A First Hazard Analysis of the Harrat Ash Shamah Volcanic Field, Syria-Jordan Borderline

By

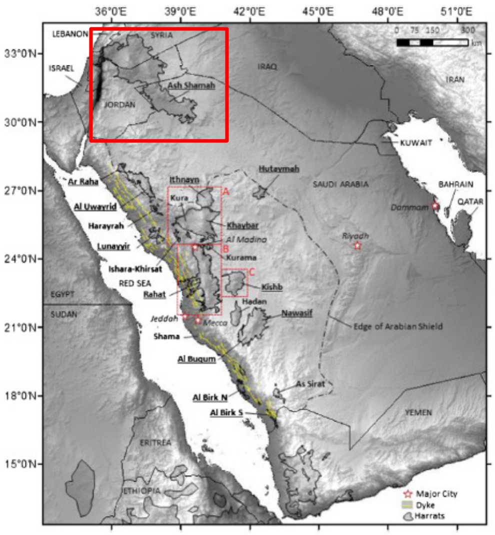
Zehra Çağnan[1], Saed Moghimi [2] and Sinan Akkar [3]

[1] Civil Engineering Department, TED University, Ankara, Turkey.

[2] Civil Engineering Department, Middle East Technical University, Ankara, Turkey.

[3] Earthquake Engineering Department, Kandilli Observatory and Earthquake Research Institute, Boğaziçi University, Istanbul, Turkey.

Objective of the Work



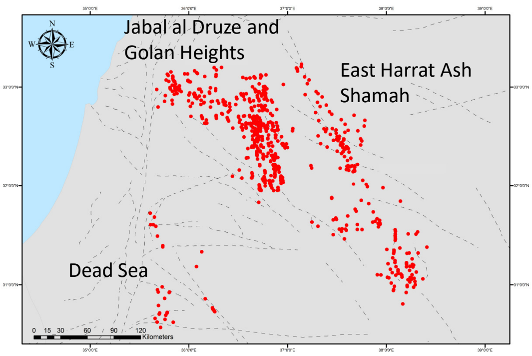
Taken from Runge et al. (2016)

- To study valocanic hazard for the Northern most point of Saudi Cenozoic volcanic fields (SCVFs): Harrat Ash Shamah by following a probabilsitic approach
- To estimate epistemic uncertainty associated with computed regional volcanic hazard distributions through adoption of the logic tree approach

Outline of the Talk

- Characteristics of the vent database in hand
- Probabilistic volcanic hazard assessment methodology followed
- Preliminary logic-tree
- Results
- Conclusive remarks

Study Area: Harrat Ash Shamah (733 vents)



Only very crude age data was available for the first phase of this work

- The database of 733 vents corresponding to Harrat Ash Shamah compiled by geologists contributing to the study: Dr. L. Serva, Dr. F. Fumanti from Italian Institute for Environmental Protection and Research
- In this work, published data on SCVF along with recent high-resolution satellite images, geologic maps from the United States Geological Survey Department and Natural Resource Authority of Jordan were collated and compared to refine the locations of vents.

- Review of view points of volcanology/geologist experts about aging and location

Considered in idensifying cluster inter-dependencies

Considered in recurrence models

Considered in anisotropic spatial density

- Number of vents in Syria

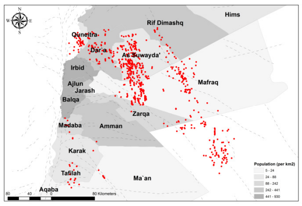
% of these in the Miocene	5
% of these in the Plio-Quaternary	75
% of these in the Holocene	20
Estimate of number of vents in a single episode in Syria	3-15
Maximum distance between vents that erupt in the same episode	11 km
Maximum distance between contiguous vents that erupt in the same episode	1 km
What is the percentage of vents that are associated with faults	85

- Number of vents in Jordan

% of these in the Miocene	10
% of these in the Plio-Quaternary	85
% of these in the Holocene	5
Estimate of number of vents in a single episode in Jordan	3-8
Maximum distance between vents that erupt in the same episode	9 km
Maximum distance between contiguous vents that erupt in the same episode	2 km
What is the percentage of vents that are associated with faults	85

- Number of vents in Saudi Arabia

% of these in the Miocene	5
% of these in the Plio-Quaternary	75
% of these in the Holocene	20
Estimate of number of vents in a single episode in Saudi Arabia	3-13
Maximum distance between vents that erupt in the same episode	10km
Maximum distance between contiguous vents that erupt in the same episode	1km
What is the percentage of vents that are associated with faults	80



[*] *Currently the given vent ages are very general (not vent-specific) and do not provide us reliable information for independency of vents. We currently identify vent cluster inter-dependencies based on degree of proximity of neighboring vents only.*

Probabilistic Volcanic Hazard Assessment

$$P(N \geq 1) = 1 - e^{-\hat{\lambda}(x) A \hat{\lambda}(t) \Delta t}$$

Probability of observing at least one new vent for a given time interval Δt (Poisson model)

spatial density of vents

affected area – adopted cell size

recurrence rate of the vent

⇩

(based on past vent data)

Average recurrence rate

$$\hat{\lambda}(t) = \frac{N-1}{t_o - t_y}$$

in terms of total number of vents in the area, N; age of oldest vent, t_o; age of youngest vent, t_y.

Computed from the age vs. vent data provided by the geologists

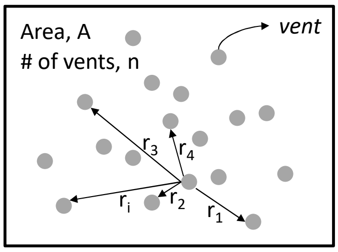
Spatial distribution of vents are determined from the past vent data by implementing different models to different regions

Spatial Density Models (based on past volcanic centers)

Cluster Analysis

$$R_{avg} = \frac{\sum r}{n} \qquad R_{\exp} = \frac{1}{2\sqrt{\lambda}}$$

λ: mean number of vents in a sub-area; n/A
r: distance between each vent and its nearest neighbour
R_{avg}: average nearest neighbour distance
R_{exp}: expected average nearest neighbor distance given spatial Poisson model



R_{avg}/R_{exp}>1 almost uniformly distributed vents. Vents are further apart than you might expect in case of spatial Poisson model ⟹ **UNIFORM DISTRIBUTION**
R_{avg}/R_{exp}=1 Vent distribution is following a spatial Poisson model (random)
R_{avg}/R_{exp}<1 Vents are closer to each other than you might expect in case of spatial poisson model (random) ⟹ **CLUSTERING**

Poisson Model:

$$P(x) = \frac{\lambda^x e^{-\lambda}}{x!}, x = 0,1,2,3,\ldots,n$$

⟹ P(x): probability of getting x vents in any one sub-area

Justification for Cluster Analysis - Clark and Evans (1954)

$$R_{avg} = \frac{\sum r}{n} \qquad R_{\exp} = \frac{1}{2\sqrt{\lambda}} \qquad \sigma_{R_{\exp}} = \frac{0.2613}{\sqrt{n\lambda}}$$

$$c = \frac{R_{avg} - R_{\exp}}{\sigma_{R_{\exp}}}$$

n: total number of vents
A: total area
λ: mean number of vents in a sub-area; n/A
r: distance between each vent and its nearest neighbour
R_{avg}: average nearest neighbour distance
R_{exp}: expected average nearest neighbor distance given spatial Poisson model
σ_{Rexp}: standard error of the means of the nearest neighbour distances

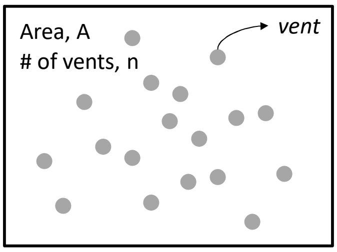
The null hypothesis that vents are randomly distributed in the considered area (follow spatial Poisson model) can be rejected with %99 confidence if abs(c)>2.58

FINDINGS ARE CONSISTENT WITH PREVIOUS STUDIES

For the given data:

λ = 0.019 vent/km^2, R_{avg} = 2.70km, R_{exp} = 3.63km, R: 0.74 < 1 therefore CLUSTERING exists
c = -13.26, |c|>2.58 therefore CLUSTERING exists

First order spatial density estimate (Cluster Analysis)



$$\lambda(x) = \frac{n}{A}$$

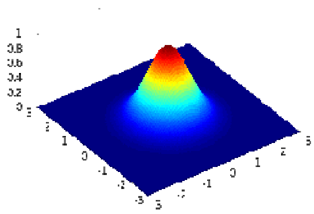
Homogenous within the considered sub-area, A

Parametric models (no clustering between vents): fit a distribution (uniform, bivariate Gaussian. <u>When clusters exist</u> within volcanic fields, these models completely smoothen them out hence not suitable for such problems.

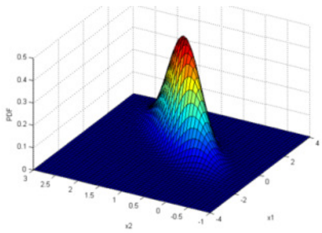
Non-parametric models (clustering between vents): Observed vent locations are used to estimate the spatial density at any point in the region using a Kernel function, $\lambda(x)$. The kernel function can be isotropic or anisotropic and depends on the distances between vents (x_i) as well as smoothing bandwidth (h).

Clustering Models

Gaussian Kernel Functions



Isotropic Gaussian – smoothing with the same bandwidth along all radial axes

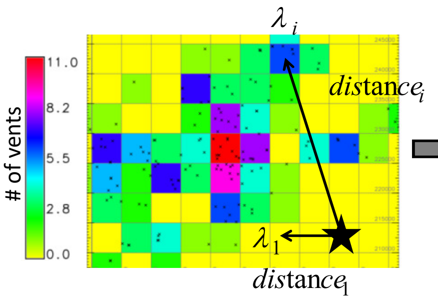


Anisotropic Gaussian – smoothing with different bandwidths along major axes

Optimal bandwidth selectors

- **Silverman's rule of thumb**
- **Multivariate Data Cross Validation**
- **Plug in Selectors**

Point data to raster data



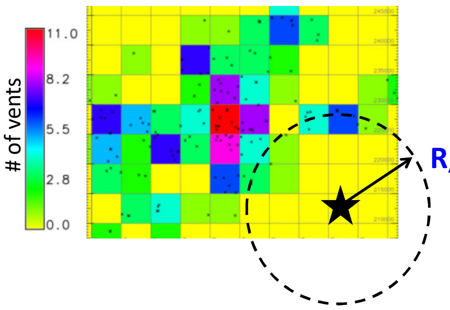
Given a sub-area and grid size (e.g., 5kmx5km) determine the number of vents at each grid and compute the spatial density for each grid (# of vents/grid area)

$$\lambda_{site} = \frac{\sum_{i=1}^{N} w_i^p \lambda_i}{\sum_{i=1}^{N} w_i^p}$$

λ_i: spatial density for each grid
w_i: weight assigned for each grid
p: power of weight

inverse of distance between the site and the grid

Raster Analysis



Smoothing **increases** with **large search radius values** and **low weight power values**

R, search radius

λ_{site} for R:50km,100km, 150km, p:1,2 or grid size:5kmx5km, 10kmx10km, 15kmx15km,20kmx20km **logic tree weights recommended based on square error values**

Cross Validation

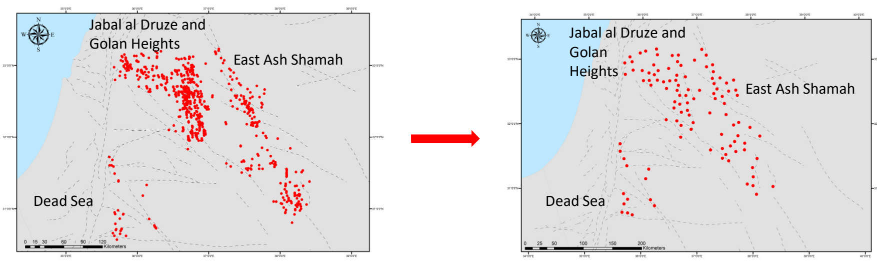
$$\lambda_{grid\_i} = \frac{\sum_{i=1}^{N} w_i^p \lambda_i}{\sum_{i=1}^{N} w_i^p}$$

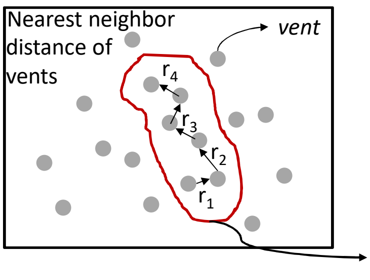
$$LSE = \sum_{i=1}^{N} \left(\lambda_{grid\_i} - \lambda_i\right)^2$$

Least Squared Error

Optimal R, p or grid size values searched

Identifying Independent Vents



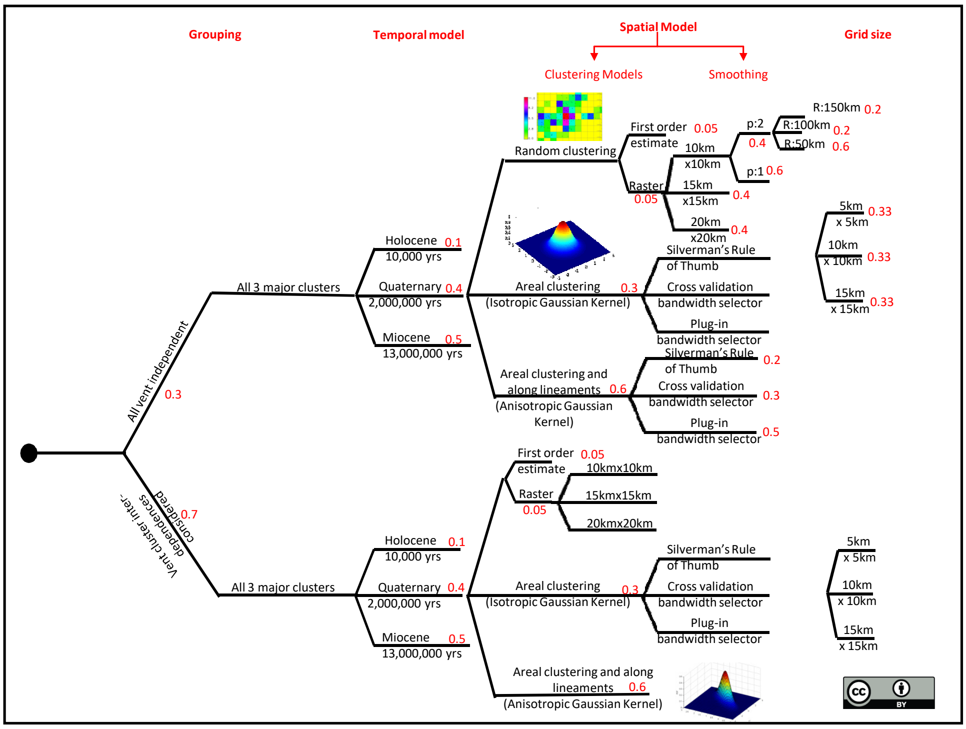


Limiting proximity values for grouping vents together:

- For Jabal al Druze cluster: 11km
- For East Ash Shamah cluster: 10km
- For Dead Sea cluster:9km

r_1, r_2, r_3, r_4 are less than the limiting max. distance for each episode

Preliminary logic-tree



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** Currently the given vent ages are very general (not vent-specific), the above general distrbutions for each major vent clustered considered as the basis of the Monte Carlo simulations conducted for assigning an age value for each vent.*

Results

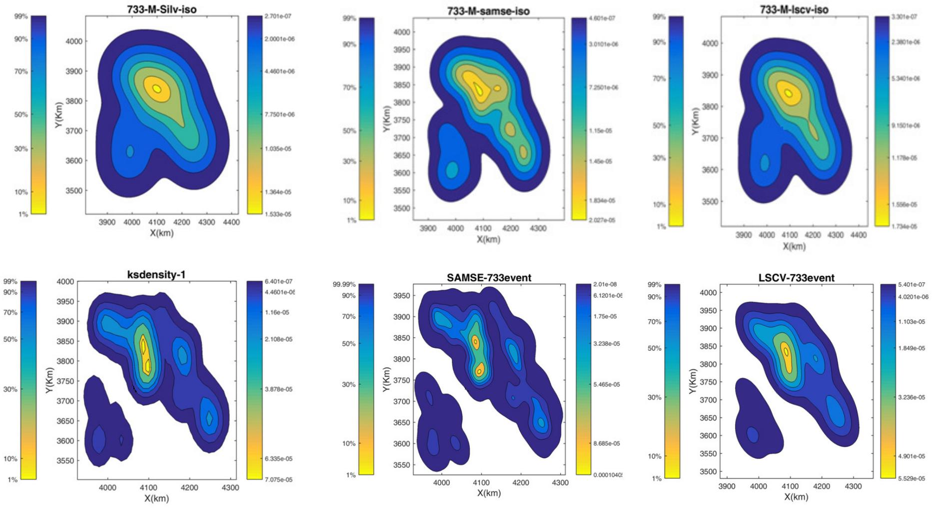
Anisotropic/Isotropic Gaussian Kernel Spatial Density Maps

Miocene to present results

λ:2.701 e-7 (99% contour)
λ:1.533 e-5 (1% contour)

λ:4.601e-7 (99% contour)
λ:2.027 e-5 (1% contour)

λ:3.301 e-7 (99% contour)
λ:1.734 e-5 (1% contour)



λ:6.401 e-7 (99% contour)
λ:7.075 e-5 (1% contour)

λ:2.01 e-8 (99.9% contour)
λ:1.04 e-4 (1% contour)

λ:5.401 e-7 (99% contour)
λ:5.529 e-5 (1% contour)

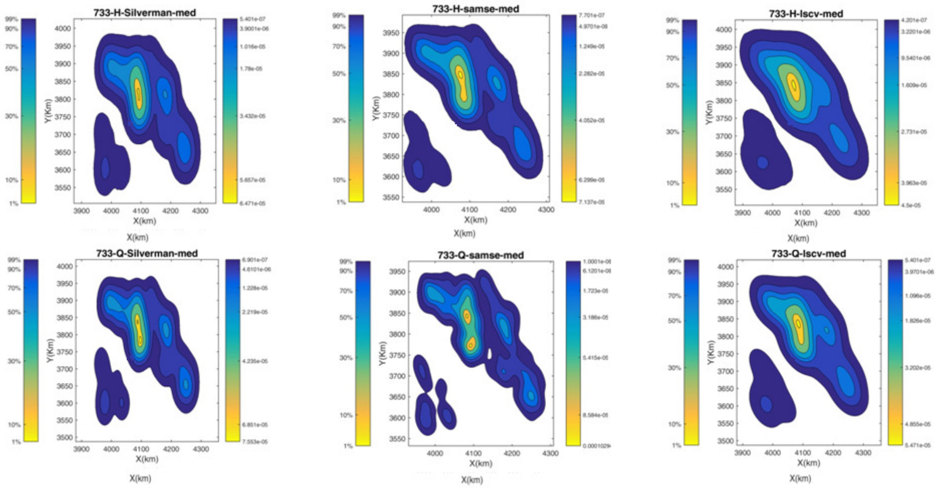
Anisotropic Gaussian Kernel Spatial Density Maps - Age Distribution Reflected

Only median results

λ:5.401 e-7 (99% contour)
λ:6.471 e-5 (1% contour)

λ:7.701e-7 (99% contour)
λ:7.137 e-5 (1% contour)

λ:4.201 e-7 (99% contour)
λ:4.500 e-5 (1% contour)



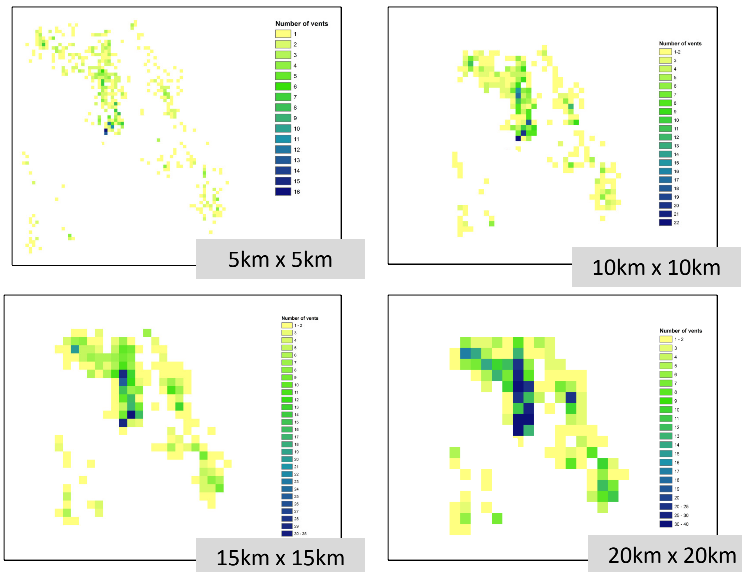
λ:6.901 e-7 (99% contour)
λ:7.553 e-5 (1% contour)

λ:1.00 e-6 (99.9% contour)
λ:1.03 e-4 (1% contour)

λ:5.401 e-7 (99% contour)
λ:5.471 e-5 (1% contour)

Raster Spatial Density Maps

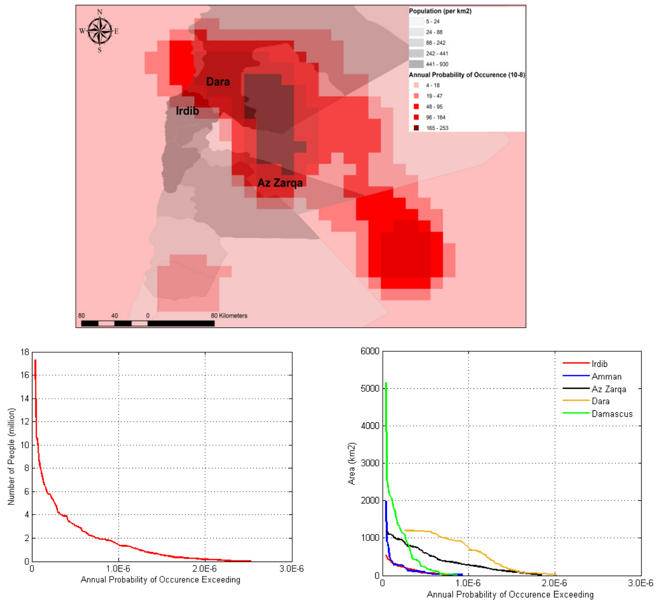
Point to Raster Data ARCGIS



$\lambda \approx$ 1e-2 vent/km^2

$\lambda_{independent} \approx$ 1e-3 vent/km^2

Annual Probability of Vent Occurence



Concluding Remarks

- 10% of the population living in the region is subjected to annual occurence probability of at least one event exceeding the level 10^{-6}
- At Irdib and Amman, all population is subjected to annual occurence probability of at least one event below the level of 10^{-6}

- **Independence**- range varies between 1e-7 and 1e-9
- **Kernel Spatial Density**- range varies between 1e-8 and 1e-9
- **First-order and Raster Spatial Density**- range varies between 1e-5 and 1e-7
- **Reccurence rate**- range varies between 1e-5 and 1e-7

As more radiometric age determinations become available we anticipate to greatly refine the recurrence rate estimates and more accurately model minor clustering structures

Thank you for listening