



# 1 **Urban gullies and their massive economic toll: insights from** 2 **Kinshasa, the world's most affected city**

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22 **Abstract.** Urban gullies (UGs) are a rapidly expanding but under-recognized human-induced hazard in cities  
23 across the Global South, causing widespread damage to housing and infrastructure. Despite their growing  
24 importance, their economic impacts remain largely unquantified. Here, we assess the costs associated with UG  
25 expansion in Kinshasa (D.R. Congo), the world's most affected city and a critical case to evaluate the potential  
26 magnitude of this hazard. Using an integrated approach combining field surveys and semi-structured interviews  
27 with 802 households, real estate data, and spatial analysis, we quantify direct damages, household-level costs,  
28 and system-wide economic impacts. Households experiencing damage (n=666) reported average material losses  
29 of 4,320 USD, while most respondents (n=606) contributed to bottom-up stabilization efforts, investing on  
30 average 335 USD. These costs are clearly substantial given that most households report monthly incomes below  
31 500 USD. In addition, UGs significantly reduce property values, with total losses in Kinshasa estimated at 979  
32 million USD. These findings reveal the massive and multi-dimensional economic burden of UGs and suggest  
33 that their impacts are likely severely underestimated in rapidly urbanizing regions. Urban gullies should  
34 therefore be recognized as a major and growing component of urban risk, requiring urgent integration into  
35 disaster risk reduction and urban planning strategies.

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39 **1. Introduction**

40 Gullies pose major challenges and have considerable impacts in various regions worldwide (e.g. Valentin et al.,  
41 2005; Vanmaercke et al., 2021). Especially in some tropical cities of the Global South, they can have  
42 devastating impacts. The formation and expansion of such urban gullies (UGs) is typically caused by various  
43 factors including dense road networks, large amounts of roofs and other impervious surfaces, lack of appropriate  
44 water storage and drainage infrastructure and compacted, low permeability soils (Makanzu Imwangana et al.,  
45 2014; Kayembe Wa Kayembe & Wolff, 2015; Ilombe Mawe et al., 2024; 2025). Given their location in densely  
46 populated areas, as well as their often very large size (e.g. in the case of Kinshasa up to 2 km long and several  
47 tens of meters wide and deep; Lutete et al., 2023; Ilombe Mawe et al., 2025) such urban gullies (UGs) can  
48 undercut buildings, roads and other infrastructure, undermining their stability and leading to collapses and costly  
49 repairs (Fig. 1; Guerra et al., 2006; Dos Santos Rotta & Zuquette, 2014; Kuhn et al., 2023a).

50 Linked to this, UGs often lead to a plethora of additional impacts. Examples include the destruction of houses  
51 and displacement of people (Ilombe Mawe et al., 2025), inaccessibility to water supplies (e.g. Zolezzi et al.,  
52 2018), reduced accessibility of neighbourhoods and/or public infrastructure (e.g. Archibold et al., 2003),  
53 interruption of public health facilities (e.g. Kuhn et al., 2023a) and costly gully site rehabilitation (e.g. Dos  
54 Santos Rotta and Zuquette, 2014). There are also many intangible socioeconomic impacts. For example,  
55 Kayembe wa Kayembe (2020) reports that urban gullies in Kinshasa can exacerbate social inequalities, as  
56 marginalized communities are often disproportionately vulnerable and affected by gulying. Residents living  
57 near gullies may experience heightened stress and anxiety due to concerns about their safety, the cost of gully  
58 control efforts, and the reduced values of their property (Kayembe wa Kayembe, 2020).

59 Similar to other geo-hydrological hazards such as floods (Jacobs et al., 2016; Ratnadiwakara et al., 2020) and  
60 landslides (Vranken et al., 2013; Dille et al., 2022), urban gullies are indeed expected to have a large impact on  
61 the nearby housing market. The presence of gullies not only affects the overall attractiveness of neighbourhoods  
62 (e.g. by impacting accessibility and public infrastructure), but also poses a direct threat to nearby houses. Once  
63 formed, urban gullies can continue to expand for several decades (Ilombe Mawe et al., 2024; 2025) while the  
64 large landscape deformations they cause are typically very costly to restore (e.g. Kuhn et al., 2024a). As such,  
65 these negative impacts on real estate can be expected to persist for long periods of time.

66 Properly stabilizing urban gullies by means of civil engineering works can easily cost several million USD per  
67 gully (Kayembe wa Kayembe, 2020). Given that cities like Kinshasa are affected by hundreds of urban gullies  
68 and financial resources are limited, initiatives like this are usually only implemented when deemed essential,  
69 e.g. to protect major roads or neighbourhoods of high economic interest (Kayembe wa Kayembe, 2020). In most  
70 other cases, it is typically the local population that undertakes bottom-up initiatives to stabilize urban gullies,  
71 often in an effort to protect their own houses. Unfortunately, the majority of these initiatives have little to no  
72 effect (Makanzu Imwangana et al., 2015; Lutete Landu et al., 2023).

73 A key step in properly addressing the numerous challenges and impacts associated with urban gullies is  
74 obtaining good insights into their costs. For example, this can contribute to cost-benefit analyses that help target  
75 remediation strategies but also the development of policies to prevent this growing issue (e.g. Bartley et al.,  
76 2020; Kuhn et al., 2023b; Lutete Landu et al., 2023; 2025; Ilombe Mawe et al., 2025). Nevertheless, very few



77 studies so far have actually quantified the costs associated with urban gullies, especially at larger scales (Kuhn  
78 et al., 2023b). Most of the research undertaken so far relates to very local case-studies, focusses only a few  
79 aspects and/or remains largely qualitative in nature (e.g. Miti & Aloni, 2005; Kayembe wa Kayembe and Wolff,  
80 2015; Makanzu Imwangana et al., 2015; Kayembe wa Kayembe, 2020; Kuhn et al., 2023b).

81 This study therefore aims to better quantify and understand the costs of urban gullies at the scale of Kinshasa,  
82 one of the cities most affected by this problem (e.g. Makanzu Imwangana et al., 2015; Ilombe Mawe et al.,  
83 2022; Lutete Landu et al., 2023; Ilombe Mawe et al., 2025). More specifically we aim to document and assess:  
84 (i) the material damages of urban gully expansion for households living in the direct vicinity of such gullies; (ii)  
85 investments made by these households in bottom-up initiatives aiming to stabilize urban gullies; and (iii) the  
86 impacts of urban gullies on housing real estate values.

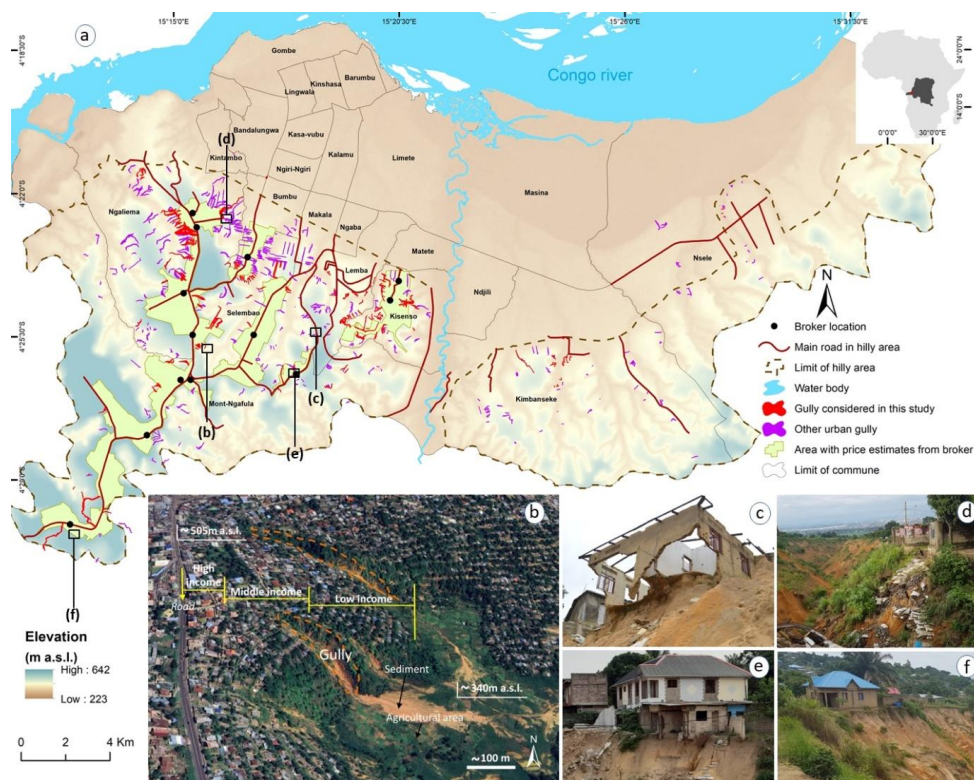
## 87 **2. Materials and methods**

### 88 **2.1. Study area**

89 This study was conducted in Kinshasa, the capital of the Democratic Republic of the Congo (DRC), more  
90 specifically in an area of 314 km<sup>2</sup> in the southern part of the city severely affected by urban gullies (Fig. 1). This  
91 area extends over 10 municipalities (communes), where at least 860 urban gullies have been identified in recent  
92 mapping efforts (Lutete Landu et al., 2023; Ilombe Mawe et al., 2025). The occurrence of urban gullies in this  
93 part of the city is largely driven by its hilly topography, highly erodible soils and chaotic urban planning (Ilombe  
94 Mawe et al., 2025).

95 While Kinshasa was originally built on the plain bordering the left bank of the Congo River (272 m a.s.l.), it has  
96 vastly expanded towards the southern hills (350 to 710 m a.s.l.) (Makanzu Imwangana et al., 2014; Bédécarrats  
97 et al., 2016). Slopes in this hilly area typically have a steepness of 10 to 15% but can attain values of up to 30%  
98 (Van Caillie, 1983). The soils consist of sandy Arenosols, derived from soft sandstones (Van Caillie, 1983,  
99 1989; Lateef et al., 2010; Dewitte et al., 2013; Jones et al., 2013), making them very prone to gully erosion. The  
100 region has a tropical savannah climate (Aw) (Beck et al., 2018) with an average rainfall of ca. 1,500 mm yr<sup>-1</sup>  
101 (Bédécarrats et al., 2016).

102 Housing in these hilly areas range from informal settlements to more structured neighbourhoods, reflecting the  
103 socio-economic diversity of the population. Nevertheless, the topographic characteristics have often led to a  
104 kind of social segregation (Kayembe wa Kayembe, 2020; Lutete Landu et al., 2025). Hilltops typically have  
105 relatively gentle slopes, a better accessibility by car, and a close proximity to a main road which is usually  
106 asphalted. As such, they are mainly inhabited by middle and higher income households. Houses or parcels in  
107 this area are usually bought and sold via brokers (real estate agents). The steeper hillslopes (>15%) and the  
108 lower parts of the hills, which often extend into wet valleys are clearly less suitable for construction and less  
109 accessible (Van Caillie, 1989). This lower suitability makes these 'marginal zones' more affordable to low-  
110 income populations (Kayembe wa Kayembe, 2020; Fig. 1). Buying and selling houses in these zones typically  
111 happens in informal ways, without the involvement of brokers. Nearly all houses in both the hilltop and  
112 marginal areas are privately owned (De Boeck, 2019).



113

114 **Figure 1** Overview of the study area. (a) Map of (surveyed) urban gullies and other points of interest, including photos b-f.  
 115 The map was created by the authors, the elevation in the background was derived from the SRTM V3 at 1 arcsecond  
 116 resolution (Rabus et al., 2003). (b) Google Earth 3-D view of a typical hillslope in the study area affected by urban gullies,  
 117 with different zones inhabited by population with different income levels; Map source data: © Google Earth 2023; image:  
 118 © 2023 Maxar Technologies. (c-f) examples of damages to houses and parcels, caused by urban gullies (c-f).

119 **2.2. Field data collection**

120 To assess the costs and impacts of urban gullies, we collected field data between July and September 2022.  
 121 More specifically, we conducted semi-structured interviews with households living near urban gullies as well as  
 122 with brokers capable of providing housing prices in the study area. Interviews were guided by a questionnaire,  
 123 asking about specific impacts, costs and/or prices. Yet, questions were adapted or expanded according to the  
 124 responses given, allowing for further clarifications or refinements where needed (e.g. Vranken et al., 2013).

125 **2.2.1 Household data**

126 Households were selected around gullies identified based on an earlier constructed inventory of existing gullies  
 127 (Lutete Landu et al., 2023), provided the interviewed persons met the following criteria: (i) living on a parcel  
 128 that is located less than 100 m away from an urban gully; (ii) living in an area that posed no significant security  
 129 issues to the researchers; (iii) being willing to collaborate, once the objectives and voluntary nature of the  
 130 research was explained; and (iv) being the owner of the parcel. With respect to criterion (i), it should be noted  
 131 that we primarily targeted households living very close to a gully sidewall (both sides), head or outlet, as this



132 allowed a better documentation of impacts and damages. In total, we interviewed representatives of 802  
133 households, living around 183 different gullies across seven different communes (administrative subunits of the  
134 city of Kinshasa) (**Fig. 1**). 69% of the interviewed households lived in ‘marginal’ zones corresponding to lower  
135 income areas, generally excluded from the formal housing market (cf. **section 2.1**). For each household, we  
136 measured and recorded the current position of the house relative to the nearest urban gully with a GPS.

137 We first asked whether the household experienced any material damage or loss due to gulying since they started  
138 living on the parcel. If so, we asked them to list these and provide estimates of the associated costs. These  
139 damages could relate to the house itself (e.g. the formation of cracks, the partial or complete destruction of the  
140 house), the surrounding parcel (e.g. reduction in size), other material goods (e.g. loss of furniture, household  
141 appliances or cars) or food production assets (e.g. losses or damages in terms of livestock, fruit trees or  
142 vegetable gardens).

143 To probe perceived risks and concerns, we asked whether the interviewees considered their parcel to be at risk  
144 of being affected by urban gully expansion. In addition, we asked whether they felt generally concerned about  
145 urban gullies in their neighbourhood.

146 We further asked whether the household was involved in communal or private efforts aiming to stabilize  
147 existing gullies. Such measures could be taken either in the upslope drainage area (e.g. the construction of  
148 retention basins, dikes and/or the planting of vegetation) or in the gully itself (e.g. installing sandbags, dumping  
149 household waste at the gully head, planting vegetation inside the gully; Lutete Landu et al., 2023). If they were  
150 involved in such initiatives, we asked them details about their type as well as their estimated financial  
151 contribution.

152 To obtain data on the potential reduction in real estate value due to urban gullies, we asked to report in which  
153 year they purchased the house and parcel and how much they had paid for it. We also asked whether they  
154 bought the house or parcel before or after the urban gully was in the vicinity of the parcel (i.e. < 100 m away).  
155 Finally, we asked to provide information on a few socio-economic characteristics, including household  
156 composition, education level and the current estimated average income level.

### 157 **2.2.2 Broker data**

158 In addition to the household interviews, mainly in areas with an informal housing market (cf. **section 2.1**), we  
159 conducted interviews with 12 brokers operating in four different neighbourhoods with a formal housing market.  
160 The goal of these semi-structured interviews was to obtain realistic prices of houses in the neighbourhood, as  
161 well as how the presence of urban gullies might affect these prices. Brokers were selected based on their  
162 willingness to cooperate, as well as whether they operated in areas where urban gullies occurred.

163 First explorative talks indicated that prices on the formal housing market strongly depend on the proximity to  
164 major roads. We therefore asked to provide estimates of typical prices for parcels with a standard (single-storey)  
165 house, located either near (< 50 m) or far (> 50 m) from a main road, in the absence of a nearby urban gully.  
166 Next, we asked them to provide estimates for the same location of property but assuming that the parcel and  
167 house were: (i) destroyed by an urban gully; (ii) close (< 50 m) to such gully; and (iii) at a distance of 50 to 100  
168 m away from the gully.

169



170 **2.3. Data processing**

171 **2.3.1. Processing of household interviews**

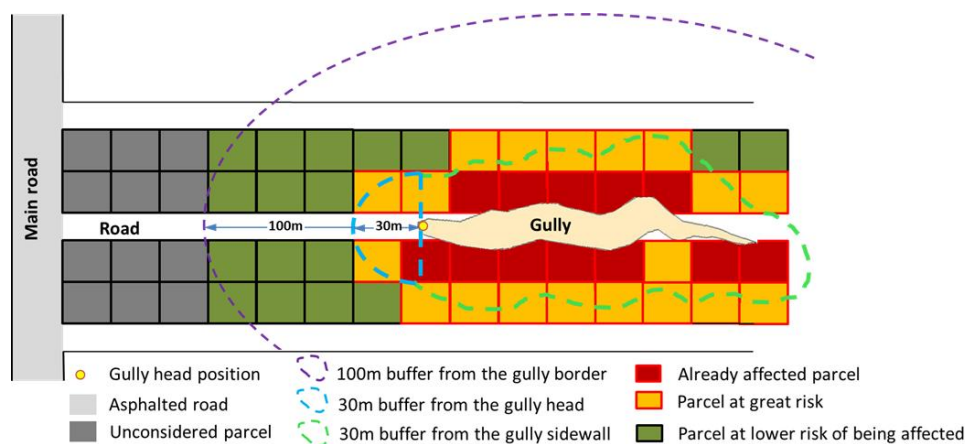
172 To understand the relations between reported damages, perceived risks, involvement in gully stabilization  
 173 efforts and the relative position of the parcel with respect to the gully, we categorized the collected data in  
 174 different classes. Differences between these classes were then evaluated based on boxplots and statistical non-  
 175 parametric Wilcoxon tests. More specifically, we categorized each parcel for which a household interview was  
 176 conducted into one of three categories (**Fig. 2**): (a) parcels already affected by the gully; (b) intact parcels with a  
 177 boundary less than 30 m removed from a current gully edge and therefore considered at great risk; and (c)  
 178 parcels located 30 to 100 m away from a gully edge. For (a) and (b), we further distinguished between parcels  
 179 located upslope of the current gully head - primarily threatened by gully head retreat - and those located  
 180 downslope - mainly threatened by gully sidewall widening. While this risk threshold of 30 m is to some extent  
 181 arbitrary, earlier work confirms that it provides a realistic estimate of parcels that are likely to get (partially)  
 182 destroyed by urban gully expansion within the next 10 years (e.g. [Lutete Landu et al., 2023](#); [Ilombe Mawe et al.,](#)  
 183 [2024; 2025](#)).

184 As damages, investments or parcel purchases may have occurred in different years, all prices and costs reported  
 185 during the interviews were corrected for inflation with 2022 as reference year. This was done using the  
 186 following equation ([Vranken et al., 2013](#)):

187 
$$PV = AV * (1 + i)^N$$
 Eq. (1)

188 Where *PV* (USD) is the value in 2022, *AV* (USD) is the value in the year the expense was made, *i* is the average  
 189 annual inflation rate (i.e. 0.0504; [Banque Centrale du Congo, BCC, 2022](#)), and *N* is the number of years elapsed  
 190 since the expense was made (with 2022 as reference year). Costs and prices reported in the local currency  
 191 (Congolese Franc) were converted to USD using the official exchange rate for the corresponding year (**Table**  
 192 **A.1**) and then corrected for inflation.

193



194

195 **Figure 2** Schematic diagram showing the categorization of parcels, based on their relative position from the current edge of  
 196 the urban gully. Each square represents a parcel, which is fairly small (500-650 m<sup>2</sup>). Parcels are owned by a household and



197 typically consist of a house and an open space, which is sometimes used as a garden. Urban gullies very often initiate and  
198 expand along dirt roads that branch off from an asphalted main road (Makanzu Imwangana et al., 2014; Ilombe Mawe et al.,  
199 2025).

### 200 2.3.2. GIS analyses

201 To allow spatial extrapolations of the costs and impacts of urban gullies, we conducted several GIS analyses.  
202 First, we mapped the extent of all marginal and non-marginal zones, based on our field knowledge and the  
203 overall steepness of the terrain. For the non-marginal zones, we then delineated the different areas in which the  
204 interviewed brokers operated, based on their description and Google Earth imagery (Fig. 1). Likewise, we  
205 further differentiated between areas that were either more or less than 50 m away from a main road, using  
206 available GIS data on the road network (JICA, 2019).

207 To assess the density of parcels in these different areas, we mapped 13,115 individual parcels across the  
208 different broker areas. This was done based on very high resolution Google Earth and/or drone images (Lutete  
209 Landu et al., 2025). From this, we calculated the average parcel size for each broker area, as well as the  
210 corresponding average parcel density. For the latter, we subtracted the area covered by roads, using a polygon  
211 layer of the road network in Kinshasa (JICA, 2019). The same strategy was used to assess the average parcel  
212 size and density in marginal zones, where we mapped 690 individual parcels in representative areas. Based on  
213 these estimated average parcel size, the price given by the brokers for the different parcel types was converted  
214 into the price / m<sup>2</sup> of the parcel.

215 To identify all areas potentially impacted by urban gullies, we made use of earlier inventories of such gullies in  
216 Kinshasa (Lutete Landu et al., 2023; Ilombe Mawe et al., 2024; 2025). These inventories indicate the spatial  
217 extent of each identified gully at different moments, based on recent Google Earth and/or Pleiades images.  
218 Where needed, the mapping was updated for 2022, i.e. the year of our assessment. Based on these mapped  
219 extents, we generated buffer areas around each gully with distances of 100 m, 50 m and/or 30 m to apply our  
220 further calculations (see below).

### 221 2.3.3. Assessing the total investment cost in gully stabilization efforts

222 Based on the household survey data and these GIS analyses, we assessed the total investment cost made by  
223 households living in the vicinity (< 100 m) of an urban gully in order to attempt stabilizing the gully. This was  
224 done according to the following equation:

$$225 \quad IC_{gully} = C_{Avg} \times PP \times NP_{gully} \quad \text{Eq. (2)}$$

226 Where  $IC_{gully}$  is the total investment cost made for a given gully (in USD);  $C_{Avg}$  is the average investment cost  
227 that a household made if they were involved in at least one initiative;  $PP$  is the estimated probability that a  
228 household living in the vicinity of an urban gully (< 100 m) participates in such an initiative; and  $NP_{gully}$  is the  
229 estimated number of household parcels in a buffer zone of 100 m around the gully.

230  $NP_{gully}$  was calculated based on the spatial extent of the 100 m buffer around the gully and the estimated parcel  
231 density (cf. section 2.3.2).  $PP$  was calculated as:

$$232 \quad PP = (FP_{<30m} \times NP_{<30m} + FP_{30-100m} \times NP_{30-100m}) / NP_{gully} \quad \text{Eq. (3)}$$



233 With  $FP_{<30m}$  and  $FP_{30-100m}$  being the fractions of household respondents living respectively  $< 30$  m or 30-100 m  
234 away from the gully, that reported having participated in at least one initiative to stabilize the nearby urban  
235 gully.  $NP_{<30m}$  and  $NP_{30-100m}$  are the corresponding number of parcels in each of these zones. Using the inventory  
236 of urban gullies for Kinshasa (cf. **section 2.3.2**), we also applied Eq. 2 to all mapped urban gullies of Kinshasa  
237 to estimate the total investment cost made by local communities to stop urban gully expansion.

#### 238 **2.3.4. Assessing the real estate impact**

239 To assess the impact of urban gullies on the real estate value of houses, we made a distinction between marginal  
240 and non-marginal zones (**Fig. 1**). In marginal zones (no brokers), we assessed potential property value  
241 reductions based on buying prices reported by households during the semi-structured interviews (**section 2.2.1**).  
242 More specifically, for built-up parcels currently less than 30 m from a gully, we compared the reported purchase  
243 prices of properties bought before the gully's approach with those bought after; with or without partial damage.  
244 Prices were corrected for inflation (cf. **section 2.3.1**). To limit uncertainties, we only considered houses  
245 purchased after 2013. Although parcels bought after the gully's approach tended to have a slightly lower value,  
246 the difference was not significant for our dataset, according to a Wilcoxon rank sum test ( $p = 0.23$ ). We  
247 therefore assumed that houses in the vicinity of an urban gully in marginal zones experienced a negligible price  
248 reduction and that only the complete destruction of parcels leads to value reductions. For the latter, we estimated  
249 that the property value dropped from the median reported purchase price (before the gully's presence) to zero.

250 For non-marginal zones, we used the broker data to assess the expected value reductions. Specifically, for each  
251 area for which prices were available, we directly used the estimates with and without gully as provided by the  
252 local broker. We made a distinction between parcels that were either close ( $< 50$  m) or far ( $> 50$  m) from a main  
253 road and parcels that were completely destroyed,  $< 50$  m away or 50-100 m away from a gully.

254 Building on this and the mapped impact zones (cf. **section 2.3.2**), we estimated the total real estate value  
255 reduction at the scale of Kinshasa. For marginal zones, we multiplied the total estimated number of parcels  
256 destroyed by urban gullies with the estimated value reduction. For non-marginal zones with broker price  
257 estimates available, we calculated the average value reductions per square meter for: (i) areas near a main road,  
258 completely destroyed by a gully; (ii) areas near a main road, less than 50 m away from a gully, with partial  
259 damage or no damage; (iii) areas near a main road, 50-100 m away from a gully; (iv) areas far from a main road,  
260 completely destroyed by a gully; (v) areas far from a main road, less than 50 m away from a gully, with partial  
261 damage or no damage; and (vi) areas far from a main road, 50-100 m away from a gully. We then multiplied  
262 each of these area-specific value reductions with their corresponding areal extent at the scale of Kinshasa.

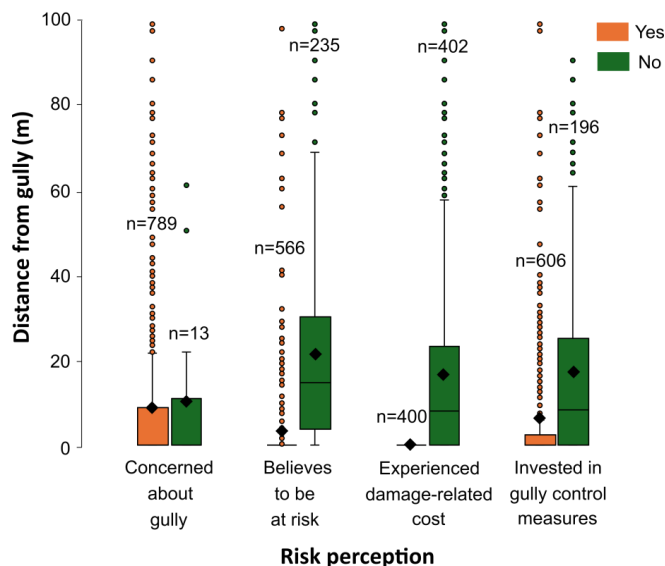
### 263 **3. Results**

#### 264 **3.1. Overview of the household responses**

265 The results of our 802 household surveys show that the overwhelming majority (98.3%) of the interviewed  
266 households is generally concerned about the presence of a nearby urban gully (**Fig. 3**). Yet, only 70.6% of the  
267 respondents also believe that they are really at risk (Fig. 3 and Table 1). Most of the latter (96.8%) live directly  
268 at the edge of a gully. However, there are also 24% of households that live less than 30m away from a gully yet  
269 which believe not to be at risk. Around half of the respondents reported that they had already experienced direct  
270 costs due to damages caused by urban gullies. All of these households live directly at the edge of a gully. 75.6%



271 of the respondents reported having contributed to one or more initiatives aiming to stabilize the urban gully.  
 272 Most, but not all, of them live nearby the gully.  
 273



274  
 275 **Figure 3** Risk perception and associated impacts and responses of households as a function of the distance between their  
 276 parcels and the gully edge within a range of 0 to 100m. Note: for the class “believes to be at risk” not all households  
 277 provided an answer.  
 278

279 **3.2. Material damages**

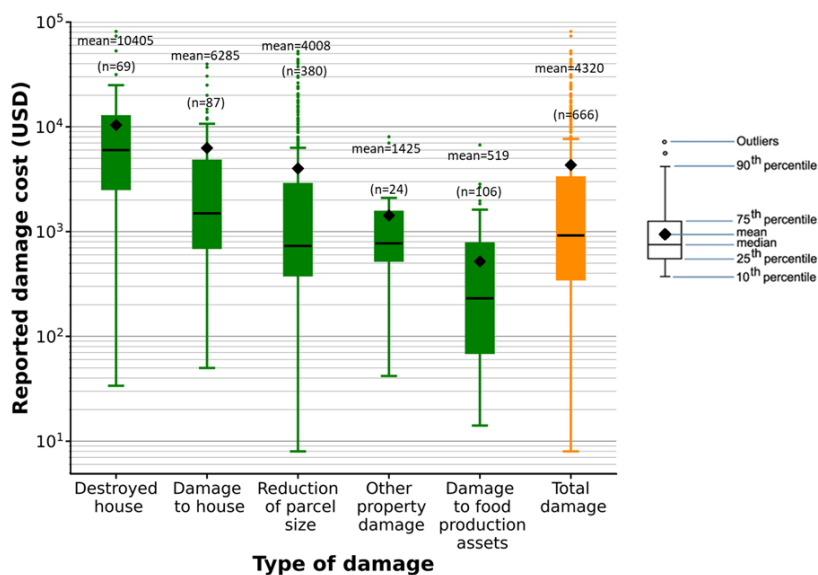
280 Urban gullies frequently lead to direct damages and costs for nearby families (**Table 1**). It is important to point  
 281 out that the large majority of interviewed households lived nearby a gully: 725 of the household parcels were  
 282 located less than 30 m away of a gully edge, while 612 parcels were located less than 10 m away. As such, the  
 283 reported damages are mainly representative of people living next to an urban gully. Within this group, damages  
 284 and impacts are widespread. 68.0% of the families living < 30m from a gully report having experienced some  
 285 form of damage. For 55.2% of the households, it was possible to obtain the direct economic costs of these  
 286 damages.  
 287  
 288



289 **Table 1** Overview of the surveyed households and their responses per distance class from the gully (n=802). Note that some  
 290 households have parcels with two houses on them that experienced different degrees of damage. For this reason, the total  
 291 sum of reported damages to houses and parcels slightly exceeds 100%.

	Fraction of parcels (%)		0 – 100m	# of gullies
	0 - 30m	30 – 100m		
# Surveyed households	725	77	802	183
Households that consider themselves at risk	75.8	23.4	70.8	169
Households reporting to have experienced material damage	68.0	3.9	61.8	169
Households reporting at least one damage cost	55.2	0.0	49.9	147
Households reporting that their parcel is still intact	34.6	100	40.9	132
Households reporting that parcel is damaged but house is still intact	38.1	0.0	34.4	135
Households reporting that the parcel and house are partially damaged	15.4	0.0	14.0	72
Households reporting the parcel is damaged and house totally destroyed	13.5	0.0	12.2	74
Households reporting damage to food production assets	14.6	0.0	13.2	61
Households reporting damages to other material properties	3.3	0.0	3.0	20

292  
 293 The most frequently reported forms of damage are reductions of parcel sizes, the formation of cracks and  
 294 damage to food production assets like fruit trees and vegetable gardens (**Table 1**). Also significant damages to  
 295 houses are frequently reported, including their partial or even complete destructions (**Fig. 5; Table 1**). Damages  
 296 to other forms of property (e.g. cars) are rarer.  
 297



298 **Figure 4** Distribution of the self-reported costs per households, associated with different types of damages caused by urban  
 299 gullies. Costs are expressed as the total cumulative costs per household since they started living on the parcel and are  
 300



301 corrected for inflation (reference year 2022). Note that not all households were able to report these costs. Hence the lower  
302 number of observations as compared to Table 1.

303 The costs of these damages are often considerable (**Fig. 5b**). Especially costs reported for the complete or partial  
304 destruction of houses are high. While they account for only 26.2% of the reported damage cases, they represent  
305 44% of the total reported costs (with an average of 8,107 USD for a damaged or completely destroyed house).  
306 Also the estimated costs associated with reductions in parcel sizes, as reported by the households (average:  
307 4,008 USD) and damages or losses to other material property like furniture, household appliances and cars  
308 (average: 1,425 USD) are often significant. Households that report experiencing at least one form of damage  
309 (n=666) estimate the total associated costs to be, on average, 4,320 USD (**Fig. 4**).



310

311 **Figure 5** Illustration of damage types observed on parcels affected by urban gullies. (a-b) houses completely destroyed by  
312 urban gullies. (c-d) houses that are significantly damaged. (e-f) houses showing cracks due to the nearby presence of urban  
313 gullies. (g-h) parcels reduced in size due to the expansion of urban gullies.

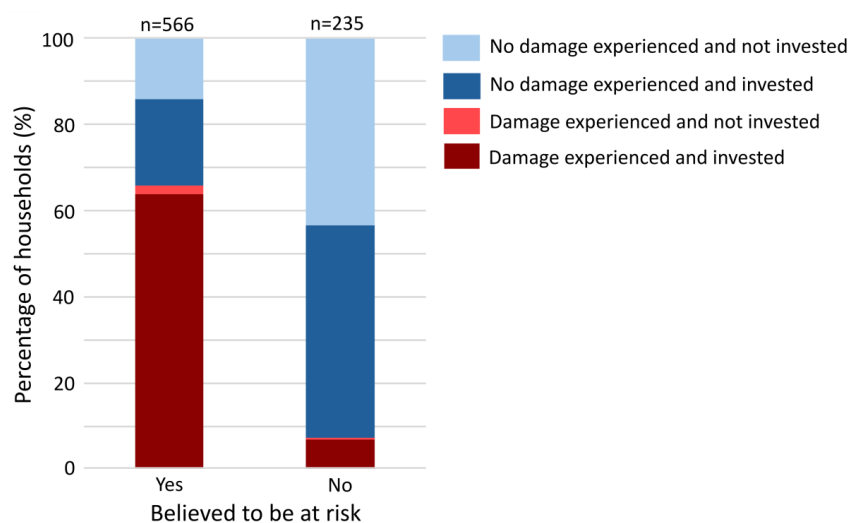


314 **3.3. Investment in gully control measures**

315 **3.3.1. Overview of the survey results**

316 As indicated, approximately 75% of the households contributed to efforts aimed at stabilizing urban gullies (**Fig.**  
317 **3**). Most of these families (78%) perceive themselves to be at risk (**Fig. 6**). Within the group of households that  
318 perceive themselves to be at risk, over 60% already experienced damages (**Fig. 6**). Only very few households  
319 that did experience damages did not invest in gully stabilization measures. Also amongst households that do not  
320 consider themselves at risk, around 55% contributed to stabilization efforts.

321



322

323 **Figure 6** Household investment rate in gully erosion control measures in relation to their risk perception and earlier  
324 experienced damages.

325 Efforts aiming to stabilize urban gullies are very diverse (**Table 2**). Based on a classification by [Lutete Landu et al. \(2023\)](#), we subdivided these according to where they are implemented (i.e. in the upslope catchment or in the  
326 gully itself) and based on the overall aim of the implemented measure. Overall, most households implement  
327 initiatives on their own parcel (e.g. installing infiltration pits or planting vegetation) or at the gully head (e.g.  
328 planting vegetation or installing sandbags).  
329



330 **Table 2** Erosion control initiatives undertaken by households living less than 100m away from a gully, grouped  
 331 by their relative location, and intended effects in preventing or stabilising gullies. Reported numbers are based  
 332 on 802 household surveys.

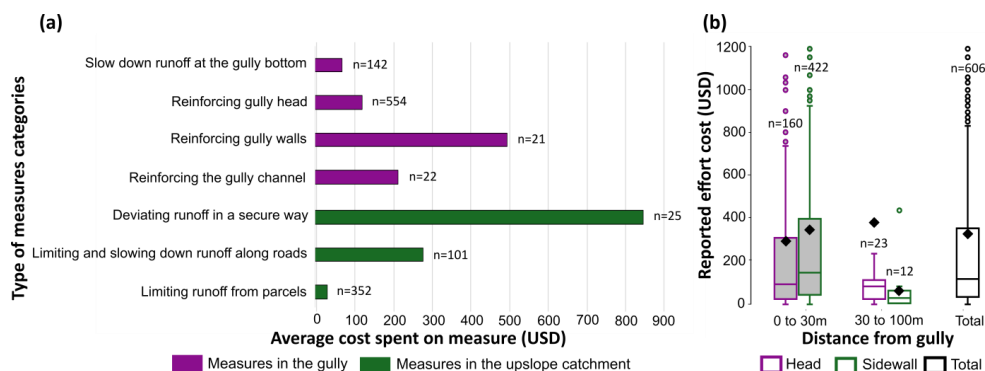
Measure category	Purpose of the measures	Type of measures	# of households*		Total # of measures of each type
			Specific measure	At least one measure of this category	
Measures in the upslope catchment	Limiting runoff from parcels	Small infiltration structures on parcels	293	352	293 structures
		Vegetation on parcels	245		245 parcels
	Limiting and slowing down runoff along roads	Small dams built with sandbags	97	101	50,964 sandbags
		Small dams built with vehicle wrecks	12		12 vehicle wrecks
	Deviating runoff in a secure way	Canalisation in the upstream area	25	25	25 structures
Reinforcing the gully channel	Canalisation of the gully channel	22	22	22 structures	
Measures in the gully	Reinforcing gully walls	Supporting walls	21	21	21 structures
		Sand bags at gully head	496		301,757 sandbags
	Reinforcing gully head	Household waste	82	554	82 locations
		Vegetation planted at the gully head	318		318 locations
	Slow down runoff at the gully bottom	Retention structures in the gully (dam)	44	142	44 structures
Water retention ponds		98	98 structures		

333 \*Note that households can implement more than one control measure

334 Our interviews indicated that the costs associated with these different measures varied widely. Initiatives that  
 335 require a significant amount of resources and engineering techniques, like reinforcing gully walls or deviating  
 336 runoff in secure ways, typically require investments of 400 to 850 USD (**Fig. 7a**). Initiatives aiming to limit  
 337 runoff from one's own parcel are typically much cheaper (average \$32 USD). The most commonly implemented  
 338 measures aiming to stabilize the gully head (typically with sandbags or vegetation; cf. **Table 2**) cost on average  
 339 122 USD.

340 As households often install or contribute to several measures, total costs per family are often considerable (**Fig.**  
 341 **7b; Table 3**). The average investment for a household that invested in gully stabilization measures is 335 USD,  
 342 from the time they installed in the area until 2022. Yet, some families reported to have invested up to 1,200  
 343 USD. Although not statistically significant, households that live less than 30m away the gully tend to invest  
 344 more (average: 339 USD) than those living at 30 to 100m away (average: 275 USD). For the first group,  
 345 families living along the gully sidewalls have invested slightly more than those living near the head ( $p = 0.014$   
 346 according to a Wilcoxon test).

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**Figure 7** Reported (a) average costs per type of measure (corrected for inflation to 2022), grouped according to the main purpose of the measure (cf. Table 2). (b) Total cost per household that invested in gully control measures, grouped according to the distance from the gully and whether the household’s parcel is located near the head or along the side of the gully. For households 0 to 30m away from the gully, the difference between head and sidewall is significant (Wilcoxon test,  $p < 0.05$ ).

**Table 3** Overview of the calculated total investment costs in stabilizing urban gullies.

Investment Cost Parameter	Distance to gully edge		
	0-30 m	30-100 m	0-100 m
# of gullies with surveyed parcels	182	45	183
# surveyed households	725	77	802
Fraction of surveyed households that invested in at least one gully stabilization effort	0.78	0.45	0.75
Average cost per household that invested ( $\pm$ std. dev.)	339 ( $\pm 671$ )	275 ( $\pm 1208$ )	335 ( $\pm 712$ )
Total average investment cost of all surveyed households ( $\pm$ std. dev.)	267 ( $\pm 612$ )	125 ( $\pm 820$ )	253 ( $\pm 635$ )

355

### 3.3.2. Total investment in gully control measures

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358

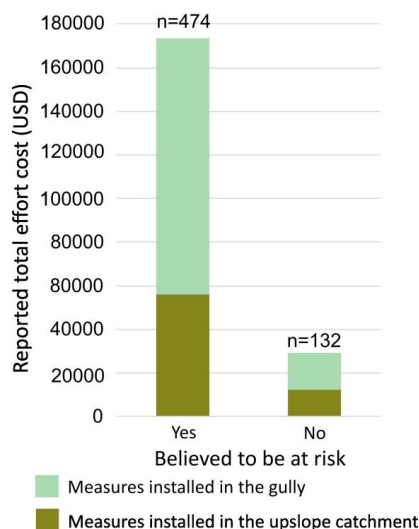
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Combined, all 606 surveyed households that implemented or contributed to gully control measures reported to have invested 202,919 USD. Over 85% of this investment was made by households that considered themselves at risk (Fig. 8). This group not only constitutes the largest proportion of households that invested ( $n=474$ ), but also invested on average more (366 USD) than households who do not consider themselves at risk (222 USD). Around 75% of this total amount is invested in measures that are installed inside the gully, and in particular the gully head.



363

364 **Figure 8** Total reported investments in gully control measures, by households' perceived exposure to urban gully expansion.

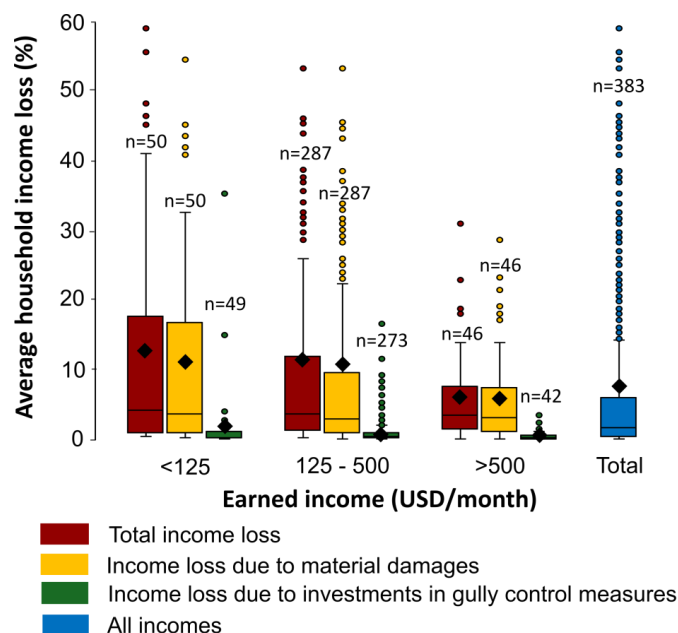
365 Extrapolating these reported investment rates and costs (Eq. 2 and 3, **section 2.3.3**) indicates that households  
 366 living less than 100 m away from an urban gully invest in total around 35,787 USD in the stabilization of this  
 367 gully. Taking into account the average age of the surveyed gullies (15 years), this corresponds to an amount of  
 368 2,386 USD per gully per year. Multiplying this value with the total number of mapped urban gullies in Kinshasa  
 369 in 2023 (n=868; Lutete Landu et al., 2023; Ilombe Mawe et al., 2025), suggests a total investment cost of 31.1  
 370 million USD or roughly \$2 million USD per year. Since we only consider investments made by households  
 371 living less than 100m away from a gully, this value most likely still underestimates the actual investment costs  
 372 in bottom-up initiatives.

373

374 **3.4. Relative costs of gully impacts**

375 To better quantify the significance of costs from direct damages (see **section 3.2**) and investments in gully  
 376 stabilization measures (**section 3.3**), we divided the total reported costs by the time elapsed since the household  
 377 acquired the parcel and by the self-reported average income of the household. These values are subject to  
 378 considerable uncertainty. Nevertheless, they indicate that, even over longer periods, the costs can still be clearly  
 379 significant (**Fig. 9**). Especially for households with an income below 500 USD per month that experienced  
 380 major damage to their house (cf. **Fig. 4**), they represent an average long-term income loss of more than 10%.

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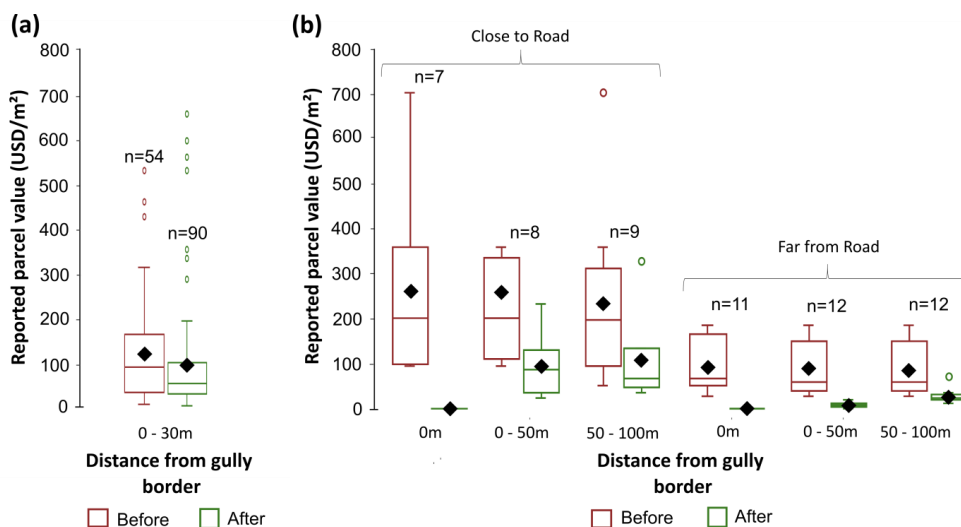
383 **Figure 9** Estimated income losses due to material damages and/or investments in gully control measures, subdivided per  
 384 self-reported monthly income. Income losses were calculated as the total reported income loss for each household, divided  
 385 by the period since acquiring the parcel and the self-reported average income.

### 386 3.5. Impact of urban gullies on housing real estate values

#### 387 3.5.1. Estimated reduction rates

388 Parcel values vary significantly depending on whether they are located in marginal or in non-marginal zones  
 389 (**Fig. 10**). Yet, in both zones, values tend to drop with an urban gully in the vicinity. In marginal zones, median  
 390 purchase prices differed by ca. 39% between parcels bought before and after an urban gully was in the direct  
 391 vicinity (<30 m), although this difference is not statistically significant. The large variability in reported prices  
 392 likely plays a role here (**Fig. 10a**). Price estimates provided by brokers in non-marginal zones reveal larger  
 393 differences. Parcels near a main road are clearly more expensive than those further away. Yet, in both cases,  
 394 values typically drop by more than 50% if a gully is nearby (**Fig. 10b**). All brokers estimate the price of a parcel  
 395 with a completely destroyed house to be zero.

396



397

398 **Figure 10** Estimated parcels values acquired before and after gully initiated within the indicated range. (a) Parcel values in  
 399 marginal zones, based on reported purchase prices (including house) during the household surveys. While median purchase  
 400 prices appear lower after a gully formed in the vicinity, the difference is not significant according to a Wilcoxon rank sum  
 401 test ( $p=0.2333$ ) (b) Differences in parcel values as estimated by brokers, depending on the distance of the urban gully. '0 m'  
 402 refers to parcels with a house that is completely destroyed by an urban gully. The number of observations (n) above each  
 403 boxplot pairs corresponds to the number of brokers that could provide price estimates (for typical parcels with a standard  
 404 single-storey house, with and without the presence of a gully) for this type of area.

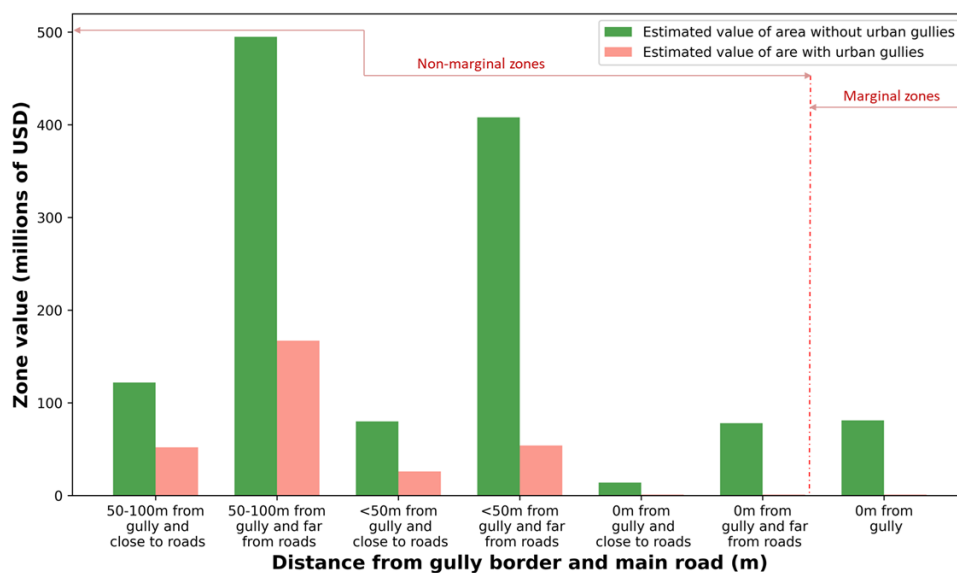
405

### 406 3.5.2. Estimated reduction in real estate value at the scale of Kinshasa

407 Combining these price estimates with data on parcel density and the extent of each area (cf. **section 2.3.2**)  
 408 allowed to assess the total real estate value reduction at the scale of Kinshasa (**Fig. 11; 12**). Based on the extent  
 409 of all urban gullies mapped in 2022, the overall value loss in housing real estate value is estimated at 979  
 410 million USD or around 1.11 million USD per gully. Assuming an average gully age of 15 years (cf. [Lutete](#)  
 411 [Landu et al., 2023](#); [Ilombe Mawe et al., 2025](#)), this corresponds to an estimated total cost of 65.3 million USD  
 412 per year. Overall, non-marginal areas that are far from a main road and located less than 50m from a gully  
 413 account for the largest losses. These zones are characterized by relatively high prices and an important price  
 414 decrease, but also cover extensive areas of the city.

415

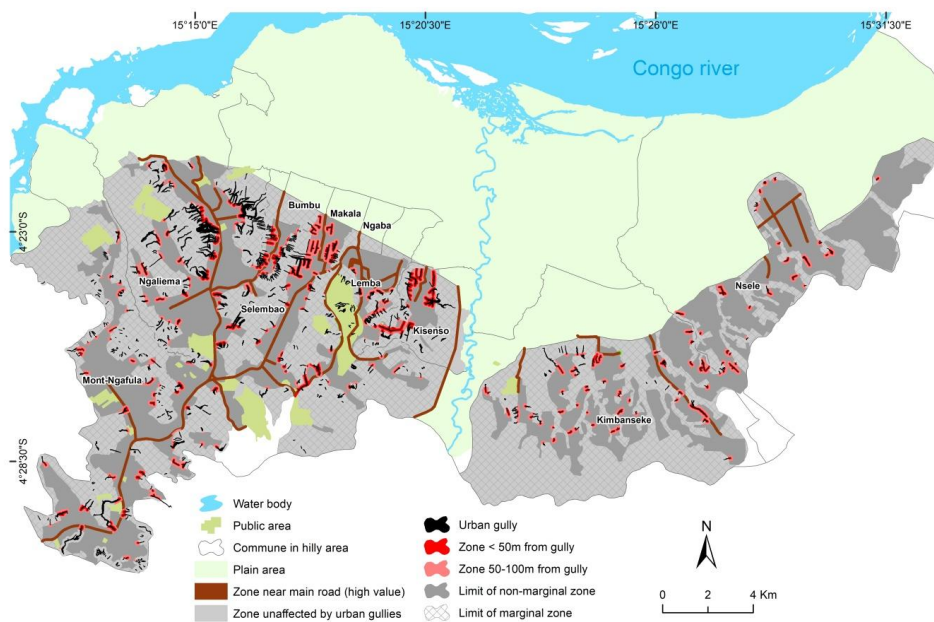
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417

418 **Figure 11** Total absolute and relative reductions in real estate parcel values for different areas. Combined, these reductions

419 represent a cost of \$979 million USD at the scale of Kinshasa. For details, see **Table A.2**.



420

421 **Figure 12** Spatial extent of areas in Kinshasa where the real estate value is likely impacted by the presence of urban gullies.

422

423



424 **4. Discussion**

425 **4.1. Scope, uncertainties and limitations**

426 The data collected in this study are subject to several limitations and uncertainties. As our main aim was to  
427 document the material impacts of urban gullies, we focused on households located directly adjacent to them.  
428 This yielded detailed information for these households but fewer observations—and hence greater uncertainty—  
429 for those living farther away, particularly regarding housing prices and investments in stabilization. The survey  
430 was also limited to households within 100 m of gullies, although those farther away may also experience costs,  
431 reduced parcel values, or other effects. Furthermore, our estimates of damages, investment costs, and real estate  
432 losses are based on self-reported data, thus depending on respondents' judgment, memory, and honesty. While  
433 such data inevitably involve uncertainty, they represent the only viable source of quantitative information in a  
434 largely informal, data-poor context like Kinshasa.

435 Nonetheless, the survey covered 802 households along 183 gullies in seven of Kinshasa's most affected  
436 neighbourhoods (**Fig. 1**) and included real estate price estimates from 12 experts. Despite uncertainties in  
437 individual responses, this extensive dataset provides meaningful insights and helps address important research  
438 gaps. Although gullies are widely recognized for their substantial impacts, quantitative data remain scarce (e.g.,  
439 Valentin et al., 2005; Vanmaercke et al., 2021; Kuhn et al., 2023b), particularly in tropical and urban  
440 environments (Castillo & Gomez, 2016). Earlier work in Kinshasa documented socio-economic impacts and  
441 infrastructure damage (Miti & Aloni, 2005; Makanzu Imwangana, 2010; Kayembe wa Kayembe, 2020) and  
442 reported some rehabilitation costs (Makanzu Imwangana et al., 2015). However, this is the first study to assess  
443 impacts at the household level, including bottom-up stabilization efforts and real estate value losses, and among  
444 the first to quantify urban gully costs at the city scale.

445 **4.2. Impacts and risk perception**

446 Our data clearly demonstrate the severe impacts urban gullies have on nearby households (**Table 1**). Over 60%  
447 of those living within 30 m of a gully reported substantial material damages (**Fig. 5**), often amounting to several  
448 thousand dollars (**Fig. 4**). Such losses can represent 10–60% of annual household earnings (**Fig. 9**). These  
449 figures exclude additional impacts on public spaces and infrastructure (Kayembe wa Kayembe, 2020) and the  
450 traumas linked to often deadly gully expansion events (BBC, 2022; Kuhn et al., 2024b). Even routine activities -  
451 such as crossing gullies - can be stressful and hazardous, especially when carrying goods or water (Bédécarrats  
452 et al., 2019; Ditona Tsumbu et al., 2020). It therefore seems logical that nearly all interviewed households  
453 expressed concern about the issue (**Fig. 3**).

454 More surprising is that only about 70% of interviewed households considered themselves at risk (**Table 1**).  
455 Most of these households live directly at the gully edge, yet half of those who do not consider themselves at risk  
456 reside less than 15 m from a gully (**Fig. 3**). Among households living 30–100 m away, only 23% perceived any  
457 risk - despite evidence that gullies in Kinshasa can reach widths of 75–150 m and expand by over 10 m per year  
458 (Ilombe Mawe et al., 2024; 2025). Meanwhile, over 60% of those acknowledging risk have already suffered  
459 material damage (**Fig. 6**).

460 This suggests that many households underestimate their exposure. Risk perception often depends on how  
461 individuals process and interpret hazard information (Paton et al., 2008; Mafuko Nyandwi et al., 2023;



462 [Nsabimana et al., 2023](#); [Maki Matezo et al., 2024](#)). For urban gullies, perceived safety may stem from temporary  
463 stability phases, underestimation of expansion rates, or a long-standing “normalcy bias” ([Drabek, 1986](#)).  
464 Furthermore, people may believe that a gully will soon be stabilized by state or NGO efforts. This may help  
465 explain why a small proportion of households that already experienced damages do not consider themselves at  
466 risk (**Fig. 6**).

467 Overall, understanding how personal experiences and knowledge influence risk perception is critical as it affects  
468 judgments and decisions (e.g., [Haynes et al., 2008](#); [Barclay et al., 2015](#); [Dieckmann et al., 2021](#)). Greater risk  
469 awareness can enhance preparedness and, consequently, reduce vulnerability ([Mafuko Nyandwi et al., 2023](#)).  
470 Our data indicates it also influences participation in initiatives aiming to stabilize gullies (**Fig. 6**; see below). We  
471 therefore recommend further research into the psychological and sociological dimensions of urban gullies,  
472 particularly regarding risk perception.

#### 473 **4.3. Gully stabilization initiatives**

474 While over 75% of interviewed households contributed to initiatives to stabilize nearby urban gullies,  
475 participation varied strongly with distance and perceived risk (**Fig. 3 & 6**): nearly 85% of households perceiving  
476 themselves at risk participated, compared to 55% of those who did not. The latter also invested smaller amounts  
477 (**section 3.3.2**). Also other factors may help explain a lack of participation, including confidence that the  
478 government or other organizations will address the issue, limited resources, and discouragement due to the scale  
479 of the problem ([Paton et al., 2008](#)).

480 Households implement a wide range of measures, ranging from simple initiatives like digging infiltration pits,  
481 installing sandbags, or planting vegetation to more elaborate civil engineering projects like constructing  
482 diversion channels (**Table 2**). However, while simple measures like sandbags are widely implemented (with one  
483 household installing on average nearly 600 sandbags), more elaborate measures are implemented only rarely.  
484 This is likely linked to their associated costs. Over longer timescales, investments in gully stabilization measures  
485 constitute only a small average income loss (**Fig. 9**). Yet, our surveys indicate that most interventions occur  
486 soon after a gully expansion event, likely driven by a heightened sense of urgency among nearby residents.  
487 Elaborate and structural investments are then often impossible, given that most involved households get by with  
488 less than 500 USD/month. Instead, they typically invest the few tens of dollars they have in cheaper initiatives  
489 like sandbags or vegetation. Nevertheless, accumulated over time, these small investments become considerable.

490 An important downside of this response strategy is the lack of planning and coordination. Our data show that  
491 especially households living at the gully edge invest in stabilization initiatives (**Fig. 3**), often after having  
492 already experienced damages (**Fig. 6**). At this stage, these measures may come too late. For example,  
493 vegetation-based measures typically require years to be effective (e.g., [Bartley et al., 2020](#); [Frankl et al., 2021](#)).  
494 Limited understanding of measure effectiveness likely reinforces this pattern. Most investments target the gully  
495 itself (**Fig. 8**), especially through sandbags—an affordable option that provides a visible, though often  
496 misleading, sense of effectiveness. Field observations confirm that such measures rarely halt gully expansion  
497 ([Makanzu Imwangana et al., 2015](#); [Lutete Landu et al., 2023](#)). In contrast, upstream interventions to reduce  
498 runoff at gully heads, such as preventing water from leaving individual parcels, are likely more effective in the  
499 long term. However, these require collective action by all households in the upstream catchment, not just those  
500 who perceive themselves at risk ([Lutete Landu et al., 2025](#)).



501 With an estimated average investment of \$35,787 per gully, community-based stabilization efforts remain  
502 modest compared to large-scale engineering projects, which can cost several million dollars per gully (Kayembe  
503 wa Kayembe, 2020; Kuhn et al., 2023b). Nevertheless, these efforts are far from negligible, even though many  
504 ultimately fail (Lutete Landu et al., 2023; 2025). Further initiatives and research should therefore focus on better  
505 planning and coordinating gully prevention and stabilization strategies. This would help prevent unnecessary  
506 financial burdens on already vulnerable households and enable earlier, more cost-effective interventions -  
507 reducing both the number of affected households and the overall intervention costs (Ilombe Mawe et al., 2024;  
508 2025).

509 This is also exemplified by the Mataba gully in Kinshasa (Miti & Aloni, 2005; Kayembe wa Kayembe et al.,  
510 2020). Preventive action in 1998 was estimated to cost only US \$50, but inaction led to escalating expenses of  
511 \$300,000 in 1999, \$1.5 million in 2001, and \$7 million in 2003 (Miti & Aloni, 2005). Given the vast scale and  
512 long persistence of Kinshasa's urban gullies (Makanzu Imwangana et al., 2015; Ilombe Mawe et al., 2025),  
513 small bottom-up initiatives like those reported here are unlikely to halt the problem, though they can still play an  
514 important role in reducing its overall costs and impacts.

#### 515 **4.4. Impacts on housing real estate value**

516 Our results clearly show that urban gullies drastically reduce private property values. Losses on the official  
517 housing market often exceed 50%, even before a house or parcel is physically damaged (Fig. 10 & 11). As with  
518 other impacts, this highlights a harsh reality for many households. In Kinshasa, as in other DRC cities, a parcel  
519 represents one of the most important assets—serving as a long-term investment, a source of income, and the  
520 primary inheritance passed to children (Lelo Nzuzi, 1992; Kayembe wa Kayembe, 2020). Exposure of such  
521 parcels to gullies therefore constitutes a major disaster for thousands of families.

522 Moreover, these property value reductions may further increase vulnerability and exposure to urban gullies.  
523 Once a parcel loses more than 50% of its value, many families have little choice but to remain, as selling to  
524 purchase elsewhere is no longer feasible. Field observations also revealed families purchasing land in hazard  
525 zones and building next to gullies because it was their only affordable option. This likely helps explain why  
526 observed value reductions near gullies are less pronounced in marginal zones (Fig. 10). Supporting this, Ilombe  
527 Mawe et al. (2025) found that over half of the estimated increase in population exposure to urban gullies in the  
528 DRC between 2010 and 2023 is due to growth within existing hazard zones.

529 At the city scale, the costs imposed by urban gullies are substantial. We estimate that they have already reduced  
530 real estate values by 979 million USD, or about \$1.11 million per gully. While subject to uncertainty, this likely  
531 underestimates the true costs. For instance, in marginal zones, our estimates only account for parcels actually  
532 destroyed, not for nearby properties that may have lost value, as our available price data showed no significant  
533 difference. Nevertheless, median purchase prices of built-up parcels within 30 m of a gully were roughly 40%  
534 lower if acquired after the gully approached compared to before (Fig. 10a). A larger dataset would likely reveal  
535 significant value reductions in these areas, potentially extending even further from the gully.

536 Similarly, our estimates for non-marginal zones are based on parcels with small, one-storey houses, the most  
537 common type in Kinshasa. Larger houses are not included, but they likely experience even greater value losses.



538 For example, [Lelo Nzuzi \(2008\)](#) reported that gully erosion damaged 68 villas in Kinshasa, resulting in costs  
539 exceeding \$27 million USD.

540 Moreover, our estimates only cover reductions in private property values and exclude damages to roads,  
541 schools, hospitals, and other infrastructure ([Kayembe wa Kayembe, 2020](#)), as well as the costs of large, top-  
542 down engineering initiatives, which often exceed one million USD per gully ([Miti & Aloni, 2005](#)). It is  
543 therefore reasonable to assume that total urban gully costs in Kinshasa alone exceed one billion USD.  
544 Meanwhile, 25 other cities in the DRC are also severely affected ([Ilombe Mawe et al., 2025](#)). These costs stand  
545 in stark contrast to current investment levels: for example, the national disaster and calamity reserve budget in  
546 2023 was only ~28 million USD ([Ministère du Budget, 2023](#)).

## 547 **5. Conclusions**

548 Urban gullies are a growing geo-hydrological hazard, yet their impacts have remained poorly quantified. This  
549 study provides the first city-scale assessment for Kinshasa, one of the most affected cities. We show that gullies  
550 frequently cause substantial material damage to parcels, houses, and other property. For the predominantly low-  
551 income households, these losses can represent a major reduction in income and are often associated with human  
552 tragedies.

553 Nearly all households within 100 m of a gully expressed concern, yet many underestimate the actual risks. This  
554 underestimation likely contributes to their vulnerability, but also to their willingness contribute to initiatives  
555 aiming to stabilize urban gullies. While most respondents invested in these initiatives, participation was higher  
556 among households at the gully edge than those living a few tens of meters away. Moreover, most efforts are  
557 small-scale, poorly coordinated, and often of limited effectiveness, constrained by budget restrictions and a  
558 limited understanding of actual risks and effective prevention strategies.

559 Urban gullies also cause massive reductions in property values, often exceeding 50% even before direct damage  
560 occurs. At the city scale, this amounts to a property value loss of at least 979 million USD. Given that a housing  
561 parcel represents the largest asset for many families, these losses further exacerbate poverty and vulnerability.  
562 These findings underscore the urgent need for coordinated and effective actions to stabilize existing gullies and  
563 prevent new ones. A better understanding of risk perceptions as well as the overall effectiveness of different  
564 gully control measures will be key in this.

565

## 566 **Data availability**

567 All data used in this study were either collected by the authors or obtained from publicly available sources. Due  
568 to privacy concerns, the datasets generated and analyzed during the current study are only available from the  
569 corresponding author on reasonable request.

570



## 571 Author contributions

572 **CRedit authorship contribution statement Eric Lutete Landu:** Writing – review & editing, Writing –  
573 original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.  
574 **Guy Ilombe Mawe:** Writing – original draft, Methodology, Data curation. **Elise Dujardin:** Writing – original  
575 draft, Visualization, Data curation. **Fils Makanzu Imwangana:** Writing – original draft, Supervision,  
576 Resources, Project administration, Funding acquisition. **Charles L. Bielders:** Writing – review & editing,  
577 Writing – original draft, Supervision, Resources, Methodology, Investigation, Funding acquisition, Data  
578 curation, Conceptualization. **Olivier Dewitte:** Writing – original draft, Methodology, Investigation, Funding  
579 acquisition, Conceptualization. **Jean Poesen:** Writing – original draft, Supervision, Funding acquisition,  
580 Conceptualization. **Caroline Michelier:** Writing – original draft, Visualization, Data curation. **Aurélia Hubert:**  
581 Writing – original draft, Supervision, Project administration. **Matthias Vanmaercke:** Writing – review &  
582 editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation,  
583 Funding acquisition, Formal analysis, Data curation, Conceptualization.  
584

## 585 Competing interests

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

588

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761 **Table A.1.** Exchange rate from USD to CDF (Source: Banque Centrale du Congo (BCC), 2022)

Year	USD	Franc Belge		Year	Zaire		Year	CDF	
		From	To		From	To		From	To
1932	1			1965			1997	155,0	110,0
1933	1			1966			1998	1,1	3,6
1934	1			1967			1999	2,5	4,6
1935	1			1968	50,0	50,0	2000	25,5	141,0
1936	1			1969	50,2	49,8	2001	313,5	311,6
1937	1			1970	49,8	49,0	2002	332,4	382,1
1938	1			1971	49,6	50,0	2003	372,5	372,6
1939	1			1972	50,0	50,0	2004	444,1	453,1
1940	1			1973	50,0	50,0	2005	453,1	431,3
1941	1			1974	50,0	50,0	2006	433,0	431,3
1942	1			1975	50,0	50,0	2007	540,2	503,0
1943	1			1976	50,0	56,6	2008	535,0	639,3
1944	1			1977	86,4	83,3	2009	710,4	902,7
1945	1			1978	82,4	76,9	2010	902,7	915,1
1946	1			1979	154,6	203,3	2011	930,5	914,0
1947	1			1980	201,9	300,5	2012	910,7	915,2
1948	1			1981	300,0	460,1	2013	916,0	926,6
1949	1			1982	550,0	469,1	2014	926,7	924,5
1950	1			1983	5,8	29,3	2015	924,0	928,0
1951	1			1984	31,6	40,4	2016	929,5	1215,6
1952	1			1985	41,9	55,1	2017	1240,1	1589,7
1953	1			1986	56,1	68,7	2018	1589,7	1632,8
1954	1			1987	79,0	130,3	2019	1637,2	1668,5
1955	1			1988	135,7	262,6	2020	1668,5	1971,8
1956	1			1989	291,8	455,0	2021	1971,8	
1957	1			1990	464,2	1710,8	2022		20500,0
1958	1			1991	2013,6	63,5			
1959	1			1992	72,1	1825,0			
1960	1			1993	2449250,0	37710000,0			
1961	1			1994	35,8	3275,7			
1962	1			1995	3621,3	15350,4			
1963	1			1996	18667,5	110773,5			
1964	1								

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763 **Table A.2** Detailed overview of estimated real estate losses at the scale of Kinshasa

Zone	Marginal Zones		Non-marginal zones					
	0 m from gully	0 m from gully and > 50 m from main road	0 m from gully and < 50 m from main road	0-50m from gully and >50 m from main road	0-50m from gully and <50 m from main road	50-100m from gully and > 50 m from main road	50-100m from gully and < 50 m from main road	
Average parcel value before gully (USD)	11589	48833	123571	46615	115000	46615	115556	
Average parcel value after gully (USD)	0	0	0	5307.692308	42400	14384.61538	57555.55556	
Average estimated zone value before gully (USD/m²)	22.07	75.36	215.89	72.22	250.61	74.36	341.82	
Average estimated zone value after gully (USD/m²)	0.00	0.00	0.00	9.59	80.56	25.11	146.83	
Area covered by broker surveys (ha)	0.0	50.9	2.8	202.6	16.6	223.9	20.8	
Area, not covered by broker surveys (ha)	368.3	52.2	3.8	362.4	15.2	442.3	14.9	
Total area (ha)	368.3	103.1	6.6	564.9	31.8	666.2	35.7	
Total value of area before gully (USD)	8.13E+07	7.77E+07	1.43E+07	4.08E+08	7.98E+07	4.95E+08	1.22E+08	
Total value of area after gully (USD)	0.00E+00	0.00E+00	0.00E+00	5.42E+07	2.56E+07	1.67E+08	5.24E+07	
Total value loss (USD)	8.13E+07	7.77E+07	1.43E+07	3.54E+08	5.41E+07	3.28E+08	6.96E+07	
Relative value loss	100.0%	100.0%	100.0%	86.7%	67.9%	66.2%	57.0%	

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