Supplement: Enhancing disaster risk resilience using greenspace in urbanising Quito, Ecuador

C. Scott Watson[1], John R. Elliott[1], Susanna K. Ebmeier[1], María Antonieta Vásquez[2], Camilo Zapata[2], Santiago Bonilla-Bedoya[3], Paulina Cubillo[4], Diego Francisco Orbe[4], Marco Córdova[5], Jonathan Menoscal[5], Elisa Sevilla[2]

[1]COMET, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK.

[2]College of Social Sciences and Humanities, Universidad San Francisco de Quito, Quito 170901, Ecuador.

[3]Research Center for the Territory and Sustainable Habitat, Universidad Tecnológica Indoamérica, Machala y Sabanilla, 170301, Quito, Ecuador.

[4]Centro de Información Urbana de Quito - CIUQ, Quito, Ecuador. - pcubillo@ciuq.ec, - dorbe@ciuq.ec

[5]Facultad Latinoamericana de Ciencias Sociales - Flacso, Quito, Ecuador. - mcordova@flacso.edu.ec

Correspondence to: C. Scott Watson (c.s.watson@leeds.ac.uk)

Supplementary Table 1. Random Forest classification parameters

Parameter	Value
Orfeo Toolbox Version	7.1.0
Maximum tree depth	15
Minimum samples in each node	10
Maximum number of trees in the forest	200

Supplementary Table 2. Tri-stereo Pleiades 1A and 1B satellite Panchromatic (P) and Multispectral (MS) imagery acquisitions over Quito

Acquisition ID	Incidence angle	Incidence angle along track	Incidence angle across track
PHR1B_P_201911051539138_SEN_5226204101-1	17.3	13.0	11.7
PHR1B_P_201911051538569_SEN_5226205101-1	14.1	2.9	13.8
PHR1B_P_201911051538363_SEN_5226203101-1	18.7	-9.6	16.3
PHR1A_P_202007281543126_SEN_5226201101-1	16.0	15.9	2.1
PHR1A_P_202007281542408_SEN_5226202101-1	6.9	-3.2	6.1
PHR1A_P_202007281542286_SEN_5226200101-1	12.9	-10.5	7.7
PHR1A_P_202006061542505_SEN_5226222101-1	15.4	14.8	4.2
PHR1A_P_202006061542505_SEN_5226219101-1	15.0	14.7	3.4
PHR1A_P_202006061542505_SEN_5226216101-1	15.4	14.9	4.1
PHR1A_P_202006061542345_SEN_5226223101-1	8.2	5.4	6.2

PHR1A_P_202006061542345_SEN_5226220101-1	7.6	5.4	5.5
PHR1A_P_202006061542345_SEN_5226217101-1	8.1	5.4	6.2
PHR1A_P_202006061542001_SEN_5226221101-1	18.3	-15.4	10.5
PHR1A_P_202006061542001_SEN_5226218101-1	18.2	-15.5	10.0
PHR1A_P_202006061542001_SEN_5226215101-1	18.3	-15.3	10.5
PHR1A_P_202002091550109_SEN_5226213101-1	18.0	10.0	-15.3
PHR1A_P_202002091549474_SEN_5226214101-1	13.1	-4.3	-12.5
PHR1A_P_202002091549241_SEN_5226212101-1	20.1	-18.0	-9.5
PHR1A_P_202001281542515_SEN_5226210101-1	16.9	16.8	1.7
PHR1A_P_202001281542515_SEN_5226207101-1	17.1	17.0	1.9
PHR1A_P_202001281542169_SEN_5226211101-1	7.2	-3.7	6.1
PHR1A_P_202001281542169_SEN_5226208101-1	7.4	-3.7	6.4
PHR1A_P_202001281542033_SEN_5226209101-1	14.2	-12.0	7.9
PHR1A_P_202001281542033_SEN_5226206101-1	14.3	-12.0	8.1
PHR1B_MS_201911051539138_SEN_5226204101-2	17.3	13.0	11.7
PHR1B_MS_201911051538569_SEN_5226205101-2	14.1	2.9	13.8
PHR1B_MS_201911051538363_SEN_5226203101-2	18.7	-9.6	16.3
PHR1A_MS_202007281543126_SEN_5226201101-2	16.0	15.9	2.1
PHR1A_MS_202007281542408_SEN_5226202101-2	6.9	-3.2	6.1
PHR1A_MS_202007281542286_SEN_5226200101-2	12.9	-10.5	7.7
PHR1A_MS_202006061542505_SEN_5226222101-2	15.4	14.8	4.2
PHR1A_MS_202006061542505_SEN_5226219101-2	15.0	14.7	3.4
PHR1A_MS_202006061542505_SEN_5226216101-2	15.4	14.9	4.1
PHR1A_MS_202006061542345_SEN_5226223101-2	8.2	5.4	6.2
PHR1A_MS_202006061542345_SEN_5226220101-2	7.6	5.4	5.5
PHR1A_MS_202006061542345_SEN_5226217101-2	8.1	5.4	6.2
PHR1A_MS_202006061542001_SEN_5226221101-2	18.3	-15.4	10.5
PHR1A_MS_202006061542001_SEN_5226218101-2	18.2	-15.5	10.0
PHR1A_MS_202006061542001_SEN_5226215101-2	18.3	-15.3	10.5
PHR1A_MS_202002091550109_SEN_5226213101-2	18.0	10.0	-15.3
PHR1A_MS_202002091549474_SEN_5226214101-2	13.1	-4.3	-12.5
PHR1A_MS_202002091549241_SEN_5226212101-2	20.1	-18.0	-9.5
PHR1A_MS_202001281542515_SEN_5226210101-2	16.9	16.8	1.7
PHR1A_MS_202001281542515_SEN_5226207101-2	17.1	17.0	1.9
PHR1A_MS_202001281542169_SEN_5226211101-2	7.2	-3.7	6.1
PHR1A_MS_202001281542169_SEN_5226208101-2	7.4	-3.7	6.4
PHR1A_MS_202001281542033_SEN_5226209101-2	14.2	-12.0	7.9
PHR1A_MS_202001281542033_SEN_5226206101-2	14.3	-12.0	8.1

Supplementary Table 3. Safe spaces identified by the Metropolitan District of Quito (DMQ). A list of 79 safe spaces was shared by DMQ over Twitter on 18 May 2016 (link below). Although details on these spaces were lacking at the time of writing, we matched geographic locations to 66 of these safe spaces for use in our analysis.

Safe space name	Type	Area (m2)
CENTRAL DE CARCELEN - BEV	Park	70,650
CARDENAL DE LA TORRE	Park	19,889
EUGENIO ESPEJO	Park	9,838
EXPLANADA DE LA UNIDAD EDUCATIVA MUNICIPAL		38,736
PLAZA QUITUMBE		192
ESTADIO LA HOSPITALARIA		9,124
LA BOMBONERITA	Recreation ground	10,840
UTAQ	Recreation ground	60,514
COMPLEJO DE PELOTA NACIONAL		11,330
PLAZA SAN BLAS		3,255
EL ARBOLITO	Park	36,187
INGLES	Park	56,669
LA MOYA	Park	65,961
DE LA VINCENTINA	Park	1,395
COOP 14 DE ENERO	Recreation ground	17,504
PARQUE CENTRAL DE LA COMUNA DE SAN MIGUEL		1,418
PLAZA GRANDE		7,412
MERCADO DE LLANO GRANDE		28,977
METROPOLITANO ARMENIA (LUCIANO ANDRADE MARIN)	Park	483,710
ISLA SEYMUR		23,488
BICENTENARIO	Park	1,376,996
LA PAMPA	Park	25,214
LAS CUADRAS	Park	198,569

Safe space name	Type	Area (m2)
YAHUACHI	Park	3,113
LIGA BARRIAL LA VICENTINA	Recreation ground	7,135
CAUPICHO	Park	41,517
PLAZA SAN FRANCISCO		6,916
METROPOLITANO NORTE GUANGUILTAGUA	Park	5,579,186
RESERVORIO CUMBAYA	Park	27,705
JAIME SALVADOR BORJA	Park	4,418
ITCHIMBIA	Park	583,832
BATALLÓN CHIMBORAZO	Park	11,618
SIMON BOLIVAR - LA ALAMEDA	Park	61,208
PARQUE DE TRATAMIENTO PUENGASI		318,137
SAN JUAN DE CONOCOTO	Recreation ground	6,426
DE LA MUJER Y EL NIÑO	Park	64,699
LA CAROLINA	Park	612,983
LA LUZ	Recreation ground	8,614
SIXTO MARIA DURAN	Park	7,054
ESTADIO LIGA ORIENTAL	Recreation ground	14,809
CONCEPCIÓN SUR		1,987
ANDALUCIA	Park	5,941
ESTADIO TOLONTAG	Recreation ground	16,765
LA BATEA B	Recreation ground	11,414
TERESA DE CEPEDA	Park	12,599
17 DE JULIO	Park	6,288
JULIO MATOVELLE	Park	10,390
EL EJIDO	Park	133,064
4 DE DICIEMBRE	Recreation ground	3,976

Safe space name	Type	Area (m2)
PLAZA SANTO DOMINGO		5,021
CUARTEL EPLICACHIMA		157,287
LA RAYA	Park	97,556
DE LAS DIVERSIDADES	Recreation ground	14,853
OBRERO INDEPENDIENTE	Park	10,617
PARQUE METRO		9,926
PLAZA CHICA		454
EINSTEIN	Recreation ground	17,937
ESTADIO CHIMBACALLE	Recreation ground	23,647
SOLANDA S2	Park	13,757
ECOLOGICO SOLANDA	Park	25,550
NUEVA AURORA	Park	51,024
LIGA BARRIAL SOLANDA	Recreation ground	29,534
METROPOLITANO DEL SUR	Park	6,669,206
BELLAVISTA ESTADIO	Park	15,342
Solanda S4	Park	18,630
HERALDO	Park	14,222

Supplementary Table 4. Land cover classification results and accuracy matrix.

Class	Area (km²)	± 95% CI	User's Accuracy (%)	Producer's Accuracy (%)	Overall Accuracy (%)
1986					
Urban	159.74	49.41	86.0	46.6	82.8
Woodland	867.30	66.70	93.0	83.4	
Agriculture/ grassland	361.96	69.47	88.5	48.0	
Scrub vegetation/bare	1,347.03	96.45	77.3	96.2	
2020					
Urban	351.76	47.02	93.4	63.6	81.1
Woodland	1,030.61	65.69	85.0	89.0	

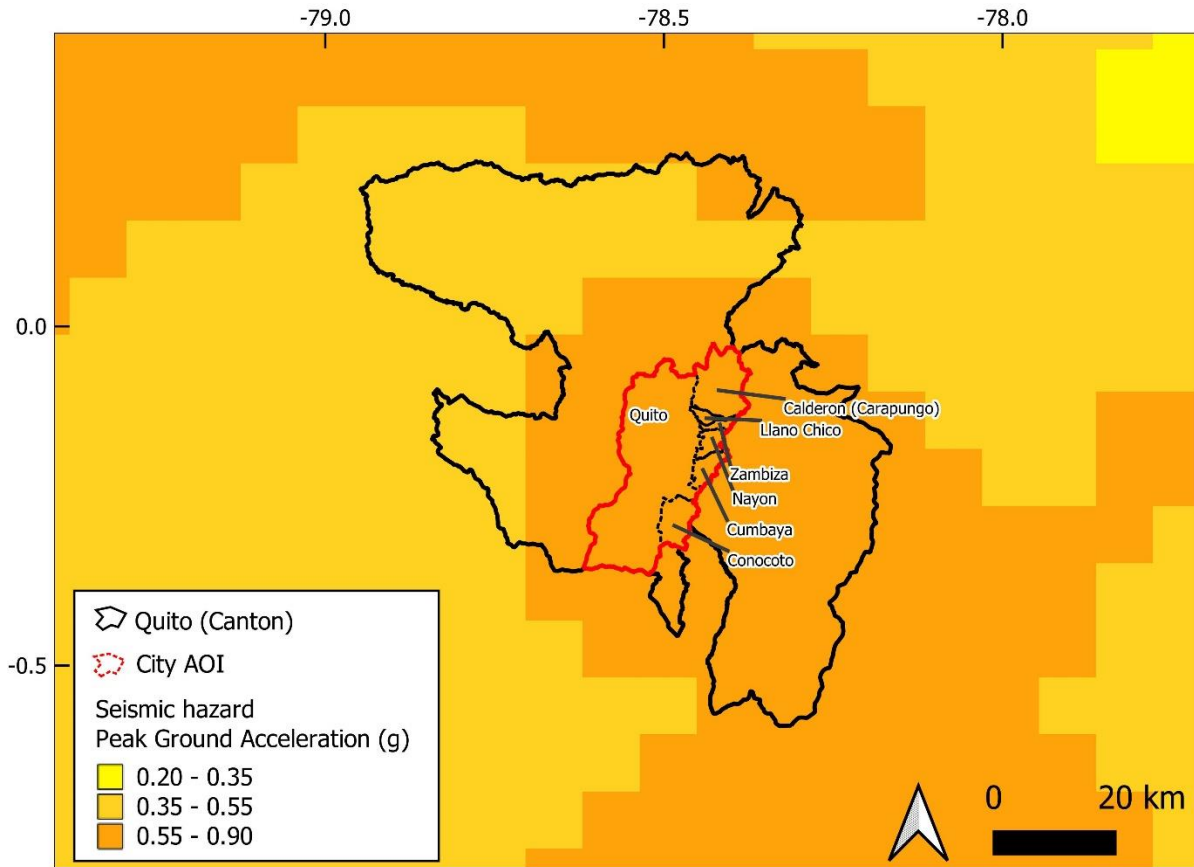
Agriculture/ grassland	484.73	62.46	88.5	56.0	
Scrub vegetation/bare	874.19	71.45	72.6	92.7	

M. Pagani, J. Garcia-Pelaez, R. Gee, K. Johnson, V. Poggi, R. Styron, G. Weatherill, M. Simionato, D. Viganò, L. Danciu, D. Monelli (2018). Global Earthquake Model (GEM) Seismic Hazard Map (version 2018.1 - December 2018), DOI: 10.13117/GEM-GLOBAL-SEISMIC-HAZARD-MAP-2018.1

Figure S1. Global Earthquake Model seismic hazard for Quito.

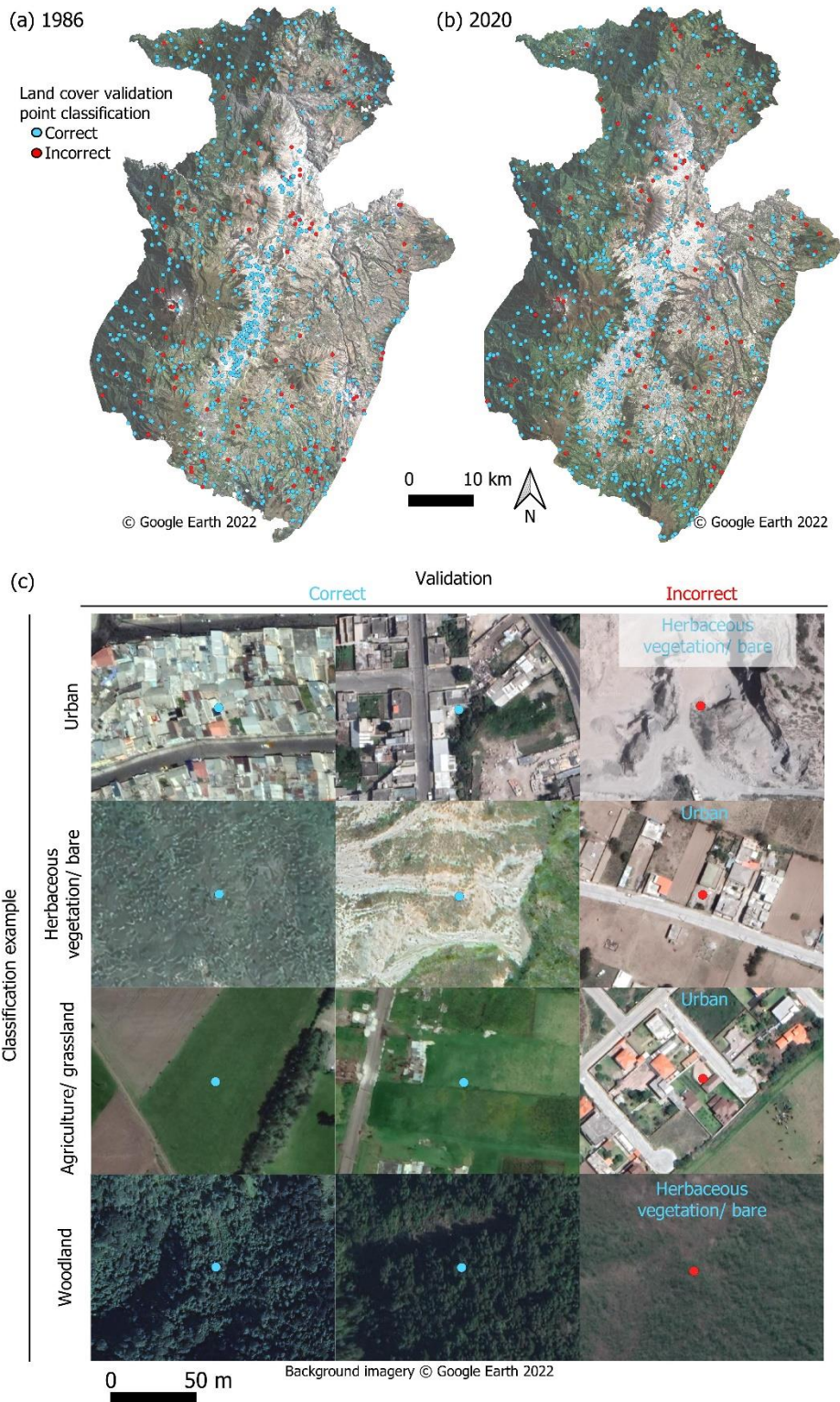



Figure S2. (a-b) Validation of the Random Forest Classification using 800 validation points. (c) Example land cover classifications and corresponding satellite imagery from a Google Earth basemap.

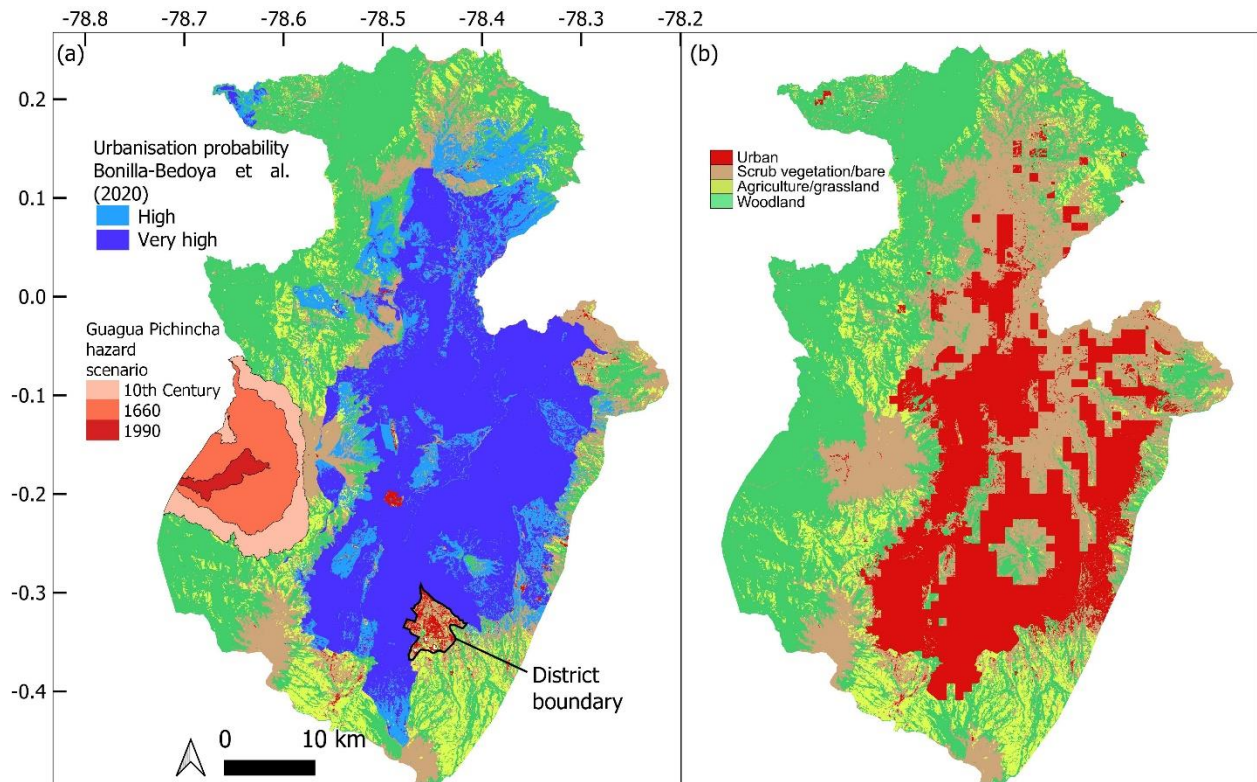



Figure S3. (a) Urbanisation probability from Bonilla-Bedoya et al. (2020). Guagua Pichincha Volcano hazards scenarios are shown from IG-EPN et al. (2019). (b) Modified Bonilla-Bedoya et al. (2020) scenario, which excludes urbanisation on the steep slopes of Guagua Pichincha Volcano and for category 5 (high) landslide susceptibility (Fig. S3) (Stanley and Kirschbaum, 2017). An urbanised area crossing the Metropolitan District Boundary was also included.

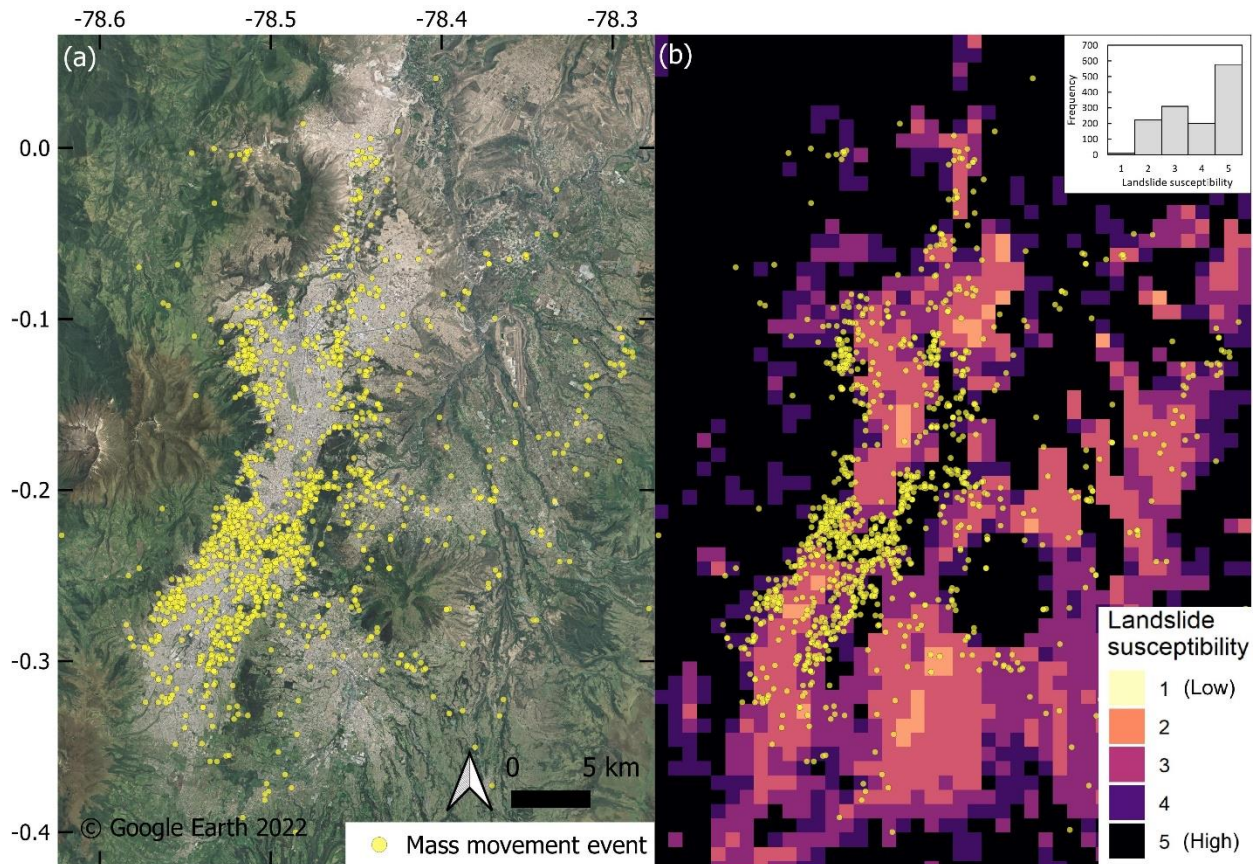



Figure S4: (a) Open Government records of movement events 2006–2017 (n = 1321). Background is a (b) Spatial distribution of the recorded mass movement events in relation to the landslide susceptibility model (Stanley and Kirschbaum, 2017).

Figure S5: Clustering of traffic collisions at junctions recorded in the Open Government 'Accidents' data (http://gobiernoabierto.quito.gob.ec/) were used as a proxy to estimate the positional uncertainty of flood records in the same database. Location: -78.47845,-0.12923.

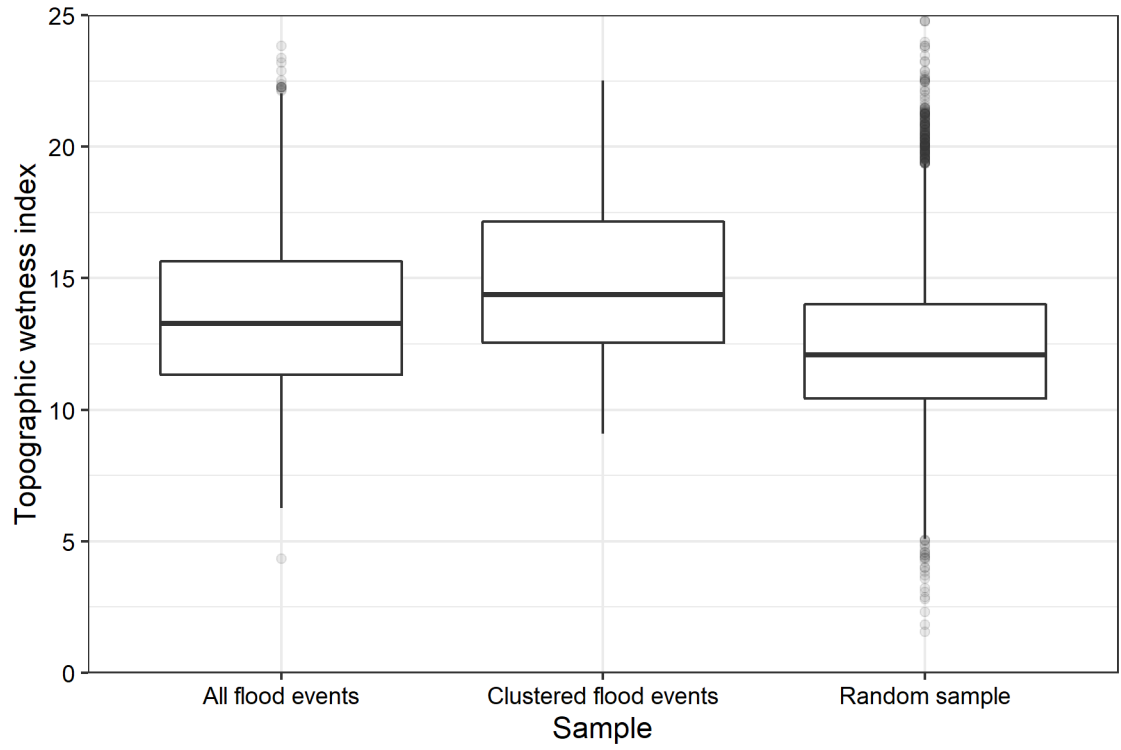



Figure S6: Topographic Wetness Index (TWI) for flood events in Quito recorded in Ecuador's Open Government Database. The TWI is shown for all flood events (n = 1,274), clustered flood events where two events are recorded within 40 m of each other (n= 125), and a random sample of TWI values (n = 10,000)

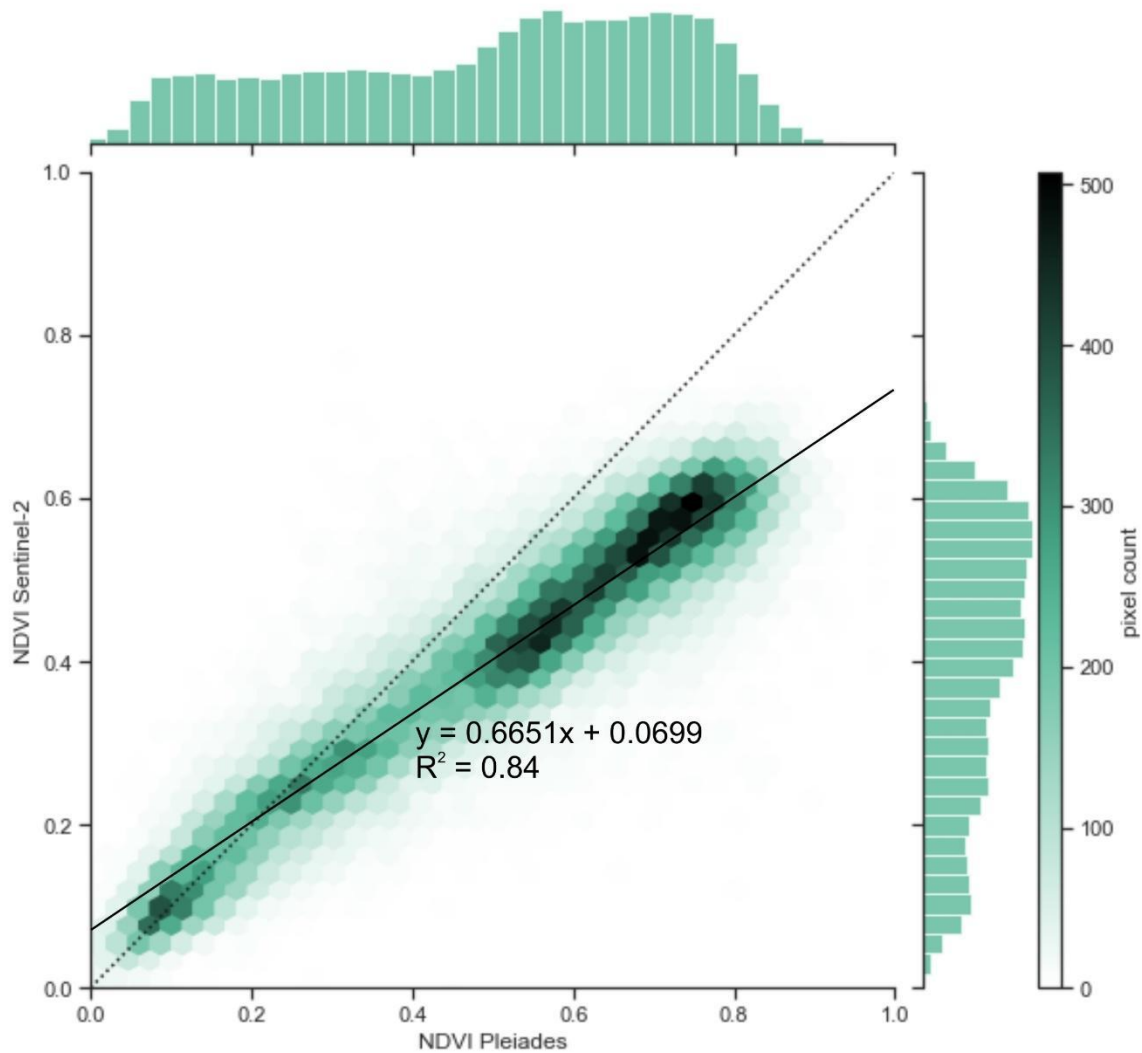



Figure S7. Correlation between Pleiades and Sentinel-2 derived NDVI values. Several factors complicate a direct association between Pleiades and Sentinel-2 NDVI values. (1) The Pleaides NDVI was derived from a composite of five image acquisitions (Supplementary Table 2) whereas the Sentinel-2 acquisition was from a single date (6th February 2020), hence the spectral characteristics of the ground would have changed. Acquisitions on 28 January 2020 and 6th June 2020 had the largest overlap with the 6th February 2020 Sentinel-2 acquisition. (2) The sensor bands have overlapping but different bandwidths (Pleaides: red 590–710 nm, NIR 740–940 nm, Sentinel-2: red 649–680, NIR 780–886).

References

Bonilla-Bedoya, S., Mora, A., Vaca, A., Estrella, A., and Herrera, M. Á.: Modelling the relationship between urban expansion processes and urban forest characteristics: An application to the Metropolitan District of Quito, Computers, Environment and Urban Systems, 79, 101420, https://doi.org/10.1016/j.compenvurbsys.2019.101420, 2020.
IG-EPN, IGM, IRD.: Mapa de Peligros Volcánicos Potenciales del Volcán Guagua Pichincha 3ra. Edición, Quito - Ecuador. Availalble online: https://www.igepn.edu.ec/ggp-mapa-de-peligros/file (accessed 10 December 2020). 2019.

Stanley, T., and Kirschbaum, D. B.: A heuristic approach to global landslide susceptibility mapping, Natural Hazards, 87, 145-164, https://doi.org/10.1007/s11069-017-2757-y, 2017.