Response to Review #1

We are grateful to Dr. I. Evans for his detailed and constructive review that will definitely help in improving our paper. We respond it by numbering the various comments to allow cross referencing. Our responses are in Italics. We also show text from the revised manuscript in quotation mark.

GENERAL COMMENTS

R01: Some of the writing is repetitive or vague. Re-writing of the paper is needed, more 'tightly' and with more precision, with focus on the main argument pointing toward conclusions, fuller explanation of the methods, and some change in the ordering. The core of the paper seems to be the relation of rockfall (past as inventoried, and potential future) to four units of the 7-unit slope model employed. This should be more fully presented and discussed. The rockfall modelling needs to be more closely related to the rockfall inventory and to the slope units.

We have considered the various suggestions written by reviewers and have accordingly rewritten the manuscript.

R02: Total rockfall volume per unit (landform class) should be tabulated, together with area of each unit.

Total rockfall volume per unit (landform class) and area of each unit have been added and tabulated (Table 3).

R03: There are quite a few grammatical and syntactic errors, most (but not all) of which are listed below: a revised paper needs to be very carefully checked.

We have carefully checked and revised the paper based on the referee comments and recommendations.

R04: References are appropriate and sufficient, and proper credit is given to related work.

We thank the referee for this comment.

SPECIFIC COMMENTS: number: page/line

R05: 21/5-14 This history does not seem to be relevant, or used below: cut?

Page 21 line 5-16 has been deleted. We have modified page 21 line 17.

"*The landform classification based on the genesis (Verstappen, 1983) and (Zuidam 1983) has been widely used in Indonesia."*

R 06: 22/15 Is eq. (1) used below? Any examples of its application?

We used *eq. (1) to show the relation of quantitative rockfall statistics to four units of the 7-unit slope model. Since the equation uses* $P(L)_{jkm}$*, as temporal probability (exceedance probability) of rockfall in the magnitude scenario (i.e. boulder volume) class j and crossing landform k for different period m, we would like to introduce the importance of landform classification in rockfall risk assessment. This explains the importance of landform*

classification and rockfall statistics in rockfall risk assessment. Detailed rockfall risk assessment (as an application) is not applied in this paper. However, we feel that eq. 1 offers an important lead to the usefulness of four units of the 7-unit slope model in preliminary risk assessment. As such we have kept it.

R07: 23/19 I do not think the 9-unit model "explains. . ."

This has been modified.

"it is also relevant for preliminary rockfall risk zoning"

R08: p.26 and Fig. 5: are the rockfall volumes all for single boulders, or are some for groups of boulders?

Rockfall volumes are for single boulders.

R09: 27/26 are convex creep slopes REALLY potential rockfall sources? Mainly "Fall Face"?

Additional discussion has been added in the text. We considered convex creep slopes as potential rockfall sources because we found several cracks in it.

"Considering that its position is adjacent to fall face, convex creep slopes and the upper part of fall face are the most potential for rockfall sources. A big boulder, which potentially fall, could be a part of convex creep slope and a part of fall face."

R10: 28/18-19 Further discussion of assumptions would be useful.

Additional discussion has been added in the text.

"Velocity and energy of rockfall, as a result of gravitational slope phenomena, may be spatially correlated. Those which are closer tend to be more alike than those that are farther apart. The spatial autocorrelation can be performed with geostatistical techniques to overcome this issue."

R11: 28 "shape complexity" needs further definition/ explanation. In Fig. 3(d) it is simply contour / altitude layers, so how can it be useful?

We have modified page 29 line 1-5.

"It was calculated using perimeter to boundary ratio of sliced feature. SCI indicates how oval feature is. Low value of shape complexity index represents how simple and compact a feature is. It predominantly influences the spatial distribution of the interfluves which has low value around 1. It means that interfluves are more oval while convex creep slope and fall face are more longitudinal. Its effect on the other landforms is not apparent because the value of the shape complexity index in lower slope is relatively homogeneous i.e. 4-5."

R12: 32/16-22 this section should come earlier, perhaps p. 26?

OK. Page 32 line 16-22 has been moved to p. 26.

R13: 32/23 – 33/7 How is this Poisson model used in this paper? Drop or apply.

OK. We have dropped it.

R14: 33/25 – 34/10 Most of this justification (for reducing 9 units to 7) should come earlier

OK. We have moved page 34 line 2-8 to page 26 line 11.

R15: Table 3 I am very surprised that there are 53 rockfall deposits on the Fall Face: please discuss.

Additional discussion has been added in the text 29/24.

"Rockfall deposited on the Fall Face are mostly found in the southern part of Gunung Kelir area. There are 47 rockfall boulders in the southern part. Southern fall face has gentler slope and softer rock than in the northern part. Gully erosion can be found in this place due to weathering and erosion. Small volumes of rockfall are mostly deposited in gullies. Those are stopped and trapped due to local surface affected by weathering and erosion. However 12.5 m contours cannot draw this phenomenon. Better resolution of DTM may be useful."

R16: Table 3 and Fig. 6: All the R2 coefficients are very high, but given the great range of rockfall volumes inventoried, this is achieved by truncating over half the logarithmic range, using thresholds of 2 to 11 m2 for the sections fitted. Table 3 should at least give the actual numbers used for the fits.

The actual number used for the fits has been added in Table 3.

R17: Fig 4 and Fig. 5 cannot readily be compared, but it is highly desirable that the pattern of rockfall should be compared with that of slope units. The areas covered seem to differ: if Fig. 5 covers the right side of Fig.4, there seems to be some inversion or transposition.

We added Fig. 5 in order to easily compare the pattern of rockfall with slope units. An insert has also been added to avoid misinterpretation.

R18: Likewise Fig. 1(d) shows "elements at risk", but how can this distribution be compared with that of boulders?

We have added Fig. 5 in order to show the elements at risk compared to the boulders and slope units.

R19: Fig. 6: Please comment on the discontinuities, at 150 for "colluvial foot slope" and 500 for "transportational middle slope".

The absent of rockfall volumes (discontinuities) in the interval 104.9 m^3 to187.8 m^3 for colluvial foot slope and 282.6 m^3 to 823.7 m^3 for transportational slope is real data. It is difficult to judge the reason behind it. However, we pay attention and relate it to the threshold of the minimum volume (around 500 m^3), classified as large boulder, falling from the source. The large boulder may be induced by great power, such as earthquakes. So we presume that the larger boulders are earthquake induced rockfall. However, there is no historical record available in this place. Dendrogeomorphology and geomorphological dating may be beneficial to overcome this issue. The discontinuities may also be affected by local surface of each generic landforms. Further field investigation and experiment should be conducted to answer this issue.

R20: Fig. 6; Presumably the green diamond masks a brown triangle for the largest "transportational middle slope" rockfall?

It seems that the green diamond masks a brown triangle because those have a small difference value. However, the actual volume is 3627 m^3 and 3600 m^3 for lower slope and transportational middle slope respectively.

TECHNICAL CORRECTIONS, DETAILS: "quote from paper" 'my suggestions'

R21: 20/4-5 the sentence "DTM pre-processing. . ." seems unnecessary – it can be 'taken as read'

OK. We deleted it.

R22: 20/5 'solely' would be better than "merely"

OK.

R23: 20/8-9 'landforms into seven. . .' [i.e. delete ". It was classified"

OK.

R24: 20/10-11 reword the sentence "The classification. . ." (as this does not "analyse" the classification)

We have reworded the sentence.

"*We draped the generic landforms over DTM and derived a power law statistical relationship between the volume of the rockfall deposits and number of events associated with different landforms."*

R25: 21/1 replace "mounds and" with 'the'

OK.

R26: 21/3 'maps'

OK.

R27: 21/14 'Verstappen'

OK.

R28: 21/22 'geomorphological'

OK.

R29: 21/23 'detailed geomorphological'

OK.

R30: 22/5 'definition was'

OK.

R31: 22/6 'terminology was'

OK.

R32: 22/7 start new paragraph

OK.

R33: 22/23 and 25 move ")" to after "bed" and delete :

OK.

R34: 23/16 ‘automatically’

OK.

R35: 24/1 ‘van Bemmelen’

OK.

R36: 24/1 replace repetitive “The evolution of K P Dome was” with ‘It’

OK.

R37: 24/2 ‘with’, not “by”

OK.

R38: 24/2 ‘geosyncline’?

OK.

R39: 24/5 ‘consisting of . . . dacite intrusions.’

OK.

R40: 24/6 ‘the Menoreh’

OK.

R41: 24/8 ‘dacitic’ ‘hornblende andesite’

OK.

R42: 24/9 delete “was”

OK.

R43: 24/10 ‘and the J. . .F. . . was formed by coral . . .’

OK.

R44: 24/12 ‘jointing and large cracks. . .’

OK.

R45: 24/17-18 delete repetitious “slope gradient . . .meanwhile” also “of”

OK.

R46: 24/20 add ‘(Fig. 1d)’

OK.

R47: 24/23 ‘geomorphological’

OK.

R48: 24/26 ‘classification based on the 9-unit’

OK.

R49: 25/14 “paddy terraces” needs definition. [also spelled ‘padi’ ?] Also, state the interpolation method that produced these [bilinear?]

We have revised the text.

“Padi terraces are usually caused by interpolation method and located in closed contour where all the surrounding pixels were assigned the same elevation value. Five meter resolution of DTM was produced by interpolation, using ILWIS linear interpolation method, from a 1:25.000 Topographical Map 1999 with contour interval 12.5 m and elevation data from DGPS profiling.”

R50: 25/16 ’12.5 m’ delete “the”

OK.

R51: 25/23 ‘by a’

OK.

R52: 25/27 delete ‘parameter’

OK.

R53: 25/29 ‘and based’

OK.

R54: 26/10 replace “modified” by ‘The’ and “applied” by ‘modified’

OK.

R55: 26/11 replace “into a” by ‘for the’ Briefly justify the exclusion.

OK. We have added an additional discussion to justify the exclusion.

"Channel wall was also modified as lower slope. Since the study area is located in the upper part of Kulon Progo Dome, the depositional process of alluvium does not work in such an area. Seepage slope was merged with interfluves because both are more related to pedogeomorphic process rather than gravitational process."

R56: 26/14 delete “volume obey a negative power law scaling”

OK.

R57: 26/15 delete “the”

OK.

R58: 26/21 ‘estimate the’ Delete after “value.”

OK.

R59: 27/3 delete “a”

OK.

R60: 27/8 ‘maps’

OK

R61: 27/12-14 sentence repeats 25/14

OK, we have deleted it and modified the first paragraph.

"*The result of DTM pre-procesing shows that padi terraces still exist where the sampling point of elevation data are unavailable."*

R62: 27/15 "sampling. . . are absent" makes no sense : please reword

We have reworded 'sampling. . . are absent' to "sampling point of elevation data are unavailable."

R63: 27/18 delete 'those'

OK.

R64: 27/24-25 more repetition. . .

OK, we deleted it.

R65: 27/26 'creep slopes'

OK.

R66: 27/28 'reaches'

OK.

R67: 28/4 'to a' replace "It" with 'This'

OK.

R68: 28/9-10 reword

We have reworded the sentence.

"Prior to morphometric variables selection, knowledge of rockfall process in relation to generic landforms should be utilized."

R69: 28/11 delete "The"

OK.

R70: 28/16 'secondary derivatives'

OK.

R71: 28/17 'derivatives (i.e. . . .aspect angle). . .'

OK.

R72: 28/22 not "rather" but 'very' !

OK.

R73: 28/23 'are influenced by'?

We have revised the sentence 'Both velocity and energy of rockfall influence the area of fall face, transportational middle slope and colluvial footslope.' to "Both velocity and energy of rockfall are mostly influenced by slope geometry, coefficient of restitution, and friction angle."

R74: 28/25-26 ‘movements, meaning that the rockfall boulders are deposited there.’

OK.

R75: 28/28 delete the strange sentence “It forms . . . channel.”

OK.

R76: 29/1 I do not understand.

We have revised and added additional discussion about SCI.

“*It was calculated using perimeter to boundary ratio of sliced feature. SCI indicates how oval feature is. Low value of SCI represents how simple and compact a feature is. SCI predominantly influences the spatial distribution of the interfluves, which has low value around 1, meaning that interfluves are more oval while convex creep slope and fall face are more longitudinal.”*

R77: 29/2-3 this is not what Fig. 3(d) shows. . .

We have revised and added additional discussion about SCI. Additional discussion explains what Fig. 3(d) shows.

“*It was calculated using perimeter to boundary ratio of sliced feature. SCI indicates how oval feature is. Low value of SCI represents how simple and compact a feature is. SCI predominantly influences the spatial distribution of the interfluves, which has low value around 1, meaning that interfluves are more oval while convex creep slope and fall face are more longitudinal.”*

R78: 29/6 This is a truism: cut?

OK

R79: 29/11-15 This does not seem helpful or relevant. Cut?

OK

R80: 29/19-20 ‘exhibits’

OK.

R81: 29/22 ‘statistics’ Reword whole heading.

We have reworded the whole heading into “Rockfall Statistics and Landform”

R82: 29/23 replace “obtained from a” with ‘in our’. [I hope that is true !]

OK, we have replaced “obtained from a” with ‘in our’.

R83: 29/24-25 reword

OK. We have reworded the sentence.

"Rockfall statistics observed based on the main landforms corresponding to rockfall deposition...."

R84: 29/25-28 combine sentences

We have combined the sentences.

"Rockfall statistics observed based on the main landforms corresponding to rockfall deposition, i.e. fall face, transportational middle slope, colluvial foot slope and lower slope indicates that the observed distributions for 53, 211, 199, 58 events larger than 2 m^3, 11 m^3, 10 m^3, 11 m^3 are well fitted by a power laws with b = 0.58, 0.73, 0.68, 0.64 respectively."

R85: 29/27 'distributions'

OK

R86: 29/ 28 'by power laws with. . .'

OK

R87: 30/2 'of the boulder'

OK.

R88: 30/4 'to the rollover'

OK.

R89: 30/12 delete 'the'

OK.

R90: 30/13 move first bracketed numbers to after 'higher b values'

OK.

R91: 30/14 'is a'

OK.

R92: 30/21 delete "compared to another landform"

OK.

R93: 30/22 'events'

OK.

R94: 30/25 'surface,'

OK.

R95: 30/26 'variables,' Delete "in a generic landform". Replace "Formerly," with 'Initially'

OK.

R96: 31/1 'slope (Table 3). But the trend only' [?]

OK

R97: 31/5 'frequency of'

OK.

R98: 31/16 'orders of'

OK.

R99: 31/19 'volume of rockfall deposits'

OK.

R100: 31/20 give actual volumes

OK. The actual volumes are 3626.97 m^3 and 372.84 m^3. We now write:

"However, it indicates a long missing gap between the largest boulder (3626.97 m^3) and the second largest boulder (372.84 m^3)."

R101: 31/22 'magnitude on lower'

OK.

R102: 31/25 'than on'

OK.

R103: 32/1 delete second "the"

OK.

R104: 32/1 'hazards'

OK.

R105: 32/2 'from' not "on"

OK.

R106: 32/5 'approaches'

OK.

R107: 32/5-6 delete vague sentence "Furthermore. . ."

OK.

R108: 32/7-8 Delete "Fall face . . . lower slope" Move 'each exhibits scale specificity' to follow "respectively" on line 10.

OK.

R109: 32/11 'statistics' Also reword sentence: "can pose" ???

We have reworded it.

"Automated landform analysis and rockfall statistics can estimate the likelihood of rockfall magnitude in a specific landform."

R110: 32/14-16 delete repetitive sentence "It . . . landform."

OK.

R111: 32/24 'rockfalls'

OK.

R112: 33/13-14 'it will improve cost efficiency by optimizing design.' [-that is how it affects the budget. . .]

OK.

R113: 33/15 'on landforms'

OK.

R114: 33/22 ‘a reasonable’

OK.

R115: 34/6 ‘in such an area’

OK.

R116: 34/7 ‘because both are more related. . .’ [i.e. delete “interfluves . . . classification is”]

OK.

R117: 34/11 ‘similar genesis’

OK.

R118: 37 Table 1: These coefficients need fuller definition, probably in the text.

We have added an additional discussion in 25/27 about normal and tangential restitution.

“There were two coefficients of restitution, i.e. normal restitution (R_N) and tangential restitution (R_T), employed in the model (Table 1). Normal restitution acts in a direction perpendicular to the slope surface and tangential restitution acts in a direction parallel to the surface during each impact of the incoming velocity of the rocks. Velocities change because of the energy loss defined by both of which. We determined normal restitution and tangential restitution by geological map representing elasticity of the surface material and landuse map representing vegetation cover and surface roughness respectively.”

R119: 38 Table 2 Why does “colluvial foot slope” have energy but not velocity? Other units have either both zero or both positive.

It was a mistake. Velocity in foot slope has been retyped to 10.

R120: 39 Table 3 Error margins on the b coefficients would aid their interpretation in the text.

We have added error margins in the Table 3

R121: 40 Fig. 1 (d) ‘Gunung Kelir area viewed from . . .[direction] : red rectangles are elements (buildings and roads) at risk.

OK

R122: 41 Fig. 2 These tiny ‘postage stamp’ illustrations are difficult to read: cut or redesign?

OK, we cut it.

R123: 42 Fig.3 Note the contoured pattern of “shape complexity”, and the almost identical patterns of velocity and energy

Since SCI was calculated based on contour interval, its pattern will be identical to the contour pattern. We have revised and added additional discussion about SCI.

“*It was calculated using perimeter to boundary ratio of sliced feature. SCI indicates how oval feature is. Low value of SCI represents how simple and compact a feature is. SCI predominantly influences the spatial distribution of the interfluves, which has low value*

around 1, meaning that interfluves are more oval while convex creep slope and fall face are more longitudinal."

Energy was calculated based on velocity. Thus, both are identical. However, energy and velocity represent different value influencing the result of automated landform classification.

R124: 43 Fig. 4 "Interfluve" areas seem more like plateau.

Yes it is. It shows small conical hill represented by closed contour. There is also an error called as "flattening" topography in the interfluves which make it seems more like plateau (27/12-19).

R125: 44 Fig. 5 This is very useful, but could it be paired with a map of land units at the same scale? It is difficult to compare a map with (Fig. 4) a perspective view.

We have added Fig. 5 in order to show the elements at risk associated with boulders and generic landforms.

Table 1. Coefficient restitution of surface type

Surface Types	R_N	R_T
Sandstone face	0.53	0.9
Vegetated soil slope	0.28	0.78
Soft soil, some vegetation	0.30	0.3
Limestone face	0.31	0.71
Talus cover with vegetation	0.32	0.8

Table 2. Class centres for each morphometric variable

Landforms	Slope (%)	PlanC	SPI	SCI	Energy (kJ)	Velocity (m/s)
Interfluve	0	0	1.0	0	0	0
Convex creep slope	6.0	5.0	3.0	5.0	0.5	0.2
Fall face	40.0	-2.0	50.0	5.5	800.0	20.0
Transportational mid. slope	10.0	-1.0	30.0	7.2	1800.0	30.0
Colluvial foot slope	4.0	2.0	15.0	5.0	400.0	10.0
Lower Slope	5.0	2.0	75.0	5.0	0	0
Channel bed	5.0	-5.0	400.0	3.0	0	0
Std/variation	5.79	4.30	158.1	1.4	138.9	3.0

Table 3. Characteristic of rockfall volume distribution in Gunung Kelir

Generic Landform	Area, km^2	N_{events}	V_{total}, m^3	V_{range}, m^3	V_{fit}, m^3	N_{fit}	b_{lr}	R^2	Error margin*
Fall Face	0.11	53	513.49	$18x10^{-4}$-$1.0x10^{2}$	2-$1.0x10^{2}$	28	0.58	0.98	0.046
Transportational Middle Slope	0.06	211	9627.59	$39x10^{-4}$-$3.6x10^{3}$	11-$3.6x10^{3}$	63	0.73	0.99	0.022
Colluvial Foot Slope	0.1	199	6287.16	$37x10^{-4}$-$4.8x10^{2}$	10.5-$4.8x10^{2}$	70	0.68	0.99	0.019
Lower Slope	4.18	58	5004.30	$21x10^{-4}$-$3.6x10^{3}$	11-$3.6x10^{3}$	21	0.64	0.97	0.071

* Assumes a 95 % level of confidence

List of Figure Captions