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Enhancement of large-scale flood risk assessments using building-material-based vulnerability curves for an object-based approach in urban and rural areas

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Supplementary Material

S1 Construction typology

In general, for the mapping of construction types, the materials used for the structural frame and the bearing walls are a main factor in order to differentiate between individual types. Furthermore, the characteristics of each type are for example also influenced by local building practices, building codes and other materials used. Therefore there are often similarities between construction types and depending on the available information further subtypes can be differentiated. For example unreinforced masonry (URM) is a general description of buildings with bearing walls made from individual units of some masonry material typically bound together by some form of mortar. With more available information on attributes such as the size of brick, the used material (e.g. clay, stone, concrete), or the type of mortar (mud or cement based), subtypes can be separated (for example the ImageCat data differentiates BRK (URM brick building), CB (URM concrete block building), UFB (unreinforced fired brick masonry building) and UCB (unreinforced concrete block building)). Similarly the very traditional buildings such as ERTH (earthen building), M (mud walls building), RE (rammed earth building), and ADB (URM adobe building) are made from soil materials mixed for example with straw and cement. The material can then be formed into bricks and sun-dried, whereas for RE buildings the soil is rammed using wooden molds. The ImageCat structure DS (stone masonry) is similar to buildings made from rubble stones. More information can be found in supplementary table 1 containing the PAGER typology or further in the descriptions of the World Housing Encyclopedia[1].

S2 Comparison of risk and flood protection influence

Risk is defined as the product of hazard, exposure and vulnerability and expressed as the expected annual damage (EAD) in this paper. The hazard component is comprised of layers of inundation extent and depth for nine return periods (50% to 0.1% annual exceedance probability). The inundation associated with each return period is assumed to occur everywhere simultaneously and we calculate the expected annual damage as the integral of the exceedance probability-impact curve. With this probabilistic analysis the total EAD for Ethiopia in our model is $213.2mln/yr ($46.7mln/yr for rural and $166.6mln/yr for urban areas).

The validation of risk values is difficult as publicly available losses for flood events especially in developing countries, are, if observed at all, rough estimates and often limited to low-frequency, high-impact events. Therefore, modelled and observed metrics are different, since the reported losses do not include information on all flood probabilities. Generating the flood events and their damage stochastically would be a different approach to calculate the risk or might be used to support a dataset of reported losses as the synthetic realizations could extend missing parts of the exceedance probability-impact curve.

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[1] http://www.db.world-housing.net/

However, this also would raise the question of the validation of those risk results and validation of the stochastic generated hazard layer of the events.

In our flood risk assessment we assume that Ethiopia is only protected against floods with a return period of 2 years, whilst in reality there may be higher flood protection in place for the most flood-prone areas, especially in the main urban areas. Estimates of EAD are very sensitive to the assumed protection standard (Ward et al., 2017). For example, if we assumed that Ethiopia was protected against floods with a return period of 5 years, the EAD would fall to $124.5mln/yr ($96.3mln/yr urban, $28.2mln/yr rural) which is similar to the country's flood risk ($135.5mln) in the 2015 Global Assessment Report (UNISDR, 2015) .

Table S1. Pager construction types with assigned flood vulnerability classes.

PAGER	Description	Vuln. Class	PAGER	Description	Vuln. Class	PAGER	Description	Vuln. Class
W5	Wattle and Daub (Walls with bamboo/light timber log/reed mesh and post).	I	UFB5	Unreinforced fired brick masonry, cement mortar, but with reinforced concrete floor and roof slabs	III	C4	Nonductile reinforced concrete frame without masonry infill walls	IV
M	Mud walls	I	UCB	Concrete block unreinforced masonry with lime or cement mortar	III	C4L	Nonductile reinforced concrete frame without masonry infill walls low-rise	IV
M1	Mud walls without horizontal wood elements	I	MS	Massive stone masonry in lime or cement mortar	III	C4M	Nonductile reinforced concrete frame without masonry infill walls mid-rise	IV
M2	Mud walls with horizontal wood elements	I	UNK	Not specified (unknown/default)	III	C4H	Nonductile reinforced concrete frame without masonry infill walls high-rise	IV
A	Adobe blocks (unbaked sundried mud block) walls	I	S	Steel	IV	C5	Steel reinforced concrete (Steel members encased in reinforced concrete)	IV
A1	Adobe block, mud mortar, wood roof and floors	I	S1	Steel moment frame	IV	C5L	Steel reinforced concrete (Steel members encased in reinforced concrete) low-rise	IV
A2	Adobe block, mud mortar, bamboo, straw, and thatch roof	I	S1L	Steel moment frame low-rise	IV	C5M	Steel reinforced concrete (Steel members encased in reinforced concrete) mid-rise	IV
A3	Adobe block, straw, and thatch roof cement-sand mortar	I	S1M	Steel moment frame mid-rise	IV	C5H	Steel reinforced concrete (Steel members encased in reinforced concrete) high-rise	IV
A4	Adobe block, mud mortar, reinforced concrete bond beam, cane and mud roof	I	S1H	Steel moment frame high-rise	IV	C6	Concrete moment resisting frame with shear wall - dual system	IV
A5	Adobe block, mud mortar, with bamboo or rope reinforcement	I	S2	Steel braced frame	IV	C6L	Concrete moment resisting frame with shear wall - dual system low-rise	IV
RE	Rammed Earth/Pneumatically impacted stabilized earth	I	S2L	Steel braced frame low-rise	IV	C6M	Concrete moment resisting frame with shear wall - dual system mid-rise	IV
INF	Informal constructions.	I	S2M	Steel braced frame mid-rise	IV	C6H	Concrete moment resisting frame with shear wall - dual system high-rise	IV
W	Wood	II	S2H	Steel braced frame high-rise	IV	C7	Flat slab structure	IV
W1	Wood stud-wall frame with plywood/gypsum board sheathing.	II	S3	Steel light frame	IV	PC1	Precast concrete tilt-up walls	IV
W2	Wood frame, heavy members (with area > 5000 sq. ft.)	II	S4	Steel frame with cast-in-place concrete shear walls	IV	PC2	Precast concrete frames with concrete shear walls	IV
W3	Wood light unbraced post and beam frame.	II	S4L	Steel frame with cast-in-place concrete shear walls low-rise	IV	PC2L	Precast concrete frames with concrete shear walls low-rise	IV
W4	Wood panel or log construction.	II	S4M	Steel frame with cast-in-place concrete shear walls mid-rise	IV	PC2M	Precast concrete frames with concrete shear walls mid-rise	IV
W6	Wood unbraced heavy post and beam frame with mud or other infill material.	II	S4H	Steel frame with cast-in-place concrete shear walls high-rise	IV	PC2H	Precast concrete frames with concrete shear walls high-rise	IV
W7	Wood braced frame with load-bearing infill wall system.	II	S5	Steel frame with unreinforced masonry infill walls	IV	PC3	Precast reinforced concrete moment resisting frame with masonry infill walls	IV
MH	Mobile homes	II	S5L	Steel frame with unreinforced masonry infill walls low-rise	IV	PC3L	Precast reinforced concrete moment resisting frame with masonry infill walls low-rise	IV
RS	Rubble stone (field stone) masonry	III	S5M	Steel frame with unreinforced masonry infill walls mid-rise	IV	PC3M	Precast reinforced concrete moment resisting frame with masonry infill walls mid-rise	IV
RS1	Local field stones dry stacked (no mortar) with timber floors, earth, or metal roof.	III	S5H	Steel frame with unreinforced masonry infill walls high-rise	IV	PC3H	Precast reinforced concrete moment resisting frame with masonry infill walls high-rise	IV
RS2	Local field stones with mud mortar.	III	C	Reinforced concrete	IV	PC4	Precast panels (wall made of number of horizontal precast panels, construction from former Soviet Union countries)	IV
RS3	Local field stones with lime mortar.	III	C1	Ductile reinforced concrete moment frame with or without infill	IV	RM	Reinforced masonry	IV
RS4	Local field stones with cement mortar, vaulted brick roof and floors	III	C1L	Ductile reinforced concrete moment frame with or without infill low-rise	IV	RM1	Reinforced masonry bearing walls with wood or metal deck diaphragms	IV
RS5	Local field stones with cement mortar and reinforced concrete bond beam.	III	C1M	Ductile reinforced concrete moment frame with or without infill mid-rise	IV	RM1L	Reinforced masonry bearing walls with wood or metal deck diaphragms low-rise	IV
DS	Rectangular cut-stone masonry block	III	C1H	Ductile reinforced concrete moment frame with or without infill high-rise	IV	RM1M	Reinforced masonry bearing walls with wood or metal deck diaphragms mid-rise (4+ stories)	IV
DS1	Rectangular cut stone masonry block with mud mortar, timber roof and floors	III	C2	Reinforced concrete shear walls	IV	RM2	Reinforced masonry bearing walls with concrete diaphragms	IV
DS2	Rectangular cut stone masonry block with lime mortar	III	C2L	Reinforced concrete shear walls low-rise	IV	RM2L	Reinforced masonry bearing walls with concrete diaphragms low-rise	IV
DS3	Rectangular cut stone masonry block with cement mortar	III	C2M	Reinforced concrete shear walls mid-rise	IV	RM2M	Reinforced masonry bearing walls with concrete diaphragms mid-rise	IV
DS4	Rectangular cut stone masonry block with reinforced concrete floors and roof	III	C2H	Reinforced concrete shear walls high-rise	IV	RM2H	Reinforced masonry bearing walls with concrete diaphragms high-rise	IV
UFB	Unreinforced fired brick masonry	III	C3	Nonductile reinforced concrete frame with masonry infill walls	IV	CM	Confined masonry	IV
UFB1	Unreinforced brick masonry in mud mortar without timber posts	III	C3L	Nonductile reinforced concrete frame with masonry infill walls low-rise	IV	CML	Confined masonry low-rise	IV
UFB2	Unreinforced brick masonry in mud mortar with timber posts	III	C3M	Nonductile reinforced concrete frame with masonry infill walls mid-rise	IV	CMM	Confined masonry mid-rise	IV
UFB3	Unreinforced brick masonry in lime mortar	III	C3H	Nonductile reinforced concrete frame with masonry infill walls high-rise	IV	CMH	Confined masonry high-rise	IV
UFB4	Unreinforced fired brick masonry, cement mortar.	III						

Table S2. Confusion matrix of urban settlement map of the ImageCat data as reference with different classification maps.

		ImageCat	
		Other land use	Settlement (urban)
GRUMP	Other land use	9,967	7,363
	Settlement	33	2,637
MOD500	Other land use	9,995	9,403
	Settlement	5	597
GUF	Other land use	9,997	8,792
	Settlement	3	1,208
HBASE	Other land use	9,999	8,618
	Settlement	1	1,382
GHS-SMOD	Other land use	9,855	5,150
	Settlement (urban centre/cluster)	145	4,850
GHS-SMOD	Other land use	9,855	5,150
	Settlement (urban centre)	145	4,850

Table S3. Confusion matrix of urban-rural map of the ImageCat data as reference with GHS-SMOD as classification maps.

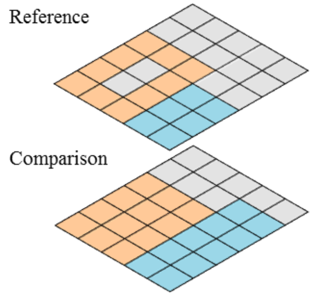
		ImageCat		
		Other land use	Rural	Urban
GHS-SMOD	Other land use	9,484	8,231	3,123
	Rural	411	1,101	2,004
	Urban (centre/cluster)	105	668	4,873

Table S4. Results of agreement for Ethiopia using the ImageCat data classified to urban settlement and other land use as the reference map.

	Settlement (urban)		Other land use		Overall Accuracy (%)	Kappa
Settlement Map	Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)		
GRUMP	26.4	98.8	99.7	57.5	63.0	0.26
MOD500	6.0	99.2	100.0	51.5	53.0	0.06
GUF	12.1	99.8	100.0	53.2	56.0	0.12
HBASE	13.8	99.9	100.0	53.7	56.9	0.14
GHS-SMOD (urban centre/cluster)	48.5	97.1	98.6	65.7	73.5	0.47
GHS-SMOD (urban centre)	25.0	99.2	99.8	57.1	62.4	0.25

Table S5. Building footprints for sensitivity analysis derived from the ImageCat data of flood risk assessment for Ethiopia.

Vuln. class	Building footprint [m^2]
I	35
II	35
III 1 floor	35
III 2 floors	251
IV	467



		Reference			
		Class 1	Class 2	Class 3	Sum
Comparison	Class 1	p_{11}	p_{12}	p_{13}	$p_{1\_}$
	Class 2	p_{21}	p_{22}	p_{23}	$p_{2\_}$
	Class 3	p_{31}	p_{32}	p_{33}	$p_{3\_}$
	Sum	$p_{\_1}$	$p_{\_2}$	$p_{\_3}$	1

Metric	Equation	Short Explanation
Overall accuracy	$OA = \sum_{j=1}^{q} p_{jj}$	proportion of samples classified correctly; refers to the probability that a randomly selected location on the comparison map is classified correctly
Kappa	see Congalton (1991)	agreement between the maps, corrected for the agreement as can be expected from random allocation of classes
Producer's accuracy	$P_j = p_{jj} / p_{\_j}$	proportion of the samples of reference class j that is mapped as class j; probability that class j in the reference is mapped as the same class
User's accuracy	$U_i = p_{ii} / p_{i\_}$	proportion of the samples mapped as class i that has reference class i; probability that an area of class i on the comparison map is also that class in the reference

Figure S1. Example accuracy assessment using a confusion matrix of q classes and p_{ij} representing the proportion of samples that has classification class i and reference class j.

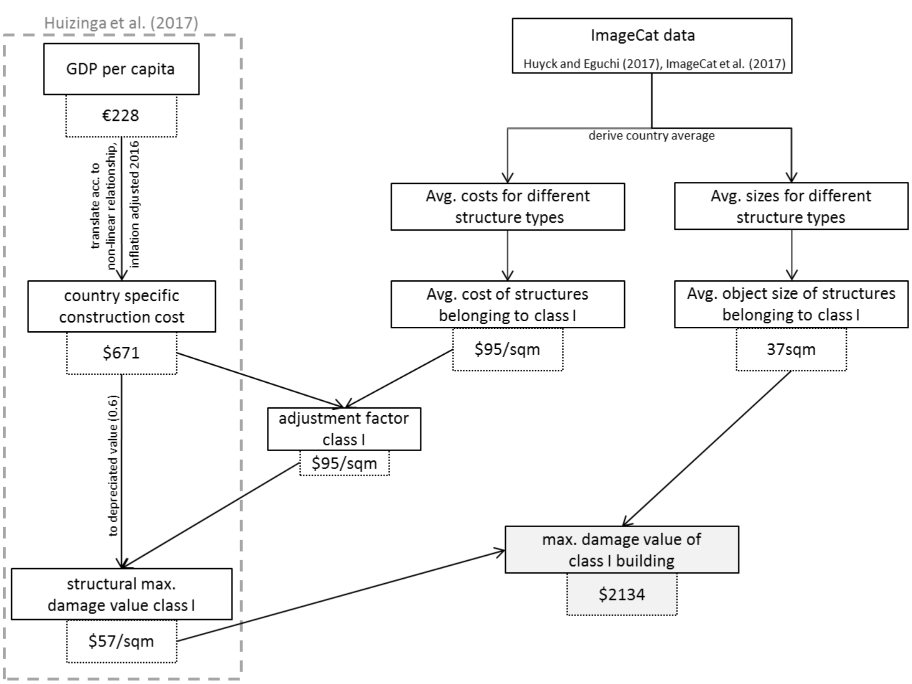


Figure S2. Process of calculating the maximum damage value for the example of a class I building.

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