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## RESEARCH ARTICLE

# SILTING OF THE KORAMA VALLEY BASINS, SOUTH-EASTERN OF NIGER; QUANTIFICATION OF CONTRIBUTIONS FROMGULLYEROSION AND ALLUVIAL CONES

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## ABSTRACT

Water erosion is a serious threat in the Hamdara watershed. It mainly manifests itself in the form of gully erosion, which directly results in the silting up of low-lying areas and basins. The objective of this study is to characterise the spatio-temporal dynamics of gully erosion at the scale of the Hamdara watershed and to quantify the sediment flow deposited at the alluvial cone. The methodological approach adopted is based on remote sensing and topography, in particular the use of DGPS for intra-annual monitoring of two representative gullies (R1 and R2). The gully network has grown from 91 gullys totalling 77.72 km in 2005 to 213 gullys representing 127.33 km in 2024, an average increase of 2.61 km/year. Drainage density increased from 0.51 km/km² in 2005 to 0.83 km/km² in 2024, representing an increase of 42.33%. The total volume of eroded soil from R1 and R2 is estimated at 742,176 m³. R2 gully, which is more active, accounts for 596.93 m³ alone. Finally, the extension of the R2 gully cone reached 1,212 m² (17% of the initial area). This dynamic is now significant and needs to be taken into account in the fight against the silting up of basins.

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# INTRODUCTION

Water erosion is one of the major cause of soil degradation in the world (FAO & ITPS, 2015; P. Panagos *et al*, 2015; R. Lal, 2015, P. Borrelli *et al*, 2021, W. Harun, 2024). In Africa, this form of erosion has degraded more than 65% of productive land in the last few decades (FAO, 2022) and affected 65% of the population (UNDP, 2022). The Sahel is one of the areas most affected by this issue (P. Borrelli *et al*, 2017). In Niger, climate variability and anthropogenic activities such as deforestation, accelerated land cultivation and inappropriate agricultural practices have a considerable impact on natural resources (F. Anthelme *et al*, 2006; A. Abdourhamane Touré, 2011; A. D.Tidjani *et al*. 2009; S. Issa Malam Salmanou *et al*, 2018; S. Noma Adamou *et al*, 2022). This leads to an acceleration of hydro-erosive phenomena through the proliferation of gully networks (A. Moussa Issaka *et al*, 2018; I. Mamadou *et al*, 2020; I. Ide *et al*, 2025). In the sandy area of south-eastern Niger, erosion (wind and water), exacerbated by environmental change, significantly compromises the sustainability and functions of ecosystems (O. Laminou Manzo *et al*, 2009; M. Karimou Barké, 2017; K. J-M. Ambouta *et al*, 2018). This phenomena significantly hampers the agro-sylvo-pastoral production functions provided by basins and lowlands, leading to food insecurity that often results in migration (Ambouta *et al*, 2018; M. M. Assane *et al*, 2021; M. M. Assane *et al*, 2024). Indeed, this resettlement of sand is one of the main causes of the partial and sometimes total degradation of fertile land (M. Karimou Barke *et al*, 2017; A. Moussa Issaka *et al*, 2018). The Hamdara watershed, situated in the eastern part of the Korama Valley, has been marked by significant hydro-erosive dynamics for several decades. These dynamics are mainly due to the return of extreme rainfall events (A. Ozer *et al*, 2009; S. E. Nicholson, 2013), the marked topography of the basin and human activities. In this watershed, gully erosion is the most dominant form of water erosion. It results in the proliferation of a network of gullies on the sides of the sand dunes.

This leads to the gradual silting up of low-lying areas (basins and lowlands) (I. Mamadou *et al*, 2020), the reduction of agricultural and pastoral areas, and the destruction of the arable layers of the land (C. Valentin *et al*, 2005; S. Noma Adamou *et al*, 2022). However, it should be noted that water erosion remains insufficiently documented in the study area, despite its increasingly pronounced manifestations. This study aims to: i) characterise the spatio-temporal dynamics of gully erosion at the watershed scale, ii) quantify the sediment flow deposited in the Illala basin.

# MATERIALS AND METHODS

***Presentation of the Hamdara watershed :*** The Hamdara watershed is located in the south-eastern part of Niger, more precisely in the eastern part of the large Zermou basin, in the Korama valley. It extends geographically between 9°21'47'"E and 9°30'23"'E longitude east and 13°34'59'"N and 13°43'45"'N longitude north (Figure 1). Relatively elongated and oriented northeast-southwest, this basin covers an area of 153 km² and has a perimeter of 71 km (Figure 1). Although it is almost exclusively part of the municipality of Hamdara, this basin administratively overlaps with the municipality of Wacha to the south (Figure 1).

The climate is semi-arid and is characterised by a long dry season lasting 7 to 8 months, followed by a short rainy season lasting 4 to 5 months. From a topographical point of view, altitudes range from 393m (occupied by basins and lowlands) to 646m (occupied by quartzite domes) with an average altitude of 445m (occupied by dune fields). Sixty-six per cent of the catchment area is occupied by elevations below 450 m and 6% by elevations above 550 m.

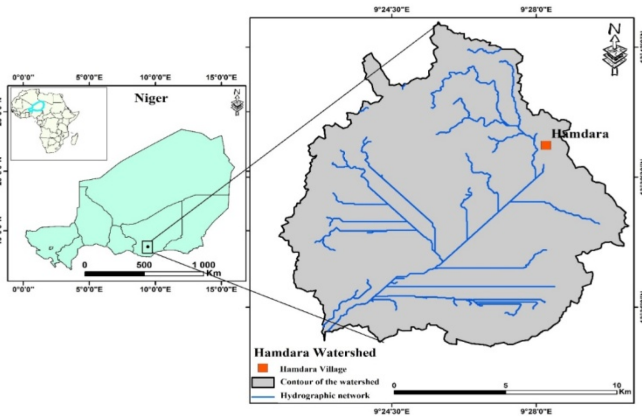


**Figure1.Geographic location of the Hamdara watershed**

The geology of the area is dominated mainly by Quaternary sedimentary formations, which are dune sands interlaced with inter-dune depressions, in this case basins and swamps. The watershed is also marked by metamorphic formations composed mainly of quartzites, which dominate the relief, calcareous gneisses and metamorphic conglomerates (F. Boubacar Abdou, 2023). There are also crystalline formations represented by ancient granites (M. M. Badamassi Kadri, 2021). Most of the dune soils are sub-arid and arid red-brown soils formed on loose sediments and crusts, tropical ferruginous soils that are undeveloped or slightly developed, and hydromorphic soils or young soils with a sandy-clay texture (found in low-lying areas) (M. Gavaud & R. Boulet, 1967). Woody vegetation is mainly represented by Acacia albida, Balanites aegyptiaca, Sclerocaria birrea, Acacia raddiana, Boscia senegalensis, Piliostigma reticulatu, and herbaceous vegetation by Adropogon gayanus, Pergularia tomentosa, Leptadenia pyrothechnica, Eragrostis tremula (S. Ibrahim, 2015).

**Methodology**

Remote sensing and topography were used to achieve the objectives of this study.

***Remote sensing :*** Remote sensing was used to map and analyse the dynamics of gully erosion. Attention was paid to land use dynamics for a complete analysis of the changes observed.

**Image pre-processing and processing:** Satellite images were downloaded from the USGS.gov platform (Table 1). Scenes without clouds or sandstorms corresponding to the months of November and December from 1984 to 2024 were selected (S. Noma Adamou *et al*. 2024).

**Table 1. Characteristics of the Landsat images used**

| Missions | Acquisition dates | Resolution | Number of scenes | Sources |
|---|---|---|---|---|
| LandSat5 | 12-1984 | 30m | 08 | USGS |
| LandSat5 | 12-2000 | 30m | 08 | USGS |
| LandSat8 | 12-2014 | 28,5 | 11 | USGS |
| LandSat9 | 11-2024 | 28,5 | 11 | USGS |

Supervised classification was used to identify the different units. Six (06) lands use units were identified in the Hamdara watershed. These are: Cultivated fields; Woody vegetation; Floodplain; Bare soil; Surface water body and Bedrock.

***Mapping of gully erosion dynamics:*** The SRTM30 digital terrain model (DTM) was used to extract the watershed in a GIS environment using ArcGIS software. The hydrographic networks (gullies) for the years 2005, 2012, 2020 and 2024 were first digitised on Google Earth Pro before being exported to ArcGIS for processing. The numbers and lengths of the gullys were determined for each period of interest (2005, 2012, 2020 and 2024). The drainage density was then calculated using the following equation:

$$Dd = \sum Li / S \qquad (1)$$

Where Dd: Drainage density; Li: Length of watercourse (km); S: drained area (km²). Shreve's order (1966) was used to determine the complexity and connectivity of the gully network.

***Topography***

***Intra-annual monitoring of sample gullies :*** Three (3) types of monitoring were adopted for this study. These were:

- Event-based monitoring of gully head progression. For this operation, markers and natural landmarks were placed upstream of the head of each gully. The monthly and annual progression of gully head retreats was determined by measurement;
- Event-based monitoring (after each significant rainfall event) of the morphometric variation of gullies at different sections through depth and width measurements (base width and bed width) (Figure 2A);
- Topographic monitoring of topographic and sedimentary changes. Real-time RTK mode DGPS (Differential Global Positioning System) was used to achieve this objective. To do this, reference points (markers and benchmarks) were created in static mode with an accuracy of one centimetre (Figure 2C-D). At each gully monitored, three cross-sections were created and marked using the markers as reference points (Fig. 2B). This operation is based on topographic survey campaigns to assess morpho-sedimentary changes (variations in cross-section, longitudinal profile and depth). Thus, the first precision topographic survey was carried out at the beginning of the rainy season (in June 2024) and a second survey was carried out after the season (October 2024).

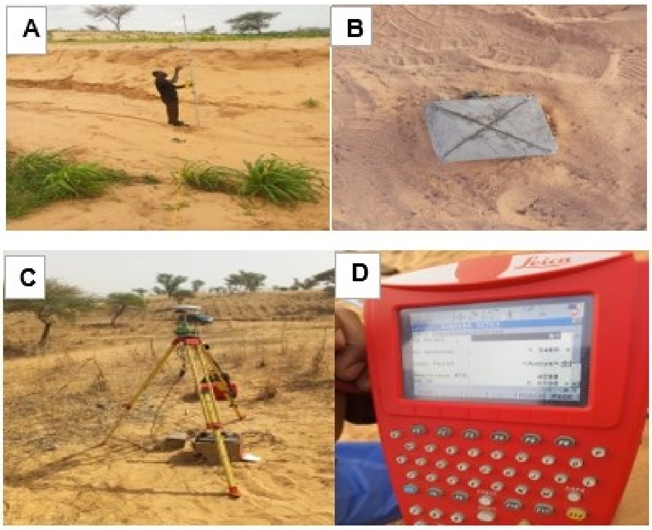


**Figure 2. Measurements of hydro-erosive dynamics. (A) Measurement of the dimensions of a sample gully; (B) Cemented benchmark; (C) and (D) Differential Global Positioning System (DGPS)**

After collecting the survey data, a quality control check was carried out, which consisted of projecting the coordinates obtained Google Earth Pro to verify the accuracy of their overlap with the ravines where they were collected.

***Quantification of water sediment flows***

The quantitative assessment of sediment flows was carried out by estimating the amount of land eroded at the gully scale and monitoring the cones, where the alluvium is deposited, using the cubing method. Two gullies (R1 and R2) were selected.

- ***Estimation of eroded land at R1 and R2***

The total volume of each section is obtained by multiplying the length of each segment by the area of its average cross-section, using the following formulas:

Volume (m³) = ((l- P) *P) *L in m³ (for a trapezoidal shape) (2)

Volume (m3) = ((P*l) /2) * L in m3 (for a V-shape) (3)

Where: V: volume of eroded land in (m3); L: length of the section (m), l: average width of the section (m) and P: average depth of the section in (m)

Thus, thanks to the surveys carried out at the beginning and end of the season, the volume of eroded land is obtained by the difference between the results of the first and second surveys.

- ***Cubic measurement of alluvial cones***

The objective is to determine the volume and surface area changes of sediments transported and deposited at two alluvial cones in ravines R1 and R2. The cone sampling operations carried out at the beginning and end of the season consisted of digging holes using a manual auger at different points equidistant from each other at 5 m intervals, following a grid pattern on the surface of two cones (Figure 3A). The clay layer, characterised by its blackish colour, represents the lower limit of each grid point. At each grid node (point), the UTM (XY) coordinates and thickness were systematically recorded using DGPS and a decameter (Figure 3B). These three-dimensional values were then integrated and processed. SURFER software was used for processing in order to obtain a digital terrain model of the cones (B. Abba, 2012).


**Figure 3. Survey of the depositional cone of the sampled gullies. (A) Hole excavation using a manual auger; (B) Measurement of depth and recording of the coordinates of the excavated hole**

# RESULTS

***Land use dynamics :*** The results obtained from processing satellite images reveal significant spatio-temporal dynamics in the landscape units of the Hamdara watershed (Figures 4 and 5). The area occupied by cultivated fields increased between 1984 and 2014, rising from 62% to 68.18% before declining to 61.56% in 2024. Woody vegetation shows a gradual increase, from 4% in 1984 to 7.01% in 2024. Bare soil occupied 10% of the basin's area in 1984, before falling to 8.37% in 2000, 5.39% in 2014 and then 8.89% in 2024.

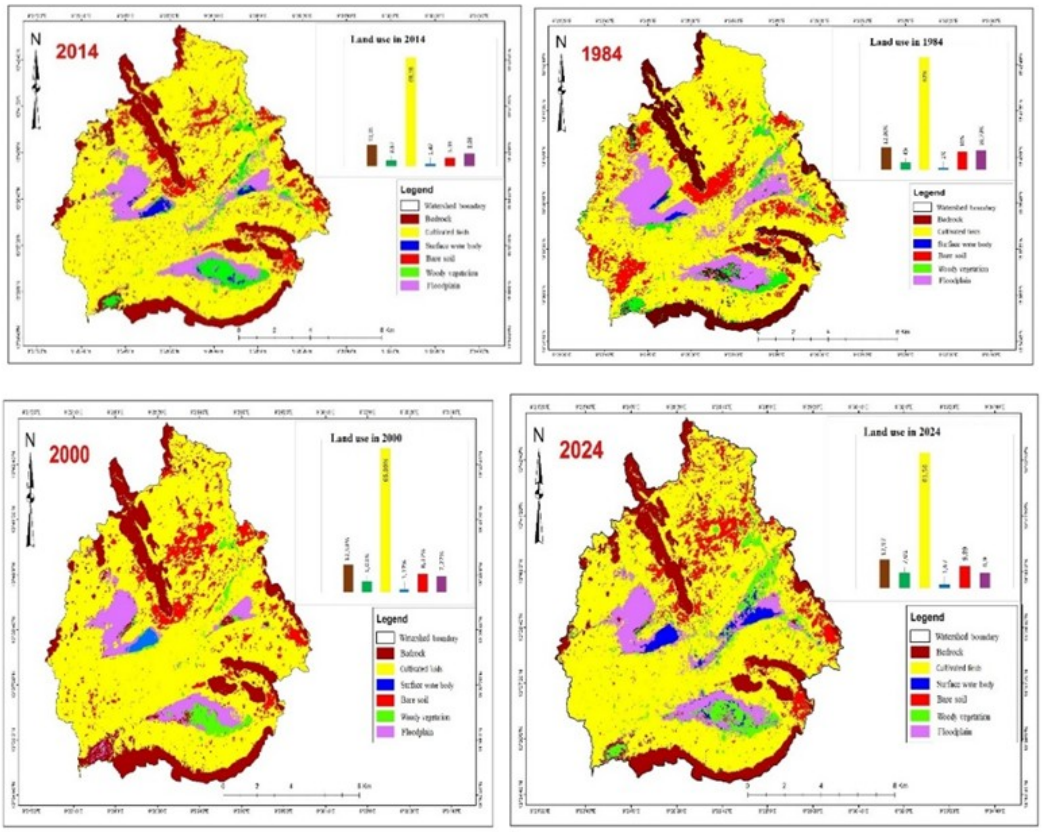


**Figure 4. Land use map of the Hamdara watershed**

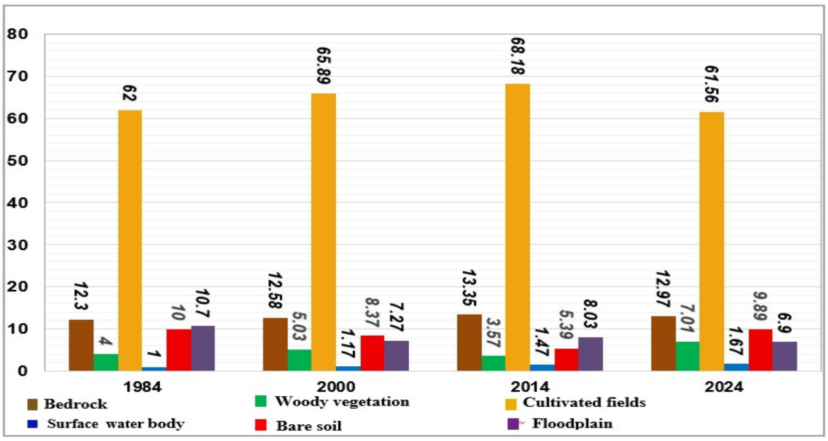


**Figure 5. Evolution of land use/land cover units in the Hamdara watershed**

The area occupied by bedrock has shown an increasing trend, rising from 12.30% in 1984 to 12.97% in 2024, via 12.58% in 2000 and 13.35% in 2014. The area of the floodpain has decreased from 10.7% in 1984 to 6.9% in 2024. In general, in the study area, from 1984 to 2024, the areas covered by surface water body have experienced a gradual change. They increased from 1% in 1984 to 1.17% in 2000, 1.47% in 2014 and then 1.67% in 2024.

***Gully erosion dynamics in the Hamdara catchment area :*** Overlaying maps of the gully network at different periods of interest shows a gradual trend in gully erosion dynamics in the watershed (Figure 6). Three types of changes were observed depending on the sections of the gullies. These were sections that remained stable (77.72 km), sections that disappeared and new sections that appeared. Thus, 77.72 km of gullies remained stable, 5.12 km of gullies disappeared and 54.73 km of gullies appeared (Figure 6). The rate of progression is thus estimated at 0.262 m/ha/year.

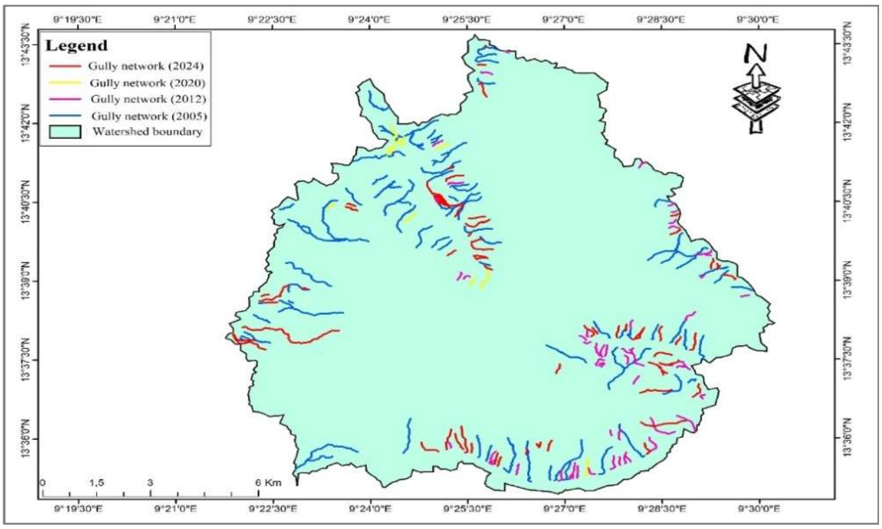


**Figure 6. Evolution of the gully network between 2005 and 2024 in the Hamdara watershed**

The dynamics of gully erosion are also reflected in an increase in the number and total length of gullies, as well as in drainage density (Table 1). The number of gullies rose from 91 in 2005 to 213 in 2024, representing a 134% increase in nineteen (19) years. The total length and drainage density increased from 77.72 km and 0.51 km/km² in 2005 to 127.33 km and 0.83 km/km² in 2024, representing increases of 63.83% and 31.37% respectively. During the period from 2005 to 2024, the Strehler order doubled from 2 in 2005 to 4 in 2024 (Table 2).

**Table 2. Changes in the network parameters of ravines in the Hamdara watershed**

| Years | 2005 | 2012 | 2020 | 2024 |
|---|---|---|---|---|
| Lenght (km) | 77.72 | 98,06 | 92,94 | 127,33 |
| Number | 91 | 149 | 139 | 213 |
| Drainage density (km/Km$^2$) | 0,51 | 0,64 | 0,61 | 0,83 |
| Strehler's order | 2 | 3 | 3 | 4 |

***Intra-annual morphodynamic evolution of ravines***

***Progression of ravine heads during the 2024 season:*** The R1 and R2 ravines monitored showed significant regressive erosion during the 2024 rainy season (Figure 7). August stands out as the period during which the heads of the ravines (R1 and R2) progressed the most, advancing by 10 m and 13.1 m respectively (Figure 7). The annual progression of the head of the ravines (R1 and R2) is thus estimated at 11.6 m and 21.11 m for R1 and R2, respectively.

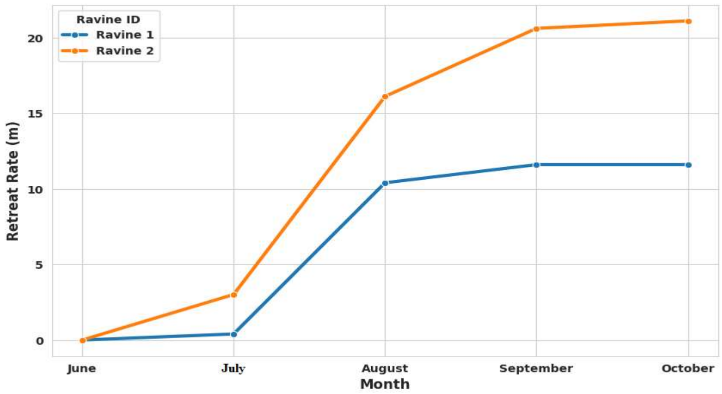


**Figure 7. Monthly progression of monitored gully headcuts during the 2024 rainy season**

***Intra-annual evolution of the morphometry of ravines R1 and R2 :*** During the monitoring period, it was observed that ravine 1 recorded relatively low hydro-erosive dynamics in terms of the depths of the different sections (Table 2).

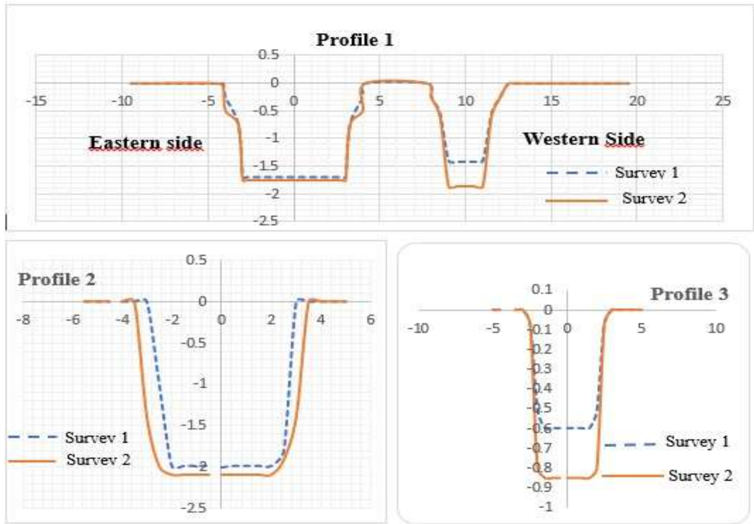


**Figure 8. Morphometric variation of sample ravine R2**

At profile 1 (R2), a widening of 0.4 m was observed on the eastern side of the upper mouth, 0.9 m at the lower mouth and a deepening of 0.05 m (Figure 8, Table 2). The western side was marked by a 0.2 m widening of the upper mouth, a 1.2 m widening of the lower mouth, and a 0.44 m deepening (Figure 8, Table 2). The measurement results reveal that profiles 2 and 3 have widened by 1.44 m and 0 m respectively at the upper mouth and by 2.48 m and 0.5 m at the lower mouth, with an increase in depth of 0.12 m and 0.30 m (Figure 8, Table 2).

**Table 3. Intra-annual morphometric evolution of monitored gullies R1 and R2**

| Month Ravine (R) | | June | | July | | August | | Evolution | |
|---|---|---|---|---|---|---|---|---|---|
| R1-P1 | Top width | 3,90 | | 3,90 | | 3,90 | | 0 | |
| | Bottom width | 2,40 | | 2,65 | | 2,67 | | 0,27 | |
| | Depth | 0,66 | | 0,84 | | 0,89 | | 0,23 | |
| R1-P2 | Top width | 4,5 | | 4,5 | | 4,5 | | 0 | |
| | Bottom width | 2,5 | | 2,5 | | 2,5 | | 0 | |
| | Depth | 1,3 | | 1,4 | | 1,4 | | 0,10 | |
| R1-P3 | Top width | 6,25 | | 6,25 | | 6,25 | | 0 | |
| | Bottom width | 4,80 | | 4,80 | | 4,80 | | 0 | |
| | Depth | 1,32 | | 1,32 | | 1,40 | | 0,08 | |
| R2-P1 | Top width | E: 7,9 | W:6,1 | E : 8,3 | W : 6,3 | E : 8,3 | W : 6,3 | E : 0,4 | W:0,2 |
| | Bottom width | E : 5 | W:1,5 | E: 5,9 | W : 2,7 | E : 5,9 | W : 2,7 | E : 0,9 | W : 1,2 |
| | Depth | E :1,7 | W:1,4 | E : 1,7 | W : 1,8 | E : 1,7 | W : 1,8 | E : 0,05 | W : 0,4 |
| R2-P2 | Top width | 9,7 | | 7,76 | | 11,2 | | 1,44 | |
| | Bottom width | 4,4 | | 7,3 | | 7,3 | | 2,48 | |
| | Depth | 1,98 | | 2 | | 2,1 | | 0,12 | |
| R2-P3 | Top width | 6,5 | | 6,5 | | 6,5 | | 0 | |
| | Bottom width | 4,3 | | 4,3 | | 4,8 | | 0,5 | |
| | Depth | 0,6 | | 0,9 | | 0,85 | | 0,3 | |

*R: Ravine, P : Profile, E : East, W : West*

***Quantification of water sediment flows :*** The monitored ravines R1 and R2 showed a loss of land during the period under consideration. The areas of R1 and R2 increased by 92 m² and 328.64 m² respectively, from 4,179.38 m² and 1,380.38 m² in the first survey to 4,268.04 m² and 1,709.02 m² in the second survey (Table 3). The volume of land lost in R1 and R2 increased from 1,615.045 m³ and 3,803.230 m³ at the end of the first survey to 1,760.290 m³ and 4,400.160 m³ following the second survey, representing an increase of 145.246 m³ and 596.930 m³ respectively (Table 4). The alluvial cones of R1 and R2 also experienced significant changes in surface area and volume. The surface area occupied by the R1 ravine cone decreased from 5,872 m² in the first survey to 4,339 m² in the second survey, a decrease of 1,533 m². However, its volume changed slightly from 58,180 m³ to 1937.760 m³ to 1995.940 m³ (Figure 9, Table 3). The surface area of the cone in ravine 2 was 7,076 m² in the first survey, before increasing to 8,288 m² at the end of the season (second survey), representing an increase of 1,212 m² (equivalent to a 17% increase in its initial surface area) (Figure 9, Table 4). In addition, the volume of this cone increased from 3,538 m³ to 4,558.42 m³ between the two measurements, representing an increase of 1,020.4 m³ (equivalent to a 28.84% increase in the initial volume) (Table 4).

**Table 4. Surface area and volumetric evolution of gullies R1 and R2 and their depositional cones**

| | Survey 1 | | Survey 2 | | Evolution | |
|---|---|---|---|---|---|---|
| | Area (m²) | Vol (m³) | Area (m²) | Vol (m³) | Area (m²) | Vol (m³) |
| **Ravine 1** | 4179,38 | 1615,04 | 4272,04 | 1760,29 | +92,66 | +145,25 |
| **Ravine 2** | 1380,38 | 3803,23 | 1709,02 | 4400,16 | +328,64 | +596,96 |
| **Cone 1** | 5872 | 1937,76 | 4339 | 1995,94 | -1533 | +58 ,18 |
| **Cone 2** | 7076 | 3538 | 8288 | 4558,42 | +1212 | +1020,4 |

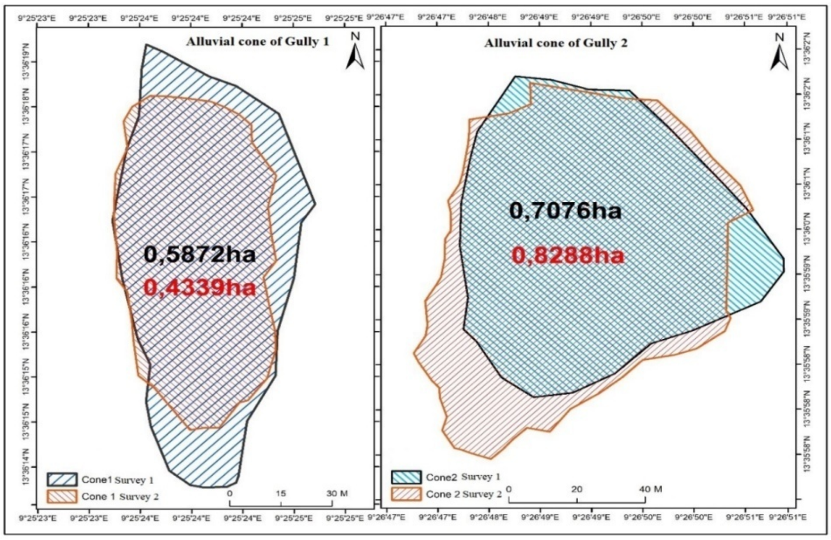


**Figure 9. Surface area evolution of the alluvial cones of the monitored gullies**

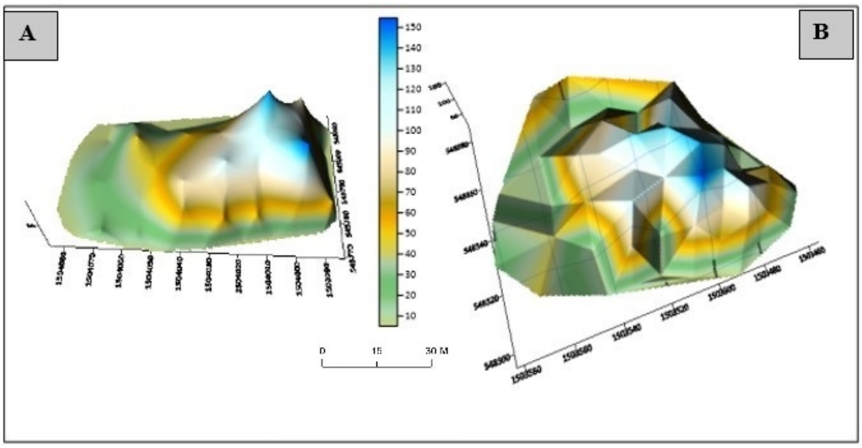


**Figure 10. Three-dimensional (3D) representation of gullies R1 (A) and R2 (B) at the end of the 2024 rainy**

# DISCUSSION

***Spatio-temporal dynamics of gully erosion:*** The study of the gully network mapping during the periods 2005, 2012, 2014 and 2024 highlighted the dynamics of gully erosion in the Hamdara watershed. This network has undergone significant changes in terms of number and total length, contributing to the silting up of basins and lowlands. The number and total length of gullies increased from 91 and 77.92 km in 2005 to 213 and 127.33 km in 2024, representing an increase of 134% in number and 63.83% in length. The increase in both the number and length of gullies could be explained by the physiognomy and reduction of natural vegetation, as well as the area occupied by outcrops and their slope. Land use dynamics show that the proportion of woody vegetation remains relatively low (approximately 4% in 1984, 5% in 2000, 3.57% in 2014, and 7.01% in 2024). Despite a slight increase in this unit in 2024, its proportion remains insufficient overall to provide effective soil protection. This would promote linear erosion and therefore an increase in gullies. A marked expansion of cultivated areas has also been observed. These increased from 62% to 68.18% between 1984 and 2014. Although this unit declined slightly in 2024 (≈ 62%), it remains largely dominant at the watershed level. The area occupied by bedrock remains significant (up to ≈ 13% in 2024) at the watershed level. This unit represents hardened surface (with virtually zero infiltration) and occupies the highest altitude (up to 646 m). This contributes significantly to the rapid generation of concentrated runoff, the deepening of gullies and the transport of materials that eventually settle in low-lying areas such as fields, basins and water bodies. This trend is evident in the dune areas of Niger. In Gayi (a village located about ten kilometres south of the study basin), I. Mamadou *et al*. (2020) reported an increase in gully erosion from 88 km in 2005 to 110 km in 2014, representing a 25% increase. In Diffa (sedimentary zone) in the Nigerien part of the Lake Chad basin, the work of (A. Moussa Issaka *et al*. 2018) also led to similar conclusions, with the gully network in Issari increasing from 910 m to 14,200 m between 1957 and 2015. In western Niger, I. Ide *et al*. (2025) documented an increase in the number and total length of gullies, which grew from 242 and 13.30 km in 1989 to 418 and 26.09 km in 2015, respectively. A similar increase in the total length of gullies was also recorded in Tunisia in a watershed by (H. Rebai *et al*, 2021), where this length increased from 20.6 km in 1952 to 35.6 km in 2009, representing an average annual increase of 262 m.

***Morphometric dynamics of the Hamdara ravines and alluvial cones:*** Diachronic analysis of topographic surveys and in situ measurements reveals surface and volume variations in the two ravines and their cones during 2024. Ravines R1 and R2 were marked by significant regressive erosion, with annual headbacks of 11.6 and 21.11 m respectively. The surface areas of R1 and R2 increased by 92 and 328.64 m² respectively, while the corresponding volumes transported increased by 145.25 and 596.96 m³. The alluvial cones of R1 and R2 also experienced significant surface area and volume variation during the period under consideration. The cone of ravine 1 decreased by 1,533 m², while that of ravine 2 increased by 1,212 m², and the corresponding volumes increased by 58.18 m³ and 1,020.4 m³. The difference in scale observed between R1 and R2 is thought to be linked to the topographical and environmental factors shaping the landscape of the study area. Ravine 2 is located on a relatively steep and long slope and has relatively sparse vegetation cover, as is the case throughout the watershed. In contrast, the site where gully 1 is located is characterised by a relatively gentler slope. The evolution of the surface area and volume of the alluvial cones could be largely due to the pronounced topography marked by steep and long slopes, the return of intense rainfall events and the poorly cohesive sandy soils in the area. These observations confirm those of (B. M. Ibrahim *et al*, 2020) in south-western Niger, where between 2006 and 2008 they measured an average annual progression per gully of 4 m for head recession, 8 m² for surface area and 10 m³ for excavated volume. In addition, (I. Mamadou, 2012) calculated an eroded volume of up to 88153981 m³ in 2009 in the Koris de Boubon area. In the Koris Ouallam watershed (south-western Niger), S. Noma Adamou *et al*. (2022) also concluded that topography can play a decisive role in soil loss processes.

## CONCLUSION

This study characterises the spatio-temporal dynamics of gully erosion and land use units at the scale of the Hamdara watershed, while quantifying the sediment flow deposited in the Illala basin. The results show that, between 1984 and 2024, some land use units in the basin are characterised by progressive dynamics, while others are characterised by regressive dynamics. Moreover, the study area was subject to profound hydro-erosive dynamics over a 19-year period (2005-2024). These dynamics resulted not only in the multiplication of the ravine network but also in variations in the surface area and volume of the ravines and their cones. The surface areas of R1 and R2 increased by 92 and 328.64 m² respectively, while the corresponding volumes transported increased by 145.25 and 596.96 m³. The annual retreat of R1 and R2 amounts to 11.6 and 21.11 m respectively. The results also revealed that the cone of gully 1 narrowed by 1,533 m², and that of gully 2 widened by 1,212 m², while the corresponding volumes increased by 58.18 m³ and 1,020.4 m³. This study highlights the significant hydro-erosive processes that are disrupting the balance and ecosystem functions in the area. It would now be useful to take water erosion into account in all conservation and development activities in the watershed concerned and in the Korama Valley in general.

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