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Assessment of soil rate distribution using Cesium-137 in disturbed and undisturbed fields in Senegal. Case study of Niankhène site."

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Abstract
This work was carried out in Niankhène, which is located in the Tivaouane department. An experimental site and a reference site were selected. The improved mass balance model was used as the model and the obtained results allowed for the observation of different estimated results. For transect 1, erosion rates varied from 12.00 t. ha.an-1 to 70.30 t. ha.an-1, with an average erosion rate of 43.96 t. ha.an-1. Deposition rates varied between 3.00 t. ha.an-1 to 198.03 t. ha.an-1, with an average deposition rate of 72.55 t. ha.an-1. It is noted that five points are eroded, such as points T1S01, T1S58, T1S86, T1S114, and T1S142, and three points show deposition, T1S10, T1S30, especially a large deposition rate noted at point T1S168, which represents 63% of the eroded surface and 37% of the deposited surface. For transect 2, the erosion rate ranges from 23.70 t. ha.an-1 to 79.40 t. ha.an-1, with an average rate of 57.91 t. ha.an-1. Among the 8 samples taken, 7 are affected by erosion and only T2S164 shows a very high deposition rate equivalent to 435.64 t. ha.an-1. The reduced cost of the studies and the speed of results provide significant advantages for this new technique.
Keywords: *soil erosion, 137Cs, mass balance model, Senegal Highlands, Niankhene*

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I. Introduction

Soil erosion is considered worldwide as the major factor of soil degradation. Indeed, the FAO (Food and Agriculture Organization of the United Nations) estimated that between 25 and 40 billion tons of soil from the surface layers are eroded each year [**1-2**], leading to a significant decrease in agricultural yields, as well as the soil's ability to store and recycle carbon, nutrients, and water. Various types of erosion exist, including water, wind, chemical, and biological, but water erosion is the most well-known form. Soil erosion is a major problem worldwide, and in Senegal, the Niayes area in the south and the region of Thiès are affected by this degradation process [**3-4**]. The samplings required fieldwork. Equipment was prepared for the collection of samples. The gamma spectrometry laboratory of the Institute of Applied Nuclear Technology (ITNA) was chosen for sample preparation and analysis. The study sites were located in Niankhène, in the department of Tivaouane, which is in the Thiès region, 184 km from Dakar. Among the study sites, there was a reference site and an agricultural site with an area of 11 hectares. The fieldwork was conducted from December 19th to 20th, 2020.

I. Materials and Method

I-1 Sample Collection

According to these surveys, these sites are composed of light sand, and the time of land use, climatic conditions, and the crops of the peasant landowners were investigated. Two locations were identified to obtain a reference site and a study site. The location of these sites is shown in the illustrations in Figure 1. A GPS was used during the fieldwork. The UTM coordinates of the five points that delimit the study site are shown in the following figure 1:

P1	354730,393	1667391,88
P2	354669,445	1667252,41
P3	354566,702	1667081,78
P4	354276,509	1667213,23
P5	354429,669	1667523,51

Figure 1: Localisation of Niankhene Study Site

For the study site, transect sampling was adopted. Sampling started from the top and went down the slope of the land. The distance between two sampling points ranged from 25 to 50 meters, depending on the accessibility of the sites **[5].** For a much deeper study, altitude slices were determined in the agricultural site, and contour lines were drawn. A contour line (or altitude isopleth) is a line formed by points on the terrain at the same altitude in cartography [**6-8**]. The closer the contour lines are, the steeper the slope is Figure 2.

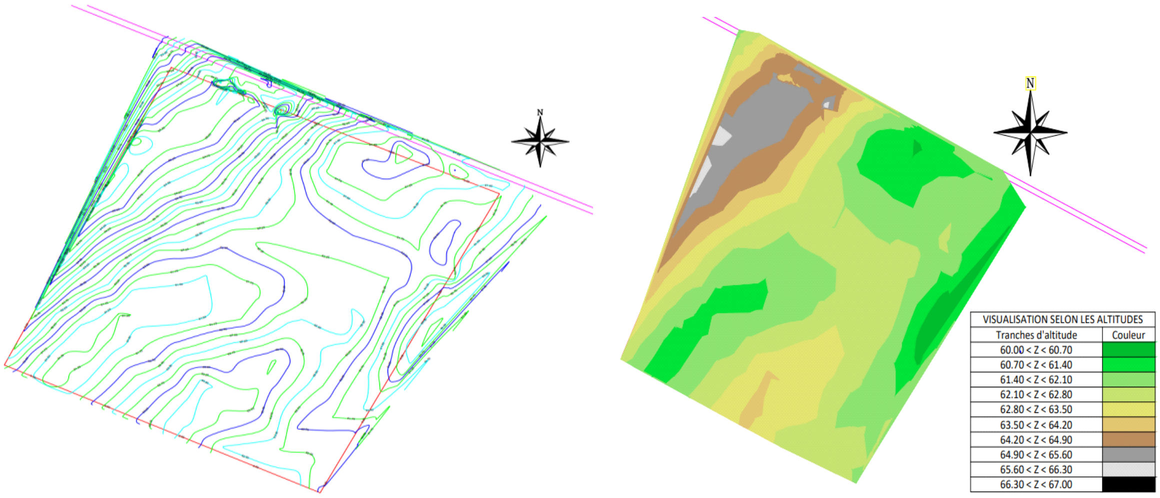

Figure 2: Level Curves and Elevation Slices of the Agricultural Site

To study soil erosion using the 137Cs technique, the chosen sites must meet all necessary conditions. The study sites were very close to the reference site. Therefore, there was no change in climate between these sites, which also justified their selection. The rainfall at the hydroelectric dam in this area must also be taken into account [**9-10**].

I-2 Sample Collection and Preparation Methods

For the study of soil erosion/deposition, suitable field and laboratory equipment were used to collect samples.

I-2-1 Sample Collection

To collect the samples, a COBRA percussion motor and a corer with 10 cm diameter PVC (PolyVinylChloride) tubes were used to contain the sample (also called the core) [**11-12**]. The following Figure 3 illustrates these materials. The first 40 centimeters of depth were taken. Plastic bags were used to package the collected samples.

Figure 3: Reference site and sampling

I.2.2 Sampling protocol

Two protocols were used during the field surveys. The first protocol was used to determine the inventories at each sampling point. A core sample was obtained and divided into sub-samples of 0 to 5 cm. For the first core sample, a depth of 75 cm was taken, while a depth of 100 cm was taken for the second and third core samples. This resulted in a total of 53 sub-samples being collected at the reference site. In the study site, the core samples were subdivided into two sub-samples of 0 to 20 cm and 20 to 40 cm, resulting in a total of 94 sub-samples being collected. The inventory of each sample was calculated as the sum of the inventory of each sub-sample from the sampling points.

I.2.3 Sample Preparation

Once arrived at the laboratory of the Institute of Applied Nuclear Technologies (ITNA-Senegal), the samples and sub-samples were weighed, separated from roots and rocks, sieved, and placed on sample holders. A portion of these samples was placed in an oven at 80°C for 24 hours to determine moisture content using watch glasses. To perform further studies, secular equilibrium was also achieved by letting the samples rest for 21 days **[13].**

I.3 Sample analysis

Sample and sub-sample analyses were carried out in the gamma spectrometer laboratory located at the Institute. The following Figure 4 summarizes the spectrometer chain installed in the laboratory. A CAMBERRA brand detector, with high-energy resolution (High Purity Germanium [HPGe] type N with 15% relative efficiency, with a carbon window and an energy range from 10 keV to 10 MeV), was used to determine natural radionuclides (40K, 232Th and Uranium 238 decay products) and artificial radionuclides such as 137Cs. Counting times were all 24 hours to provide measurement accuracy [**14-17]**

Figure 4: ITNA gamma spectrometer

The activities of 137Cs for each analysis were determined from the net areas at the energy of 661.7 keV [**18-19**]. Calibration and quality control of gamma spectrometry analyses were performed following the protocol proposed by Shakhashiro and Mabit (2009), which involves the use of reference materials and the use of the ISOCS/LabSOCS method for geometry calibration and validation, as geometry is a crucial part of the measurements **[20].**

II. Results and data processing

This section covers the analysis and interpretation of the results obtained from the reference site and the agricultural site. It includes the presentation of specific activities and inventories of 137Cs, profiles of each site, and those of the selected transects in the agricultural field, as well as the use of conversion models such as MBMII and MODERN, and comments on the findings.

II-1 Analysis

- **Reference site**

At the reference site located 7km away from the study site, we selected three points for a depth of 40 cm. These three profiles were named Top for profile 1, Cuvette for profile 2, and Plateau for profile 3. The following **Table 1** summarizes the variation of cesium-137 Cs for the Top, Plateau, and Cuvette profiles

Table 1: Distribution of cesium from the three profiles for a depth of 20cm

Depth (cm)	Activity of Cesium 137(Bq.kg-1)		
	Top	**Cuvette**	**Plateau**
0-5	0.51 ± 0,06	0.30 ± 0.06	0.39 ± **0.04**
5-10	0.44 ± 0,06	0.50 ± 0.10	0.29 ± **0.19**
10-15	0.49 ± 0,09	0.85 ± 0.10	0.37 ± **0.06**
15-20	0.58 ± 0,09	0.32 ± 0.08	0.16 ± **0.08**
20-25	0.65 ± 0,07	0.19 ± 0.08	0.00 ± **0.00**
25-30	0.34 ± 0,06	0.15 ± 0.04	0.00 ± **0.00**
30-35	0.33 ± 0,05	0.11 ± 0.06	0.00 ± **0.00**
35-40	0.00 ± 0,00	0.09 ± 0.05	0.0 ± **0.00**

In these data, we can see that for the top profile, we don't have the distribution of a reference site. This profile shows that the activity of cesium is higher for the depth of 20-25 cm and zero for the depth of 35-40 cm, with an average activity of (0.42 ± 0.06) Bq.kg-1. For profile 2, Cuvette, we have a distribution that corresponds to that of a reference site, with the value of cesium activity increasing for the depth of 5-10 cm, reaching a maximum value of 0.95 ± 0.10 Bq.kg-1 and then decreasing until the depth of 35-40 cm, with a value of 0.09 ± 0.05 Bq.kg-1. The average value for this profile is 0.40 ± 0.07 Bq.kg-1. Profile 3, Plateau, cannot be considered as a reference site due to the distribution of cesium activity with depth. The activity of cesium is higher for the depth of 0-5 cm, with a value of 0.39 ± 0.04 Bq.kg-1, and then decreases for the depth of 5-10 cm, with a value of 0.29 ± 0.19 Bq.kg-1. For the depth of 10-15 cm, there is a slight increase compared to the previous depth, giving a value of 0.37 ± 0.06 Bq.kg-1. The smallest non-zero specific activity of cesium-137 for this profile is given by the depth of 15-20 cm, with a value of 0.16 ± 0.08 Bq.kg-1. There is no activity for the remaining depths. The average value of cesium activity for this profile is 0.15 ± 0.05 Bq.kg-1. The following **Table 2** summarizes the average, minimum and maximum values for each profile of the reference site.

Table 2: Summarizes the average, minimum and maximum values for each profile of the reference site

Profile	Specific activities of Cs 137 ($Bq.kg^{-1}$)		
	Minimum value	Average value	Maximum value
Top	0.00 ± **0.00**	0.42 ± **0.06**	0.65 ± **0.07**
Cuvette	0.09 ± **0.05**	0.40 ± **0.07**	0.95 ± **0.10**
Plateau	0.00 ± **0.00**	0.15 ± **0.05**	0.39 ± **0.04**

Based on these results, we can say that the Top and Plateau profiles are disturbed or do not have good vegetation cover, unlike the Cuvette profile which corresponds to a reference site profile [**21-22**]. The following **Figure 5** shows the distribution of specific activity of Cesium-137 for a depth of 40 cm for the Top, Cuvette, and Plateau profiles.

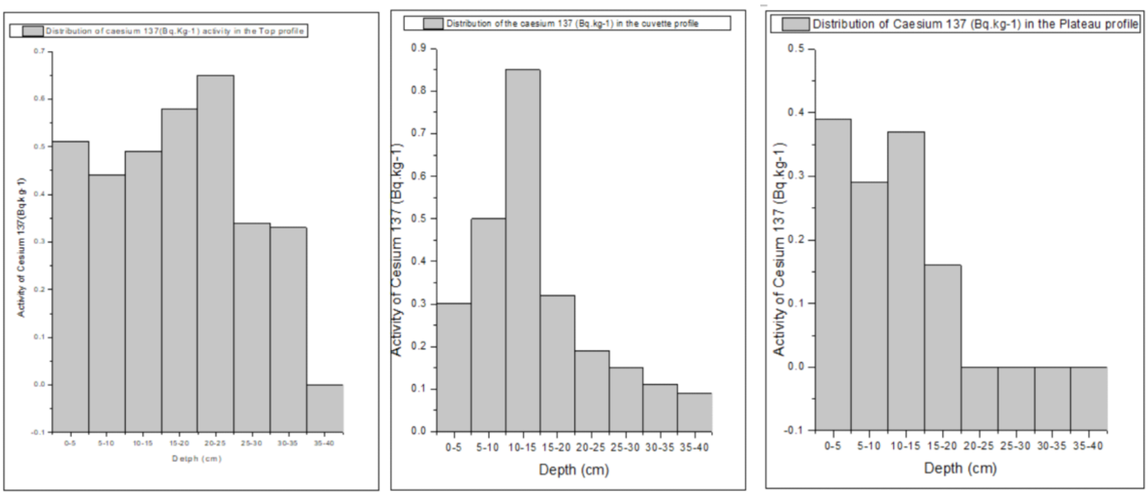

Figure 5: Distribution of the specific activity of Caesium-137 in Bq.kg-1

To calculate the inventories of each core at a depth of 40 cm, the following formula was used:

The inventory values for the three profiles of the reference site are given in the following table

Table 3: The inventory values for the three profiles of the reference site

Depth	Inventory of Cesium-137 (Bq.m-2)		
	Profile Top	Profile Cuvette	Profile Plateau
0-5cm	31.58±**6.24**	26.45±**5.11**	32.58±**5.93**
5-10cm	23.38±**5.06**	54.49±**10.10**	16.69±**12.27**
10-15cm	28.09±**7.41**	46.94±**8.17**	20.90±**5.05**
15-20cm	37.62±**8.85**	17.82±**5.88**	09.17±**5.32**
20-25cm	39.01±**7.32**	4.15±**2.08**	0.00±**0.00**
25-30cm	16.72±**4.29**	2.28±**0.79**	0.00±**0.00**
30-35cm	19.19 ± **4.44**	02.63±**1.64**	0.00±**0.00**
35-40cm	0.00 ± **0.00**	01.92± **1.22**	0.00±**0.00**

To obtain the total inventory of a profile for a depth of 40cm, we sum the inventories obtained from 0-5cm up to 35-40cm. The following Figure 6 illustrates the distributions of the cesium-137 inventories for a depth of 40 cm for the three profiles.

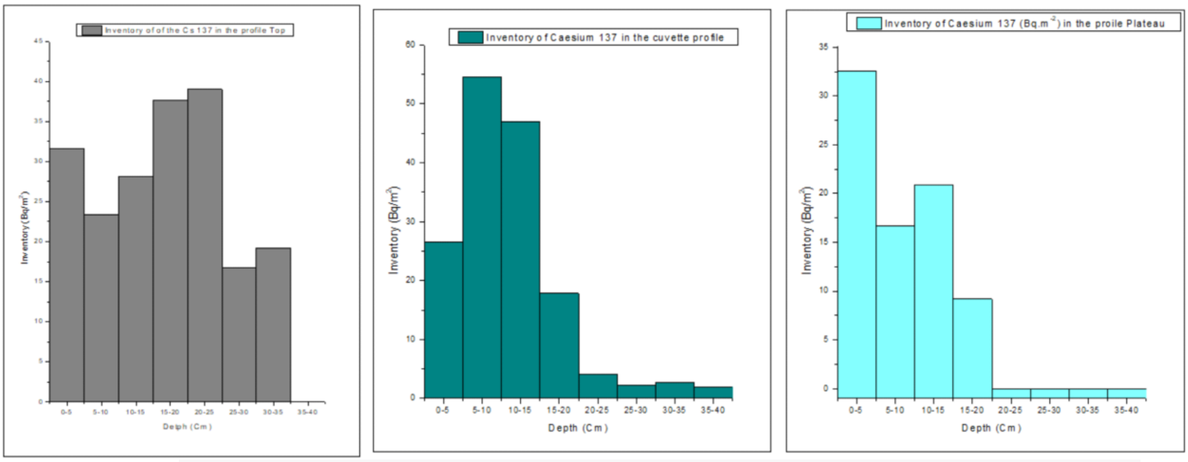

Figure 6 : The distributions of the cesium-137 inventories for a depth of 40 cm for the three profiles.

The following Figure 7 illustrates the distributions of cesium-137 inventories to a depth of 40 cm for the three profiles.

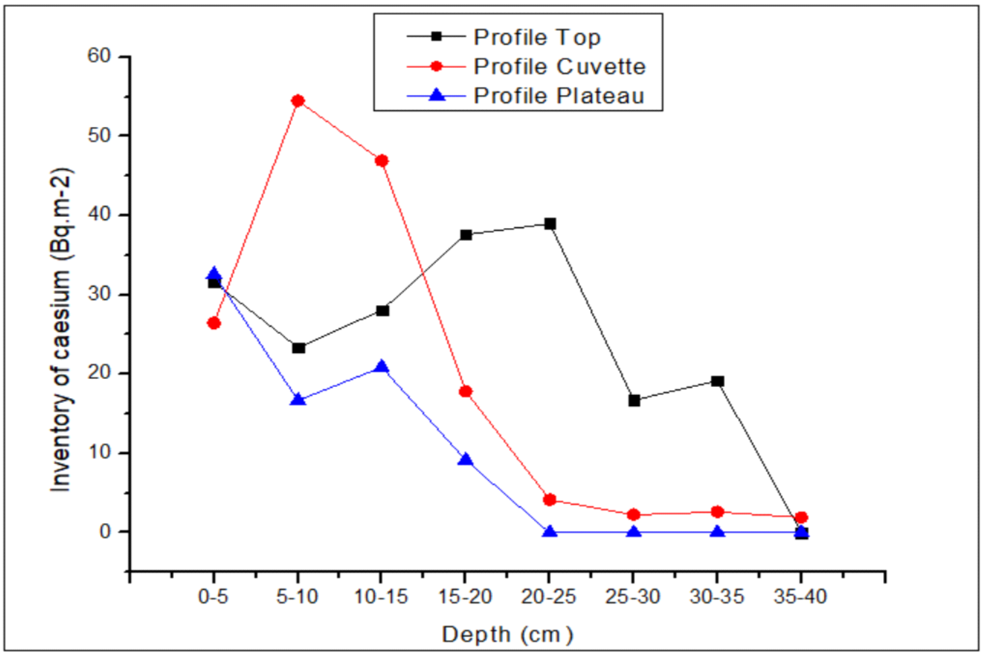

Figure 7: Distributions of cesium-137 inventories to a depth of 40 cm for the three profiles.

The inventory for the Top and Plateau profiles are approximately equal and higher than the inventory for the Cuvette profile for a depth of 0-5 cm. For depths of 5-10 cm and 10-15 cm, the Cuvette profile has a higher inventory than the Top and Plateau profiles. From a depth of 15-20 cm, the Top profile has the highest inventory compared to the Cuvette and Plateau inventories. According to the calculations, the Top profile has a total inventory of 195.59 ± 17.05 Bq.m-2, the Cuvette profile has an inventory of 156.49 ± 15.46 Bq.m-2, and the Plateau profile has an inventory of 79.35±15.47 Bq.m-2.

- **Agricultural Site**

In the agricultural site, which has an area of 11 hectares, two transects, T1 and T2, were selected. Eight points were taken at a depth of 40cm in each transect. The specific activities of 137Cs in both transects are more or less low, ranging from (0.19 ± 0.04) Bq.kg-1 to (4.72 ± 0.55) Bq.kg-1 for T1, and from (0.12 ± 0.05) Bq.kg-1 to (7.77 ± 0.73) Bq.kg-1 for T2. The average values are (1.20 ± 0.12) Bq.kg-1 for the first transect and (1.25 ± 0.13) Bq.kg-1 for the second transect. The following figure illustrates the distribution of specific activity of Cesium-137 in the two transects selected in the agricultural site.

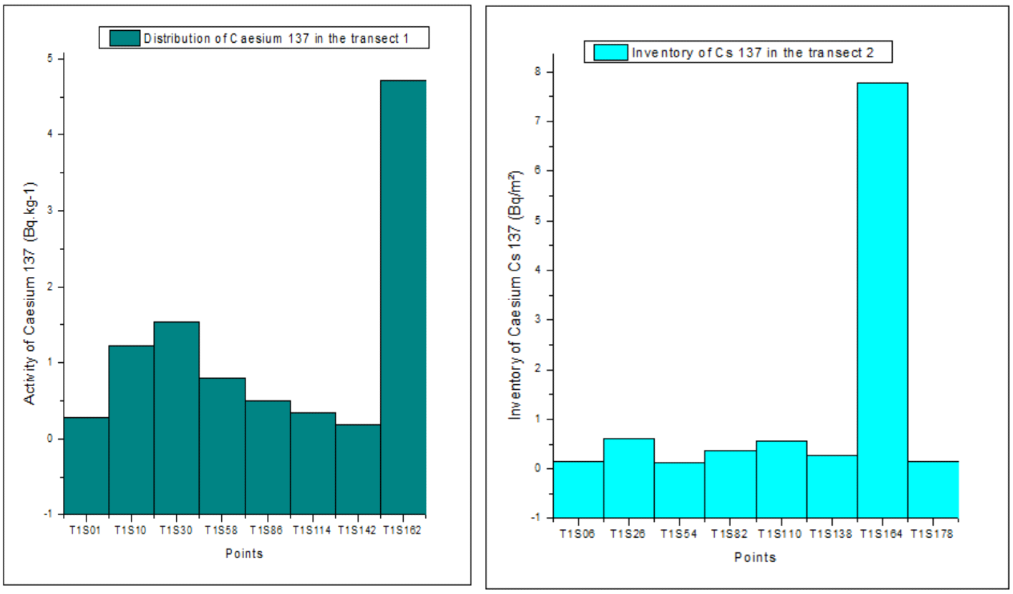

Figure 7: Figure: Distribution of specific activity of Cs-137 in the agricultural site.

After calculating the inventories for each point in the two transects using the previous formula, the following **Table 4** summarizes these values.

Table 4: Inventory of points in the two transects at the agricultural site

Transect 1	Inventaire (Bq.m-2)	Transect 2	Inventaire (Bq.m-2)
T1P1	39,01 ± 10,92	**T2P6**	24,10 ± 05,90
T1P10	183,56 ± 25,16	**T2P26**	89,74 ± 14,39
T1P30	219,48 ± 27,21	**T2P54**	15,53 ± 07,52
T1P58	124,06 ± 18,49	**T2P82**	55,78 ± 09,45
T1P86	66,99 ± 10,26	**T2P110**	83,15 ± 13,61
T1P114	50,68 ± 09,04	**T2P138**	38,46 ± 12,26
T1P142	28,59 ± 07,71	**T2P164**	1177,61 ± 173,54
T1P168	690,97 ± 120,52	**T2P178**	23, 36 ± 06,02

These results show that the inventories vary from (28.59 ± 7.71) Bq.m-2 to (690.97 ± 120.52) Bq.m-2 for the first transect, and from (15.53 ± 7.52) Bq.m-2 to (1177.61 ± 173.54) Bq.m-2 for the second transect

II-2 Discussion

The results obtained in this study can be validated using references such as the following. In the European continent, according to Theocharopoulos et al. (2000), the specific activity of Cesium 137 was evaluated between 16 Bq.kg-1 and 63 Bq.kg-1 in the reference site and from 5.40 Bq.kg-1 to 81 Bq.kg-1 in the studied sites in Central Greece [**23**]. In the African continent, specifically in Morocco, the value of 137Cs concentration was between 5.90 Bq.kg-1 in cultivated land and 16 Bq.kg-1 in reference sites [**24**], the level of 137Cs concentration is low. The calculated specific activities were below 1.00 Bq.kg-1 in Madagascar [**25**]. In Senegal, the specific activity of Cesium 137 is practically zero in the reference site and varies from 0 to 0.95 Bq.kg-1. In all three profiles, the concentration is less than 1.00 Bq.kg-1, as in Madagascar. In agricultural sites, the activity value varies from 0.12 Bq.kg-1 to 7.77 Bq.kg-1. These results can be explained by the fact that Senegal is located in the northern hemisphere above and near the equator. These industrialized countries in the northern hemisphere, such as Morocco and Greece, have a higher concentration compared to Senegal. This difference in the activity of Cesium 137 can be explained by the proximity of these countries to the locations of nuclear accidents that have occurred in the world. The concentration is higher in Senegal compared to countries belonging to the southern hemisphere due to the dispersion of the radionuclide leaving these polluted areas towards the south of Africa. Counting times had to be long, that is, all times were at 86,400 seconds. For the two transects of the agricultural site, there is a higher activity of 137Cs in the first twenty centimeters of the soil surface. Thus, these activities will exponentially decrease, indicating that 137Cs has attached to the fine soil particles [**26**].

- **Use of Conversion Models**

To determine the erosion and deposition rates in a site, we used conversion models such as mass balances. According to the work of Mamadou Lamine Sané, the Improved Mass Balance Model (MBMII) is more suitable for studying soil erosion in Senegal [**27**]. The reference inventory of 176 Bq.m-2 was obtained by taking the mean value of inventories in the reference site and its coefficient of variation, calculated by dividing the mean by the standard deviation, resulting in a value of 16%. To estimate erosion or deposition rates, several conversion parameters were used. These conversion parameters are described in the following **Table 5.**

Table 5 : Conversion parameters models

Parameters	Transect 1	Transect 2
Density (kg.m-3)	734	734
Ploughing layer (m)	0,4	0,4
Year of commencement of cultivation	1963	1963
Sampling year	2020	2020
Relaxation depth (kg.m-2)	4	4
Proportional factor	0,8	0,8

The obtained density corresponds to the average of all the densities of the different samples taken. The year of the beginning of the crops in the agricultural site being around the year 1963. The proportional factor is defined as the ratio of the average precipitation during the period of July-August-September, which is equal to 500 mm, to the average annual precipitation, which is equal to 600mm. The calculation gives a value of 0.8. These data are already integrated into the conversion software "Radionuclides Inventories Conversion" that Walling et al. (2001) have developed, and the proportional factor has been introduced as well [**28**]. The results obtained with the mass balance of the two transects are given in the following **Table 6**.

Table 6: The results obtained with the mass balance

Transect 1	**MBMII**	**Résultats**	**Transect 2**	**MBMII**	**Résultats**
T1S01	-56.80	Erosion	T2S06	-78,00	Erosion
T1S10	3.13	Deposition	T2S26	-23,70	Erosion
T1S30	18.02	Deposition	T2S54	-98,40	Erosion
T1S58	-12,00	Erosion	T2S82	-42,00	Erosion
T1S86	-34.80	Erosion	T2S110	-26,50	Erosion
T1S114	-45.90	Erosion	T2S138	-57,40	Erosion
T1S142	-70.30	Erosion	T2S164	435,64	Deposition
T1S168	198.03	Deposition	T2S178	-79,40	Erosion

For transect 1, the erosion rate varies from 12.00 t. ha.an-1 to 70.30 t. ha.an-1 with an average erosion rate of 43.96 t. ha.an-1. The deposition rate ranges from 3.00 t. ha.an-1 to 198.03 t. ha.an-1 with an average deposition rate of 72.55 t. ha.an-1. Five points (T1S01, T1S58, T1S86, T1S114, and T1S142) show erosion, while three points (T1S10, T1S30, and T1S168) indicate deposition, with a high deposition rate of 63% observed at point T1S168 for the eroded surface and 37% for the deposited surface. For transect 2, the erosion rate ranges from 23.70 t. ha.an-1 to 79.40 t. ha.an-1 with an average erosion rate of 57.91 t. ha.an-1. Among the 8 samples collected, 7 were affected by erosion, and only T2S164 showed a very high deposition rate of 435.64 t. ha.an-1. The variation in erosion rates in the sloping study site can be explained by the morphology of the agricultural site, as well as the presence of rocks, roots, or insects in the cores taken from the fields. However, the logic is respected for uniform slopes. Along the transect, obstacles such as changes in the direction of runoff occurred. With the MBMII model, we obtained the gross erosion rate, net erosion rate, and proportion of sediment delivered for transect 1 and transect 2, as shown in the **Table 7**.

Table 7: The gross erosion rate, net erosion rate, and proportion of sediment delivered for transect 1 and transect 2

Parameters	Transect 1	Transect 2
Gross erosion rate (t. ha. year-1)	**27,50**	**50,7**
Net erosion rate (t. ha.year-1)	**1,00**	**3,8**
Proportion of sediment delivered (%)	**-**	**-7**

These results require correction to correspond to a result of a slope, which is why we tried to correct them by taking only the first transect since the values of the second transect are much lower than the reference inventory. In the first transect, we eliminate the points T1S01 and T1S168 to create a new transect represented in the following **Table 8.**

Table 8: Results obtained with MBMII

Points	MBMII	Comments
T1S142	-70,30	Erosion
T1S114	-45,90	Erosion
T1S86	-34,80	Erosion
T1S58	-12,00	Erosion
T1S30	16,31	Deposition
T1S10	02,84	Deposition

For this transect, the erosion rate varies from 12.00 t. ha.year-1 to 70.30 t. ha.year-1 with an average erosion rate of 40.75 t. ha.year-1. The gross erosion rate and net erosion rate are 27.2 t. ha.year-1 and 24 t. ha.year-1, respectively. The deposition rate ranges from 2.84 t. ha.year-1 to 16.31 t. ha.year-1 with an average of 9.58 t. ha.year-1. There are 4 points on the transect that are eroded, accounting for 66% of the eroded surface and 34% of the deposited surface. The proportion of delivered sediment is 88%. The data is summarized in the following **Table 9**.

Table 9: Results for the transect

Parameters	Transect
Crude erosion rate (t. ha.year-1)	**27,20**
Net erosion rate (t. ha.year-1)	**24,00**
Average erosion rate	**40,75**
Average deposite rate	**9,58**
Proportion of sediment delivered (%)	**88**
Eroded area (%)	**66**
Deposited area (%)	**34**

In the agricultural site, the soil density is the same, but the terrain slopes are slightly different. Therefore, the phenomenon of transport (or displacement) of fine particles has not been the same [**29-30**]. Crop types, land use, and conservation practices have played important roles in soil conservation (for example, cereal crops such as millet, cowpea, and crop rotation) [**31-32**]. Precipitation patterns depend on climate, terrain, and region. However, precipitation and its intensity can play a very important role in the movement of fine particles. For example, in an environment with intense but short duration rainfall, the erosion rate may be higher than in an environment with non-intense but long duration rainfall.

III. Conclusion

Quantitative estimation of soil erosion using nuclear techniques has been studied for the second time in Senegal with the application of another conversion model. These techniques were applied to soil samples from the Niankhene agricultural site located in the Thiès region. The aim of this work was to use the 137Cs technique (a nuclear technique for Fallout RadioNuclide: FRN) to study soil erosion/deposition in Senegal. Its feasibility will contribute to improving the results of already established techniques. The 137Cs technique converts mass activities into rates of soil erosion/deposition. To obtain this rate, the establishment of inventory calculations (in Bq.m-2) is a mandatory step, regardless of the conversion model used. The MBMII and MODERN models were used to convert inventories into erosion and deposition rates. MBMII takes into account numerous factors that can influence soil redistribution. A net erosion of 24.0 t ha-1 yr-1 was found for the Niankhene agricultural field.

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