Spatio-temporal clustering of polygon objects and per object interventions

Optimizing remediation of spatially dispersed contaminated parcels under an annual budget constraint

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Floris Abrams received his master degree in Agro-and Ecosystem Engineering from the university of KU Leuven (Belgium) in 2019. He is currently a PhD researcher at the Belgium Nuclear Research Facility (SCK CEN) working on Combining Machine Learning and Operations Research methods for Optimizing Remediation Efforts in Response to Large-Scale Nuclear Emergencies Affecting Food and Agriculture.

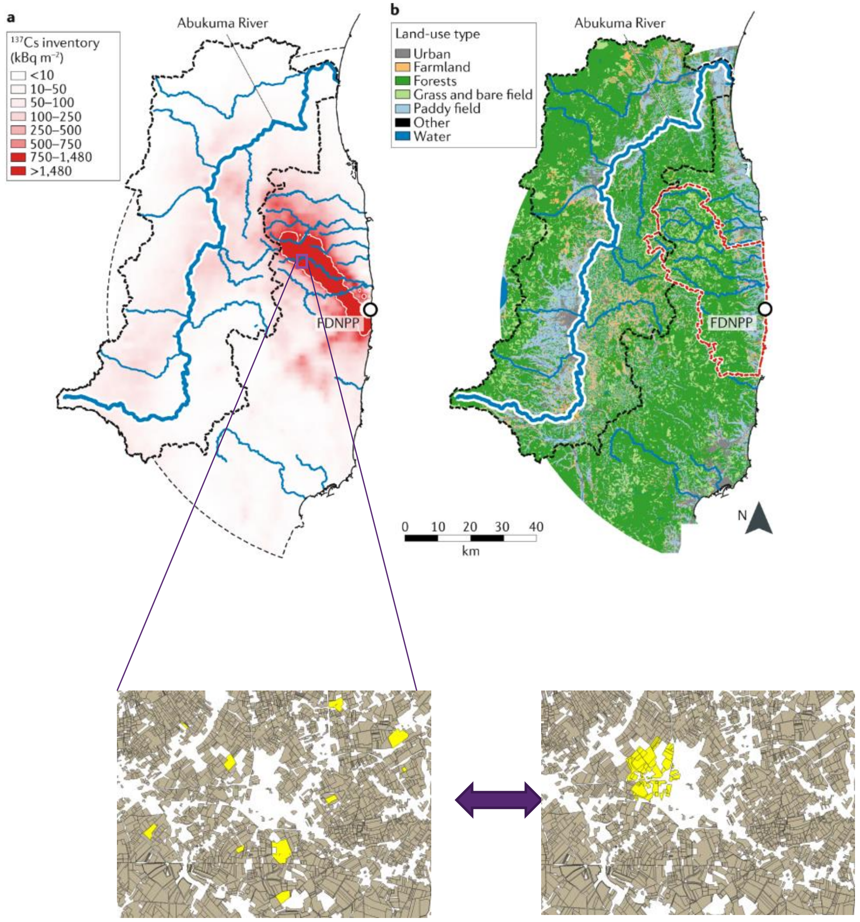
Aims and contributions of our paper

- Aims of our paper
  - Improve spatial decision-making for distributed polygon-based parcels and parcel-specific interventions
  - Improve feasibility and reduce cost of remedial actions
- Contribution of our paper
  - Proposed an algorithm to cluster polygons in space and time to improve overall feasibility and cost of interventions given an annual budget

Problem statement

- Polygons provide a natural representation for many types of geospatial entities → smallest unit of decision making of real world problems
- When addressing large scale contamination situations not all sites can be acted on at the same time
- Searching for individual optimality for these dispersed entities could result in a heterogeneous and difficult to perform action plan

✓ Clustering of objects in multi-parcel management units, can improve feasibility and reduce cost



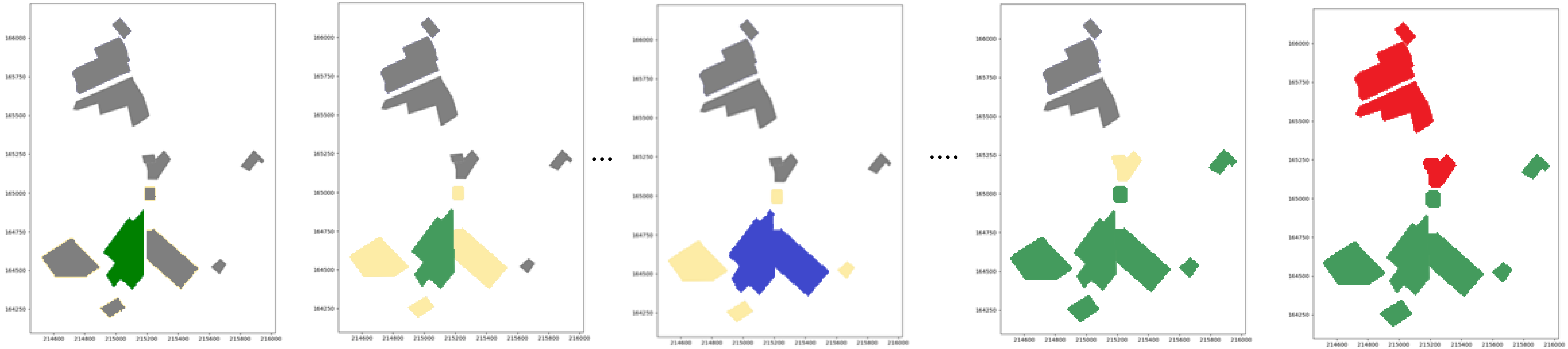
Case study:
Optimizing remediation of spatially dispersed contaminated agricultural parcels

- Pollution is one of the main threats affecting soils and the ecosystem services they provide.
- Due to the persistent nature it requires intensive and active management to reduce the contamination in a reasonable time span.
- Agricultural areas are of major concern as they serve a multitude of ecosystem services to the population.

Cluster methodology

Cluster 1 Cluster 2

Start cluster Grow cluster Stop cluster

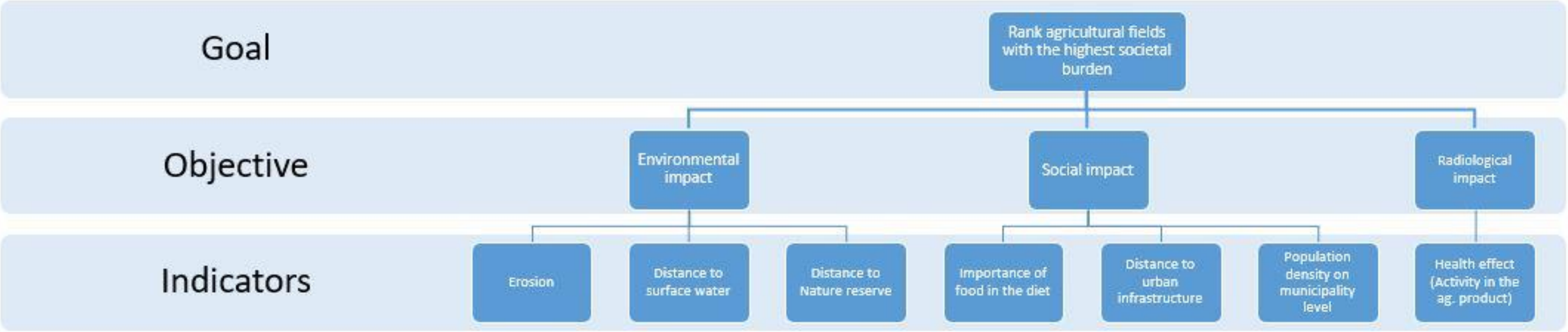


Remedial actions

- Potassium fertilizer
- Shallow ploughing
- Awaiting remediation
- Topsoil removal
- Skim and burial
- Possible neighbors

Determining the Parcel Priority (PPS)

- The seed parcel is determined based on a parcel priority score (PPS)

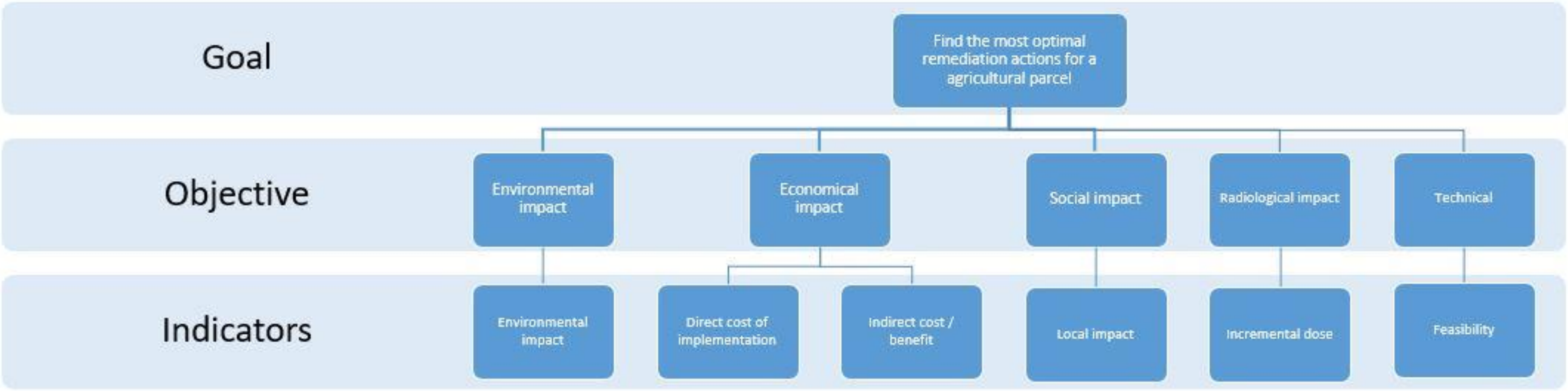


- Score is based on a distance measure
- Compromise programming MCDA
  - Distance to most optimal point to determine parcel priority
  - Small distance → high priority

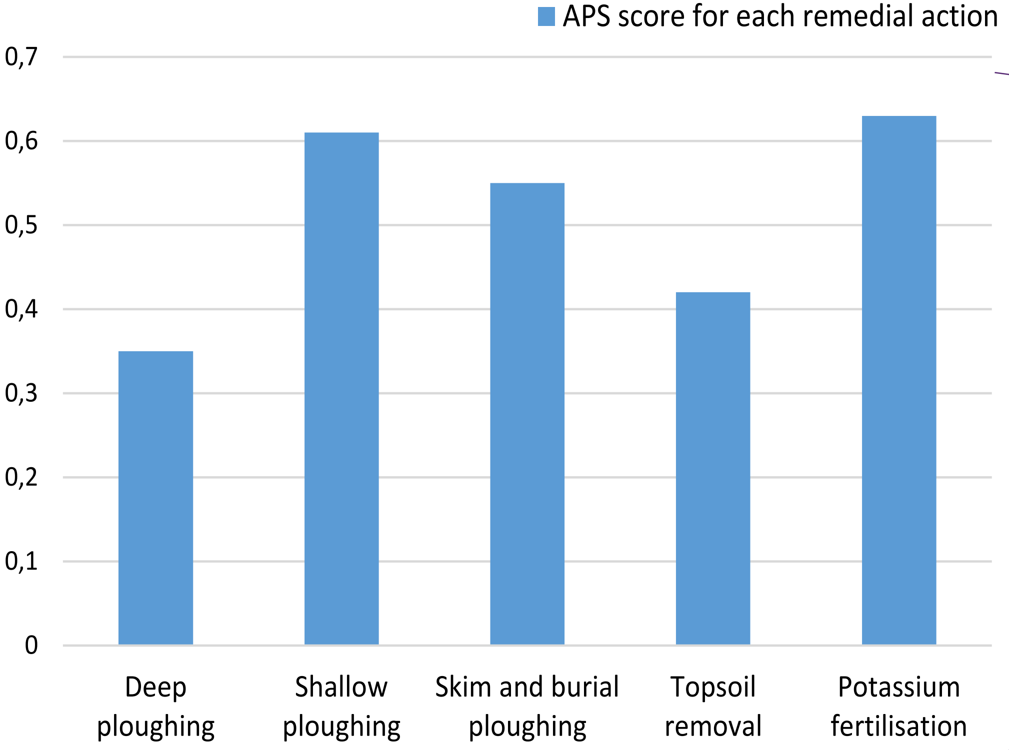
$$L = \left[\sum_{i=1}^{n} w_i^p \left[\frac{f_i^+ - f_i(x)}{f_i^+ - f_i^-}\right]^p\right]^{1/p}$$

Determining the optimal remedial technique (APS)

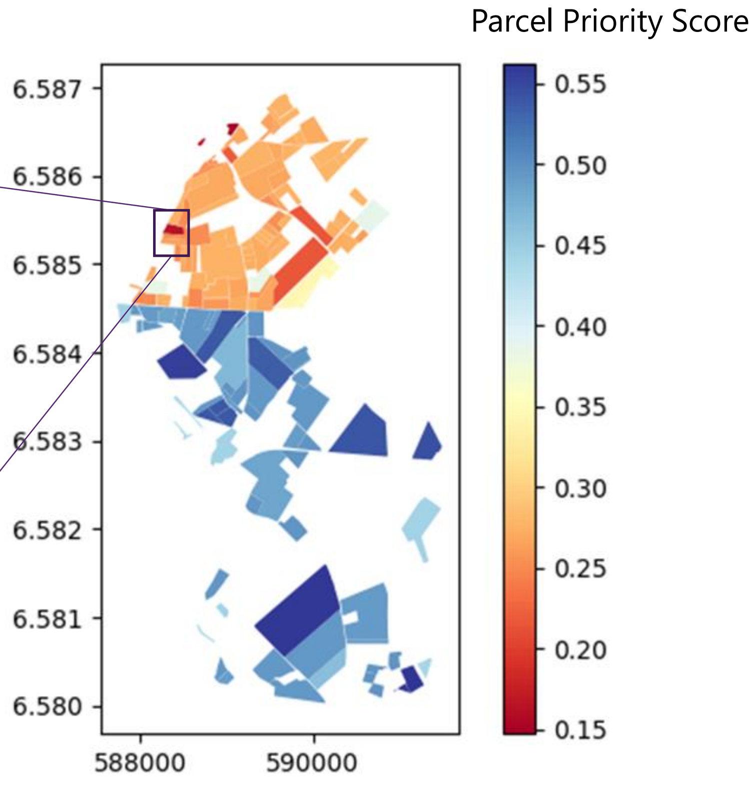
- For each parcel the optimal remediation action is determined from the feasible alternatives.



- Distance based for each individual parcel
  - Only feasible techniques based on parcel & contamination characteristics
  - Low distance → Good technique



Action Priority Score (APS) for the different candidate remedial actions for an agricultural parcel with cereal cultivation.

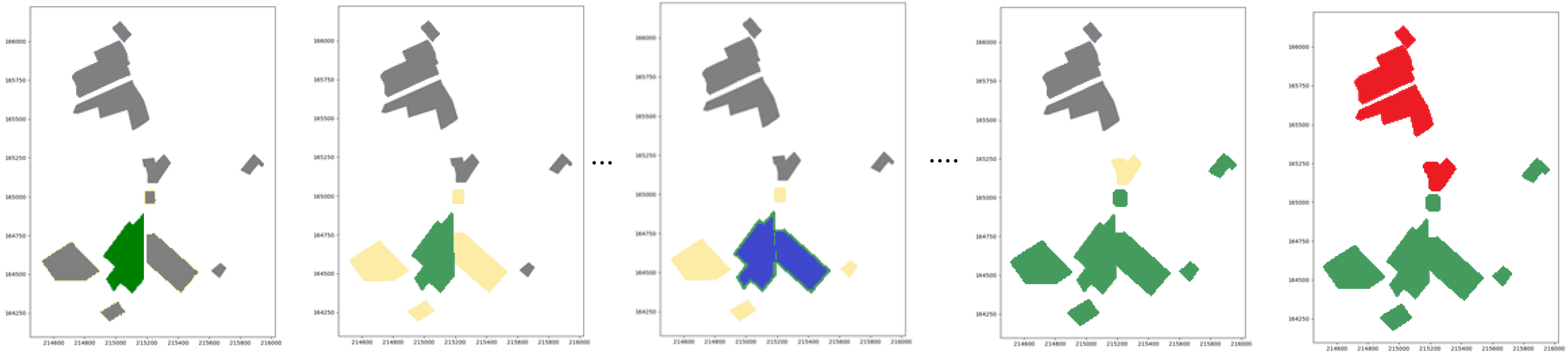


Parcel priority score (PPS) for the affected agricultural parcels, the smaller the more urgent the remediation.

Cluster methodology

Cluster 1 | Cluster 2

Start cluster | **Grow cluster** | Stop cluster



Remedial actions

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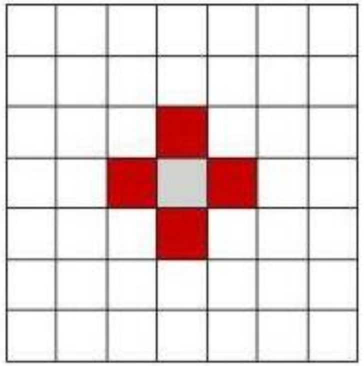
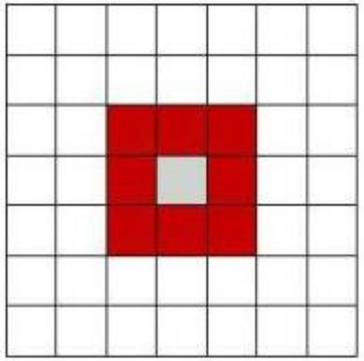
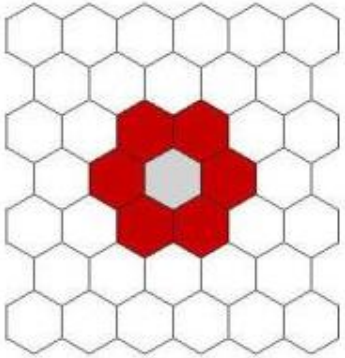
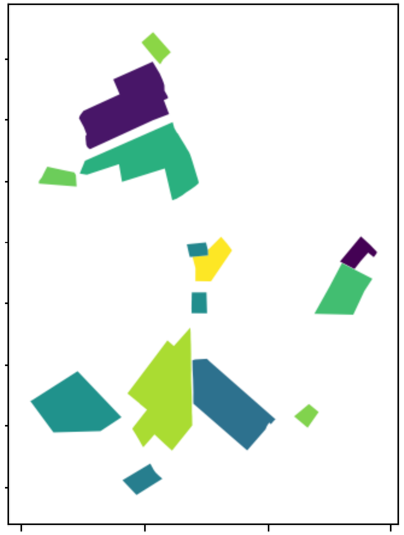
How to determine geospatial neighbors?

- Not always straightforward
- Adjacency is context specific
- What are spatial neighbors in a dispersed context?

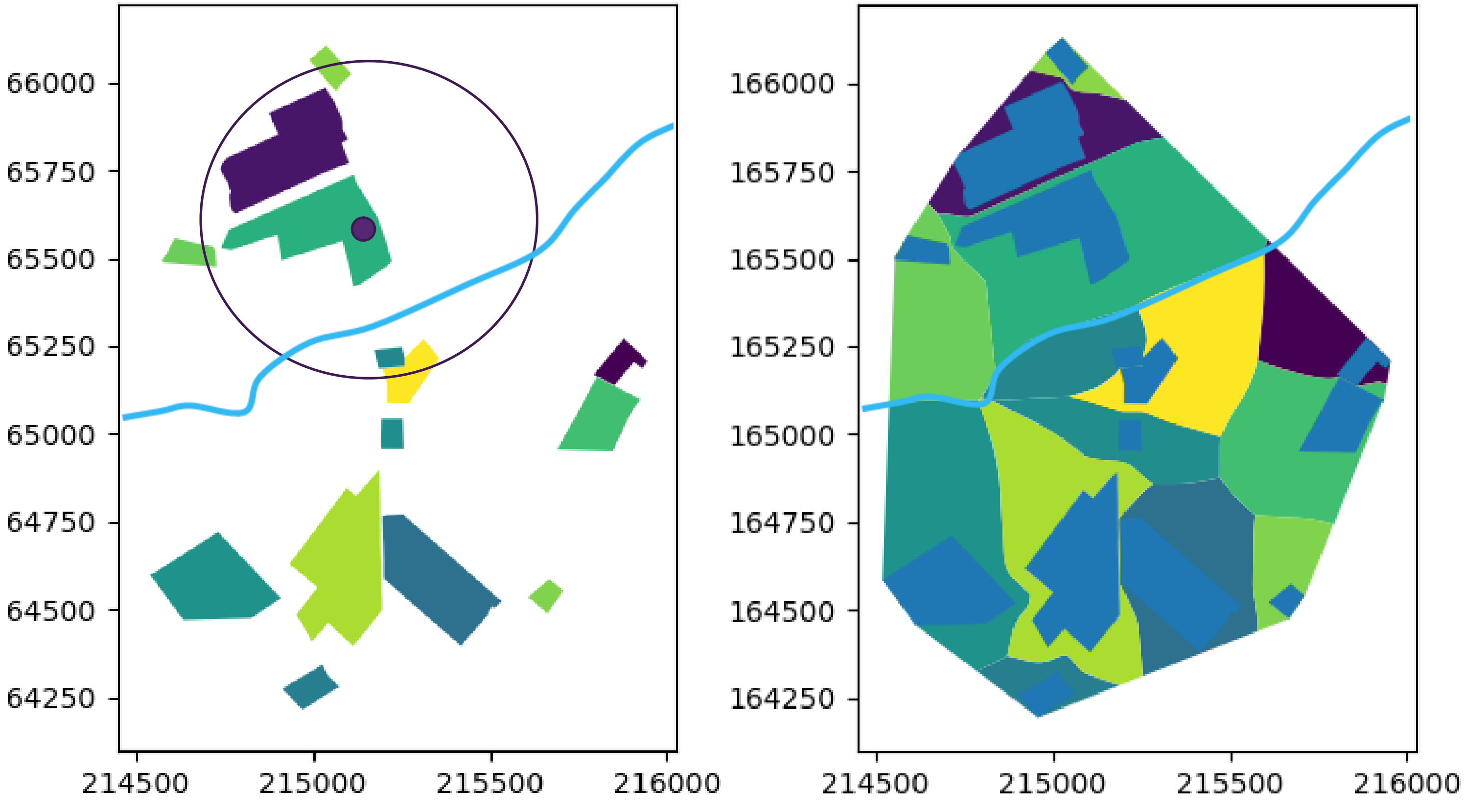






Spatial neighbors in a dispersed context

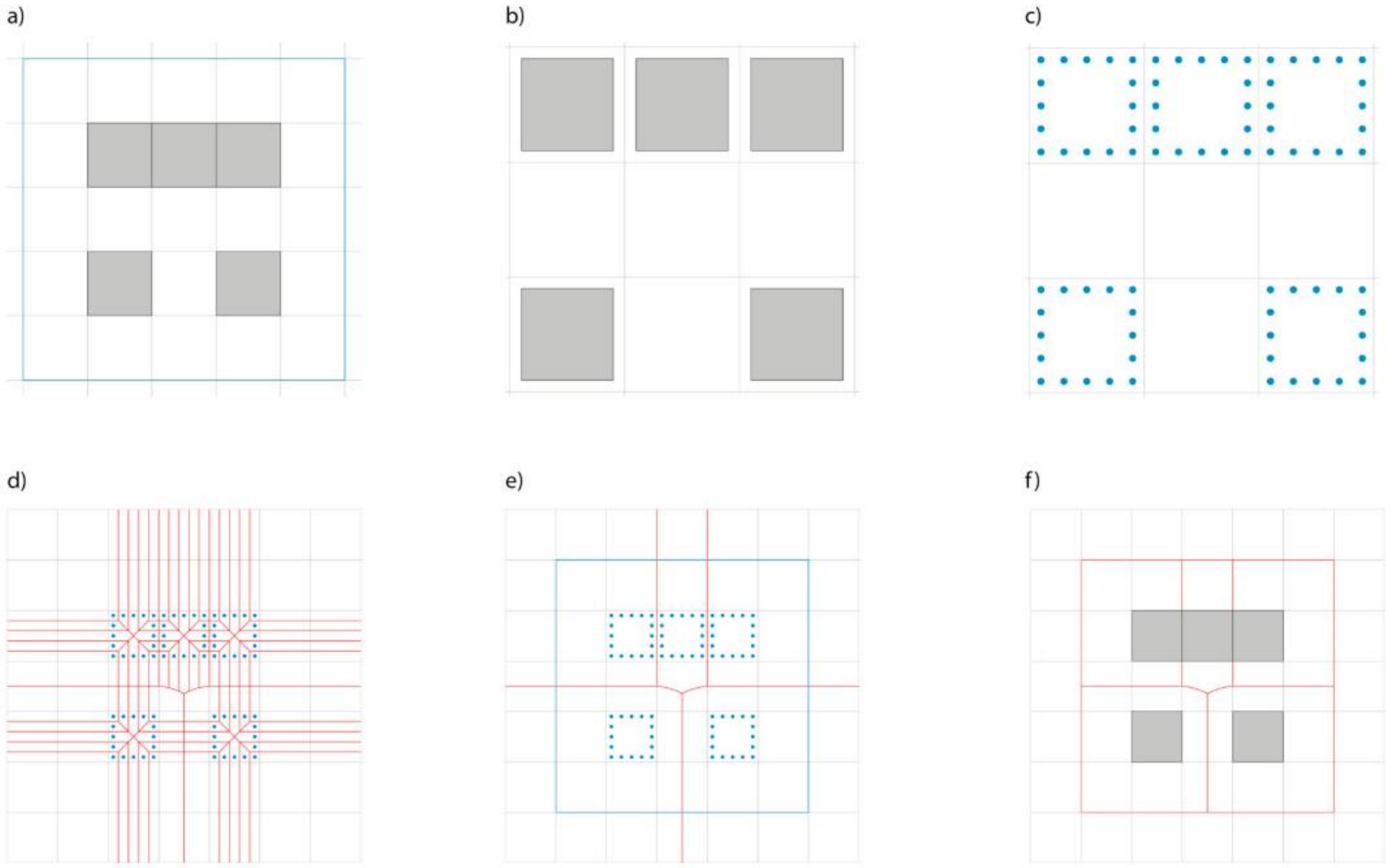
- Within a certain range?
- Difficult to surpass structures between the polygons

We use Enclosed Morphologic tessellation[1]



Initial set of distributed parcels (left) and VP computed by the EMT, resulting in a partitioned space.

Reference [1] Fleischmann, M., 2019. momepy: Urban Morphology Measuring Toolkit. J. Open Source Softw. 4, 1807. https://doi.org/10.21105/joss.01807



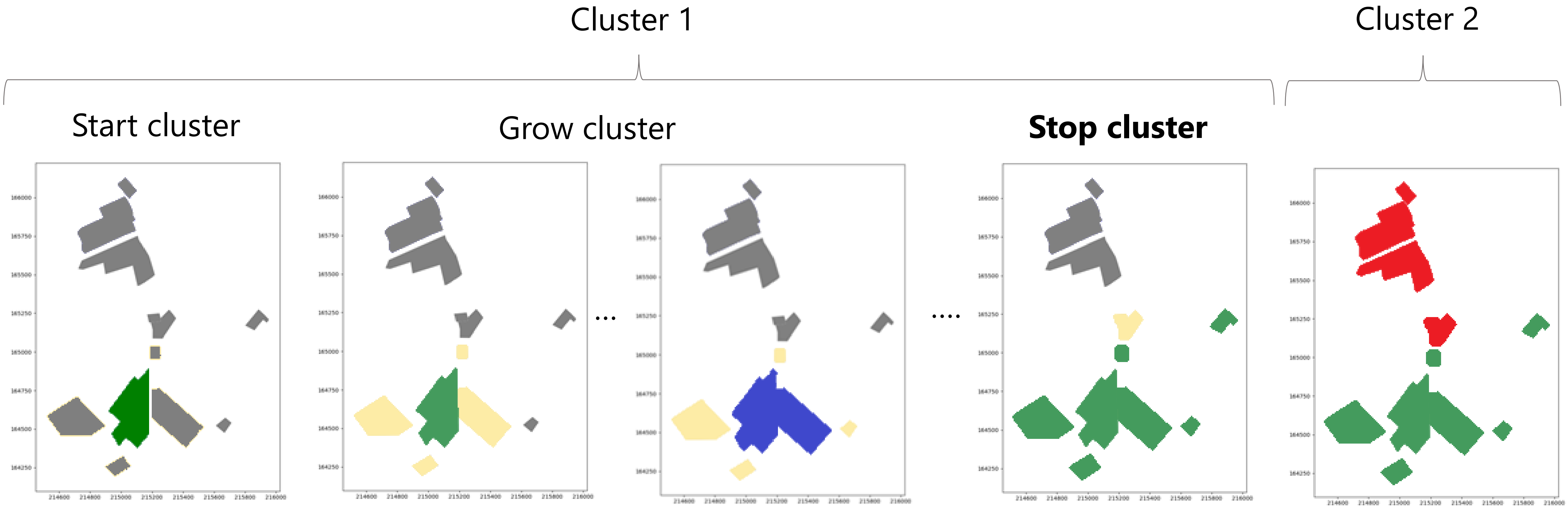
Reference Fleischmann, M., 2019. momepy: Urban Morphology Measuring Toolkit. J. Open Source Softw. 4, 1807. https://doi.org/10.21105/joss.01807

Finding the optimal neighbor for the growing cluster

Parcels / Iterations	A PPS = 0.15	B PPS= 0.17	C PPS= 0.28	D PPS= 0.35	E PPS= 0.41
Iteration I (Seed parcel)	**APS_1: 0.17** APS_2: 0.22 APS_3: 0.33	**APS_1: 0.18** APS_2: 0.23 APS_3: 0.20	APS_1: 0.30 APS_2: 0.24 **APS_3: 0.11**	APS_1: 0.20 **APS_2: 0.11** APS_3: 0.17	**APS_1: 0.15** APS_2: 0.22 APS_3: 0.26
Iteration II (A+B)	**APS_1: 0.35** **PPS: 0.32** **Composite $score_1$: 0.67**				
Iteration III (A+B+C)	**APS_3: 0.64** **PPS: 0.60** **Composite $score_3$: 1.24**				
Iteration IV (A+B+C+D)	**APS_2: 0.80** **APS: 0.95** **Composite $score_2$: 1.75**				
Iteration V (A+B+C+D+E)	**APS_1: 1** **PPS: 1.36** **Composite $score_1$: 2.36**				

The growing procedure of a cluster for 5 iterations

Cluster methodology



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End of growth

1. No more neighboring parcels
2. The optimal neighboring parcel has a priority difference with the seed parcel larger than the predefined threshold
3. The annual budget of remediation is reached
    1. Further remediation is done in t+1

The time of remediation

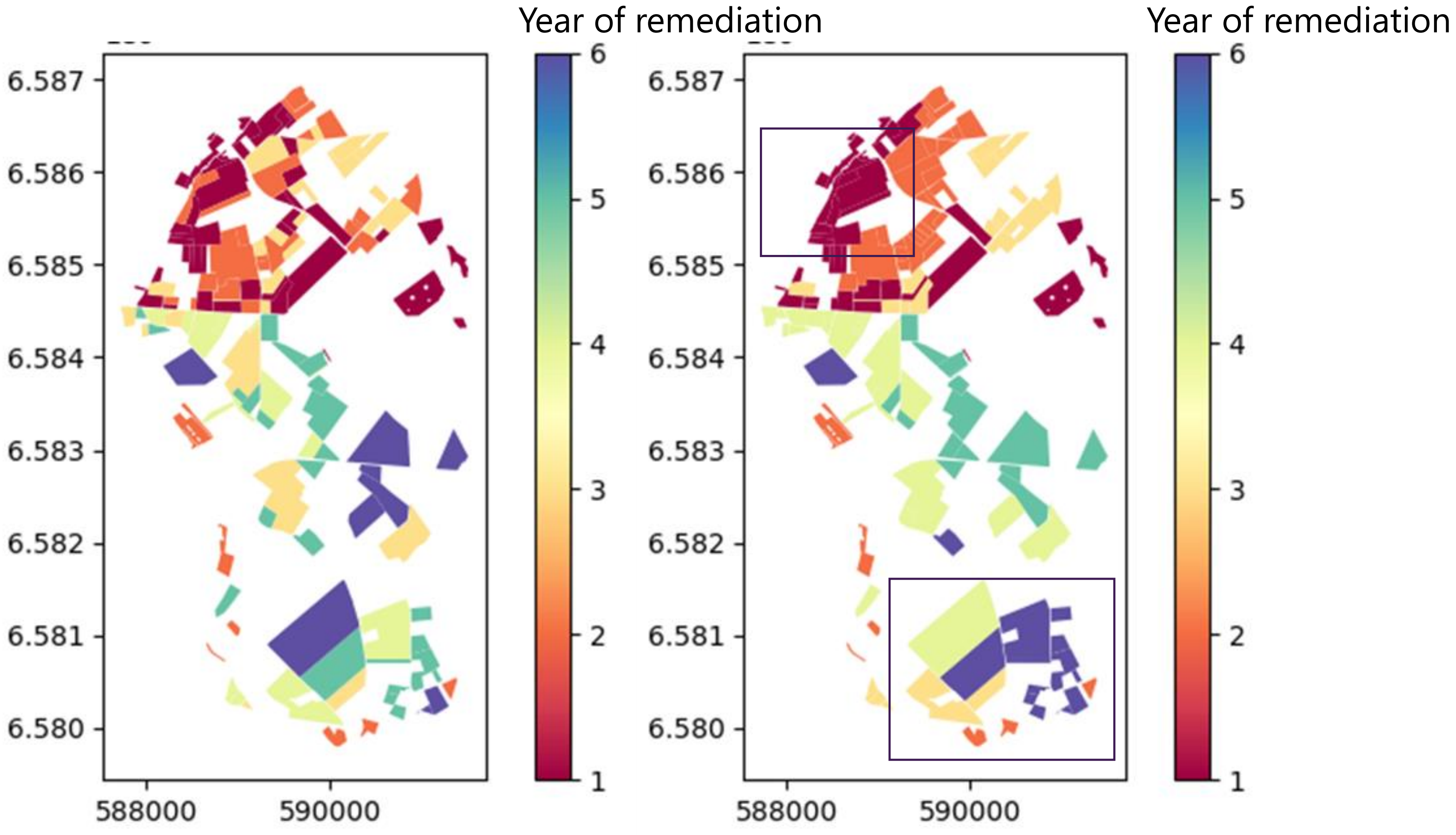

Figure : Spatial distribution of the remediated parcels per year after spatio-temporal clustering with similarity thresholds (threshold=0) on the Left and low similarity threshold (threshold=0.25) on the

Impact of the priority threshold value

Priority Threshold value	Increase in PPS Score	Increase in APS score	Number of clusters	Number Remedial Technologies
0.00	0,0	0,0	157	5
0.25	16,0	5,8	34	3
0.42	39,5	7,8	3	1

Impact of the allowed remedial alternatives

- Remedial techniques are allowed if they are able to reduce the contamination level below the allowed concentrations
  - Semi-compensatory techniques in MCDA

When larger clusters are discounted

Food restriction levels [Bq/kg]	Numbers of clusters	Number of remedial technologies	Total cost	Waste volume produced [m^3]
Less restrictive	6	2	293 398	61 795
More restrictive	37	5	499 813	232 476

Conclusion

- The proposed algorithm can cluster polygon-based parcels by type of intervention in space and time for given annual budget.
- The model is based on MCDA scores, with their own limitations (compensatory techniques)
- The predefined thresholds have a large influence on the model results
- Future work will focus on off-site effects, through erosion modelling

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