Supplementary Appendix

This appendix has been provided by the authors to give readers additional information about their work.

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Supplemental materials

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I. Survey Instrument

INITIAL QUESTION
1) How many people in total have lived in your household from the start of 2017 till now?
HOUSEHOLD ROSTER [questions are repeated based on # household members listed above]
2a) Gender (choose one) o Male o Female
2b) Age (continuous)
2c) Did they join the household in 2017? o Yes / No
(If 2c is yes): When? o Jan - Dec
(If after September 20th) Did they join the household because of the hurricane? o Yes / No
2d) Status o Still living in household o Died in 2017 o Left household in 2017 and did not return o Missing (since which month)
MORTALITY REPEAT [questions are repeated based on # of household members listed as "died" in 2d]
3a) In which month did this person die? (choose one) o Jan - Dec
3b) Did they die before or after Hurricane Maria? o Before / After
If person died before Hurricane Maria, skip to next repeat, otherwise continue
3c) What was the cause of death? o Died before hurricane *will be auto-selected if death before hurricane* o Trauma from vehicle accident o Trauma from building collapse o Trauma from landslide o Trauma from other o Drowning o Fire o Electrocution o Disruption of usual medical care (medications, dialysis, doctor, nursing facility) o Medical complications from injury, trauma or direct illness due to the hurricane o Suicide o Other o Causes not related to the hurricane
(If other) 3d) Please describe other cause of death: (open text field)
LOCATION REPEAT [question are repeated based on # of household members listed as "left" in 2c]

4a) In which month did this person leave? (choose one)

- Jan - Dec

4b) Did they leave before or after Hurricane Maria?

- Before / After

If person left before Hurricane Maria, skip to next repeat, otherwise continue

4c) Where did they go first? (choose one)

- Elsewhere in PR
- Florida
- New York
- Texas
- Other State
- Outside the United States

4d) Where are they now? (choose one)

- Elsewhere in PR
- Florida
- New York
- Florida
- Other State
- Outside the United States

DATE REPEAT [question are repeated based on # of household members listed as "after" in 2d]

5) In which month did this person move in? (choose one)

- Jan - Dec

DELAY IN MEDICAL CARE

6) Did the hurricane lead to any of the following problems among members in your household that didn't exist before the hurricane? (If so, for how many days?)

	0	1	2	3-7	8-30	30+	NA
6a) Unable to get to medical care because the member was too ill to leave the house							
6b) Unable to get to medical care because there was no means of transport							
6c) Unable to get to medical care because the roads were damaged							
6d) Unable to get medical care because the healthcare facility was damaged or closed							
6e) Unable to get medical care because the doctors were unavailable							
6f) Unable to continue dialysis							
6g) Unable to use breathing treatment that required electricity (CPAP, BiPAP or nebulizer)							
6h) Unable to get medicines							
6i) Unable to afford care							

(If other) Please explain:

RESOURCES

For the following questions, replace the _____ with a) Water b) Access to Drinking Water c) Electricity and d) Cellular coverage, respectively

7) Did you lack _____ before the hurricane?

- Yes / No

(If yes) 7b) How frequently?

- Once daily
- Once weekly
- Once monthly
- Less frequently

8) After the Hurricane, did you lose _____?:

- Yes / No

(If Yes) 8b) How many days did you lose access to _____ in the following months?

	0	1-7	8-14	15-30	30+
Sept					
Oct					
Nov					
Dec					

NEIGHBORHOOD QUESTIONS

9a) Do you know of anyone who died in your "barrio", or how many neighbors - (within five minutes walking distance from your house, or equivalent), since the hurricane? (choose one)

- No
- 1
- 2
- 3
- 4
- 5
- >5

9b) Do you know of anyone in your "barrio" who moved away, since the hurricane? (choose one)

- No
- 1
- 2
- 3
- 4
- 5
- >5

10b) How many neighbors do you have?

- <10
- 10-25
- 25-50
- 50-100

II. Supplementary Methods

Survey methodology

Stratification by remoteness

To ensure sampling of households across regions of Puerto Rico that may have been differentially impacted by the hurricane, we stratified the population by remoteness. We obtained barrio boundaries from the official administrative level shapefiles and calculated remoteness for each barrio using road network and population data.[1,2] We transformed all spatial data into the WGS84 coordinate reference system datum for comparisons and analysis. Smaller, unpopulated islands were removed resulting is a sampling frame of 900 barrios. The road network and population data were used to create a friction layer for Puerto Rico based on the travel time in hours to the nearest city with a population of at least 50,000 people. Barrios were then stratified into 8 distinct strata, based on percentiles of the total range of the average remoteness measure. We randomly sampled 13 barrios from strata and additionally ensured that there was at least one barrio captured from Vieques and Culebra. We created survey design weights for each household based on the inverse of the probability of sampling that household.

Sampling buildings using OpenStreetMap

Households within barrios were identified using OpenStreetMap (OSM) layers for structures identified as "buildings". For each randomly selected barrio, we iteratively downloaded structure information using the OSM overpass API, calculated centroids for structures identified as buildings, and randomly sampled 35 locations. We generated geospatial PDFs for each barrio level with an OSM base layer, a barrio boundary and the sampled building points. The geospatial PDFs were loaded on Samsung Tab A 7" Android devices and displayed using PDFMaps. Enumerators were trained to load maps, identify their position and navigate using these geospatial PDFs.

Survey operations

We also loaded Samsung Galaxy 7" Tab A tablets with CommCare for data collection, a random number generator, and Kids Place app to lock down devices and restrict usage. Enumerators navigated to available points, identified a respondent that was able to provide consent and conducted the survey. Data was collected offline on tablets and uploaded automatically at the end of each day using a Wi-Fi connection at a central staging area. We partnered with local academic institutions to recruit clinical psychology doctoral students. They had been part of earlier outreach operations, and were familiar with the terrain and the mental health issues communities may be facing. All enumerators received training, and group-wide debriefs were conducted at regular intervals.

Captured households

We selected 13 barrios in each of our 8 strata and selected an extra barrio at random on the islands of Vieques and Culebra. Of these, two were found to have no population and were dropped. Our final spatial selection included 104 barrios with 13 barrios per strata of remoteness. We attempted to capture 35 points per barrio resulting in an estimated sample of 3,640 households. Due to low population densities in some barrios, we were unable to capture a full 35 households. We, therefore, obtained a total sample of 3,299 households.

Adjustment for household size biases

Multiple kinds of adjustment can be made to our estimates to account for possible biases, but here we chose to focus on household size. It is impossible to capture deaths in single person households in a survey, and deaths in smaller households are also less likely to be captured given the reduced likelihood of someone being home when our enumerators visited the house. To evaluate how this bias might affect our estimate of mortality, we stratified our data into household sizes in which we could be sure that the death rate was always decreasing as household size increased or was monotonic. The death rate for single-person households is 0, which of course cannot be the case: if the person in a one-person household dies, there is no one left in the household to interview. Smaller households were also under-sampled, exacerbating this bias. We calculated a per household size annualized mortality rate (Table S7a) for before and after the hurricane. Incorporating a conservative assumption that the hurricane had no effect and that individuals in one-person households had the same death rate before and after the hurricane, we find that our pre and post mortality rates increase (Table S7b). The counts for both before and after the hurricane in smaller households are therefore likely to be underestimated.

In addition to the bias caused by uncounted deaths in single person households, the probability of being included in our survey is higher for larger households since they are more likely to be occupied. This is confirmed by comparing our sample household size distribution to the ACS 2016 (Figure 1 in the main manuscript). Adjusting for this deviation in distribution, in addition to the lack of deaths in one-person households, our overall rate increases again, bringing a crude estimate of excess deaths post hurricane to 5,740 [95% CI: 1,506-9,889]. A consequence of these biases is that our death rates are likely higher throughout 2017 than we have calculated here. However, to properly adjust for these estimates we would need to use more sophisticated assumption-dependent models. In our main manuscript, we report the raw value as our official estimate acknowledging that these are very likely underestimate death rates both before and after the hurricane.

Calculation of excess deaths

Our study was primarily intended to assess whether there had been a change in this mortality rate. To calculate the excess deaths, therefore, the rate difference must be multiplied by the total population size. In our case, we calculated the excess deaths using the up-weighted population estimate from our survey (3,030,307 individuals), although this number is likely to be low. Use of different numbers for the population estimate in either 2016 or 2017, or different vintages of the census estimate, would change the estimate of excess deaths. Here we use our survey estimate, rather than census predictions, to account for the possibility that the population size was reduced due to hurricane-related out-migration. We used a Poisson approximation[3] to construct confidence intervals for the adjusted rates. We have made data available for transparency and to encourage other researchers to conduct more sophisticated analyses. We plan to investigate them ourselves in future work.

III. Figures and Tables

Figure S1: a) Heatmap of average travel time to population centers of at least 50,000 individuals using local road networks across Puerto Rico; b) A simulation of sampled barrios, with 13 barrios chosen from each stratum. Note that these are not the barrios from the survey, for reasons of protection of survey respondents' privacy.

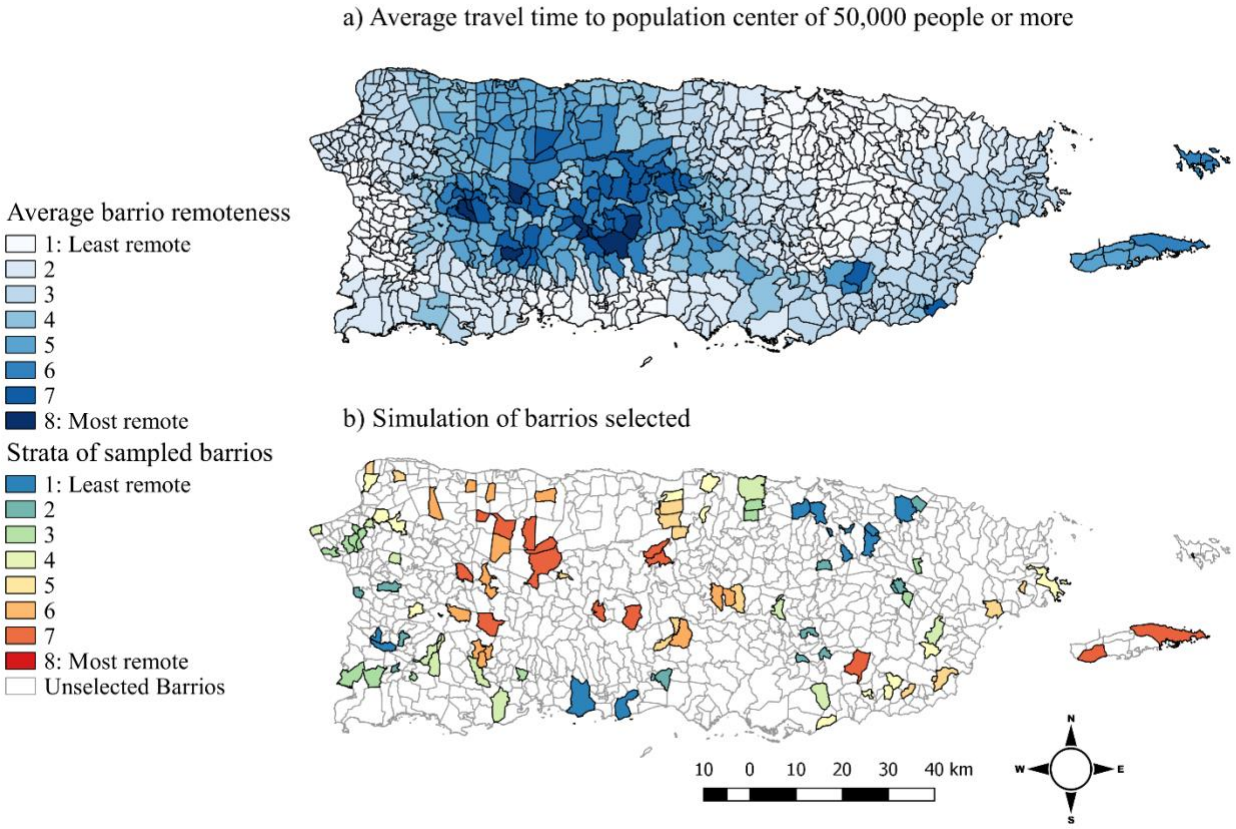

Figure S2: Official monthly deaths in Puerto Rico from 2010-2016 (grey lines) and in 2017 (blue points).

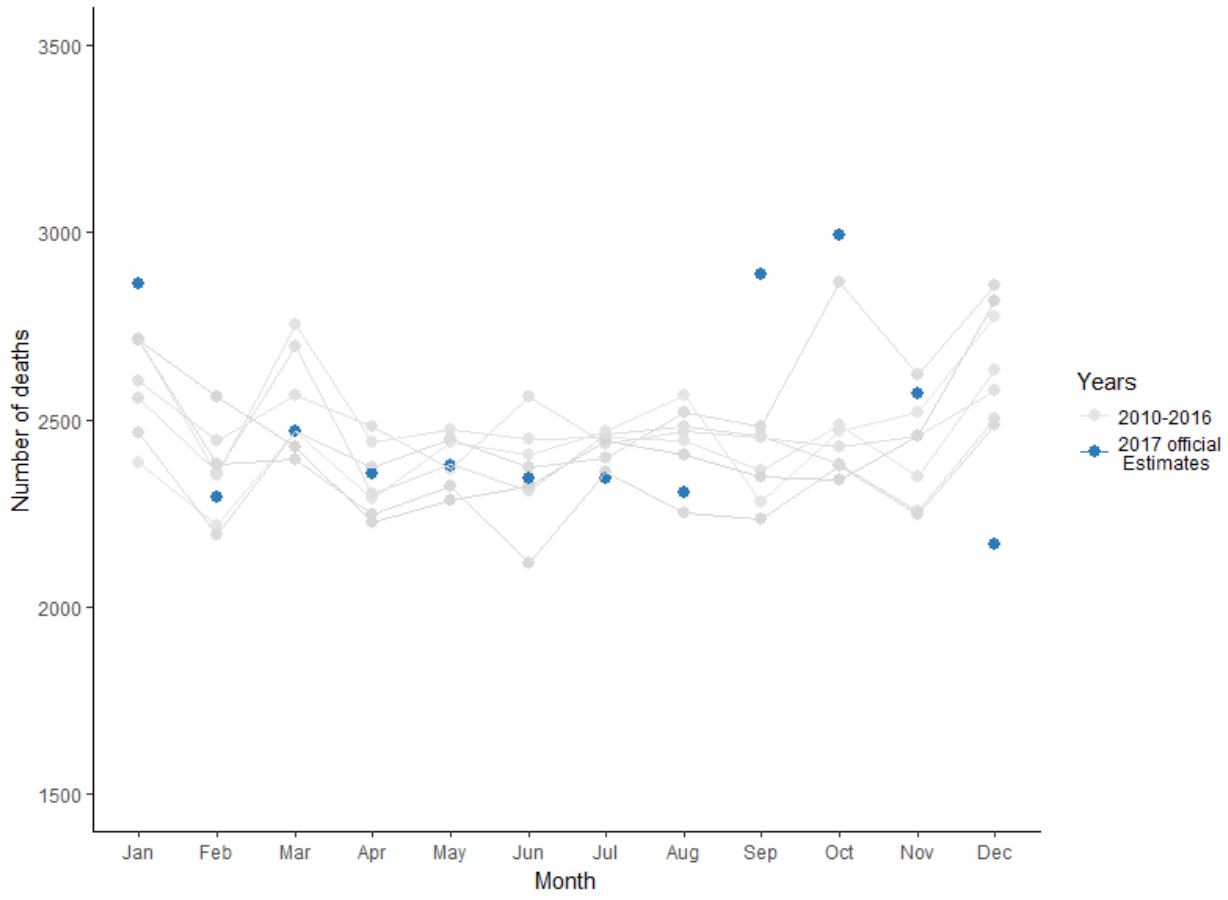

Figure S3A: Histogram of proportions of household sizes in the surveyed population.

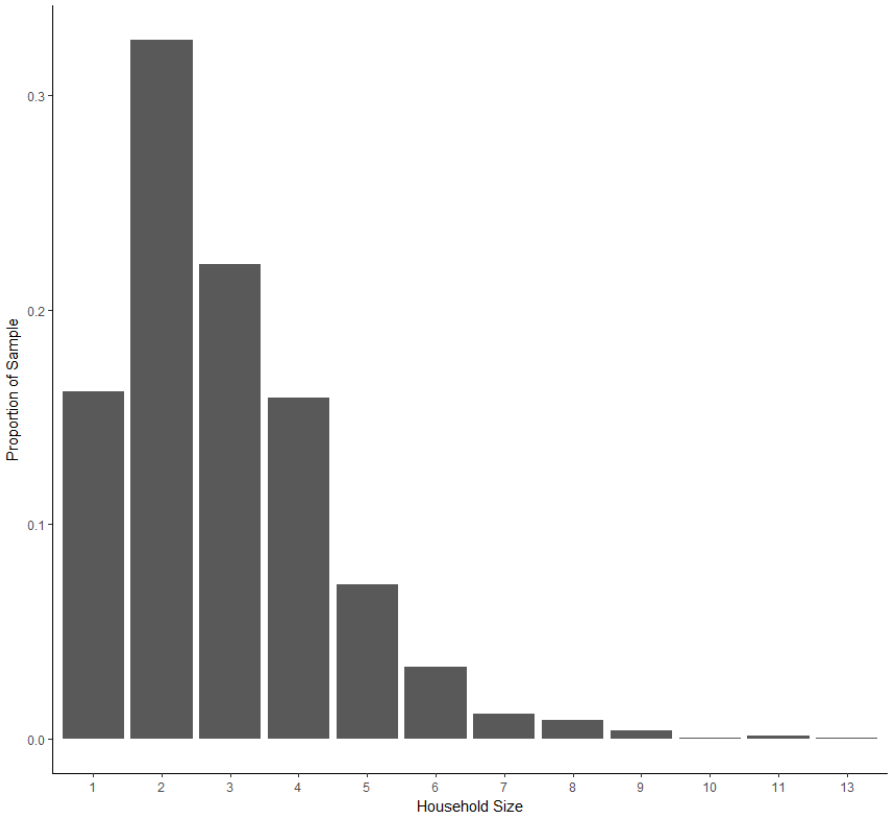

Figure S3B: The relationship between median household age and household size in the surveyed population; boxplots show interquartile range and outliers.

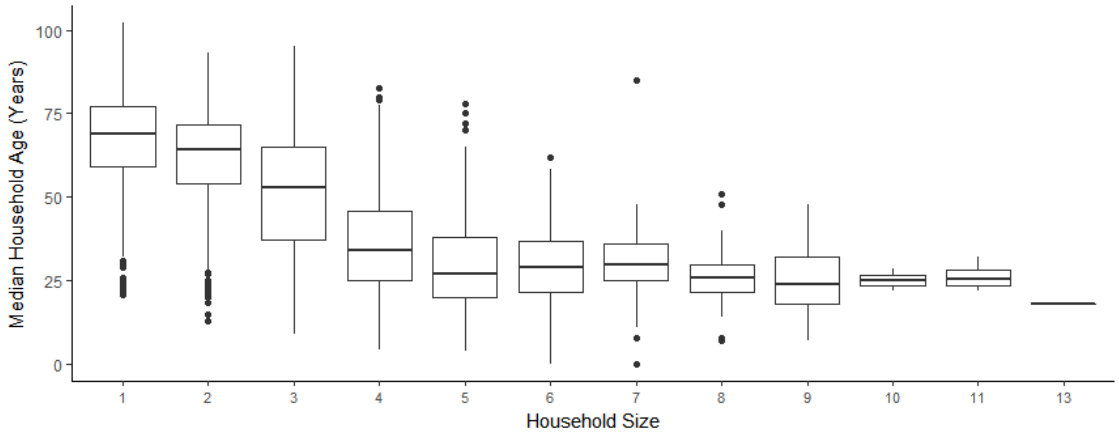

Figure S4: We encountered a higher than expected number of abandoned houses as the survey began, so we recorded the number of houses unable to give consent for any reason after January 26. This could be due to the building being abandoned or not a household. The histogram shows the proportion of houses in each strata of remoteness that was not able to provide consent.

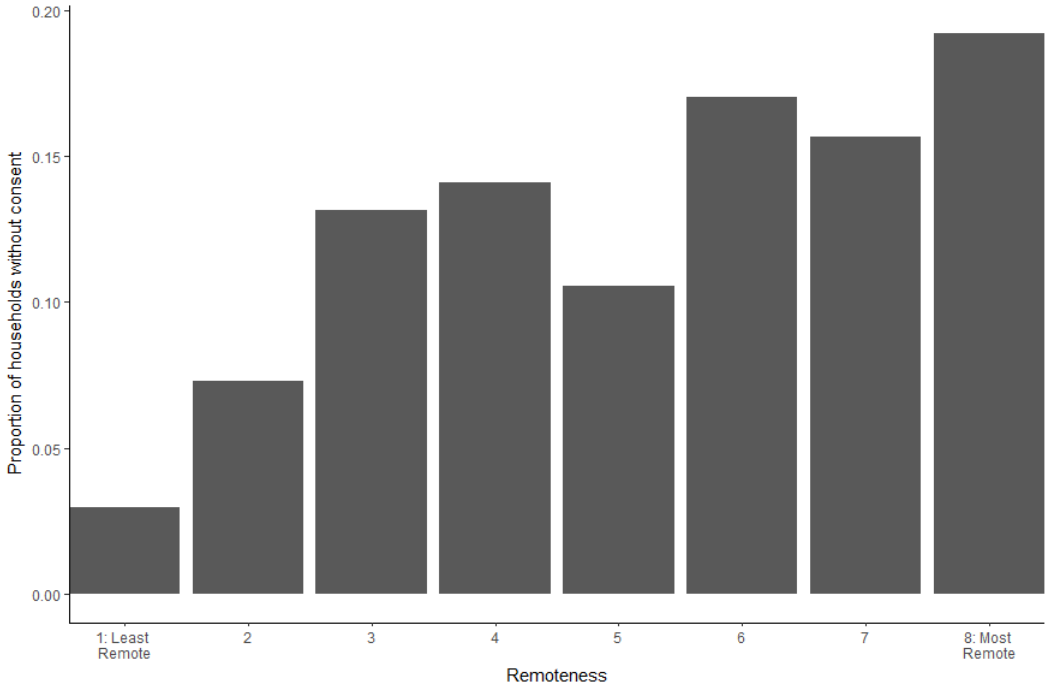

Figure S5: Proportional distribution of average of the lower bound of total number of days between the hurricane and December 31 without a) water, b) cell service, and c) electricity. Distributions are ordered by remoteness strata from most remote (8, bottom) to least remote (1, top).

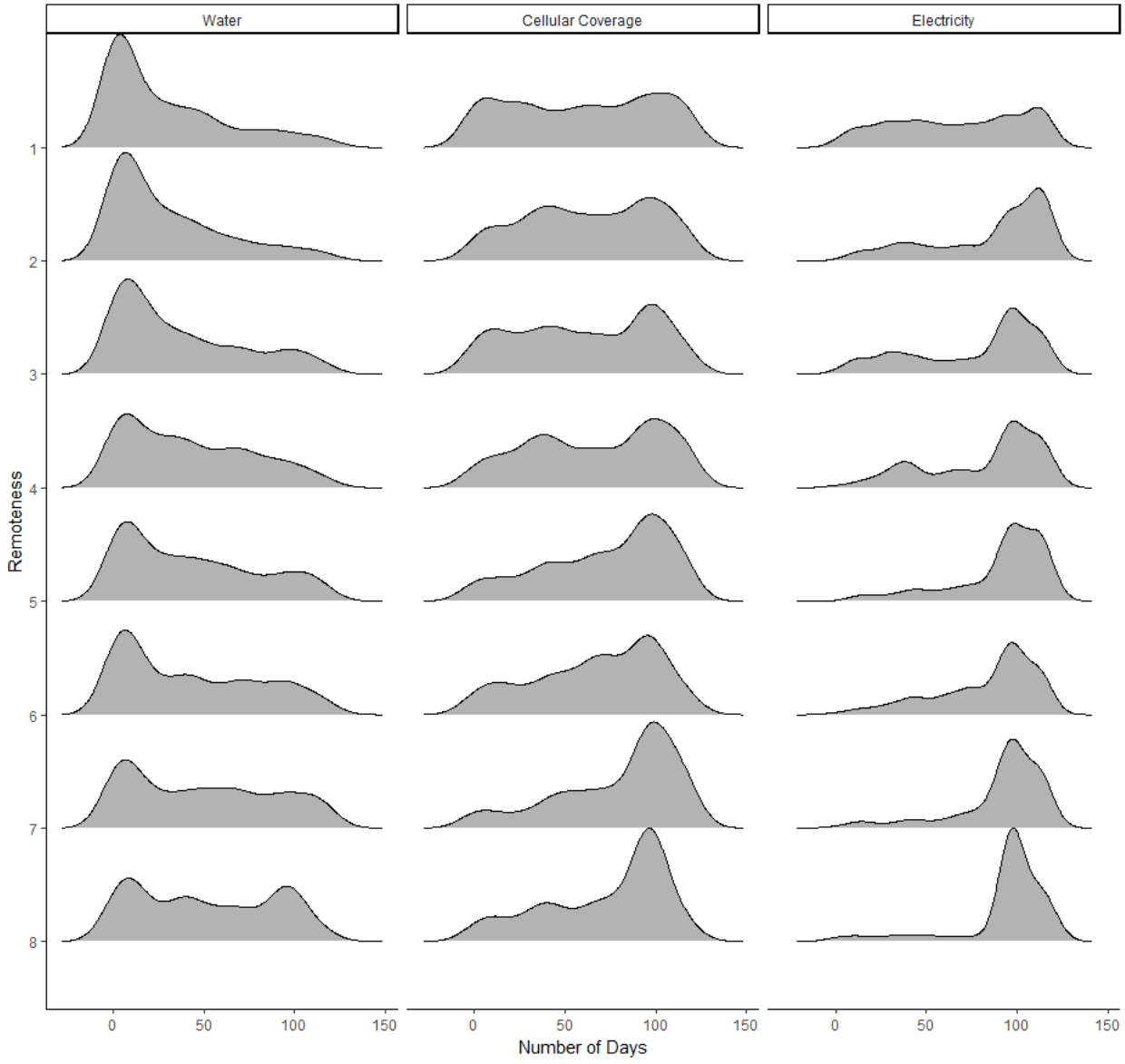

Figure S6: Mortality rates calculated using reported deaths among neighbors, by remoteness stratum. Mortality among neighbors was calculated by having respondents estimate the number of neighbors within a five-minute walk in categories ranging from <10, 10-25, 26-50, 51-100, >100 and the number among them that they know to have died after Hurricane Maria. We used the upper bound of each of these categories as a conservative lower bound of the mortality rate by strata and compared this to the post-hurricane mortality rate estimated in our survey

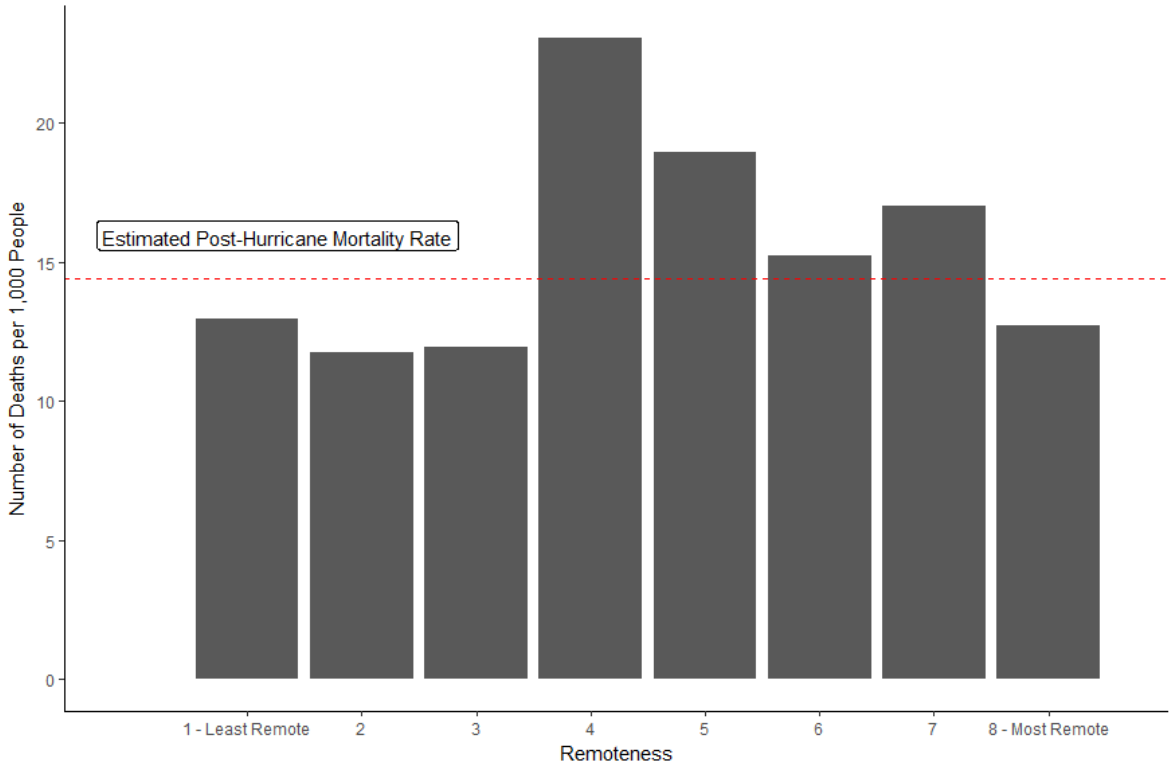

Table S1: Demographic characteristics of our sample compared to ACS 2016 estimates. The variance in the weighted estimates are calculated taking into account the survey weights. "Survey" refers to our survey of Puerto Rico, "ACS" refers to the American Community Survey.

Table S1: Survey Demographics compared to the American Community Survey 2016				
	Survey	*Population Estimate*	*95% Confidence intervals*	*ACS 2016*
Households	3,299	1,052,957	[496,248- 1,609,668]	1,251,554
Population	9,522	3,030,307	[1,466,680 - 4,593,934]	3,529,385
Median age	48.00	49.00	N/A	39.40
Proportion female	48.60%	48.86%	[48.2% - 49.5%]	52.20%
Mean household size	2.88	2.88	[2.76 - 2.99]	2.82

Table S2: The percentage of households missing utilities for entire months, by remoteness strata (1=least remote, 8=most remote).

Table S2: Percent of population missing utilities for the entire month by strata												
	Electricity				*Water*				*Cell Service*			
Remoteness	*Sept*	*Oct*	*Nov*	*Dec*	*Sept*	*Oct*	*Nov*	*Dec*	*Sept*	*Oct*	*Nov*	*Dec*
1	9%	70%	46%	27%	4%	21%	12%	5%	10%	59%	41%	21%
2	8%	84%	73%	53%	3%	29%	14%	4%	5%	69%	46%	21%
3	8%	76%	63%	41%	4%	36%	20%	10%	9%	63%	43%	26%
4	11%	88%	68%	49%	8%	42%	24%	9%	10%	69%	50%	31%
5	4%	92%	80%	64%	2%	45%	25%	9%	3%	79%	58%	34%
6	3%	88%	73%	50%	2%	48%	29%	14%	3%	74%	54%	31%
7	3%	94%	86%	64%	3%	54%	36%	18%	6%	84%	68%	49%
8	7%	92%	88%	83%	5%	59%	36%	21%	6%	82%	62%	42%

Table S3: Proportion of households that went at least one day without access to some medical resources post-hurricane; Minimum number of days households lacked access to utilities averaged by strata of remoteness; Minimum rate of mortality reported among neighbors averaged by strata of remoteness.

Table S3: Survey Characteristics								
Proportion of households with lack of access to medical care for at least one day (95% CI)								
Remoteness	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
No 911	0.015 (0.0019, 0.027)	0.025 (0.0096, 0.04)	0.019 (0.006, 0.032)	0.0095 (0.00022, 0.019)	0.015 (0.003, 0.026)	0.026 (0.012, 0.041)	0.02 (0.0063, 0.034)	0.027 (0.012, 0.041)
No transport	0.029 (0.011, 0.047)	0.025 (0.0096, 0.04)	0.0096 (0.00023, 0.019)	0.021 (0.0076, 0.035)	0.041 (0.022, 0.061)	0.02 (0.007, 0.033)	0.02 (0.0063, 0.034)	0.051 (0.031, 0.071)
Road damaged	0.05 (0.027, 0.073)	0.079 (0.053, 0.11)	0.041 (0.022, 0.06)	0.048 (0.027, 0.068)	0.12 (0.092, 0.16)	0.079 (0.054, 0.1)	0.11 (0.075, 0.14)	0.17 (0.13, 0.2)
Facility closed	0.067 (0.041, 0.094)	0.096 (0.068, 0.13)	0.062 (0.039, 0.086)	0.069 (0.045, 0.094)	0.08 (0.054, 0.11)	0.11 (0.081, 0.14)	0.078 (0.052, 0.1)	0.12 (0.09, 0.15)
No doctors	0.073 (0.045, 0.1)	0.069 (0.044, 0.094)	0.034 (0.016, 0.051)	0.048 (0.027, 0.068)	0.088 (0.06, 0.12)	0.057 (0.036, 0.078)	0.048 (0.027, 0.069)	0.075 (0.051, 0.1)
Dialysis	0 (0, 0)	0.0099 (0.00023, 0.02)	0.0024 (-0.0023, 0.0071)	0.0095 (0.00022, 0.019)	0.02 (0.0061, 0.033)	0.0022 (-0.0021, 0.0065)	0.01 (0.00024, 0.02)	0.0066 (-0.00086, 0.014)
Respiratory mach.	0.09 (0.06, 0.12)	0.11 (0.083, 0.14)	0.096 (0.068, 0.12)	0.079 (0.053, 0.1)	0.11 (0.079, 0.14)	0.088 (0.062, 0.11)	0.063 (0.039, 0.087)	0.12 (0.086, 0.14)
Medications	0.13 (0.093, 0.16)	0.13 (0.096, 0.16)	0.11 (0.078, 0.14)	0.13 (0.099, 0.16)	0.18 (0.14, 0.22)	0.17 (0.13, 0.2)	0.14 (0.1, 0.17)	0.17 (0.13, 0.2)
Affordable meds.	0.035 (0.016, 0.054)	0.049 (0.028, 0.071)	0.031 (0.015, 0.048)	0.053 (0.031, 0.074)	0.032 (0.015, 0.049)	0.031 (0.015, 0.047)	0.038 (0.019, 0.056)	0.038 (0.02, 0.055)
Other	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
Average number of days without utilities post hurricane [mean (95% CI)]								
Electricity	62 (58, 66)	80 (77, 84)	72 (68, 75)	78 (75, 81)	86 (84, 89)	79 (76, 82)	87 (85, 89)	91 (89, 93)
Water	24 (21, 28)	27 (24, 30)	33 (30, 37)	38 (35, 41)	38 (35, 42)	40 (36, 43)	45 (42, 49)	48 (45, 52)
Cellular Coverage	54 (50, 58)	59 (55, 62)	57 (53, 60)	62 (59, 66)	67 (64, 71)	63 (60, 66)	75 (72, 78)	70 (67, 73)
Lower bound of estimated mortality rate of neighbors [deaths/1,000 people]								
Mortality rate	12.97	11.27	11.62	23.97	18.33	15.49	16.71	12.96

Table S4: Estimate of excess mortality in Puerto Rico post hurricane Maria when compared to the same time period in 2016.

Table S4: Estimate of excess mortality post Hurricane Maria in Puerto Rico	
Avg monthly mortality rate per 1,000 people between September 20 and December 31, 2016, using official Department of Health Counts	8.82
Avg monthly mortality rate per 1,000 people between September 20 and December 31, 2017, in this survey	14.31 [9.76, 18.86]
Rate Difference [95% CI]	5.49 [0.94, 10.03]
Excess Deaths [95% CI]	4,645 [793, 8498]

Table S5: Count of population and deaths in survey with crude estimated mortality rate by remoteness; Estimated population and death counts with weighted mortality rates by strata. Annualized mortality rates showed overlapping confidence intervals across strata with no clear directionality of effect by level of ordinal increases in remoteness.

Table S5: Survey, estimated population and deaths by strata in 2017						
Survey				**Weighted population estimates**		
Remoteness	*Population*	*Deaths*	*Annualized mortality rate per 1,000*	*Population*	*Deaths*	*Annualized mortality rate per 1,000*
1	960	6	6.25 [1.25-11.25]	1035193.98	6694.817	6.47
2	1236	9	7.28 [2.52-12.04]	489425.288	3182.929	6.5
3	1161	5	4.31 [0.53-8.08]	295770.497	1773.067	5.99
4	1125	5	4.44 [0.55-8.34]	260242.155	1099.33	4.22
5	1293	12	9.28 [4.03-14.53]	305909.206	3220.782	10.53
6	1273	8	6.28 [1.93-10.64]	286182.153	1926.381	6.73
7	1087	6	5.52 [1.1-9.94]	220049.623	1199.469	5.45
8	1287	5	3.89 [0.48-7.29]	137533.593	468.9526	3.41

Table S6: Count of population and deaths in survey with crude estimated mortality rate by age

Table S6: Estimate of mortality rates by age group						
Age Strata	*Deaths before Sept 20th*	*Deaths after Sept 20th*	*Total Population*	*Rate before*	*Rate after*	*Average monthly rate ratio per 1,000 people*
[0,55)	2	4	5628	0.49	2.56	5.2
[55,70)	3	11	2158	1.92	18.35	9.53
[70,80)	4	8	1129	4.91	25.51	5.2
[80,90)	6	11	488	17.02	81.16	4.77
[90,Inf]	3	4	119	34.9	121.02	3.47

Table S7: Adjustment for biases in one-person households and in the distribution of household sizes in our survey; In our survey, we are unable to capture deaths that occurred in one person households. The first adjustment assumes that the death rate stayed the same in one person households before and after the hurricane. The second adjustment standardizes the household size estimates of rate to the historic proportions. a) Household size specific average monthly mortality rates, and b) resulting adjustments of mortality and total excess deaths.

Table S7(a): Household size specific average monthly mortality rate per 1,000 people

Household Size	*Median Age*	*Total Households*	*Population*	*Deaths before Sept 20th*	*Deaths after Sept 20th*	*Rate before Sept 20th*	*Rate after Sept 20th*
1	69	534	534	0	0	0	0
2	64.2	1074	2148	9	15	5.815	24.99
3-4	44	1255	4290	8	16	2.588	13.35
5+	27	436	2550	1	7	0.544	9.82

Table S7(b): Average monthly mortality rates per 1,000 people adjusting for biases

Adjusting for:	*After Sept 20th*	*95% CI*	*Estimate of excess deaths*
one-person households	14.78	[10.2, 19.4]	5045 [1133, 8958]
one-person households + ACS household adjustment	15.6	[10.6, 20.5]	5740[1506, 9889]

Table S8: Reported cause of death after the hurricane (see Survey instrument).

Table S8: Cause of death post hurricane	**Count**
Causes unrelated to the hurricane	12
Interruption of necessary medical services	12
Other reason	9
Medical complications from an injury, trauma, or illness directly due to the hurricane	3
Trauma (other)	1
Suicide	1
Trauma (vehicle accident)	0
Trauma (building collapse)	0
Trauma (landslide)	0
Drowning	0
Fire	0
Electrocution	0

IV. Citations

1. U.S. Census Bureau QuickFacts: Puerto Rico [Internet]. [cited 2018 Feb 12];Available from: https://www.census.gov/quickfacts/PR
2. Puerto Rico Spatial Data [Internet]. PR.Gov. 2017 [cited 2018 Oct 1];Available from: http://www2.pr.gov/agencias/gis/Pages/default.aspx
3. http://www.health.state.pa.us