Response to the comments of Dr. Amaury Frankl (Reviewer 1)

We very much appreciate the detailed comments of Dr Frankl. These comments have helped us to improve the manuscript. Below we have repeated the comments followed by our responses. The changed text is highlighted in blue and for ease of reading, the deleted text is not displayed here.

Comment 1, Line 32: not the right reference to use for such a statement
Response 1: We have replaced to two references with Poesen et al. (2003).

Comment 2, line 39: do you mean by undercutting the slope?

Response 2: We have changed the paragraph as follows:
Gullying is a threshold-dependent process controlled by a wide range of factors (Valentin et al., 2005), including rainfall and flowing water, soil properties, and drainage area. Capra et al. (2009) and Campo et al. (2013) found that most of the gully erosion took place during heavy rainfall events, i.e., the storm events were one of the main drivers for gully erosion. The mechanic actions of the flowing water can result in a rapid mass movement in the gullies by undercutting the banks (See Fig. 1, Lanckriet et al., 2015).

Comment 3, line 43: refer to Vanmaercke et al., 2016, ESR instead.
Response 3: Vanmaercke et al., 2016 is referenced

Comment 4, line 50: For Ethiopia: Frankl et al., 2014; Integrated solutions for combating gully erosion in areas prone to soil piping: innovations from the drylands of Northern Ethiopia, LDD
Comment 4: Thank you, Frankl et al., 2014 is referenced.

Comment 5, line 55: not clear what you mean by this sentence. Is it important that ALL pipes are connected; are they not always connected, draining the slope? Rephrase or just remove
Response 5: we removed the sentence

Comment 6, line 57: also ad reference of Vanmaercke in Earth science reviews here. On a global scale, also rainfall normal plays an important role
Response 6: we added a citation of Vanmaercke et al., 2016 here

Comment 7, line 67: note here also that in my paper of 2011: Quantifying long-term changes in gully networks and volumes in dryland environments: The case of Northern Ethiopia, Geomorphology, I calculate the percentage of stabilized gullies to by about 25%, but that this mainly considers the first order gullies. You should add such details to your paper to allow the reader to fully understand the current knowledge
Response 7: We looked up the reference" A. Frankl, J. Nyssen, M. De Dapper, Mitiku Haile, P. Billi, R.N. Munro, J. Deckers, J. Poesen 2011. Linking long-term gully and river channel dynamics to environmental change using repeat photography (Northern Ethiopia).

Geomorphology 129: 238–251. We found that the publication mentioned 23% which is close to the 25%. We inserted the following text in the manuscript:

> "Frankl et al. (2011) found using repeat photographs taken between 2006 and 2009 that about 23% of the assessed gully sections were stabilizing. Similarly, Frankl et al. (2013) reported that low-active gully segments accounted for 25% of the gully network, which is attributed to the result of siltation behind check dams".

Comment 8, line 75: OR: in the humid region, high groundwater tables/ more interflow play an extra role. Not that the hydrology of the surface runoff is so different.
Response 8: the text is rephrased as:

> "Conservation structures that are effective in preventing gullying by overland flow in semi-arid regions (Nyssen et al., 2004a, 2006), may not be effective in the humid Ethiopian highlands regions where interflow elevates groundwater tables in the valley bottom that promote gully formation and expansion (Tebebu et al., 2010).

Comment 9, line 89: Hydro-
Response 9: reworded as hydro-geomorphology….The sentence reads now

> "The hydro-geomorphology of the Debre Mawi watershed is strongly controlled by geological settings. The lava dykes in the watershed affect the hydrology upslope, forcing subsurface flow to the surface resulting in saturated source areas for surface runoff (Abiy, 2009)."

Comment 10, line 92: no villages, roads, etc?
Response 10: We changed the sentence to include the village and the rural road from Bahir Dar to Adet (the old road linking Bahir Dar and Addis Ababa).

> "Soils are mainly Nitisols in the uplands, Vertisols in the bottom slopes, and Regosols on the steep hillslopes. 92% of the watershed is cultivated, 6% is rangeland and the remaining 2% is mainly covered by eucalyptus trees and shrubs, a small village and the road linking Bahir Dar with Adet. The small indigenous shrubs are predominantly found on the steep hillslopes.

Comment 11, line 116: do you only look at headcut retreat? or also at gully deepening and widening over the fully channel downslope? This should be clear from the text, and say also at what ground distance interval you measured gully cross-sections.
Response 11: The changed the text as follows:

> During the 2013 and 2014 monsoon rain phase, we made measurements of 13 gullies: (1) their headcut retreat (longitudinal growth) and bank widening (or lateral retreat) for the

first 10-30 m downslope from the headcut, and (2) the gully expansion rates and associated amount of soil loss along the total gully length.

To measure the headcut retreat and widening of the 13 gullies, the first 10 to 30 m of each gully was divided into 3 to 8 topographically uniform segments whose cross sections were surveyed. The average ground distance between two consecutive cross sections was 3.6 m and varied from 1 m to 10 m with a standard deviation of 2.68 m. This method is relatively precise, simple and low-cost compared with other methods (Casali et al., 2006, 2015). Gully cross-sectional geometry was surveyed by dividing each cross section into several trapezoidal segments at abrupt changes in profile, and measuring the width and depth of each segment (Fig. 3).

…….

Measurements were carried out repeatedly (about 8 times for large gullies to five times for small gullies or following large rainstorms, but not more than two weeks) using a tape meter and benchmark pins installed 5 to 10 m from the gully edges. However, a few gullies expanded more than this distance and the affected pins were reinstalled 5 to 10 m upslope of the newly formed gully bank.

Comment 12: line 147: I also calculated this in my ESPL paper: Factors controlling the morphology and volume (V)–length (L) relations of permanent gullies in the Northern Ethiopian Highlands

Tricky is however when the gully length you apply this equation on is much larger than the range on which it was computed; as it is very sensitive to large A - V datasets. Example, if you compute this for gully area ranges of 10 to 100 m², but apply it to 100 - 1000 m² gullies, your error marge will be huge, van you comment on this?

Response 12: Thanks, in any case, the surface area of the gullies in the study watershed were in the same range. The implication of the equation is discussed in the discussion section. Now the paragraph reads as follows:

“Gullies were digitized by determining the location of each gully in the watershed using a hand-held GPS with a horizontal accuracy of about 3 m in August 2013, after which its coordinates were imported into Google Earth to situate all gullies on the aerial imagery. The gully edges were then digitized using Google Earth’s polygon mapping tool. Finally, the digitized polygons were converted to shape-file format using ESRI’s ArcGIS software, which was also used to calculate the surface area and the length of each gully. Since gully volume could not be obtained from aerial measurements, it was derived from the digitized gully surface area through a surface area to volume, V_T, relationship (Eq. 4) that was obtained from the detailed measurements of the 62 representative trapezoidal segments of the 13 gullies whose surface area in 2013 ranged from 1 to 550 m^2 calculated using Eq. 2 and 3. Since Eq. 4 was developed in gullies found in the sub-humid

Debre Mawi watershed, it may not be applied for arid or semiarid regions (Frankl et al., 2013) where gullies have shallow bedrock depths that control the vertical growth of a gully.

Comment 13, line 149: ok for the range it was calculated for
Response 13: yes it is. We looked at the relationship and removed outliers in gully G6 and obtained a slightly better fitting relationship. We changed the paragraph as indicated in response 12 above.

Comment 14, line 155: what is 'near'? The distance to the headcut will obviously strongly affect the groundwater depth, and in vertisol, such measurments near to gullies are very variable. Would the occurrence of baseflow in the gully be more relevant, as then you know for sure that the gully is draining the groundwater table and that there will be interaction effects.
Response 14: We improved the text and the paragraph reads as:

> "Ground water elevation is believed to be one of the most important factors for gully formation and bank instability (Tebebu et al., 2010). Therefore, ground water depths were measured using a piezometer installed 5-10 m above each gully head. Intrusion of silt and sand to the piezometer was prevented by wrapping filter fabric around the 40 cm-long screened bottom end. All piezometers were capped to prevent rainwater entry and were set in concrete to prevent any physical damage. Groundwater table elevations were read using a measuring tape twice a day: in the morning and in the evening."

Comment 15, line 163: Which can be very problematic in an agricultural area where farmers try to modify surface runoff patterns to their convenience.
Response 15:
We agree. In the Debre Mawi watershed, however, the terrain is steep enough that we did not think it was a great problem

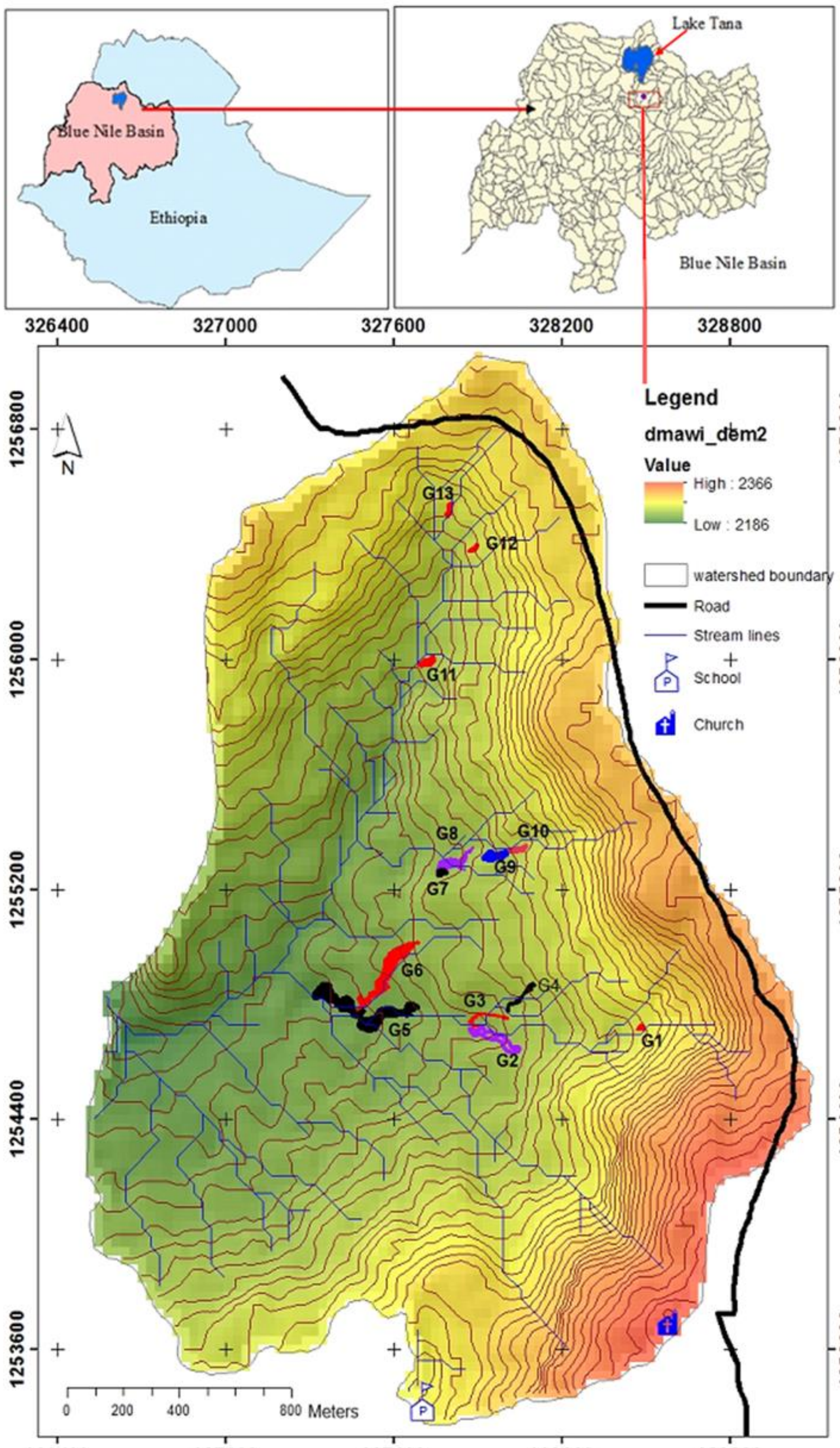
Comment 16, line 352: can you clearly show this from this study; the longer term erosion rate is 155 ton ha; what is on the 2013-2014 short term; much higher?
Response 16: The short term soil loss rate from the 13 gullies explained in Sect 3.2 is paraphrased as the first paragraph below. And the second paragraph in Sect. 4.4, describes the effectiveness of soil bunds in the watershed studied by our groups.

> "In this section we discuss the 13 gullies (G1-G13) in which physical dimensions were determined. They have a combined watershed area of 200 ha. Measurements were used from both aerial imagery (up to 23-3-2013) and manual measurement (2013-2014 rainy phases) (Table 2). The surface area of the thirteen gullies was 0.7 ha in 2005 and expanded to a total of 3.8 ha in 2014. The corresponding soil loss from these gullies was estimated at 175 thousand tons (Table 2). This is equivalent to 88 ±3 t ha^{-1} yr^{-1} (ranging from 10 to 384 t ha^{-1} yr^{-1} and SD was 101 t ha^{-1} yr^{-1} for the individual gullies). During the last two

years of the study (2013-2014), the area of land lost by the 13 gullies was 0.17 ha, which is about 11thosand tons of soil (of which about 80% or 43.3 t ha^{-1} was in 2013) which is equivalent to 27 t ha^{-1} yr^{-1}. The soil loss over the 2013-2014 period ranged from 1.8 t ha^{-1} yr^{-1} for gully G10 to 214 t ha^{-1} yr^{-1} for gully G6 and SD = 57 t ha^{-1} yr^{-1} (Table 2). In 2014, the headcuts of six gullies such as: G1-G3, G7, G10 and G13) were stable and hence reduced the annual soil loss."

"Our monitoring data also contained valuable information regarding the effectiveness of soil and water conservation measures such as soil bunds that were extensively installed across the upper portion of the catchment since 2012. Dagnew et al. (2015) in the same watershed reported that soil bunds reduced runoff by 60%, sediment concentration by 36% and sediment load by 80%, resulted in a significant reduction of runoff volume and sediment loads in the first two years of implementation while a reduction of sediment concentration was not significant due to the presence of large gullies near the watershed outlet. Further, the SWC measures (soil bunds), aimed to reduce the development of rills and gullies in the area, were implemented on saturated Vertisol areas, but have rather led to gully initiation and development (see Fig. 7f; Steenhuis et al., 2014, Dagnew et al., 2015). These soil and water conservation measures appear to be ineffective on these locations as they cannot reduce or stop upward headcut migration of gullies downslope, which requires alternative, structural measures. Similarly, diversion waterways have been tested in the watershed to arrest gully heads, but have produced new gully branches (Zegeye, et al., 2014). Our data therefore supports the findings of Dagnew et al. (2014, 2015), which indicate that the extensive implementation of soil and water conservation measures on periodically saturated Vertisols areas may have exacerbated, rather than mitigated gully formation and expansion".

Comment 17, Fig1: the drainage area mapping is not consistent with the watershed boundary, and poses a serious error to the work. Also, the map is very sterile, and not really worth looking at; really not much to see. No contour lines, no placenames, major roads, maybe slope gradients. Also, are all drainage lines gullies? What is a drainage line? Just an arcgis exercise? A scale bar stopping at 1100 m is strange. Debre Mawi is floating just somewhere? Why also leave the area next to the watershed blank? Is very uncommon for a map.
Response 17: We have prepared a new figure.



Lake Tana
Blue Nile Basin
Ethiopia
Blue Nile Basin
Legend
dmawi_dem2
Value
High : 2366
Low : 2186
watershed boundary
Road
Stream lines
School
Church
G1
G2
G3
G4
G5
G6
G7
G8
G9
G10
G11
G12
G13
N
0 200 400 800 Meters
326400
327000
327600
328200
328800
1256800
1256000
1255200
1254400
1253600

Fig1 (now Fig2). Location of the Debre Mawi watershed within the Blue Nile River basin, Ethiopia (top figures). The watershed map (bottom) shows the contour lines, elevation, stream lines, and the 13 studied gullies (indicated by the labels beginning with the letter G).

Comment 18, Fig 2a: I am a bit surprised that such good cover grows in a gully that changed shape so dramatically over only 3 months. When was the photo taken?

Response 18: My apologies, the picture was used only to show how the gully cross-section measurements were performed but this gully came from another locations where the cross-section was measured for other studies in 2010. So it is replaced by the actual measured gully in the Debre Mawi watershed as shown below.

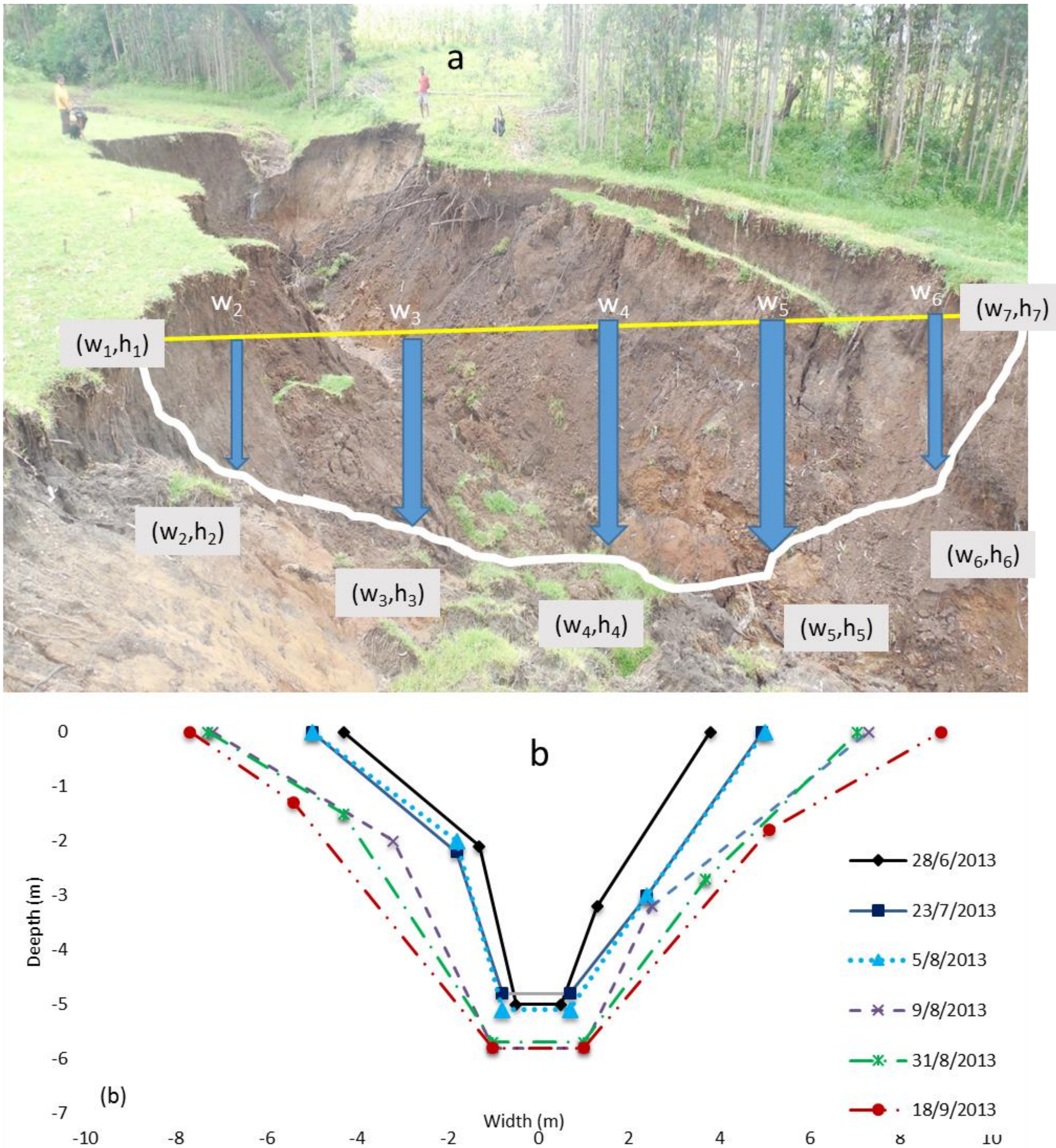


Fig 2 (now 3). (a) Cross section segmentation methodology to determine the cross-sectional area of the gullies. (b) Measured profiles of a cross-section located on gully G6 during the 2013 rainy season, showing the lateral and downward expansion of the gully.

Comment 19, Fig 2b: use: day/month/year system! according to journal style
Response 19: we adjusted as per the comment as shown in the figure above (response 18).

Comment 20, Fig 3: poor resolution. add what you explain as bottomland and so in the study area description, use consistent international system!, scale should use round numbers
Response 20: We have improved this figure.

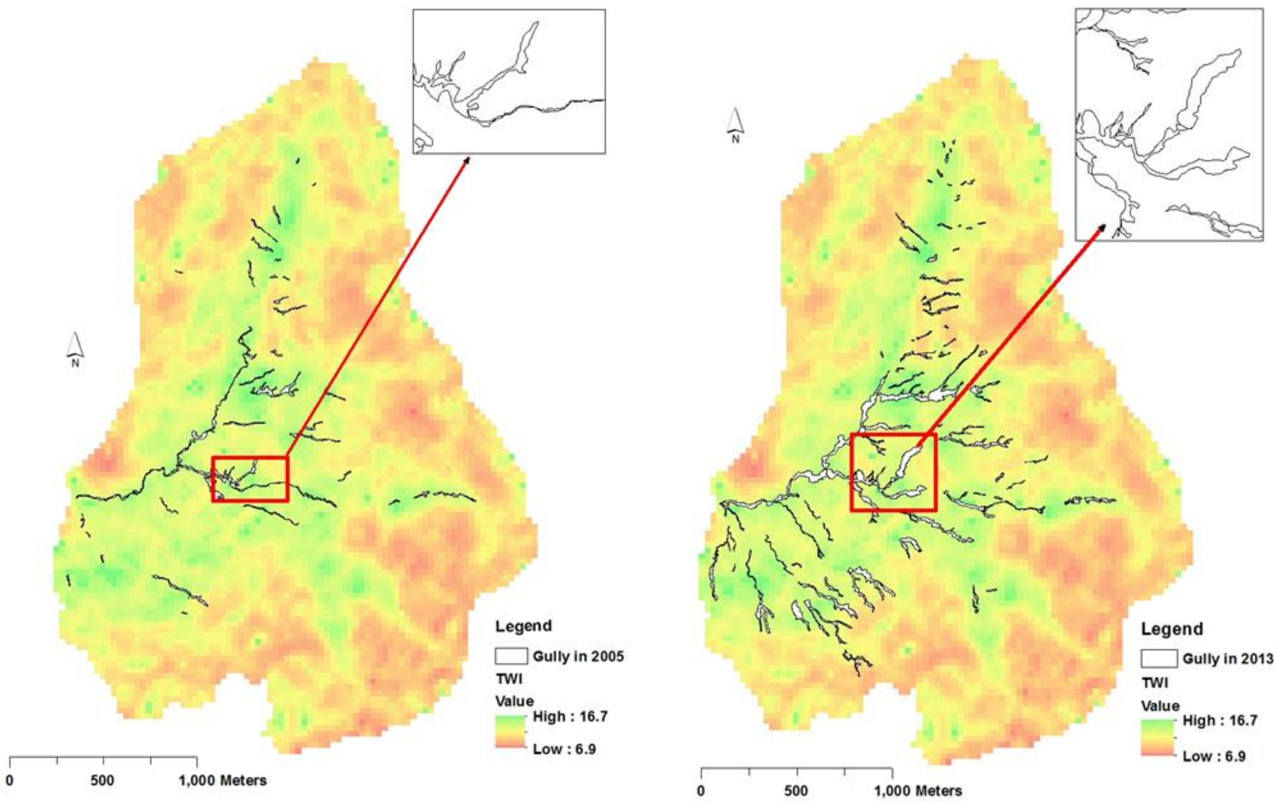


Fig3 (now4). The relationship between gully formation and topographic wet index (TWI), and gully expansion rate between (a) 2005 and (b) 2013 in the Debre Mawi watershed, Ethiopia. Lines represent gully edges digitized from aerial imagery.
Comment 21, Fig 4a: comm? Meaning
Response 21: It was to say "cumulative" but was wrongly abbreviated. So adjusted as a full word 'cumulative" (see response 22).

Comment 22, Fig 4b: there is no reason why the dots should be connected by a line, volume?
Response 22: We agree, it must have not been connected and now is disconnected as shown below. Volume was wrongly spelt as "volumee", now is spelt correctly

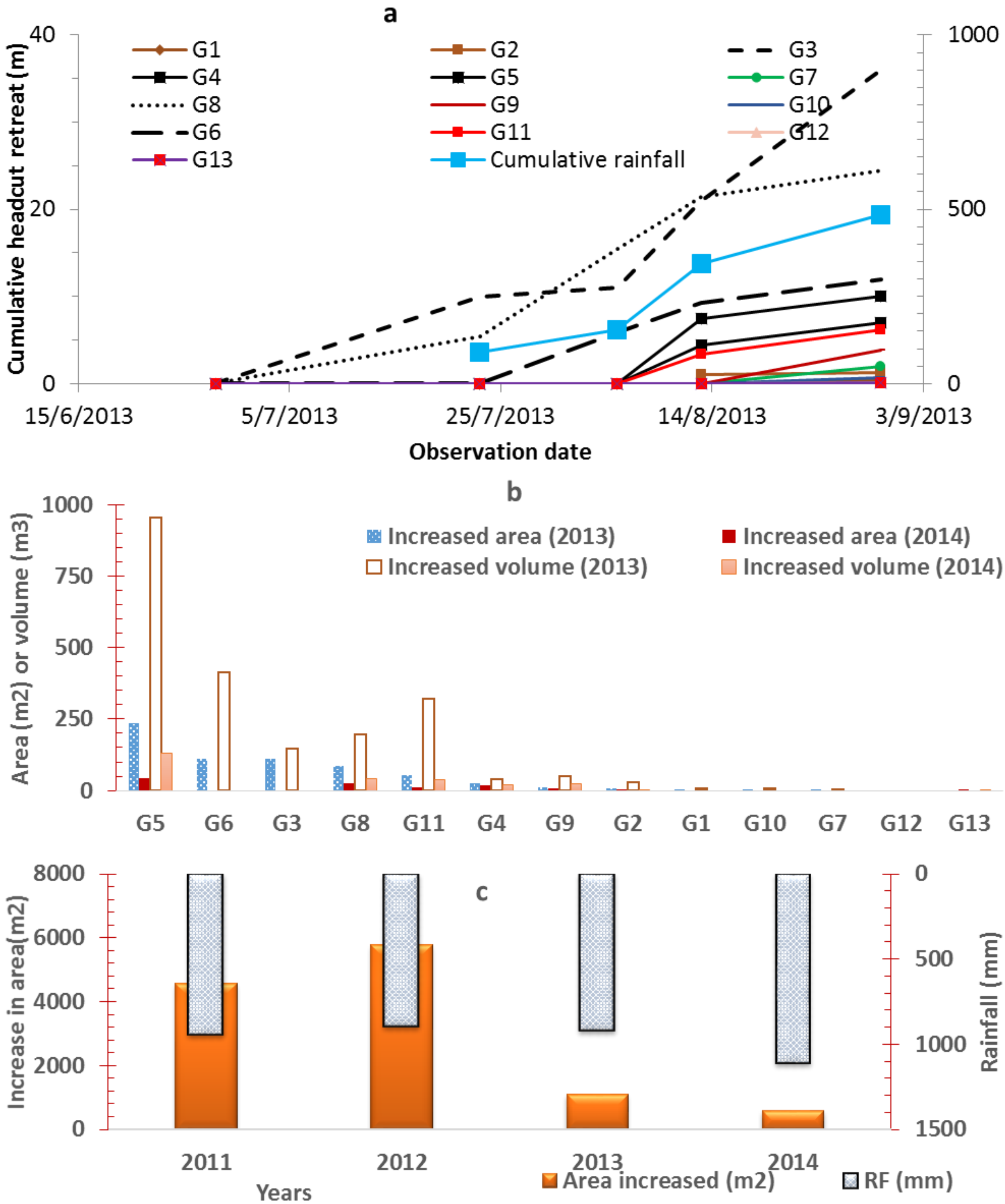


Fig. 4 (now 5). The observed expansion of the 13 study gullies in the Debre Mawi watershed (see Fig. 2 for gully location): (a) cumulative headcut retreat and rainfall during the 2013 rainy season, (b) increase in gully surface area and volume during the 2013 and 2014 rainy seasons, and (c) increase in the combined gully surface area and the total summer rainfall (RF) between 2011 and 2014.

Comment 23, Fig4c: maximum rainfall intensity might be more relevant to show than the total rainfall. why these dates 2011-2014, and not from 2005
Response 23: Total rainfall is likely a better predictor for predicting peak runoff in watersheds where saturation excess is the principal runoff mechanism. For the dates chosen (2011-2014) both the rainfall and the increase in area data were available.

Comment 24: Fig 5: what do we really learn from this? Are the days with baseflow not more relevant as related to headcut height than a seasonal minimum?
Response 24: We assumed that the seasonal minimum water table depth is a good indicator of a saturation of the surrounding soil. So, we could learn from the figure is that the ground water levels are all above the gully bottom indicating gully bank saturation, which can result in bank failure.

Comment 25, Fig 6-G6: remove space
Response 25: we removed (see figure 6 below)

Comment 26, Fig6-G11: stretched
Response 26: We corrected (see the below)

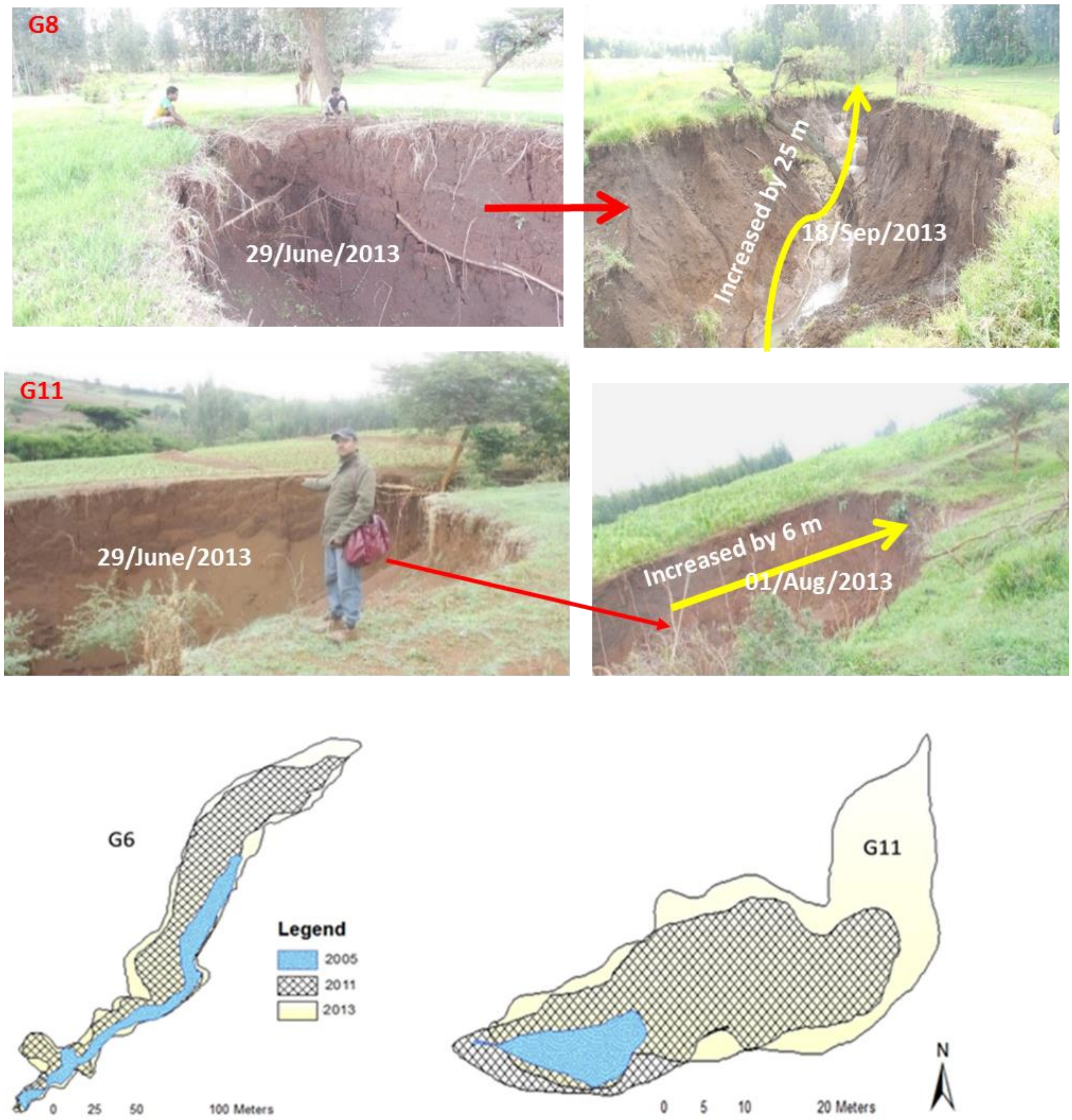


Fig. 6 (now 7). Examples of gully expansion in the Debre Mawi watershed: (Top photo) expansion of gullies G8 and G11 during the 2013 rainy season, the trees which were upstream of the two gullies felled down in to the gullies; (Bottom image) expansion of gullies G6 and G11 between 2005 and 2013.

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