the years before 1970. Soil2 is chosen for the current agricultural intensification, particularly the implementation of the rotation cotton - cereal (sorghum, millet, maize) and technologies advocated by the Malian Company for Textile Development (CMDT). Soil3, which is covered by seasonal flooding, is used for rice monoculture.

Globally, in the watershed, there are areas continuously cultivated since 10 to 40 years and areas under natural vegetation, so uncultivated since long time (more than 40 years). Uncultivated areas are mainly observed on soil1, but also on soil 2 and soil3. According mapping results by Bengaly (2009) [12], land use and cover is changing in Belekoni watershed, but there are until enough surface under natural vegetation (Table 4).

Table 2: Basic characteristics of top soil (0-20 cm) Belekoni watershed

Characteristics		Soil 1 (n= 4)	Soil 2 (n= 17)	Soil 3 (n= 10)
Relief		Glacis Slope = 3-6%	Glacis Slope = 1-2%	Depression
Soil total depth (cm)		15 to 35	>100	>100
Top soil color		7,5YR6/1 Reddish yellow	10YR4/3 Brown	10YR 7/1 Light gray
Gravel content (g.kg^{-1} of soil)		300	71	15
Particle size distribution (% of dry soil)	Clay	8 ±2.5	18 ±11.1	22± 6.8
	Silt	30± 4.5	33± 15.8	47± 19.0
	Sand	62 ±5.3	47± 13.1	31± 17.2
CEC (meq/ 100 g of soil)		1.8± 0.4	1.5± 0.7	2.7± 0.6

n : Number of analyzed samples

Table 3: Land use categories in the watershed of Belekoni

Land use	Utilization /Main crops	Soil type		
		Soil 1	Soil 2	Soil 3
Natural vegetation since more than 40 years	Area of quite free logging and grazing	+	+	
Natural vegetation since 30 to 40 years		+	+	
Continual cropping since 10 to 40 years	Cotton, maize, sorghum		+	
	Rice			+
	Millet, peanut	+		

Table 4: Land use evolution in Bélékoni watershed [12]

Land use and cover	1975	1986	1999	2005
Natural vegetation (% of watershed surface)	77	68	57	53
Cropping area (% of watershed surface)	23	32	43	47

According the basic characteristics, soil1 has severe constraints for agricultural use, due to its thickness and gravel content. These two characteristics are unfavorable to water holding. Soil 2 and 3 are enough depth for crops normal growing. Concerning top soil, all the soil types of the watershed have very low CEC, a consequence of the low content in clay, the mineralogical family of this clay (kaolinite) and low content in organic matter.

Concerning, land use change in the watershed, it can be explained by three main factors:

- the abandonment of cropping on soil1 is the result of combined effects of rainfall reduction and agricultural practices evolution; it is important to note that soil1 has a low water holding capacity and is unfavorable to agricultural mechanization;
- cropping area extension on soil 2 and 3 is explained by the factors mentioned previously, but also by population augmentation in the watershed.

3.2 Land use and soils quality

Land use impacts on soil properties are shown in Table 5 and 6 and on figure3. Concerning soil structure, natural vegetation and cultivation have the same impact on bulk density (Bd), an indicator of soil quality: 1.5g.m^{3} for soil 2 and respectively 1.5 and 1.4 for soil3 (Table5). Concerning soil organic matter (SOM), the results related to top soil (0-20 cm) did not show difference between land use categories, whatever the soil type (table 6). This horizon shows an overall average rate of organic matter from 0.8 to 1.2%. The C/N ratio is good for any type of soil and land use category (average 8 to 15). Detailed observation of some profiles of cultivated soils shows a surprising vertical distribution of organic matter (an example is given in Figure 3): depth layers often contain more organic matter than 0-10 cm layer.

Table 5: Land use and bulk density of top soil (0-20 cm) in Bélekoni watershed

Land use	Bulk density (Bd) g.cm^{-3}	
	Soil 2	Soil 3
Natural vegetation (n1 = 4; n2 = 3)	1,5 ± 0,2	1.5 ± 0.2
Cropping lands (n1 = 7 ; n2 = 4)	1,5 ± 0,2	1.4 ± 0.2

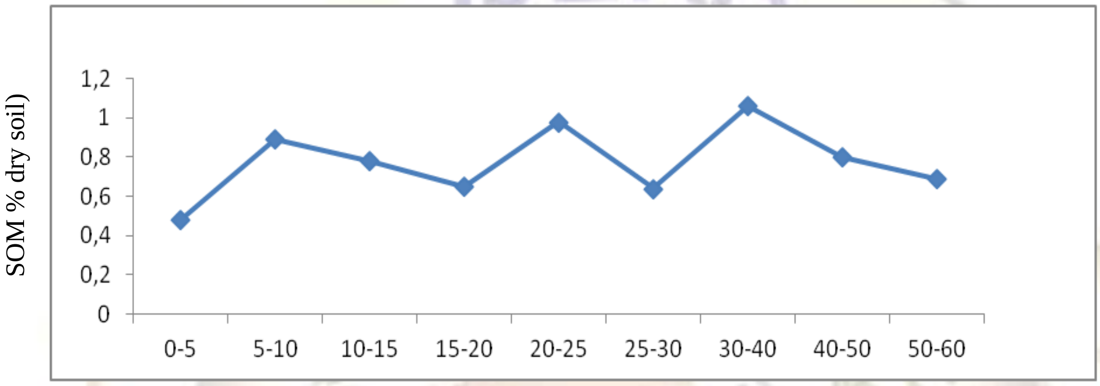
n1: Number of soil samples from soil2; n2: Number of soil samples from soil3

Table 6 : Top soil (0-20 cm) contents in carbon (C), nitrogen (N) and organic matter (OM); Bélekoni watershed

Soil properties	Land use

	Soil 1 (0-20cm)		Soil 2 (0-20cm)		Soil 3 (0-20cm)	
	Natural vegetation (n= 3)	Cropping (n = 2)	Natural vegetation (n= 4)	Cropping (n = 7)	(Natural vegetation n= 3)	Cropping (n= 4)
C %	0.7 ± 0.3	0.6	0.5 ± 0.1	0.4 ± 0.2	0.5 ± 0.1	0.5 ± 0.2
N %	0.1± 0.1	0.1	0.1± 0.03	0.03± 0.01	0.1± 0.02	0.1± 0.01
C/N	15± 8.2	8	11± 5.2	13± 7.7	9 ± 1.4	10 ± 3.6
MO %	1.2 ± 0.5	1.0	0.9 ± 0.3	0.7 ± 0.4	0.9 ± 0.2	0.8 ± 0.3

n : Soil sample number



Soil depth (cm)

Figure 2 : Vertical distribution of SOM (case of a profile of soil 2 continuous cultivated since 10 years)

The negligible difference between carbon contents of land under natural vegetation and the cultivated one surprise, but could be the result of poor management of natural vegetation fallow. Indeed, as pointed out by some authors, as Mass (2007), fallows, to ensure their effectiveness on soil quality must be managed to maximize production and plant diversity. In Bélékoni watershed, land occupied by natural vegetation is subject of bush fires and overgrazing. So the production of a biomass capable to properly maintain soil organic reserves is compromised. The surprising vertical distribution of SOM, observed in some profiles, can be explained by a disturbance due to repeated plowing and also the depletion of surface horizons due to sheet erosion.

Soil organic carbon (SOC) stock measured in the first 30 cm of the profile is low in the Bélékoni watershed (Table). The average value (20.2 t. ha^{-1}) is low in comparison with values obtained in Djitiko watershed, also located in the Sudanian zone [11] and in others regions. That might be a consequence of the non reliable management system natural vegetation as previously describe.

Land use and soil erosion

Erosion measurements on Soil2 (the most cultivated in the watershed) show the impact of natural vegetation and cultivation on soil loss (Table7): respectively 5.4 ± 1.5 and 5.9 ± 2.5 $t.ha^{-1}.yr^{-1}$. These two land uses have negative impact on soil. If the erosion-sedimentation balance is considered, according soil type (Table 8), the differences are evident. Soil1 and Soil2 are affected by erosion, whereas Soil3 is a sedimentation site. Soil 2 is more affected by erosion than soil1: respectively 5.7 ± 2.1 and 2.7 ± 2.5 $t.ha^{-1}.yr^{-1}$ or 0.4 ± 0.1 and 0.2 ± 0.2 $cm.yr^{-1}$.

Table 7: Erosion-sedimentation balance according land use (Soil2, Bélékoni watershed)

Erosion	Soil 2	
	Natural vegetation (n= 5)	Cultivated land (n = 7)
$t.ha^{-1}.yr^{-1}$	5.4 ± 1.5	5.9 ± 2.5
$cm\ yr^{-1}$	0.4 ± 0.1	0.4 ± 0.2

n : Soil sample number

Table 8: Erosion-sedimentation balance according soil type (Bélékoni watershed)

Soil type	Erosion- sedimentation balance		
	Quantity		Comment
	$t.ha^{-1}.yr^{-1}$	$cm.yr^{-1}$	
Soil 1 (n = 4)	- 2.7 ± 2.5	- 0.2 ± 0.2	Erosion site
Soil 2 (n= 12)	-5.7 ± 2.1	- 0.4 ± 0.1	
Soil 3 (n= 7)	+ 10.1 ± 11.2	+ 0.7 ± 0.8	Sedimentation site

n : Soil sample number

In addition to the erosion-sedimentation balance overall score for sols1 and 3, we note sites showing processes opposed. And bearing the glaze on g1, there is accumulation of sediment with micro depressions. In the depression along the river, there are sites of erosion.

Erosive behavior noted for soil1 and 2 is quite comprehensive. Concerning erosion of soil1, the main favorable factors are the relief, the thickness of the soil due to the presence of ferruginous cuirass. Indeed, in a high aggressiveness climate context as in sudano-sahelian region, a slope class of 1-2% is sufficient for important runoff. Low SOC in soil2 is an important erosion factor; the erosion dynamic observed is quite important and contributes significantly to the decline of ferruginous soils fertility.

All current land use and management methods are not reliable for soil erosion control on soil1 (Lithosol) and 2 (Tropical ferruginous soil) of Bélékoni watershed. A previous study related to the second soil type with a pedotransfer function, at regional level, show that 37% of surface horizons are completely unstructured and 24% are unstable. It follows a high risk of erosion
[21](Diallo et Keita, 2001).

In the depression along the river system (relief of soil3), the accumulation of sediment is a dynamic representative of this relief at the bottom of the toposequence. Material removed upstream, from reliefs occupied by Soil1 and 2 spreading succeed with runoff.

5. Conclusion

In Bélékoni watershed, management (forest fires, vainly pasture) of natural vegetation is not reliable for soil quality. In this context, erosion-sedimentation balance is mainly explained by the watershed morphopedological organization. Major process currently affecting the study area is land degradation and sedimentation in the river. Radionuclides utilization in erosion and sedimentation investigations seem reliable in the sudanian zone of Mali.

Acknowledgments

We thank the French cooperation (SCAC) of French Embassy in Bamako, and the staff of CORUS program in France for the adequate granting and advice provided throughout the research work. We also thank the French academic and scientific institutions (CIRAD, IRD, LSCE) and Malian ones (IPR/IFRA Katibougou, FAST, ENI-ABT) for the excellent cooperation.

References

[1] (Lambin EF., Turner B.L., Geist H.J., Agbola S.B., Angelsen A. Bruce J.W., Connes O.T et al, 2001; The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change* 11 (2001) 261-269

[2] Lepers E., Lambin E. F., Anthony C., Defries J.R., Achard F., Ramankutty N., Scholes R.J, 2005 A synthesis of information on rapid land-cover change for the period 1981-2000. *BioScience*, February 2005/Vol.55 No.2 :115-124

[3] Wei W., Chen L., Fu B., Huang Z., Wu D., Gui L. 2007. The effect of land uses and rainfall regimes on runoff and soil erosion in the semi-arid loess hilly area, China. Journal of Hydrology (2007) 335, 247-258

[4] Odunze A.C., Jinshui W., Shoulong L., Hanhua Z., Tida G., Yi W., Qiao L. 2012 Soil quality changes and quality status: a case study of the subtropical china region Ultisol. *British Journal of Environment & climate change* 2(1):37-57, 2012

[5] Masse D (1987) Changements d'usage des terres dans les agro-systèmes

d'Afrique sub-saharienne. Propriétés des sols et dynamique des matières organiques. Mémoire pour l'obtention du diplôme d'Habilitation à Diriger des Recherches, soutenu à l'ENPT- ENSAT : 82 p

[6] Post W.M., Kwon K.C. (2000) Soil carbon sequestration and land-use change: processes and potential. *Global change Biology* (2000) 6, 317-327

[7] Ostle N.J., Levy P.E., Evans C.D., Smith P. (2009). UK land use and soil carbon sequestration. *Land use policy* 265 (2009) 5274-5283

[8] Diallo D., Boli Z., Roose E (2007). Influence of No-Tillage on soil conservation, carbon sequestration and yield of Intensive rotation Maize-cotton: Research on Sandy Alfisoils of Cameroon and Mali. World Association of Soil and Water Conservation, special publication No.3, 383-392

[9] Wijesekara G.N., Gupta A., Valéo C., Hasbani J.G., Marceau J. (2010). Impact of land- use changes on the processes in the Elbow river watershed in southern Alberta. International Environmental Modelling and Software Society (iEMSs) 2010 International Congress on Environmental Modelling and Software Modelling for Environment's Sake, Fifth Biennal Meeting , Ottawa, Canada. David A.Swayne, Wanhong Yang, A.A Voinov, A.Rizzoli, T.Filatova (Eds). https://www.iemss.org/iemss2010/index.php?n=Main.Proceedings : 8p Consulted 07 January 2013

[10] DeFries R., Eshleman K.N. (2004). Land-use change and hydrologic processes: a major focus for the future. *Hydrol. process*. 18, 2183- 2186

[11] Diallo D., Barthès B., Orange D., Roose E. (2004). Comparaison entre stabilité des agrégats ou des mottes et risques de ruissellement et d'érosion en nappe mesurés sur parcelles en zone soudanienne du Mali. *Sécheresse*, 15, 1, 57-64.

[12] Bengaly A (2009). *Erosion des sols et sédimentation dans le bassin versant de Bélékoni en zone soudanienne du Mali.* Thèse de doctorat de l'Université de Bamako : 120p

[13] Droux J.P. (1999). *Hydrologie et flux de matières solides particulaires et dissoutes sur petits bassins versants du bassin du fleuve Niger au Mali (bassins versants du Doufing, de Djitiko et de Bélékoni*). Thèse, Université Louis Pasteur-Strasbourg1 : 304 p.

[14] Huston A., Tranter G., Miller T (2002.) Bulk density. https://www.usyd.edu.au/agric/web04/Bulk%20density%20the%20final.htm: 6p Consulted 07 January 2013

[15] Arrouays D., Feller C., Jolivet C ., Saby N., Andreux F., Bernoux M., Cerri C. 2003 Estimation de stock de carbone organique des sols à différentes échelles d'espace et de temps. *Etude et gestion des sols*, Volume 10, 4,2003, pages 347-355.

[16] Appleby P.G., Olfield F. (1992). Application of lead-210 to sedimentation studies. In Uranium-series Disequilibrium: Applications to Earth, Marine, and Environnemental Sciences, Ivanovich R.S; (Editor), Clarendon Press, Oxford: 731-778.

[17] Zapata F (2002). Handbook for the assesment of soil erosion and sedimentation using environmental radionuclides. Edited by Zapata, Kluwer Academic Publishers: 219 p

[18] Walling D.E., Quine T.A. (1991) - Use of ^{137}Cs measurements- to investigate soil erosion on arable fields, in the UK : potential applications and limitations, *Journal of Soil Science*, 42, 147-165

[19] Martz L.W. et De Jong E. (1987) – Using Caesium-137 to assess the variability of net soil erosion and its association with topography in Canadian prairie landcape, *Catena*, 14, 439-451.

[20] sComission de Pédologie et de Cartographie des sols , CPCS (1967). Classification. 96 p (multicopie)

[21] Diallo D., Keita D. (2001) Etude de l'état structural de l'horizon superficiel du sol de bas glacis de la zone de savane du Sud Mali. Revue malienne de Sciences et de Technologie, 5,4-16