INOSR Experimental Sciences 13(1):80-85, 2024.
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International Network Organization for Scientific Research
https://doi.org/10.59298/INOSRES/2024/1.808510

ISSN: 2705-1692
INOSRES1.8085

# The Influence of Human Activity and Environmental Factors on Gully Erosion

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## ABSTRACT

Gully erosion, far from confined to specific terrains like badlands or mountainous areas, stands as a global issue contributing significantly to land degradation across various soil types susceptible to crusting or piping. Even after initial triggers cease, formed gullies can persistently generate sediment. This study delves into the multifaceted influences of geology, climate, slope morphology, vegetation, human impact, and soil properties on gully development and broader soil erosion. Drawing from empirical examples globally and locally, it underscores the pivotal role of local soil characteristics in propagating erosion, particularly the gully variant. Anthropogenic factors, especially land use practices and their impact on vegetation, weigh heavily. Rampant deforestation coupled with insufficient re-vegetation or afforestation initiatives have exacerbated the looming erosion threats, contributing to catastrophic consequences. Despite the effectiveness of various strategies in preventing and addressing gully erosion, their sustained implementation on a large scale remains elusive. Thus, research priorities must encompass sub-surface flow erosion mechanisms, predictive models, and the intricate dynamics influencing farmers' adoption or rejection of conservation strategies. To combat soil erosion comprehensively, a holistic approach to soil conservation becomes imperative. This entails employing hydrological or bioenvironmental processes to regulate overland flow and curb excessive runoff. Prioritizing these aspects can inform more robust strategies for soil conservation, mitigating the pervasive impact of erosion on our lands.

Keywords: Influence, Human, Activity, Environmental Factors and Gully Erosion

## INTRODUCTION

Gully erosion holds a global footprint, representing a colossal environmental menace that leads to the loss of valuable land earmarked for agricultural, domestic, industrial, and aesthetic purposes. Its repercussions extend to property loss and, tragically, even human lives [1]. This erosion process entails runoff water accumulating and recurring in narrow channels, swiftly removing soil over short periods to considerable depths. Soil erosion, a broader phenomenon, results from multiple factors acting in tandem or independently, causing detachment, transportation, and deposition of soil particles away from their origin. The consequential landscape exhibits deep cuttings and ravines that cleave through entire terrains. Earth scientists widely acknowledge that various environmental and pedological parameters influence soil erosion globally, often guided by anthropogenic factors. While humanity has contributed to shaping and conserving the Earth's surface, it has also destabilized the natural ecological equilibrium, fostering the rapid proliferation of environmental woes like soil erosion [2]. Anthropogenic factors, as highlighted by [2], primarily encompass technical elements encompassing land use practices, tillage methods, crop choices and distribution, and the nature of agro-technology. Studies in the Northern Hemisphere, including parts of Europe, as noted by [3], emphasize the factors fostering soil erosion: vegetation clearance, intensive harvesting, over-grazing that leaves soil exposed, and soil compaction from heavy machinery. The latter reduces soil infiltration capacity, promoting excessive water runoff and consequent soil erosion.

## Human and Environmental Impacts on Gully Erosion

### Farming systems

Soil erosion, often attributed to the significant decline in soil fertility, has garnered attention for its adverse impact on agricultural productivity. [4] highlights that while gradual erosion has a relatively subdued effect on crop yields, the abrupt removal of a substantial portion of topsoil, simulated in one-time desurfacing experiments mimicking inter-rill erosion, poses a significantly greater threat to crop productivity. In the context of gully erosion, the outcomes are typically unpredictable and markedly severe, encompassing the loss of available land and increased labor costs. To address gully erosion, upland rice farmers commonly employ a technique of filling gullies with wood and discarded vegetation (such as weeds from cropland), effectively restraining the expansion of existing gullies. In Southeast Asia, deforestation initially commenced on gentle slopes before encroaching upon entire hillsides. This led to the delineation of plots, with fallow and cultivated lands nearly contouring each other, creating plots with relatively short slope lengths (less than 50 meters). Fallow plots strategically positioned could trap sediment from cultivated fields located upslope. However, as gullies form along steeper slopes, they create new boundaries between parcels, elongating parcel lengths and subsequently accelerating water erosion rates in a self-reinforcing feedback loop.

### Hydrological functions

Gullies have often been associated with intensified drainage patterns and hastened aridification processes [5]. In the arid Negev highlands of southern Israel, gully incisions erode alluvial sediments and loess deposits within valleys, confining agricultural fields and primary floral biomass to narrow strips. These gullies act as conduits, channeling runoff into narrow pathways that restrict floodwater from adequately irrigating the entire valley width. This alteration in irrigation efficiency results in an 80% reduction in biomass and a substantial decline in the region's agricultural potential [6]. In the Ethiopian highlands, gully formation has expanded drainage in intergully regions, leading to diminished soil moisture and subsequent crop yield reductions in plots adjacent to gully walls [7]. Conversely, in severely crusted environments, gully bottoms serve as primary conduits for runoff, crucial for recharging groundwater in semi-arid settings, as evidenced in southern Niger [8]. However, exceptions to this rule have surfaced, such as in northern Burkina Faso, where recent electrical resistivity mapping surveys revealed a lack of deep infiltration processes beneath a gully situated on the hillslope [9].

### Sediment production

Understanding the origins of sediments within catchments has become crucial for assessing potential pollution sources and formulating erosion management strategies. Managing sedimentation in large reservoirs necessitates catchment-scale soil conservation. Within vast, heterogeneous catchments, planning soil conservation efforts relies on pinpointing significant sources and sinks, as well as major contributors of sediment reaching reservoirs. Various tracers such as carbon, nitrogen, the nuclear bomb-derived radionuclide 137 Cs, magnetic elements, strontium isotopic ratios, and neodymium isotopic ratios have gained traction for sediment fingerprinting. In tropical northwestern Australia, a staggering 96% of sediment in the Lake Argyle reservoir originates from less than 10% of the catchment area, notably from erodible soils formed on Cambrian-age sedimentary rocks. Gully and channel erosion account for about 80% of the reservoir sediment [10]. Similarly, within a 1.2 km2 gullied catchment in southeastern New South Wales, comprehensive sediment fingerprinting in downstream pools revealed gully walls contributed between 90% and 98% of the accumulated sediment, in comparison to grazed pasture surfaces as the alternative potential source [11]. Moving to the outer Warragamba catchment in southern New South Wales, gullied catchments ranging from 29 to 510 hectares exhibited sediment yields at least one order of magnitude higher (around 1 Mg ha1 year1) than ungullied catchments [12]. In the Wildhorse Creek drainage, an intensively cropped tributary of the Umatilla River in northeastern Oregon, USA, sediment tracers were utilized to quantify erosion from cultivated fields, identifying channel and gully banks as major contributors to channel-bottom sediment [13]. On the Chinese Loess Plateau, rill and gully erosion contribute between 60% and 70% of all sediments [14, 15]. Similarly, in northwestern highland Ethiopia, a reported 70% of sediment originates from such erosion processes [16].

## Factors Controlling Gully Erosion

### Topographic Thresholds

**Slope gradients and soil crusts:** Gullies are prevalent in mountainous or hilly regions characterized by steep slopes, which foster the initiation of rills and gullies due to high runoff velocity. Surprisingly, recent findings in northern Thailand [17] reveal that despite the inclination favoring high runoff velocity, steep slopes can yield lower runoff volumes compared to gentler slopes due to specific climatic conditions. The lower crusting rate on steep slopes, as evidenced by studies [18], is attributed to a reduced impacting kinetic energy and continuous erosion of the surface seal. Unlike lower slopes where higher runoff promotes soil crust development, steep slopes experience a slower crust formation process. This distinction is crucial; for seriously crusted soils, like in the loamy plateaux of southeastern Niger, the slope threshold for rill initiation can be exceptionally low, as low as 1% [19].

**Slope and critical drainage area:** Considering that for a given slope (S), a critical drainage area (A) is necessary to produce sufficient runoff to concentrate and initiate gullying, thresholds lines (S =aAb) have been recently produced by scientists with the constant a and the exponent b depending on environmental characteristics [18]. Using a global positioning system (GPS) to measure the morphology and the location of gullies in a small catchment near Suide, Shaanxi Province, representative for the loess plateau in [20] established the critical relationship of S = 0.1839A 0.2385. Topographic threshold conditions for hillslope gully initiation in cultivated land in the Chinese loess plateau plot above those needed to initiate ephemeral gullies in cultivated land under Mediterranean and European conditions [18]. The values of AS2, considered as an indicator for the gully initiation point range between 41 and 814 m2, are much smaller than those commonly observed by [21], which range between 500 and 4000 m2. These two threshold relationships (S and AS2) are suggested as indexes for the position of hillslope gully heads from DEM in small watersheds on the Loess Plateau of China.

## Soil and Lithologic Controls

**Soil/Lithologic/Geomorphology Factors**: The formation and layout of gully networks, along with their evolution rates, heavily hinge upon soil and lithological properties [22]. Field observations have revealed a correlation between landform development and tectonic forces, which can induce compressional or tensional stress. Even without substantial tectonic movement or displacement, these forces often result in the creation of fractures or cracks in rocks. These structural weaknesses subsequently serve as initial points for weathering processes.

These fractures facilitate the formation of sub-surface concavities that concentrate throughflow. This concentration of water tends to hasten the eluviation of soil particles, leading to a gradual lowering of the soil surface. These depressions, which could also include old landslide scars, emerge as focal points for surface flow concentration, thereby triggering gully erosion.

**Soil Crusting:** Soil crusting exhibits a dual impact on gully formation. On one hand, it can postpone the onset of gullies due to its higher shear strength compared to non-crusted soils. However, headcuts often manifest at points where surface crusts develop cracks [23]. While soil crusts can delay gully initiation, they tend to concentrate runoff downslope, making soils prone to crusting susceptible not only to sheet erosion but also to gully erosion. Even on very slight slopes, areas affected by crusting commonly witness the development of rills and gullies. This emphasizes that regions facing crusting issues tend to experience the formation of gullies and rills despite gentle slope gradients.

**Piping**: While previous studies predominantly associated gully morphology with surface water flow, recent attention has shifted towards the significance of piping and tunnelling processes, as highlighted in [24]. There's a growing recognition of the influence of soil chemistry on soil hydrological pathways. Dispersive soils featuring sodic layers are particularly prone to pipe development, which can eventually lead to the formation of rills or gullies when these pipes collapse, as observed in studies like [25]. This process isn't limited to sodic soils; it can also occur in non-sodic soils that are highly eluviated, as shown in research such as [26], or in soils rich in smectite clay minerals [27, 7]. These sub-surface seepage processes significantly shape the features and morphology of channels within gullies.

## Land use change

**Present land use changes:** The acceleration of natural gullying processes is closely linked to intensified farming practices. Depletion of soil organic matter diminishes soil structural stability, leading to increased crusting, runoff production, and consequent gully erosion [19]. This phenomenon is observed not only in mountainous areas but also in vineyards within Mediterranean regions, where annual cropping intensification has been reported to escalate rill and gully erosion processes. Interestingly, irrigation channels themselves can contribute to gully erosion. Additionally, overgrazing emerges as a significant driver of gully erosion in rangelands, as highlighted by [28]. For instance, sheep grazing on Easter Island has led to astonishing gullying rates exceeding 190 Mg ha1 year1 [29]. While long fallow periods have been historically considered a means to restore soil structural stability and mitigate gully hazards, recent observations in sandy Sahelian soils challenge this notion. During fallow periods, soil crusts develop due to dust deposition and colonization by blue-green algae, ultimately exacerbating gully development. In these scenarios, tillage practices might limit water erosion but worsen wind erosion [30].

**Roads and construction sites**: The escalation of gully erosion isn't solely attributed to agricultural and pastoral activities. Recent studies increasingly highlight gully development stemming from forestry, road construction, and urban building activities. In particular, selective harvesting in tropical rainforests contributes significantly to sediment sources, primarily through the creation of building access roads and log haulage tracks. Left unchecked, these tracks evolve into gullies that persist in eroding long after logging activities cease [31]. While the direct damage caused by runoff to the roads themselves might seem limited, the off-site effects are often substantial. These roads induce the concentration of surface runoff, divert concentrated runoff to other catchments, and increase catchment size, all of which significantly amplify gully development post-road construction [7]. To mitigate risks, road design should prioritize minimizing runoff interception, concentration, and diversion.

**Climate change**: Limited information exists regarding how gully systems might respond to climatic changes [14]. In regions where annual rainfall has notably decreased while high-intensity rain events persist, such as in the Sahel and western Australia, the absence of concurrent decreases in high-intensity rainfall is a concerning trend. Prolonged droughts lead to vegetation decay, leaving vast areas vulnerable to splash erosion and soil crusting. Consequently, runoff increases and concentrates, intensifying gully erosion. A drier climate in semi-arid zones is anticipated to exacerbate the development of rills and gullies [19]. Moreover, under colder conditions, global warming is projected to elevate the frequency of freeze-thaw cycles, heightening the risk of gullying. Studies in southern Saskatchewan, Canada [32], and southern Norway [33] have highlighted how these intensified freeze-thaw cycles contribute to the increased likelihood of gully formation.

## Prevention and control of gully erosion

**Vegetation cover:** Above ground vegetation plays a critical role in facilitating water infiltration and shielding soil from erosion. However, for this protection to be effective, the topmost layer of intercepting vegetation must be in close proximity to the soil surface. Tall trees without an understorey can lead to larger intercepted drops with higher kinetic energy, potentially favoring soil crusting, increased runoff generation, and gully initiation. The progression of gully retreat often hinges on the resilience of the tree root mat that binds surface soils until the underlying trees eventually collapse [32]. The impact of plant roots on soil resistance to concentrated flow erosion is increasingly significant and primarily relies on the characteristics of effective roots, particularly fibrils less than 1 mm in diameter, densely distributed in the 0–30 cm depth range [14]. Plant roots contribute to reducing gully erosion by enhancing soil physical properties like structural stability and infiltrability [14].

**Soil conservation works:** According to insights from [12], the effectiveness of sediment trapping and grade stabilization efforts in reducing sediment yields relies significantly on the activity within the treated gully and the mobility of bed sediments. At the catchment scale, the combined implementation of conservation measures, encompassing interventions not only within the gullies (like check dams) but also in the intergully zones (such as stone bunds and exclosures), has been observed to lead to decreased soil erosion rates, particularly noted in the northern Ethiopian highlands [7]. Regarding check dams, the authors emphasized certain crucial features: these structures require a spillway, apron, and a concave plan form when viewed downslope. Moreover, they should be built at vertical intervals and heights that result in a negative slope gradient from the top of the spillway to the foot of the upstream dam. The frequent collapse of these dams (39% after 2 years) is strongly associated with the drainage area (A) and slope gradient (S) of the soil surface near the gully. The product of these factors (S × A) serves as a proxy for runoff energy [7].

## CONCLUSION

Gully erosion isn't confined solely to rugged terrains like badlands or mountains; it's a pervasive global issue causing significant land degradation across various soil types prone to crusting or piping. Even after initial triggers cease, gullies persist in generating sediment. Despite effective strategies existing to prevent and combat gully erosion, farmers seldom adopt them consistently or on a large scale. Therefore, research should focus on understanding sub-surface flow erosion, developing predictive models, and examining the factors influencing farmers' adoption or rejection of conservation strategies.

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**CITE AS: Arikpo Jacintha Jackie (2024). The Influence of Human Activity and Environmental Factors on Gully Erosion INOSR Experimental Sciences 13(1):80-85. https://doi.org/10.59298/INOSRES/2024/1.8085**