Assessment of Soil Erosion Risk from Runoffs under Arid and Semi-arid Climate Zones in Africa

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ABSTRACT

Soils are a vital natural resource that deserves more attention and affection, because they are full of everything that living beings need to survive. Now, soil hydric erosion is a phenomenon that causes serious problems of flooding and limiting food production in semi-arid climate zones, leading to a chronic socio-economic and environmental disasters. This process is further exacerbated by the ever-increasing global warming. This study aims to better understand the processes and consequences of water erosion, in order to better prevent the risks that could be associated with rising of global temperature. The study area is located in the semi-arid climate of Isser watershed in the northern-west of Algeria. Soils of the area have a silty-clay texture. The surfaces are covered with little gravel (8%), covered to 72% of vegetable debris and are cracked up to 53%. These characteristics may reduce the runoff velocities and protect soils to erosion. However, clearing, overgrazing and farming systems favor runoffs that cause transfers of sediments through the destruction of the surface physical-chemical properties and thereby its natural structural stability. The study shows a slowdown in the infiltration rate of runoff water when soils are severely dehydrated. This may be an explanation for the paradoxes of the recent floods in arid and semi-arid areas of the world. Soils aridification due to global warming could increase its cracking and damage their structural stability. This climatic phenomenon will result in the recurrence of floods and the massive infiltration of surface water into groundwater, thus generating their pollution. The study also shows that the sum of all chemical properties (moisture, OM, soil carbon, calcite, and total nitrogen) in percentage is highly correlated with soil structural stability. Therefore, the key factor in mitigating this process would be to maintain a sufficient level of organic matter in soils.

Keywords: Key words: Soil, Hydric Erosion, Runoff, Catchment area, Organic matter, Climate change, Climate warming.

1. Introduction

Healthy soil is essential for the survival of living beings. It is a critical component of ecosystems and the terrestrial system that supports primary ecosystem service delivery (Amundson et al., 2015; Keesstra et al., 2016; Robinson et al., 2017). The African continent faces multiple environmental challenges and must reconcile many conflicting priorities, including promoting economic diversification, ensuring water supply and food security, but also to promote the protection and conservation of the environment in order to adapt to the impacts of global warming (Radhouane, 2013). Northern Africa and the Sahel zone are highly vulnerable to recent climate change (IPCC, 2001; Huqand Reid, 2004). Variability of rainfall, land degradation and desertification are some of the factors that combine to make life extremely difficult in these parts of the World. Here, wind and water erosion of soils are remaining the predominant natural processes that threaten all ecosystems. With exponential population growth (UN, 2024), followed by poor waste management produced in huge quantities in urban and rural areas, soil water erosion increases the risk of groundwater pollution with serious consequences for human and plant health (Chia et al.,2022; Mounkaila et al., 2025). An assessment of water erosion processes is more than necessary for low-resource countries located in the arid and semi-arid regions of Africa in order to prevent the risk of contamination of aquifer water useful for consumption and irrigations. Infiltration is the flow of water through the soil surface into a porous medium under gravity action and pressure effects. Therefore, soil infiltration is a critical physical parameter of soils conditions. Various studies have shown that the soil's seepage capacity is dependent on the physical and chemical properties of the soil (Bouwer,1986; Hillel,1998; Gonzalez-Sosa et al., 2010; Yu et al., 2015; Sheng and Dong,2016). The properties are among others texture, structure, porosity, organic matter content, clay type, retention capacity and hydraulic conductivity; precipitation, climate, meteorology and land uses (e.g. Gonzalez-Sosa et al., 2010; Tamir et al., 2014; Isreal et al., 2018). Water infiltration is governed by complex interfering actions between bulk density, porosity, particle size distribution, organic matter (OM), water-stable aggregates and soil moisture content (Fischer et al., 2015; Zhu et al., 2020). These soil hydraulic properties control water retention, water flow and fate of nutrients, chemicals and pollutants in the soil, thereby determine the accessibility of plants to water absorption, crop growth and environmental health. The Universal Soil Loss Equation (RUSLE) enables planners to predict the average rate of soil erosion for each feasible alternative combination of crop system and management practices in association with a specified soil type, rainfall pattern, and topography. When these predicted losses are compared with given soil loss tolerances, they provide specific guidelines for effecting erosion control within specified limits (Wischmeier and Smith,1958; Wischmeier and Smith,1978). Originally, the universal soil loss equation (USLE) was developed by Wischmeier and Smith (1965). This is a commonly used model, then modified to become the revised universal land loss equation (RUSLE) by Williams (1975) and reformulated by Renard et al. (1997). Recent studies combine both geospatial technologies and modeling approaches extensively to estimate soil erosion rates and map areas at risk of erosion worldwide (Desmet and Govers,1996; Ganasri and Ramesh, 2016; Mohammed et al., 2022; Mengie et al., 2022; Yusron and Eko, 2023). The studies led significant and sustainable results. Among the various models for estimating erosion, the RUSLE equation is distinguished by its consistency and minimum data requirements (Fredj et al., 2024; Borrelli et al., 2017). According to Borrelli et al., (2017), based on the RUSLE model, reported that the GPS are overestimated. For the African continent, soil losses vary considerably from 0 to 750 t ha^{1} y^{-1}, and are mainly influenced by slope, land cover and rainfall intensity (Deore and Shruti, 2023; Benselama et al., 2018). Water erosion is a common phenomenon that affects all continents and in all climatic conditions. Africa has an increase in soil erosion rate of about 10% in 2012, it is also one of the highest (3.88 Mg $ha^{-1}y^{-1}$) in the world (Borrelli et al., 2017). The largest projected increases are in sub-Saharan Africa. The least developed countries are most likely to experience this phenomenon (Borrelli et al., 2017). As elsewhere in the world, soil erosion caused by rainfall and runoff poses a major challenge to sub-Saharan and Mediterranean countries in Africa, leading to declining agricultural fertility. Soil erosion is one of the major causes of soil degradation in the Isser region in northern Algeria, and significant damage is caused each year by floods and flooding aggravated by anthropologic factors. Another major concern that requires a lot of remediation among the scientific community is the impact of climate change on water erosion and its adverse consequences on drinking groundwater quality in arid and semi-arid environments.

The aim of this work is to develop of consequents and comprehensives relationships between surface physical states, infiltration, soil physico-chemical properties on the hydric erosion processes in arid and semi-arid regions. Soil data from the Isser watershed in the northwestern Algeria will be used to assess erosion processes and runoff risks. Our working hypothesis is that it would be necessary to develop a hierarchical model of the factors indicating the risks of degradation of the natural environment. This model will be validated by comparison with the work already carried out in order to draw the best conclusions. We will base our analysis on the role that soil physico-chemical parameters may play in the decohesion of soil particles and their transport by infiltration and runoff.

2. Matériels et Méthodes

Since the late 1980s, there has been a need to determine the causes and factors of various erosion processes and to apply a new strategy: conserving water and soil fertility management in the present study area (Ross,1993; Mazour, 1992). for the rational and continuous exploitation of natural resources. To this end, in 1989, Ross (1993) installed 17 experimental erosion plots in the main ecological stations of the Isser watershed with the collaboration of the INRF station of Tlemcen and ex ORSTOM (current IRD) To quantify runoff and erosion in the various Agro-Sylvo-pastoral production systems. The plots installed are inspired by Wischmeier (1959).

2.1. Study area

The study area covers the watershed of the Oued Isser which is located in the northwest corner of Algeria in North Africa (Fig. 1a). This area extends in between latitude 34°41'22' and 35°09'37' N and longitude 1°20'31' and 0°52'28' W. It covers an area of 1122 km^2 for a perimeter of 207.7 km. The climate is of semi-arid Mediterranean type to temperate winter. It can be distinguished two seasons: one cold and rainy (from November to mid-March) and the other hot and dry (extending from mid-March to November). Rainfalls are usually of high intensity and irregular in time and space. The watershed system is dense and consists of a main Oued (Oued Isser) and many tributary systems. The topography highly rugged terrain.

The lithology (Fig. 1b) is defined by 597 of soft rocks (marls and soft sandstone) with intersections of hard rocks (calcareous), which predisposes these areas to different erosion processes (Boughalem et al., 2012).

The regions located in the southern and central part of the basin are characterized by the predominance of shale with easily eroded limestone from the Upper Cretaceous and extend over about 1/3 of the area. Rock formations represent 12%, and extend over all parts of the basin. About 8% of the northern surface is characterized by low Miocene-age argillite and clay rocks, while the middle part comprises schist with sandstone and limestone, and the southern part has red sandstone rocks with conglomerate, resistant to erosion.

Sandstone rocks with green schists of different ages (Lower Miocene, Upper Eocene and Marine Oligocene) constitute 30% of the Isser region, distributed in and dominating the northern and central regions. Remaining formations, including limestone, eruptive rocks, metamorphic rocks and calcareous sands, constitute a minority of the total catchment area (Fredj et al., 2024).

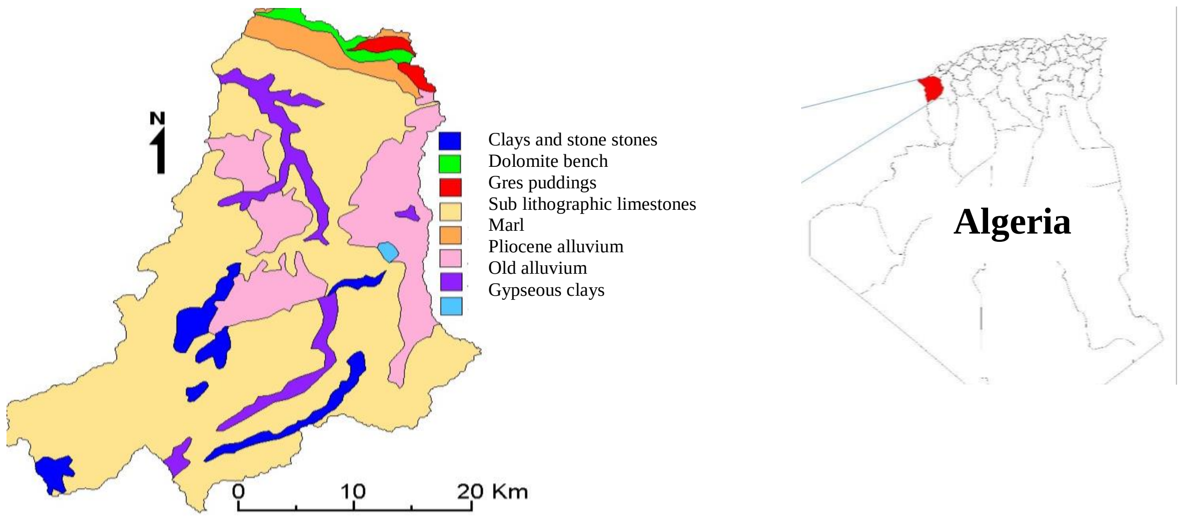

Figure 1. Present: (a) Location map of the study area in Algeria. (b) Lithological map of the study area. Source (Boughalem et al., 2020).

2.2. Methods

Soil surface components (texture, organic matters…etc.), may intercept the rainfall reducing its energy the which favor the increase the water infiltration rate. In 1989, 17 experimental plots were installed to study water erosion in the main ecological station of the Tlemcen watershed in collaboration with INRF of Tlemcen and the former OROSTOM (IRD).

For the quantification of runoff and surface erosion in different agro-sylvo-pastoral production systems according to Boughalem et al. (2012).

To determine soil erosion risks in the natural conditions following tests and analysis were performed on the site and in the laboratory. The tests consist to estimate surface state, and water infiltration. The physico-chemical parameters to be determined are the granulometry, the structural stability, soil bulk density, and soil humidity, soil permeability, the electric conductivity (EC), the color, soil organic matter, total azote and carbonate contents.

2.2.1. Test of surface conditions

This test defines whether a soil surface is well or poorly protected according to the quantitative contents of cracks, pebbles and plant debris. The method used consist to draw on the ground a square of one m^2, randomly taken and representative of the plot (Roose, 1996). Thus, for each square by choosing adequate spacing according to the objectives (5cm, 10cm or 20cm) we attribute the value **(1)** if **yes,** the element is present **or no (0)** if not contained from each intersection.

Table 1. Test bord (Roose, 1996): A grid indicating the percentage contents yes (1) or no (0) of (a) cracks; (b) pebbles and (c) plant debris in 1 m^2.

(a) % of Cracks						***(b) % of Peebles***						***c. % of plant debris***					
1	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	1	1
1	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	0
1	1	0	1	0	1	0	0	0	1	0	0	0	1	1	0	1	1
1	0	0	1	1	1	1	0	0	0	0	0	1	1	1	1	1	1
0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	1	1	0
1	1	0	0	1	1	0	0	0	1	0	0	1	1	1	0	0	1

2.2.2. Test of infiltration

The test allows to estimate the water infiltration rate in the soil. Due to the lack of equipment's, a very simple method was used in order to appreciate this infiltration. Here, we used a cylinder, which was driven into the ground about 5cm and then filled with water. This test was performed at decreasing load on wet and dry soil in the same location.

2.2.3. Determination of physicochemical properties

(a) (a) Particle size analysis

The liquid limit test is one of the most widely used tests in soil mechanics, with the value obtained being correlated against a variety of soil properties such as soil strength (Casagrande,1932). According to FAO (1979) the susceptibility to physical degradation (SDP) is calculated as follows:

$$SPD = (1{,}5\ Lf + 0{,}75\ Lg)/(A + 10\ MO). \ (1)$$

Where Lf: ٪ fine silt; Lg: ٪ coarse salt; A: ٪ clay; MO: ٪ organic matter

(b) Structural stability

Structure is defined as the architecture of the various components of soil: elementary or complex particles resulting from the agglomeration of elementary particles into aggregates of variable size and shape. The three main processes leading to aggregate destruction are (i) total breakup, (ii) microcracking, and (iii) mechanical breakdown without burst in the saturated state. The subsidence of bonding forces and the increase in breaking forces due to air trapping within the aggregate during rewetting and the mechanical effect of rainwater droplets on soil particles (Nelson,1997; Morsli,1996). On this basis, a classification of structural stability, soil sealing and erosion based on the average diameter by weight after disaggregation according to (Le Bissonnais, 2016) is established.

Table 2: Stability class, soil sealing and erosion as a function of the average diameter by weight MWD after dissolving (Kemper and Rosenau 1986). The results of the structural stability test are shown in the following table.

MWD	***structural stability***	***soil sealing***	***Runoff and diffuse erosion***
<0,4mm	highly unstable	systematic	Significant and permanent risk in all topographical conditions
0,4-0,8mm	unstable	very frequent	Common risk in any simulation
0,8-1,3mm	moderately stable	frequent	Variable risk depending on climatic and topographical parameters
1,3-2mm	stable	occasional	limited risk
>2mm	highly unstable	extremely rare	extremely low risk

(c) Bulk density and Soil moisture.

- *Soil moisture*

Soil moisture is determined by the following formula.

$$Humidity = \frac{\text{Weight-loss}}{\text{Weight of the oven-dried soil}} \times 100 \ (2)$$

- *Bulk density*

The bulk density is the density of the soil, dry for the whole, solid fraction and pores. The 250-cc metal cylinder method is used, which consists of carefully pushing into the ground. The cylinder is then removed with its contents, avoiding any compaction. Generally, for soils, the apparent density varies from 1 to 2. The value of the apparent density will be used to estimate the total porosity.

(d) La perméabilité à l'eau

The permeability of a soil is defined by the rate of infiltration of water by gravity. Two samples were analyzed in the laboratory to determine the permeability by using constant load permeability. The percolation at one hour is determined by the coefficient k

$$k = \frac{l \times v}{H \times S} (3)$$

$l = Height\ of\ the\ earth\ column$

$v = Volume\ in\ ml\ of\ water\ collected\ in\ hour$

$H = Height\ of\ load\ in\ cm$

$S = Innet - tube\ section\ in\ cm2$

(e) pH and Electric Conductivity (EC)

The soil pH is recorded from the using of a field pH-meter with a relatively satisfactory accuracy. Electrical conductivity is measured using an electric conductometer.

(f) Soil organic matter contents

0.5 to 1g of each sample will be placed in different beakers. A mixture of 15 ml of Sulphuric acid and 10 ml of potassium dichromate is added to 1000 ml with distilled water. 50ml of the last solution will be introduced into each beaker containing soil samples. Then, we drain with Mohr salt at 0.2 N which will allow us to do the titration. The percentage of carbon is calculated by:

$$\%C = \frac{control - the\ reading\ of\ titration}{50} (4)$$

The amount of soil organic matter is estimated by measuring organic carbon.
organic matter= C * 2 in Forest soils.
Organic matter = C * 1.72 in cultivated soils.
We used the latter (1.72) because our plots are located on agricultural land.

(g) Azote total.

The Kjeldahl method was used for the determination of total nitrogen. It has three phases: mineralization, distillation and titration.

(h) Determination of total limestone

This test concerned only the samples of Madjouj, it is made with the help of the Bernard calcimeter

$$\%CaCO_3 = \frac{p \times V}{p \times v} (5)$$

3. RESULTS AND DISCUSSION

2.3. RESULTS

2.3.1. State of surfaces

The results of surface physical state are represented in table 3 and figure 2 below. The test indicates that cracks represent 53%, gravel (or pebbles) content is about 8% of the surface. Plant debris cover up to 72% of the surface. Components onto surface layer may reduce the flow energy of rainwater and thus promote its infiltration inside of the subsoils. Water retention also promotes the vertical migration of finer particles (clay and silt) as well as elemental constituents depending on soil texture and porosity.

Tableau 3: Surface States in the Sidi Ahmed Cherif plot

Surface components	**Percentages**
cracks	53.33٪
pebbles	8.33٪
plant debris	72.22٪
average	46.82٪
total	138.82٪

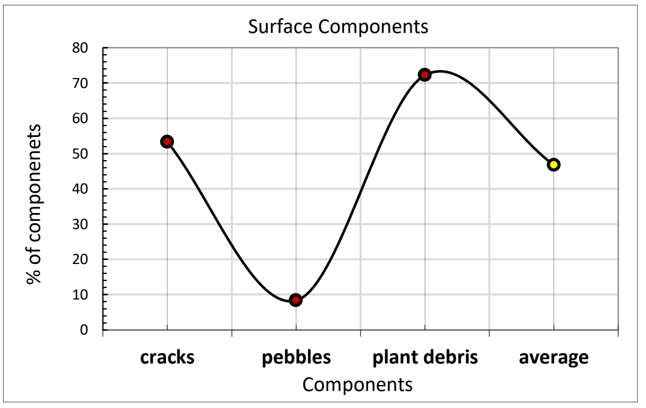

Figure. 2. Surface components showing that about 53 % of the surface is cracked, low (8%) of pebbles are contained and 72% consists of plant debris

3.1.2. Water infiltration

Test results demonstrate that infiltration is a function of time and soil physical conditions (Table 4). There are strong linear correlations between time of infiltration and amount of water in both experiments. The Pearson coefficients (R^2) are 0.99 for wet soil and 0.95 for dry soil respectively (Fig. 3). The comparative analysis conducted shows that at the beginning of the experiment water penetrates the dry soil more quickly than wet soil (Fig. 3). After a few minutes, the trend is reversed with more infiltration for wet soil than for dry soil. This result is quite unexpected. Normally the dry infiltration is highest. However, unexpectedly the curve shows that, dry infiltration is lower. We assume that other physico-chemical factors such as surface components (plant debris, pebbles etc.), particle size could contribute to the process of water infiltration either by accelerating or slowing down the rate.

Table 4. Variation in water infiltration between dry soil, wet soil and weather

Test infiltration dry soil		**Test of infiltration moist soil**	
Accumulated time (min)	*accumulated distance(cm)*	*Accumulated time (min)*	*Cumulated distance (cm)*
0	1	0	1
1	1,5	1	1,8
2	2	2	2,1
3	2,1	3	2,8
4	2,3	4	3,2
5	2,5	5	3,8
6	2,9	6	4,4
7	3	7	5,2
8	NA	8	5,8

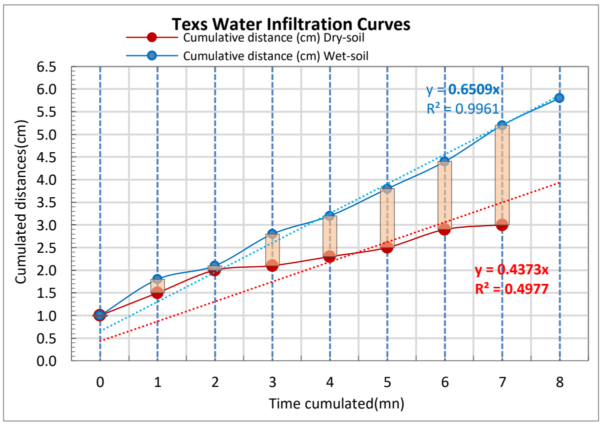

Figure 3: Evolution of water infiltration in wet and dry soils as a function of time. We note

that infiltration is more important and faster in the case of moist soils than for dry soil.

3.13. Structural stability

The results of studies show that the fallow at Sidi-Ahmed-Chérif (Table 5, Fig. 4) is more stable than the ploughed plot. The bare soil plot has a low level of stable micro aggregates, this may be due to the erosion in the layer which is selective and insidious. The fallow plot and the treatment (E_4) show a balance of micro and macro aggregates. As for the ploughed site and the regional control a clear imbalance is detected. It can be assumed that the lack of soil cover is a condition for the deterioration of its structural stability, which is accentuated by the land use processes (tilled).

Table 5: Structural stability.

Samples	Structural stability	
	Ma (g.kg^{-1}) Standard values	Ma (g.kg^{-1}) calculated
E_1	611,77	227,87
E_2	511	389,25
E_3	572,75	323,62
E_4	470,62	442,75
P. fallow	483,25	411,75
P. ploughed	565,5	340,75

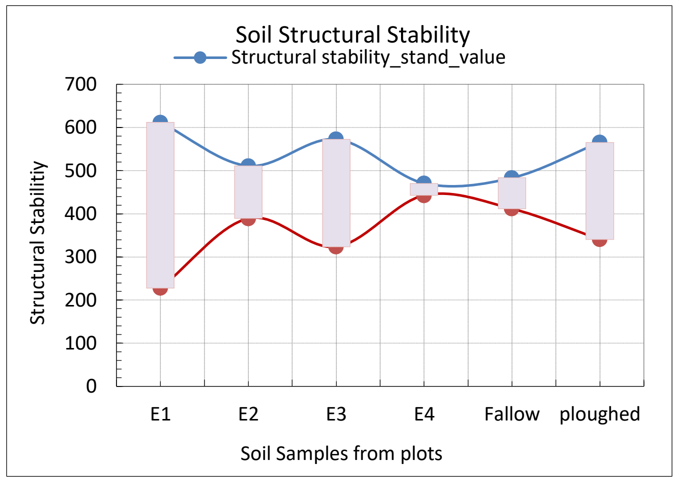

Figure 4: Structural stability of soils from different plots. The figure 4 showing. (E1) Bare soil Madjouj; (E2) Regional control plot; (E3) Madjouj Treatment plot; (E4) Madjouj freeze treatment plot; Fallow plot Sidi Ahmed Chérif and the Sidi Ahmed Chérif ploughed plot.

3.1.4. Granulometry analysis

The particle size analysis of soil samples (0-10 cm) from different plots indicates a predominance of silt (C. Si and f.SI) and clay (Clay) fraction (Table 6. and Fig. 5). The loamy-clayey soils are characterized by a difference in susceptibility to physical degradation according to their content and treatments they have undergone. Thus, the susceptibility of soils to physical degradation SDF is average for experimental plots (Fig. 6b). According to the texture diagram a balanced texture should be for clay soils (0-30); silt (20-50); and for sandy soils (20-60).

Tableau 6: Results of particle size analysis

Samples	Deep	Coarse Silt⁄.	Fine Silt⁄.	Clay⁄.	Fine Sand⁄.	Coarse Sand⁄.	SPD⁄.
E_1	0-10 cm	15,75	33	29,25	16,45	5,25	0,92
E_2		18,75	30	27,45	19,5	2,9	0,65
E_3		12,75	34	28,5	17,65	6,9	0,6
E_4		22	24	29,84	16,9	3,3	0,85
E_5		23,5	41,75	19,8	12,9	1,85	0,82

NB: E_1: Bare plot; E_2: Regional control plot; E_3 Treatment plot; E_4; Treatment plot; E_5: Sediment
SPD: Susceptibility to Physical Degradation

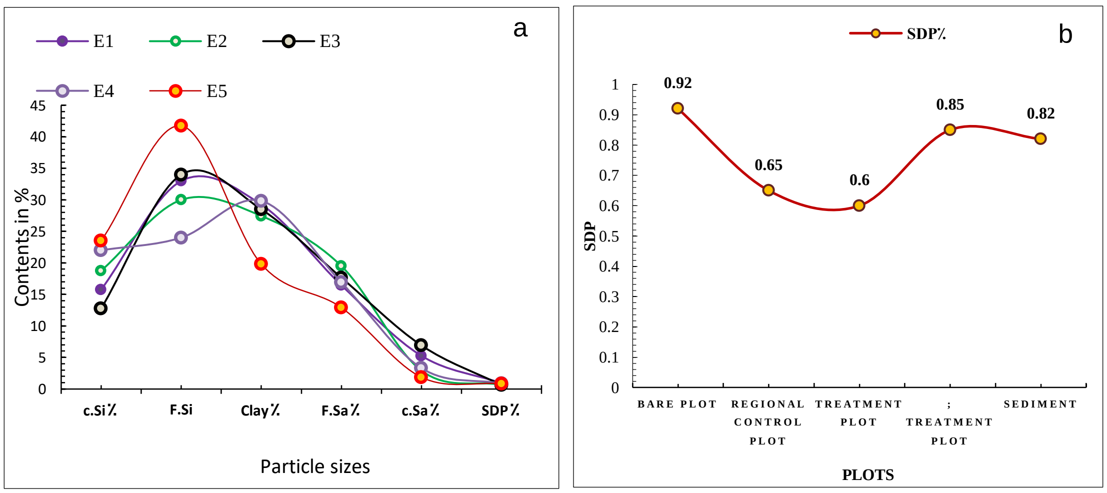

Figure 5: Granulometric analisis of soil samples. (a) Show the variability of uppersoil surface (0-10 cm) grain size indication a predominance of silt and clay fraction (Loami-clay). (b) represents the variation of surface susceptibility of physical degradation (SPD). The figure b show show a relative low susceptibility of physical degradation comapred to bare (0.92) and sediment surface (0.82)

3.1.5. Bulk Density (BD) and Air capacity (AC)

Results of analysis of soil air capacity (SAC) and bulk density are presented in the table 7. BD is a measure of the weight of soil per unit volume, which includes the volume of soil particles and the pores between them (Archer, 1972). SAC is therefore related to bulk density and at some point, continuous compaction of the soil will decrease water content and cause air capacity to approach zero. SAC of soil is a good indicator of its ability to store root-zone air. In ideal conditions for fine-textured soil; the average of SAC should be about 12 % in order to maintain good atmospheric concentrations of O_2 and CO_2 in. Lower critical limit where fine-textured soil becomes susceptible to periodic anaerobiosis is AC = 9% (Reynolds et al., 2015). The average determined from this study is about 12.37% indicating good condition for soils.

Table 7. Table Bulk density (BD) and Soil Air Capacity. Data from litterature have been used to determined the tested samples colleted in the study area.

Literature		***Calculated***	
BD, bulk density	*%AC, air capacity*	*BD, bulk density*	*%AC, air capacity*
1.1	20	*1.25*	*14.50*
1.2	15	*1.35*	*11.83*
1.5	6	*1.4*	*10.50*
1.8	1	*1.33*	*12.37*

3.1.6 Soil sample permeability

3.1.7

In this study, two samples are analyzed in the laboratory (Table 8). The result is indicated in the table 6. It can be observed that, bare soil and the regional witness have a rapid infiltration.

Table 8: Value of percolation (k) in the Madjouj parcel.

SAMPLES	1 HOUR	2EME HOUR	3EME HOUR	AVERAGE
E_1(20G)	129ml	92ml	112ml	
PERCOLATION K.	18,39	13,12	15,97	15,82
E_2(20G)	92ml	68ml		
PERCOLATION K.	17,80	13,16		15,48

3.1.7. Physicochemical analytical results

Results of pH, electrical conductivity (EC), the contents of carbon (c), limestone (calcite), organic matters (OM) and nitrogen (N) are shown in Table 9 below.

Table 9. Analytical data of soil surface layer (0-10cm) physicochemical properties measured in the laboratory

Samples	**pH**	**EC ($uScm^{-1}$)**	**Moisture (⁒)**	**% Carbon**	**Calcite-carbonates (%)**	**% OM**	**Total Nitrogen (%)**	**Structural stability Ma ($g.kg^{-1}$)**
E_1: Bare soil	7.5	1.3	3.09	0.02	3.60	0.03	0.46	227.87
E_2: Regional control plot	7.4	0.7	2.04	0.04	1.10	0.06	0.23	389.25
E_3: Treatment plot	7.8	0.7	3.09	0.04	1.00	0.08	0.22	323.62
E_4: Treatment plot	7.6	0.7	1.18	0.02	3.78	0.04	0.27	442.75
$E_{5: S}$ediment	7.6	NA	2.66	0.05	2.60	0.08	0.00	350
Sediment Sidi Ahmed Cherif	7.4	0.8	0.5	0.02	1.80	0.04	0.05	400
Fallow Sidi Ahmed Cherif.	7.	0.9	1	0.04	1.10	0.06	0.07	411.75

	6							
Ploughed Sidi Ahmed Cherif.	7.6	0.8	0.8	0.02	2.20	0.03	0.04	340.75

The results indicate that the pH of the soils analyzed is borderline or slightly basic and varies in between 7.4 and 7.8. The EC recorded are very low for all soil samples. The very low EC values indicate that these soils have low salinity. The humidity measured at the various sites of Madjouj and Sidi Ahmed Cherif shows that soil samples are relatively dry and are characteristic of semi-arid areas. Analysis of the variation between the physical properties pH, EC and moisture shows that there is no relationship between these soil physical parameters (Fig. 6a). Carbon (C) and organic matter are poorly contained in soil samples of the semi-arid zones. The variations in the curves of C and OM show that there is a high dependence between both parameters. The C versus OM plot allow to obtain strong positive correlation between soil carbon and organic matter (OM) content with a Pearson correlation coefficient R^2 of about 0.99 (Fig. 6c). We can therefore say that C contain of soils comes from organic matter and more precisely from plant origin since soils contain 72% plant residues (Fig 2). Finally, to identify the soil parameters that control structural stability, we study the behaviors of the different curves of constituents (moisture, carbon, organic matter, limestone and total nitrogen) with respect to structural stability. The result is illustrated in Figure 6b. It can be observed that organic matter and total nitrogen are two dependent and determining parameters of structural stability for the Sidi Ahmed Cherif sites. However, on the sites of Madjouj they are high significant variations between the total nitrogen- and organic matter contents. This difference is much greater for bare soil than for soils from treated sites. It emerges from this observation that agricultural and soil management practices that consisting of ploughing and the fertilizer application have contributed to influencing their structural stability. Thus, the contribution of all the soil constituents (moisture, carbon, organic matter, limestone and total nitrogen) to the determinization of its structural stability must be considered. This is confirmed here from the scatter plot of the sum of all parameters (cited here) versus the structural stability and has allowed to define a significantly high correlation coefficient with a Pearson correlation coefficient R^2 of about 0.87 (Fig. 6d).

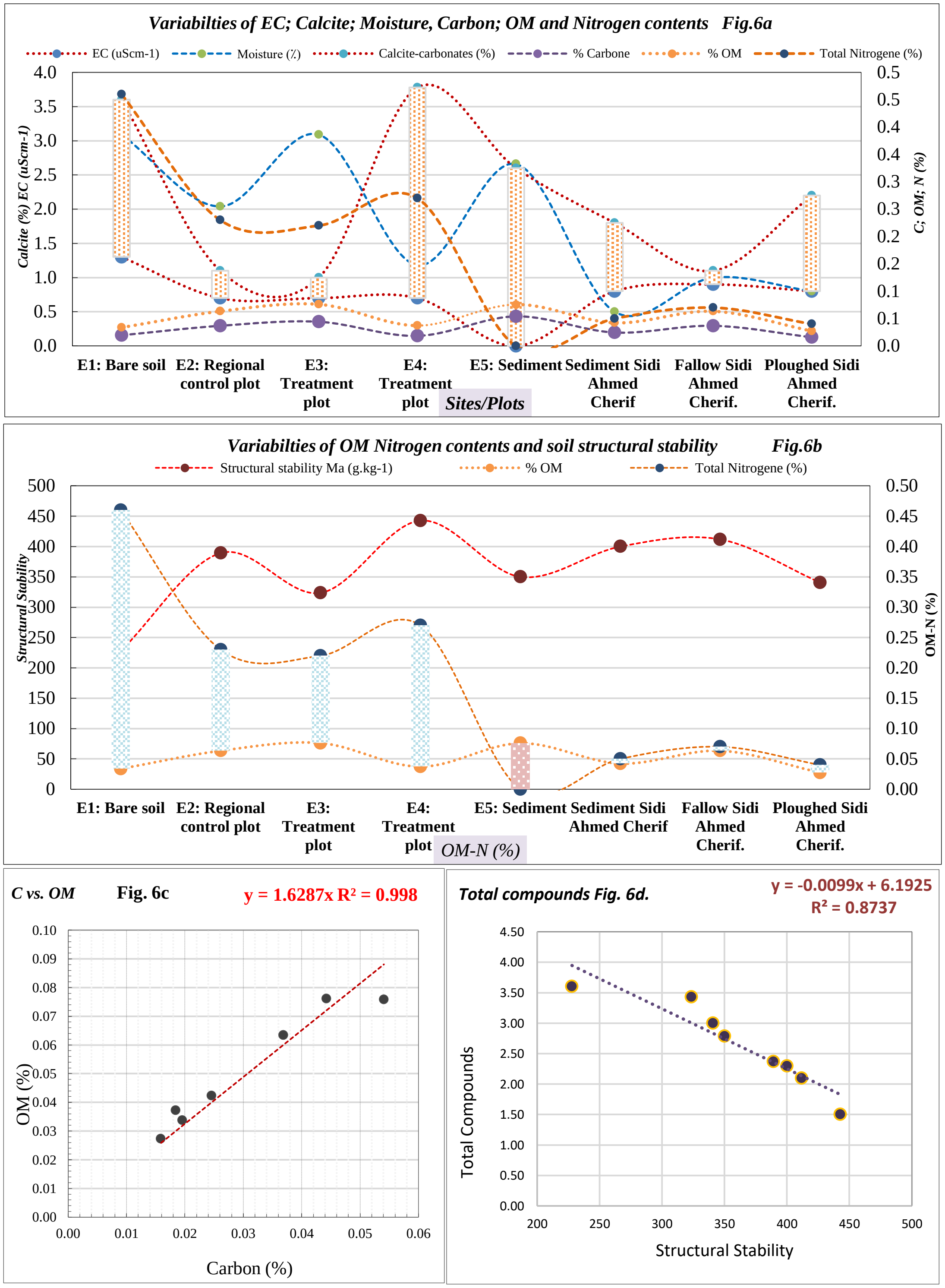

Figure 6. Variabilities of topsoils (0-10cm) samples properties and their relationships. (6a) variabilities of EC; Calcite; Moisture, Carbon; OM and Nitrogen contents. The figure 6a highlights deviations in OM and Nitrogen content according to land use type. It also

indicates high dependency between OM and carbon. Ahigh significant correlation is determined and shown by the figure 6c. (6b) shows the variabilities between OM, Nitrogen contents and soil structural stability. It indicated that in OM is in good relationship with soil structural stabilities in case of Sidi Ahmed Cherif plots which not always the case of the plots of Madjouj. This indicates a contribution of N and other soil parameters. This is confirmed the figure 6d showing high correlation between soil stability and the total of moisture, carbon, calcite, OM and total nitrogen.

3.2. DISCUSSIONS

Land cover condition, land productivity, soil condition, biological diversity are the main parts of land degradation's evaluation. In arid and semi-arid regions, land cover is either absent or very sparce leaving soil to metrological events such as insolation, winds and rainfalls. Furthermore, soil degradation can only be assessed in a specific temporal and spatial context using several indicators (Tully et al., 2015; Kihara et al., 2023). However, the extent and rate of land degradation in sub-Saharan Africa is still under discussion as there are no reliable data, only rough estimates (Tully et al., 2015). To date many countries located in arid and semi-arid zones of Africa are challenged by land degradation, low soil productivity and high rainfall variability that are often associated with climate change (KaranjaNg'ang'a et al., 2016; Woldearegay et al., 2018). Land degradation is a major cause for poverty in rural areas of developing countries (Mesfin, 2018). Mitigation of land degradation impacts depends on understanding the natural cause of degradation (Mohamed, 2019). The lack of sufficient knowledges of soils in sub-Saharan Africa, especially semi-arid and arid zones, is much more contrasting. This lack of detailed knowledge of soils is a major handicap for models predicting wind and water erosion in time and space. Soil degradation affects its physico-chemical, and biological properties and is caused by an unsustainable land use practice (van Ittersum et al., 2016; Bado and Bationo, 2018; Kihara et al., 2023). Climate change characterized by the increase in global temperature, the strengthening of rain showers and winds, accelerates natural processes of soil erosion. The magnitudes and extent of increased rates of soil erosion and runoff that could occur under future precipitation regimes are large. Analyses have shown that changes in precipitation are already happening with a clear trend toward more extreme events. We will be going around this discussion to try to understand what are the risks of climate change and anthropogenic activities on soils and groundwater. The present study shows that runoff and infiltration are strongly correlated with rain quantities at the beginning of the rainy season (Fig. 3). This result is also reported by many authors. (e.g. Medjdoob, 1990; Bouziane, 1992; Karambiri et al., 2003, Ferré, and Warrick, 2005) which demonstrated that there is a relationship between the physico-chemical properties and soil erodibility. The soil erodibility can be influenced by its physical properties such the content of gravel that may play a significant role in controlling the runoff energy and the water infiltration rate. Gravel content is estimated at 8% (Fig. 2). This fraction of gravel is relatively low; therefore, soils are more susceptible to water erosion that consists to the fine particles transport, and infiltration as shown by the Figure 3. According to Bouziane (1992), pebbles covering surfaces can increase the coefficient of erosiveness. Mandal et al., 2005; Urbanek and Shakesby, 2009; Ban et al., 2023, have demonstrated that gravels onto the surface of the soil enhance infiltration and protect the soil against erosion. In addition, an experimental study led by Liu et al. (2023), has shown that the flow depth increases linearly with the rate of gravels coating. The author Liu et al. (2023) observed a reduction percentage of flow velocity ranged from 13.62 % to 72.4 % on gravel-covered slopes. It is shown that the exclusion of gravel in crop fields is a serious threat to soils, because they promote and facilitate the transport of arable land and reduce any capacity for rainwater infiltration. This practice is very harmful to the environment, which could promote large-scale flooding and soil degradation processes. The rate of plant debris in the study sites are estimated at about 72% (Fig. 2) and can contribute to reduce the energy of water flows and also promote infiltration and to mitigate soil fine material transfers. The contents of plant debris indicate the presence of organic matter. In the same vein, Rasoulzadeh et al. (2018) suggests that, the presence of plant residues in soil is the best residue management practice to reduce soil flow volume and control soil erosion in semi-arid regions. Other authors claiming that overall, vegetation affects runoff and soil erosion via intercepting rainfall, eliminating rainfall kinetic energy, preventing soil surface from raindrop splash, increasing land surface roughness and infiltration capacity, and decreasing runoff erosive power, soil erodibility, detachment capacity, and sediment transport capacity directly and indirectly (Sun et al., 2013; Wang et al., 2014; Zhu, 2020a; Zhu, 2020b; Zhu, 2020c). When the vegetation cover is lacking, this mulch forms pebbles that divert infiltrations in a very significant way. The high proportion of cracks (53%) is linked to the soil grain size distribution (Fig. 5) and its mineralogical composition. The texture analyze indicated that all soils are loamy-clayey with a predominance of silt and clay fractions. This is evident for clay-loam or clay soils in arid and semi-arid zones, where alternation of humidification and desiccation can effectively decompose the particles by weakening their bonds (Gens,2010; Burton et al.,2016). Desiccation cracking is a common phenomenon in clayey soils due high-water loss under drought climate (Vardon, 2015; Zeng, 2020). Once the tensile stress increases with decreasing water content and exceeds the tensile strength of soil, desiccation cracking may develop (e.g. Tang et al., 2011; Cheng et al., 2011). Soil texture and mineralogical composition with specific swelling clay species, water infiltration can influence permeability by altering the arrangement of soil particles architecture. Many studies have shown that desiccation cracking depends upon a large number of factors: mineral composition, fine content, temperature, boundary conditions, relative humidity, drying-wetting cycles, sample size, etc. (Morris et al., 1992; Pérez-Rodríguez et al., 2007; Tang et al., 2011; DeCarlo and Shokri, 2014; Tollenaar et al., 2017; Levatti, 2023). For water infiltration into cracked soils, it is expected that these cracks will promote water infiltration into surface or deeper groundwater. This investigation (Fig. 3) shows high rate of water infiltration from moist soil compared to the dried soil surface. This result was unexpected and can only be explained by the fact that finer surface particles, infiltrating the subsoil, temporarily accumulate and block the pores between larger dry particles. This allegation was reported by Abou (2024) which suggested that, in well graded soils, infiltration can help create better particle interlocking thus, reducing its permeability. This observation deserves further study. It may be of great importance as this phenomenon could be a good explanation for the floods frequently observed in arid and semi-arid regions of the world, such as the Sahara and the Sahel in Africa and, in any other places where prolonged drought periods may occur. The African continent has been warming at a slightly faster rate than the global average, at about +0.3 °C per decade between 1991 and 2023 (WMO, 2024). Global warming could lead to an extension of the already very weakened soil cracking zones, increasing the ease and risk of surface-polluted water infiltrating into groundwater. Groundwater could be dramatically contaminated with pollutants from waste accumulated on the earth's surface by human activities. This is facilitated by the enormous production of waste and its poor management following an unprecedented population growth and socio-economic activities (UNEP 2024). World regions most exposed to these risks are economically underdeveloped countries, most of which are in sub-Saharan Africa (UNEP 2024). In addition, excessive water infiltration can lead to erosion, where water flow removes soil particles from one location and deposits them elsewhere. This process, can weaken slopes and undermine structures (Abou, 2024). It represents a negative impact for the development of agriculture and the environment health. The granulometry analysis (Fig. 5a) are also in agreement with the measurements of the bulk density (BD) and the soil air capacity (AC) for the site of Madjouj determined here as indicated in table 7. The average value of 12.33% is characteristic of the predominance of fine particle sizes (silt and clay). High bulk density may affect available water capacity, movement of air and water through soil and thereby root growth. The average of AC obtained demonstrates that soils are well aerated and favorable to infiltration by the water follows (Schindler,1980; Rosolem et al., 2002; Reszkowska et al., 2011; Reynolds et al., 2015). BD is an indicator of soil health and compaction that can affects infiltration, water availability, soil porosity, plant rooting depth / restrictions (USDA, 1987), nutrient availability and microbial activity which influence significant processes productivity of soil (Nyéki et al., 2017). BD also depends on organic matter contents, mineral density and the soil texture (Brady, 1990; Sheba et al.,2019). Soil composition is high significant integrative measure of soil degradation. Result (Table 9) of pH, EC, soil moisture (physicals), organic matter (OM), soil organic carbon (c), calcite, and total nitrogen are important key indicators of soil degradation. In order to investigated the parameters that influence soil degradation, we analyzed the variabilities of all properties and compared with the physical stabilities. First, there is no clear direct effects between pH, EC, moisture and soil physical stability. In this study all soil samples have a pH (Table 9) values ranged in between 7.4 and 7.8. Ideally, soil pH is close to neutral and indicating that most nutrients are available (optimally in 6.5 to 7.5 pH), which is generally compatible for plant root growth (Yan et al., 2006; Jensen, 2013). Therefore, soils of this study area appear in good state. Sample analyzed indicates that carbon and OM are low contained (Table 9). The study also demonstrated that soil carbon contents and the organic matter are highly correlated (Fig 6c). In the arid and semi-arid areas soil carbon contents are in general very weak contained. The low carbon content derives from the very sparce and weak vegetations (OM) that occur during a short period of rainy seasons. In the semi-arid areas, natural resources are being continuously degraded due to the misuse and inadequate use of agricultural techniques. According to the above table, organic matter can be increased by 4% on a treatment plot. Regarding Sidi Ahmed Cherif, the organic matter content of the sediments is lower than the fallow plot, which may be illogical. Generally, in semi-arid soil organic carbon content is below 1.8 and now decreases yearly to 2.8 to 13.0 t. C. ha^{-1} (FAO and ITPS, 2015; Namirembe et al., 2020; Bolo et al., 2023). Indeed, organic matter is a fundamental component of the soil, which partly controls the physical, chemical and biological properties affecting its production capacity. According to (Armstrong and Tanton,1992; Baldock et al., 1994; Chenu et al., 2000; Wuddivira and Camps-Roach, 2007), the cationic bridging effect of the calcium ion (Ca^{2+}) and the flocculating ability of clay and organic matter are crucial in the formation and stability of soil aggregates. In this study, organic matter (OM) appears more related with the soil physical stability and affects both the chemical and physical properties of the soil and its overall health. The properties of soils influenced by the presence of organic matter are: soil structure; moisture retention capacity; diversity and activity of soil organisms. These properties can be both beneficial and detrimental to crop production; and nutrient availability (e.g., Carter, 2002; USDA-NRCS, 2014). We found that the sum of soil chemical properties (moisture, soil carbon, OM, calcite and total nitrogen) is highly correlated to the soil physical structural stability (Fig 6d). Nitrogen is important to all life. Nitrogen in the atmosphere or in the soil can go through many complex chemical and biological changes, be combined into living and non-living material, and return back to the soil or air in a continuing cycle (Lai et al., 2022). In term of climate change, and climate warming, maintaining OM and nitrogen in soil will contribute to its physical stability and to avoid the erosion by water and wind processes.

4. CONCLUSION

An assessment of water erosion processes is more than necessary for low-resource countries located in the arid and semi-arid regions of Africa in order to prevent the risk of contamination of aquifer water useful for consumption and irrigations. The study indicates that topsoil samples (0-10cm) have a good apparent density, quite good surface conditions, and therefore resistant to rainfall splash. However, they are very sensitive to erosion by runoff in just 10 minutes of rain and sometimes 4 minutes when several showers follow each other. Both stations have a low RUSLE erosion index and do not exceed the tolerance. Soils have good porosity and air capacity due to the texture. These physical characteristics allow a good infiltration of rainwater, facilitated by the significant presence of cracks (53%). The study also highlighted the importance of physico-chemical properties for maintaining soil structural stability. Our study showed that soil moisture, carbon, calcite, organic matter and total nitrogen contribute to the maintenance of soil stability. Organic matter is the important factor determining for the soil structural stability. This study is especially revealing of the risks of deep erosion that could bring global warming. Indeed, the soils in arid and semi-arid regions could be affected by climate leading to an increasing of sol cracks, decreasing of organic matter, nitrogen content and other important physico-chemical properties. Consequently, it could induce a drastic loss of soil structural stability. This vulnerability of the soils also may result in loss of fertility, increase in the process of infiltration by surface waters that will facilitate of groundwater tables contamination very useful for consumption and irrigation. A key factor in climate change resilience will be the maintenance of sufficient amount of organic matter in soils to ensure their structural stability. Even more in-depth studies with broader data are needed to better understand the processes of rainwater infiltration, and their consequences on flood phenomena and groundwater contamination risks.

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COMPETING INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

AUTHORS' CONTRIBUTIONS

Mounkaila Mohamed and Zeinabou Mahamadou: Writing the original draft the methodology, formal analysis conceptualization and resources. Abass Saley Abdoulatif: Formal analysis, data curation and reviewing**.** Rabilou Souley Moussa: reviewing. INOUSSA Maman Maarouhi: Supervision.

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