Open Source GIS tools for local administrations: pursuing the economic sustainability of Solid Waste Management in low-income countries

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Final Defense
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UNIVERSITÀ DEGLI STUDI DI BRESCIA

Università degli Studi di Brescia
Dottorato di Ricerca in Ingegneria Civile, Ambientale, della Cooperazione Internazionale e di Matematica

OUTLINE OF THE PRESENTATION

Dottorato in Ingegneria Civile, Ambientale, della Cooperazione internazionale e di Matematica
(coordinatore prof. Paolo Secchi)

Curriculum: Metodologie e tecniche appropriate nella cooperazione internazionale allo sviluppo
(referente prof.ssa Sabrina Sorlini)

Ph.D. Candidate: Francesca Villa, XXXII ciclo

Tutor: prof. Mentore Vaccari

Co-tutor: prof. Mario Grosso (Politecnico di Milano)

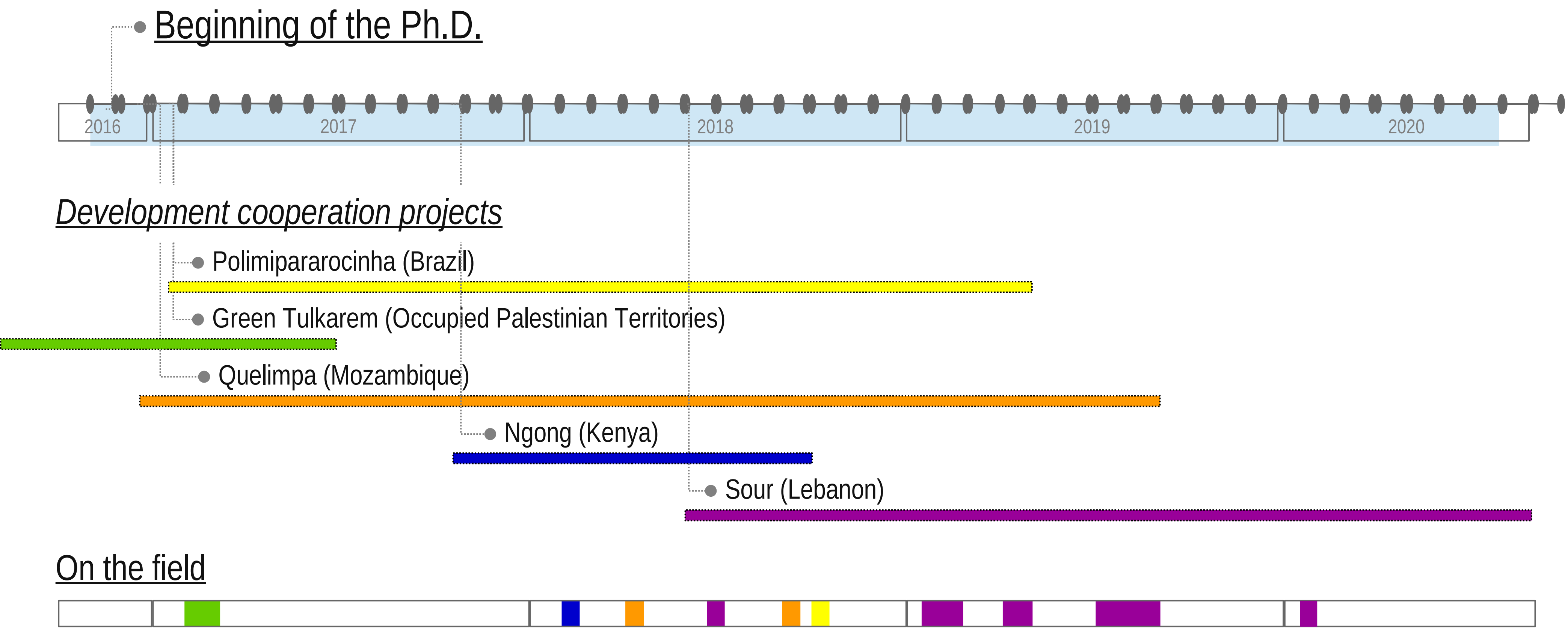
Main topic: Gestione dei rifiuti solidi nei contesti a basso reddito

Titolo della tesi: Open Source GIS tools for local administrations: pursuing the economic sustainability of Solid Waste Management in low-income countries

Outline:

- Research background
- Material and methods
- Case study
- Results
- Conclusions

RESEARCH BACKGROUND



RESEARCH BACKGROUND: SWM in low-income countries

Main characteristics:

- **Solid waste composition vary for each country,** it is usually characterized by a high rate of the organic fraction
- **Improper management of solid waste in low-income countries affect all stages,** from collection to final disposal
    - Authorities often manage only the collection and disposal, not ensuring the coverage of all areas
    - Uncollected waste are burned, buried or thrown away in open spaces
    - Final disposal is usually in uncontrolled dumpsites
- **Consequences of improper management affect public health and environment**
- **Solid waste management depends often on public funds**
    - Collection and fuel
    - It is not clear whether they are coming from central governments or aid agencies
    - Scarce contribution of direct fees

RESEARCH BACKGROUND: SWM in low-income countries

Lesson learned from the field:

Quelimane / Ngong	Green Tulkarem		Polimipararocinha
Disequalities and social impacts of a improper SWM system	Scarce feasibility of the introduction of fees (reluctance of authorities) End of the project	Difficulties in planning, lack of time and knowledge	Importance of geographical data / complexity of SWM data (Disequalities)

Needs

Equity in the service coverage	**Economic and social sustainability** Savings / improved use of available resources	**Tools for remote planning** Support for local management of the system	**Data accessibility / reliability**

RESEARCH BACKGROUND: GIS, FOSS and Open data

GIS – Geographical Information Systems

lead to a deeper understanding of places, having a significant role in environmental planning

GIS & SWM

- Several spatial aspects
- Geographical features influence SWM

Implementation may encounter some obstacles (e.g. accessibility of data and software), failure of ICTs is frequent

Adoption of FOSS (Free Open Source Software) as a strategy:

- Lower costs, independence from proprietary technology, availability of efficient tools, customizable (embedding local knowledge, internationalization & localization, language gap)
- Relevant aspects: national policies, committment of local authorities, accessible basic Internet networks, education

Open data:

- satellite data and digital terrain models made available to the public, other important sources as OpenStreetMap
- important role in providing support during emergencies (e.g. HOSM, CrisisMapping)
- mismanagement is dangerous

RESEARCH BACKGROUND: Sustainability & Appropriate technologies

Leading principles:

- Intervention on SWM are designed to pursue sustainability (cfr. SGDs Agenda 2030; Ali and Di Bella, 2018)
- Tools are chosen according to the concept of Appropriate technologies (Schumacher, 1973)

		Tools for remote planning: **Free Open Source Software (FOSS)**	**Data accessibility / reliability:** **Open data**
Economy	Affordable	✔	✔
Environment	Preserving resources	n.d.	n.d.
Society	Fair Answering to actual needs Socially accepted	✔ ✔ Confidence ?	✔ Reliability ? Confidence ?
Technology	Accessible	✔	✔
	Manageable, understandable	?	✔
	Suitable for maintenance/repair on the spot Adaptable to boundary conditions	✔	✔

RESEARCH BACKGROUND: Research questions

Main research question

Development of a simple procedure which integrates data collection and spatial analyses in order to provide a practical support to local administrations charged with waste management.

Secondary research questions

- Evaluation of the level of accurateness of the procedure depending on the availability of data
- Evaluation of the level of appropriateness of the developed procedure considering its implementation through a free open source GIS (QGIS) (training + evaluation by trained people)

Development:

- Screening of scientific theories
- Development of GIS tools
- Remote data collection

Application to a case study: Lebanon

- Field data collection
- Local support
- Trainings

MATERIALS AND METHODS

Spatial aspects of SWM	
Waste generation Understanding quantities and distribution of generated waste	• MSW generation forecasting models • Geo-demograpic methods • Predictors for MSW
Waste Collection and Treatment Optimizing collection routes in terms of economic and ecologic impacts	Location of collection points Network analysis Fuel consumption & related emissions
Treatment facilities and disposal sites Finding proper locations	• Criteria for the location of facilities • Route optimization

Considered spatial aspects:

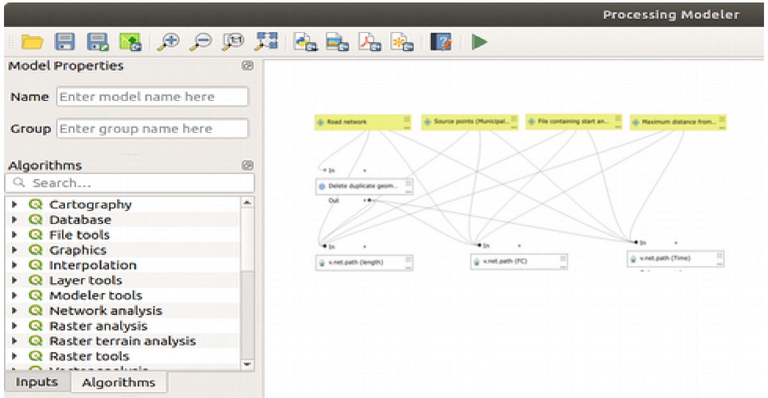
- Waste generation
- Waste collection and treatment

- Tools
- Data sources
- For each spatial aspect of SWM relevant for this research:
  - Methods (scientific theories)
  - Implementation
    - Developed models OR procedures
    - Data

MATERIALS AND METHODS: Tools

QGIS

- Raster and vector analysis
- Processing Toolbox:
  access to several libreries
  containing powerful algorithms
- Processing Modeler:
  development of personalized procedures
  - different types of input
  - using available or self-elaborated algorithms
  - SQL Queries



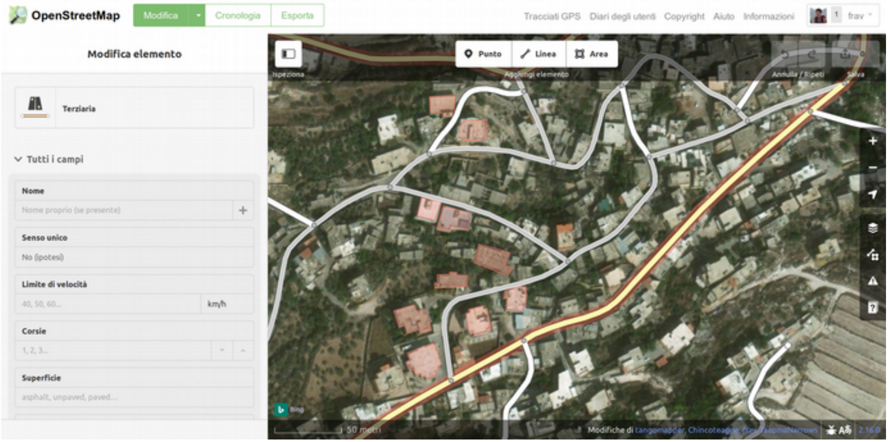
Others: Ubuntu (OS), LibreOffice, Rstat...

MATERIALS AND METHODS: Data sources

- Different sources of remote data depending on the context (e.g. DEM/DTM, land use/land cover, soil and geology…)
- Field collection

OpenStreetMap

- Buildings
- Road network



Procedure:

- ✓ Check and update
- ✓ Download

Geographical data for SWM
Population data
Satellite images
Inventories (relevant facilities / industries)
Land use/land cover
Road network
Conditions of the road network
DEM/DTM (slope)
Collection routes
Collection points
Soil and geology

MATERIALS AND METHODS: WASTE GENERATION

Methods

- Models in the literature
    - Descriptive statistical methods
    - Regression analysis
    - Material flow model
    - Time series analysis
    - Artificial intelligence / machine learning
- Data
    - Availability / resolution
    - Stream (e.g. households waste, commercial waste, industrial waste, C&D waste...)
- Stage of the SWM system:
    - production
    - collection
    - transfer to a treatment plant
    - final disposal at the dumpsite / landfill

Implementation

Simplified methods adopted depending on available data, considering:

- Statistics:
    - Average values for waste generation (kg/hab/day)
    - Population (number of inhabitants)
- Geographical data:
    - Buildings (distribution and number, number of floors according to urban patterns)
    - from satellite images

Procedures in QGIS

Manual generation of maps:

- Households' simple distribution

same number of inhabitants for each building

- Households' pattern distribution

number of inhabitants per building depending on number of floors

MATERIALS AND METHODS: WASTE C&T – Location of collection points

Methods

- Several methods applied in literature
- Dimensioning:
    - Minimum distance from Buildings
    - Minimum distance from road intersections
    - Maximum number of Buildings disposing in a certain collection point
- Given:
    - the desired frequency of collection
    - the characteristics of HH waste
    - the dimension of bins and vehicles

→ calculation of the minimum number of bins for collection point

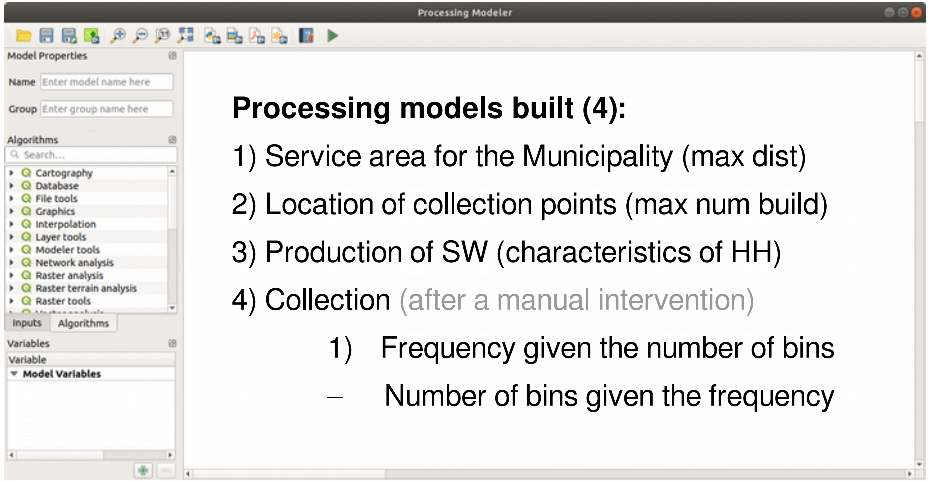
Implementation

Moving from

- Map of buildings with number of inhabitants (from previously calculated **Waste generation*)
- Road network from OpenStreetMap

Procedures in QGIS:

sequential implementation of following models



Processing models built (4):

1) Service area for the Municipality (max dist)
2) Location of collection points (max num build)
3) Production of SW (characteristics of HH)
4) Collection (after a manual intervention)
    1) Frequency given the number of bins
    – Number of bins given the frequency

MATERIALS AND METHODS: WASTE C&T – Route optimization

Methods

- Network analysis
  - Collection:
    application of the “shorter closed path” for shorter collection route (travelling salesman)
  - Transfer:
    applicaton of the “shorter path” to the facility

- Different variables which can be optimized:
  - Distance covered
  - Travel time
    - Depending on:
      - Speed
  - Fuel consumption
    - Implementation of the method COPERT III (Tier 3) for Diesel Light Commercial and Heavy-duty vehicles
    - Depending on:
      - Gradient
      - Load
      - Speed
      - Vehicle category

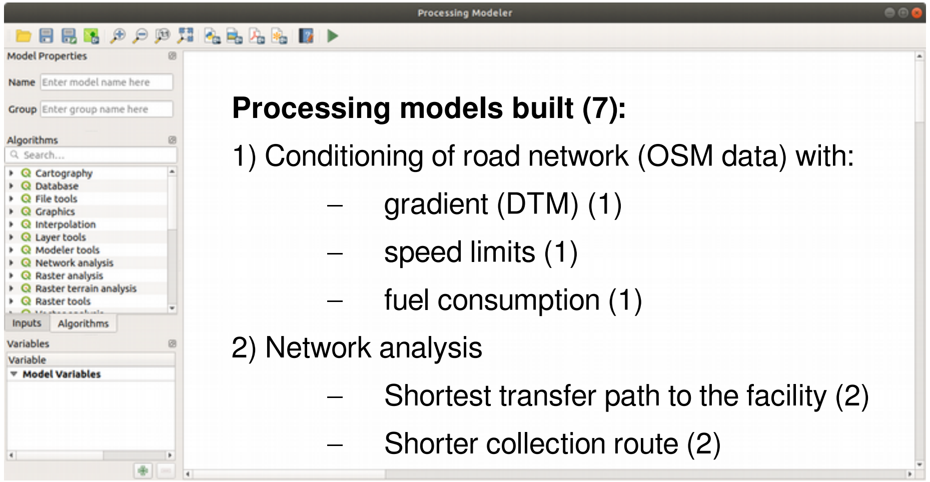
Implementation

Geographical information needed:

- Road network from OSM
- DTM/DEM
- Collection: Location of bins
- Transfer: Starting / ending point

Procedures in QGIS:

sequential implementation of following models



Processing models built (7):

1) Conditioning of road network (OSM data) with:
   - gradient (DTM) (1)
   - speed limits (1)
   - fuel consumption (1)
2) Network analysis
   - Shortest transfer path to the facility (2)
   - Shorter collection route (2)

MATERIALS AND METHODS: WASTE C&T – Conditioning of road network

Speed limits

Processing module (1) for

***Conditioning / claning / extraction of road network**

1) Conditioning with speed limits (speed_limits.csv)

2) Cleaning wrong geometries

3) Extraction of road networks depending on the purpose:

e.g. “standard” network (all roads)

"highway" IN ('motorway','motorway_link','trunk','trunk_link','primary','primary_link','secondary','secondary_link', 'tertiary','tertiary_link','residential','road','unclassified','service','pedestrian','living_street','track')

Gradient

Processing module (1) for

*** Calculation of the gradient for each segment of the road network**

- Input:
  - DEM / DTM
  - Road network (conditioned/clean)

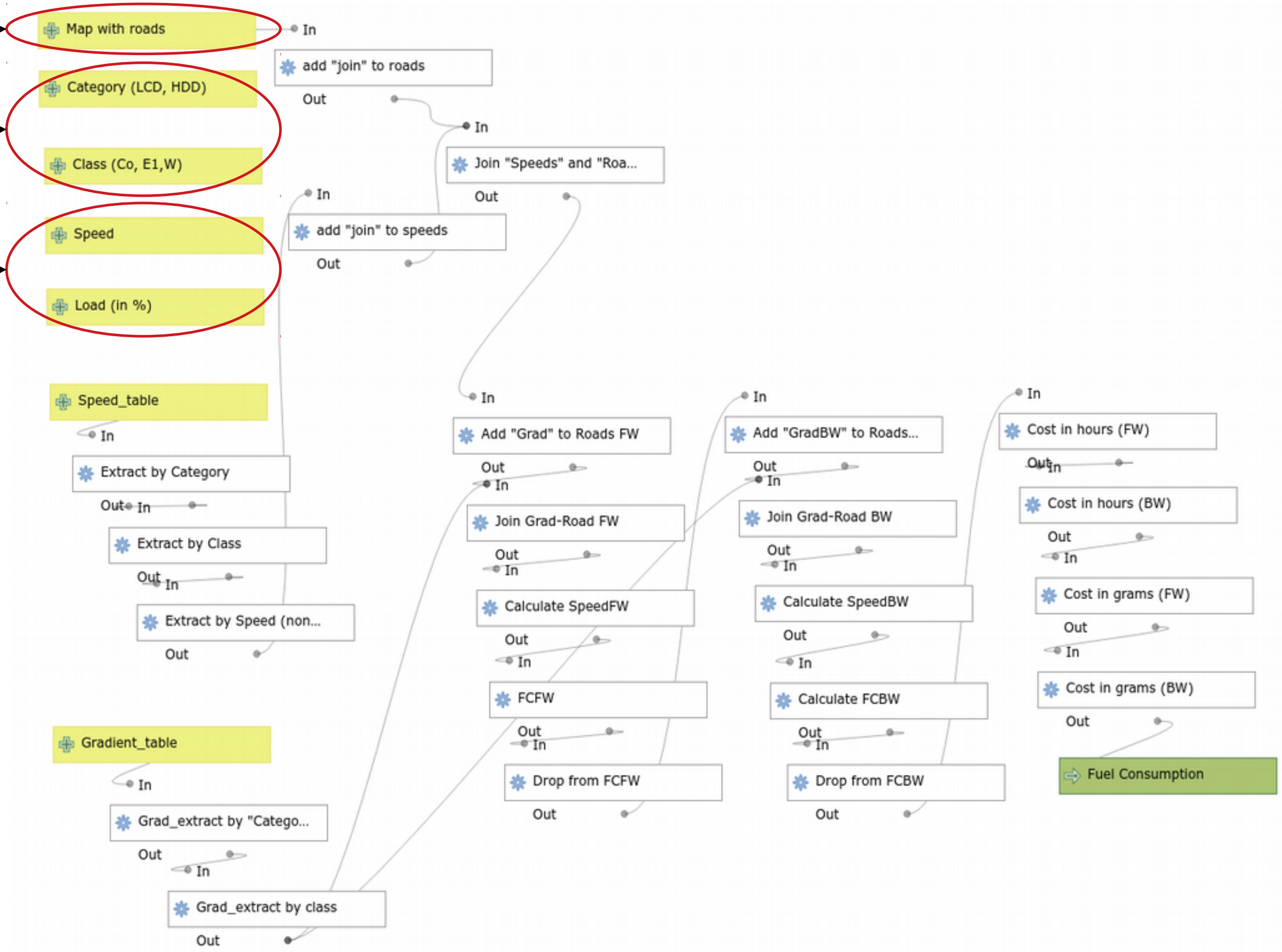
$$m=\frac{\Delta y}{\Delta x}=\frac{vertical change}{horizontal change}=\frac{rise}{run}$$

$$\Theta=\arctan(m)$$

MATERIALS AND METHODS: WASTE C&T – Conditioning of road network

Fuel consumption

- Geographical ASPECTS (slope, maximum speed according to road category)
- Vehicle characteristics
- Operational choices



MATERIALS AND METHODS: WASTE C&T – Conditioning of road network

Fuel consumption

- COPERT III
  FC = FCSp * FCGr * FCLo

1) Speed dependency (FCSp):

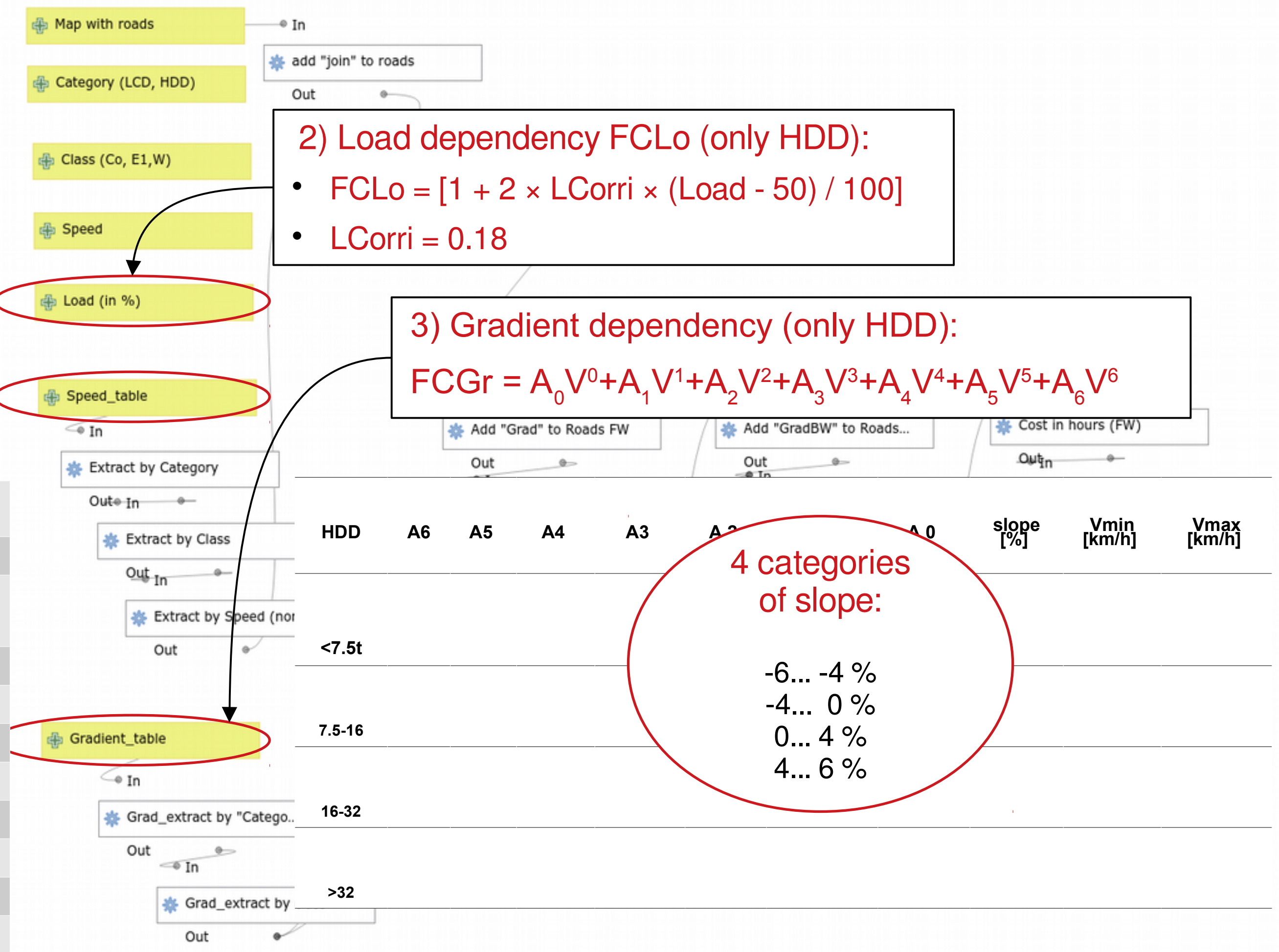
Category	Class	Speed Range	Emission Factor [g/km]	R^2
LCD Light commercial Diesel < 3.5 t	Conventional	10-110	$0.02113V^2 - 2.65V + 148.91$	0.486
	EURO I	10-110	$0.0198V^2 - 2.506V + 137.42$	0.422
HDD Heavy duty Diesel > 3.5t	Weight<7.5t	0 - 47	1425.2V^(-0.7593)	0.990
		47 - 100	$0.0082V^2 - 0.0430V + 60.12$	0.798
	7.5<Weight<16t	0 - 59	1068.4V^(-0.4905)	0.628
		59 - 100	$0.0126V^2 - 0.6589V + 141.18$	0.037
	16<Weight<32t	0 - 59	1595.1V^(-0.4744)	0.628
		59 - 100	$0.0382V^2 - 5.1630V + 399.3$	0.037
	Weight>32t	0 - 58	1855.7V^(-0.4367)	0.914
		58 - 100	$0.0765V^2 - 11.414V + 720.9$	0.187

2) Load dependency FCLo (only HDD):

- FCLo = [1 + 2 × LCorri × (Load - 50) / 100]
- LCorri = 0.18

3) Gradient dependency (only HDD):

$$FCGr = A_0V^0+A_1V^1+A_2V^2+A_3V^3+A_4V^4+A_5V^5+A_6V^6$$



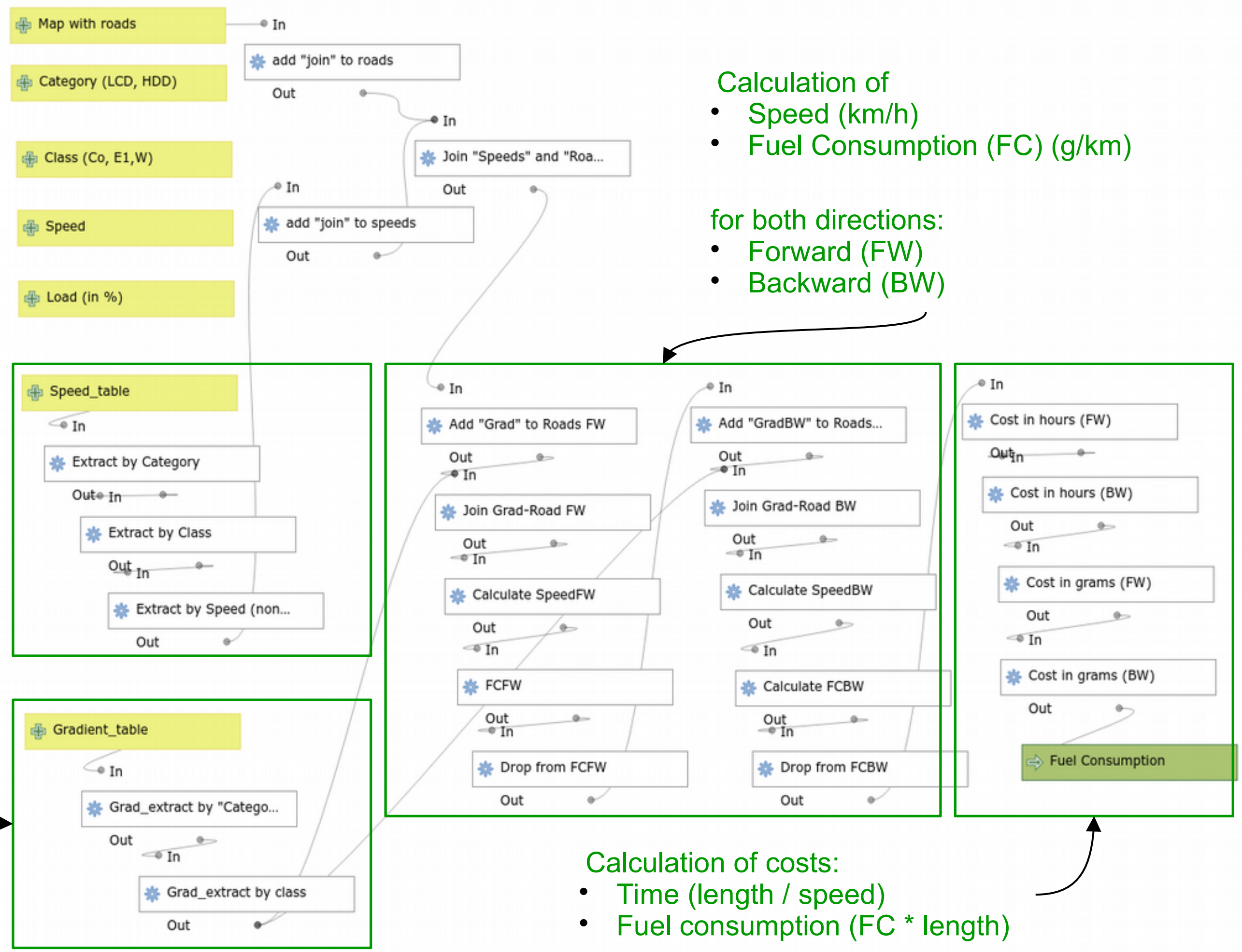
4 categories of slope:

-6... -4 %
-4... 0 %
0... 4 %
4... 6 %

MATERIALS AND METHODS: WASTE C&T – Conditioning of road network

Fuel consumption

- Vehicle characteristics
  +
- COPERT III coefficients



Calculation of
- Speed (km/h)
- Fuel Consumption (FC) (g/km)

for both directions:
- Forward (FW)
- Backward (BW)

Calculation of costs:
- Time (length / speed)
- Fuel consumption (FC * length)

MATERIALS AND METHODS: WASTE C&T – Network analysis

Collection

- **Shorter route for the collection*
- Resolution of the Traveling Salesman Problem:
  - closed path
  - best route to reach all the collection points

Procedures in QGIS

- Input:
  - Output of * *Location of collection point*, manually modified to assign to each collection point a number of route (identifier)
  - Starting point and ending point
  - Road network (conditioned)
- Based on the algorithm v.net.salesman
- Different modules: “best” route is chosen on
  - Speed
  - Fuel consumption
  - Length

Transfer

- Shortest route between two points

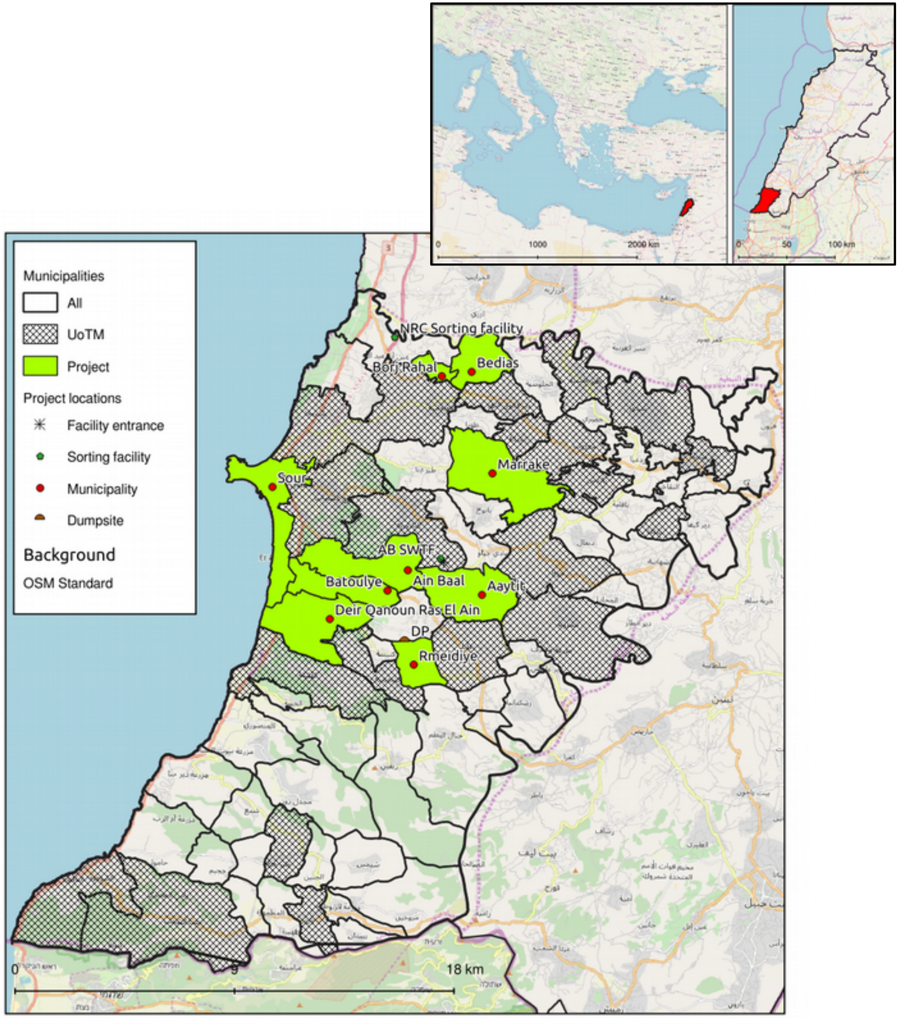
Procedures in QGIS

- Input:
  - Starting point and ending point
  - Road network
- Based on the algorithm v.net.path
- Different modules: “shortest” route is chosen on
  - Speed
  - Fuel consumption
  - Length

APPLICATION: CONTEXT

Developed modules / procedures have been applied to a real case study (the district of Sour, Lebanon)

- Donor: Agenzia Italiana per la Cooperazione allo Sviluppo (AICS)
- Partner: INTERSOS, Arcenciel (AEC), Union of Tyre Municipalities (UoTM)
- Intervention area:
  - 8 municipalities, 2 neighborhoods in Tyre (about 120’000 inhabitants)
- Period: June 2018 – August 2020



Politecnico di Milano → technical support for:

- Creation of Collection Municipal Plan for MSW
- Identification of a landfill for undifferentiated waste
- Improvement of Ain Baal Sorting and Recycling unit
- Interchange journey

ITALIAN AGENCY FOR DEVELOPMENT COOPERATION INTERSOS arcenciel.org engage in development POLITECNICO MILANO 1863 DIPARTIMENTO DI INGEGNERIA CIVILE E AMBIENTALE

APPLICATION: CONTEXT

Organization of SWM system in the district of Sour:

- Collection → Municipalities
- Treatment:
  - Ain Baal SWTF (new operation since April 2019)(150 t/day)
  - Borj Rahal (test)
  - Maarake (in construction)
- Final disposal:
  - no authorized nor sanitary landfill
  - several dumpsites located in the district, used by the Municipalities

District of Sour:

- 0.8 kg/inhab./day MSW
- About 400’000 inhabitants
- 315 t/day MSW

	MSW in Sour (2019)
Organic fraction	59.60%
Paper and cardboard	9.00%
Plastic and metals	18.80%
Glass	2.58%
Residual fraction	10.02%

APPLICATION: Baseline + Data Collection

Baseline

- Project information
- Literature analysis
  - General information about SWM system in Lebanon
  - Data about SW and population

Data collection:

- *Municipality Assessment, details about*
  - Population
  - Urbanistic (buildings, schools, shops…)
  - SWM system (fleet, workers, organization, final disposal…)
  - Financial situation (costs related to SWM)
- *Logbooks (fuel consumption)* [NOT AVAILABLE YET]
- *GPS on collection trucks*
  - 7 municipalities, one for each municipality
  - Data: GPS tracks with stops [LIMITED ACCESS]

- *Geographical information from National Center for Remote Sensing (CNRS)*
  - DTM 10m, land use, groundwater vulnerability, wells…
- *SWTF DATABASE (Waste data at Ain Baal facility)*
  - Collected Household waste: detailed records of trucks entering the facility (time, origin, weight…) since April 2019
  - Secondary raw materials: Detailed records of trucks coming out from the facility (time, origin, weight…) since April 2019

RESULTS

Different levels:

- Current situation
  understanding of the local context, analysis of field data and preparation of dataset
- Application of tools to the local context, validation of tools
  verify the functioning of models implemented within QGIS through the cross-check of results with field data.
- Creation of scenarios for further interventions
  Comparison of scenarios based on different data (literature / field data) and different functioning hypothesis.
- Economic analysis

RESULTS: Current situation

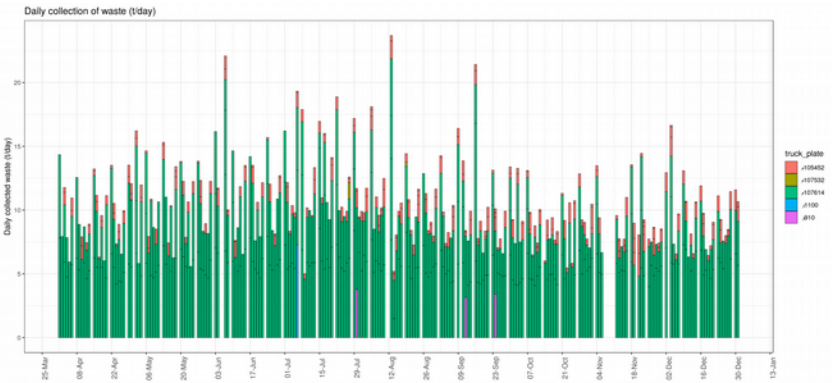
Available information on SWM in the district

Analysis:

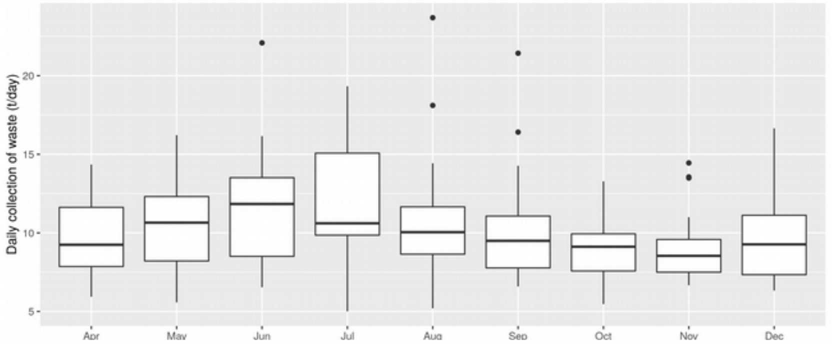
- Streams of waste entering to SWTF
- Streams of materials coming from the SWTF
- Kind of vehicles
- Amount of waste
- Quality of waste
- Timeseries (overall / for each village):
  - on daily, weekly, monthly basis...

	B	C	D	G	H	I	J	K	L	
1	invoice	truck_plate	company_name	material_name	weight_1	time_1	weight_2	time_2	net_weight	co
26	52	332873م	الجبل	عوادم	20,150	02/04/2019 19:24	16,110	02/04/2019 20:05	4040	
27	42	109519م	صور	نفايات منزلية	23,130	02/04/2019 19:25	14,090	02/04/2019 19:39	9040	
28	37	337850م	دير قانون راس العين	نفايات منزلية	8,870	02/04/2019 19:27	4,840	02/04/2019 19:29	4030	Deir Q
29	38	332087م	السماعية	نفايات منزلية	10,460	02/04/2019 19:29	5,410	02/04/2019 19:31	5050	
30	43	34171	باتولية	نفايات منزلية	13,780	02/04/2019 19:35	10,470	02/04/2019 19:46	3310	
31	47	923142م	صور	نفايات منزلية	21,600	02/04/2019 19:43	12,490	02/04/2019 19:54	9110	
32	48	106520م	صور	نفايات منزلية	23,150	02/04/2019 19:50	14,730	02/04/2019 20:00	8420	

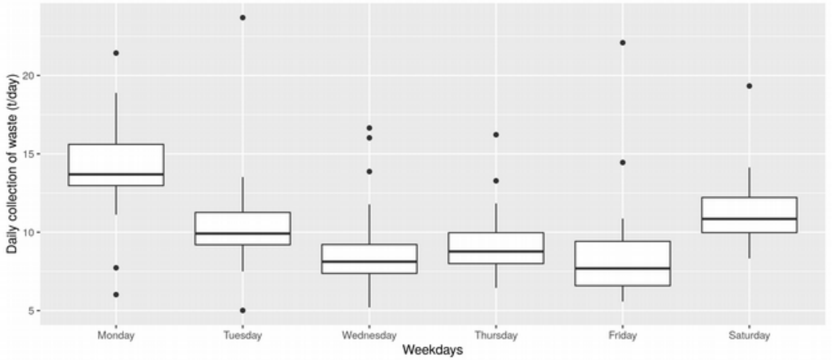
(Presented data: Municipality of Ain Baal)



Daily collection of waste (t/day) - variation within the year



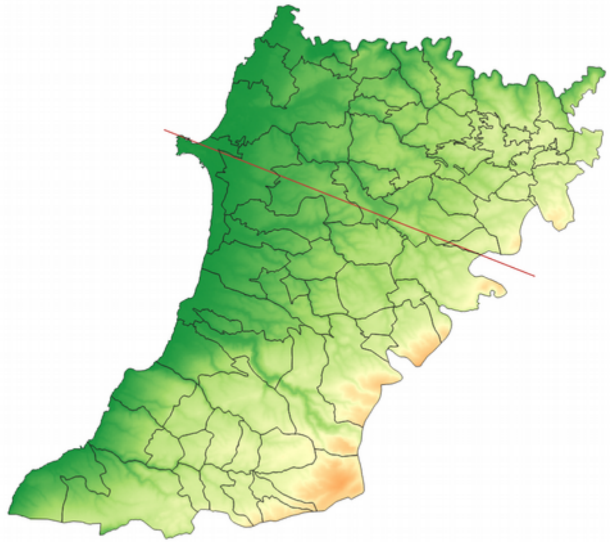
Daily collection of waste (t/day) - variation within the week

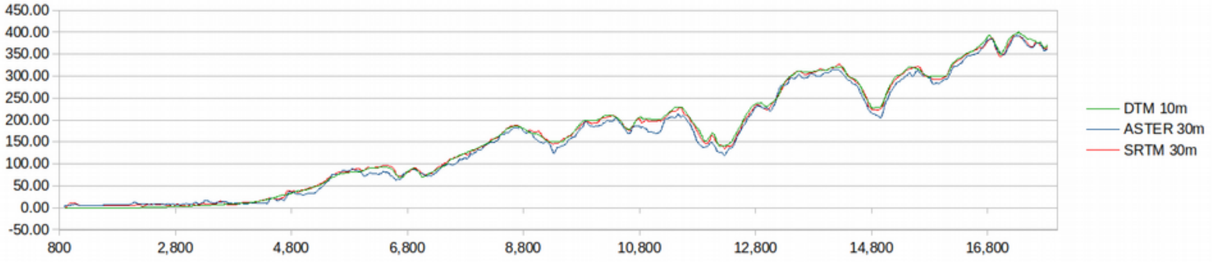


RESULTS: Current situation

Available geographic information

- Slope
  - Comparison between different DTM: which free / accessible DTM can be used if higher resolution DTM is not available or expensive?
    - ASTER 30m (free)
    - SRTM 30m (free)
    - DTM 10m (provided by CNRS)
- Speed
  - Roads from OpenStreetMap
  - Speed and road category added
- Buildings:
  - Identified manually in QGIS





RESULTS: Ain Baal Municipality

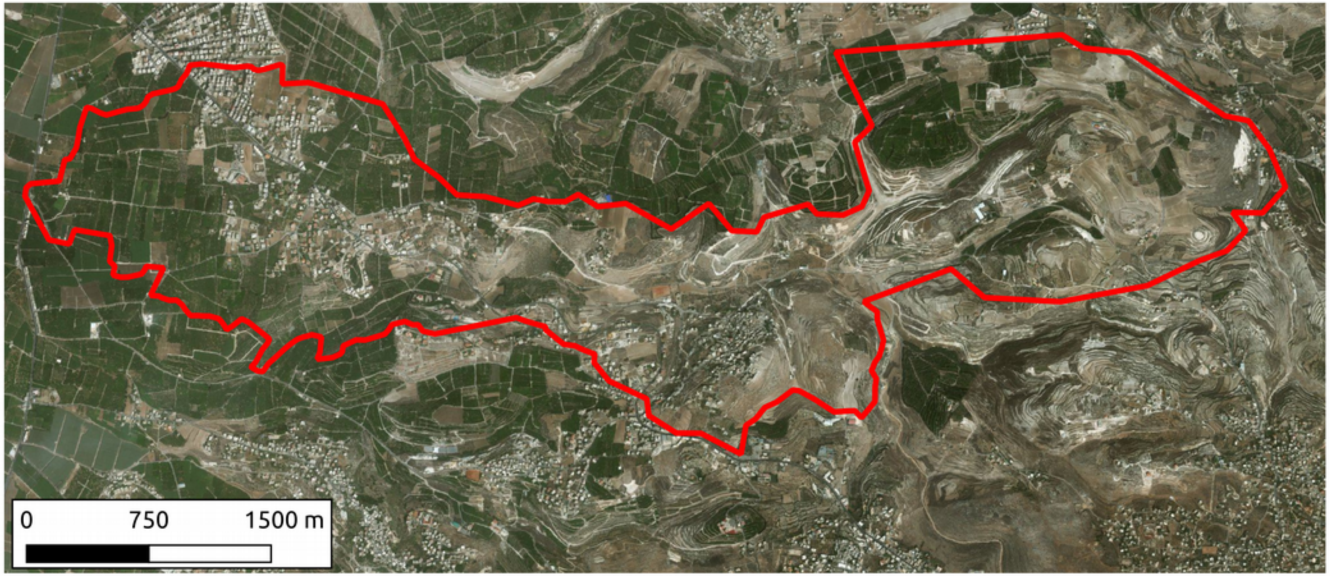
MSW:

- 8.45 t/day
- 0.88 kg/inh./day

Collection:

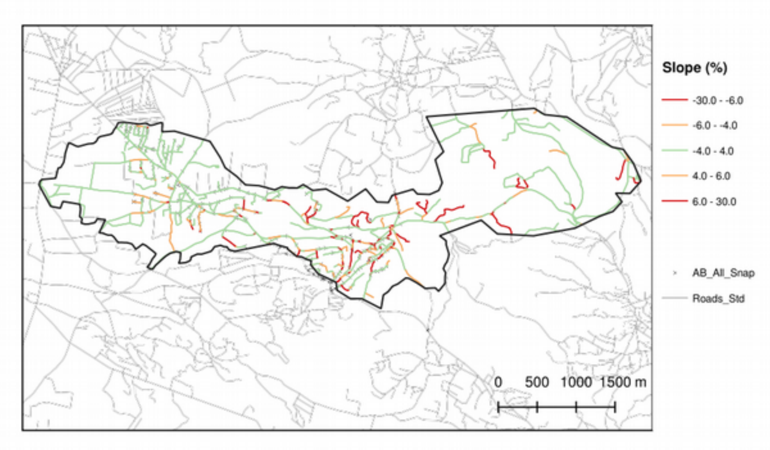
- 2 vehicles
  - HDD 16-32 (92% of collection)
  - HDD 3.5 – 7.5
- 6 days a week
- 4 workers
- about 250 containers (installed volume130 m^3)

Ain Baal SWTF is within 2 km



RESULTS: Existing routes and fuel consumption

- Extraction of existing routes from GPS data
- Calculation of fuel consumption on existing routes

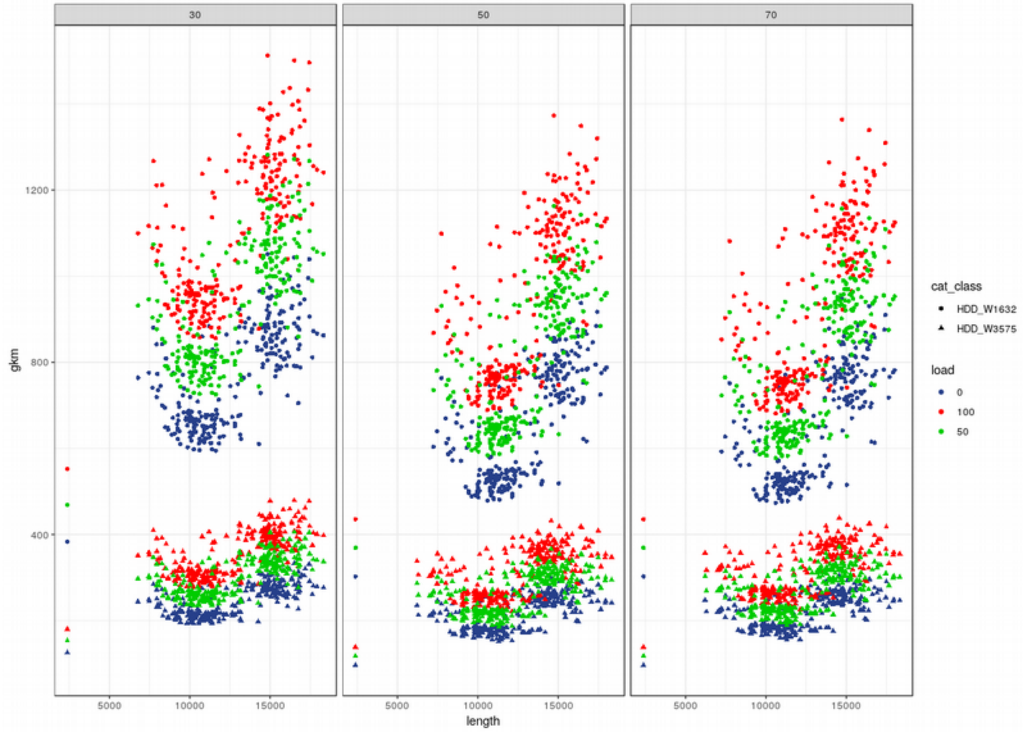


-
  - Specific consumption:
    - variation with routes (gradient), category, class, speed
    - 303 – 1512 g/km (HDD 16 – 32 t)
    - 96 – 479 g/km (HDD 3.5 – 7.5 t)
  - Fuel costs for the Municipality:
    - estimated 700,000 – 1,200,000 LBP/month
    - Municipality: 2,500,000 LBP/month
    - no validation with logbooks
  - Statistical descriptor: 0.39 t/km

<u>Diesel</u>

Density: 840 kg/m^3

Cost: 1320 LBP / L



Specific consumption of fuel (g/km) compared with the length of the routes (m) in the Municipality of Ain Baal,divided according to category and class of the vehicle, load and speed.

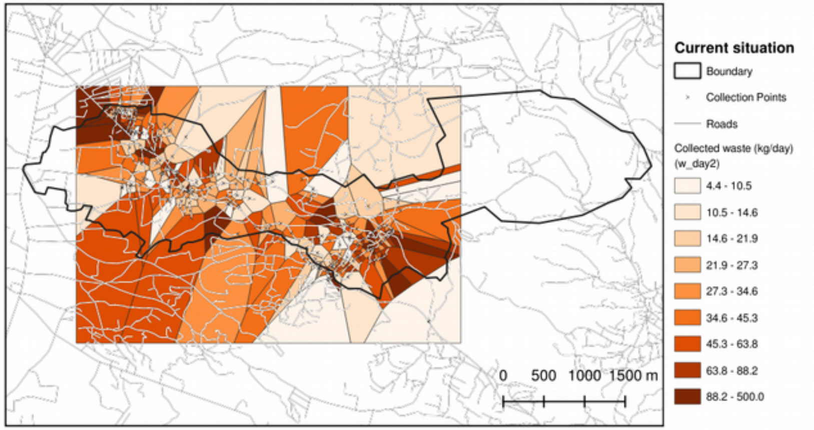
RESULTS: Existing collection points and waste distribution

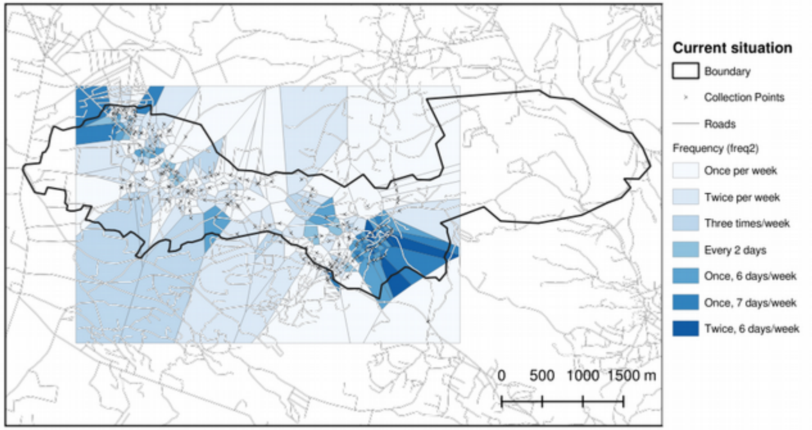
Manual analysis:

- Match between tracks and Ain Baal SWTF database → amount of waste collected for each route
- Attribution of amount of collected waste to each collection point
- Correction considering all trucks operating in the area

Results:

- Assessment of waste generation
- Assessment of the frequency of collection

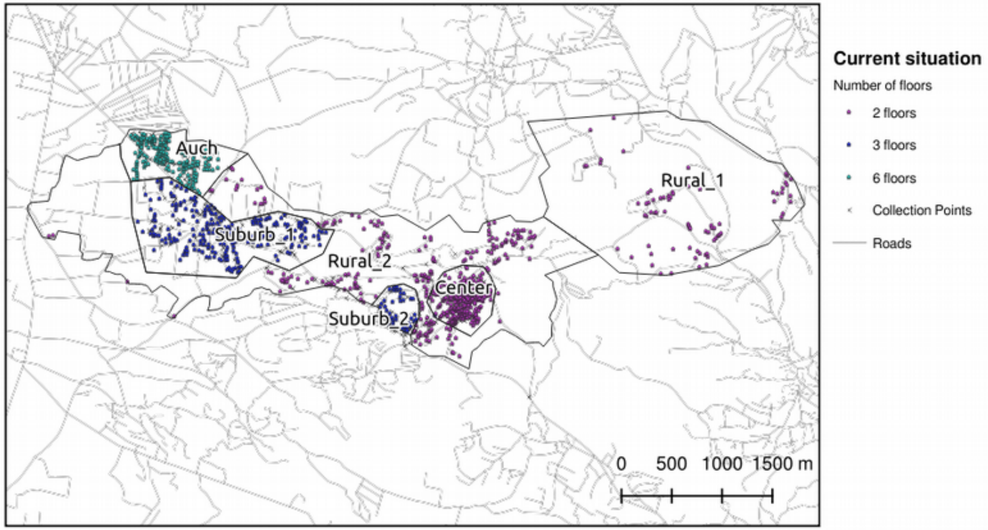




RESULTS: Waste generation – simulating urban patterns

Two approaches, about 1055 buildings:

- Households' simple distribution
- Households' pattern distribution (as in figure)

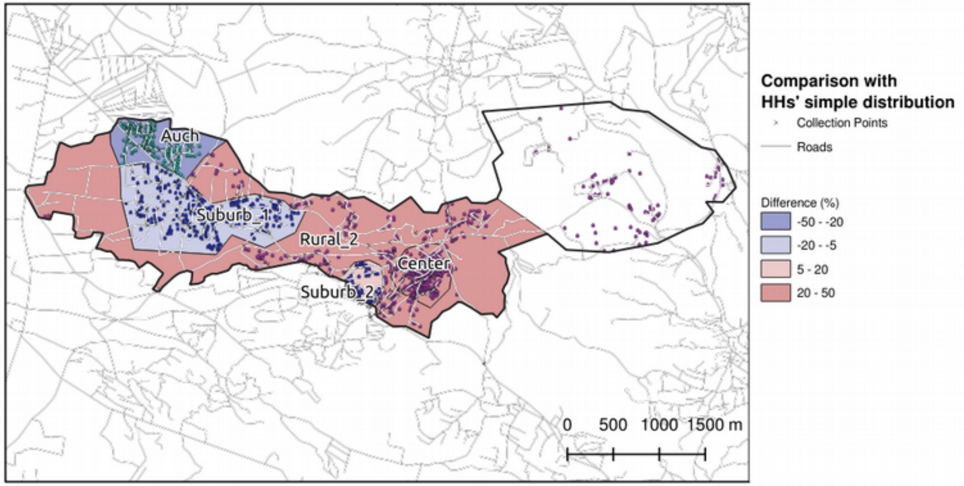


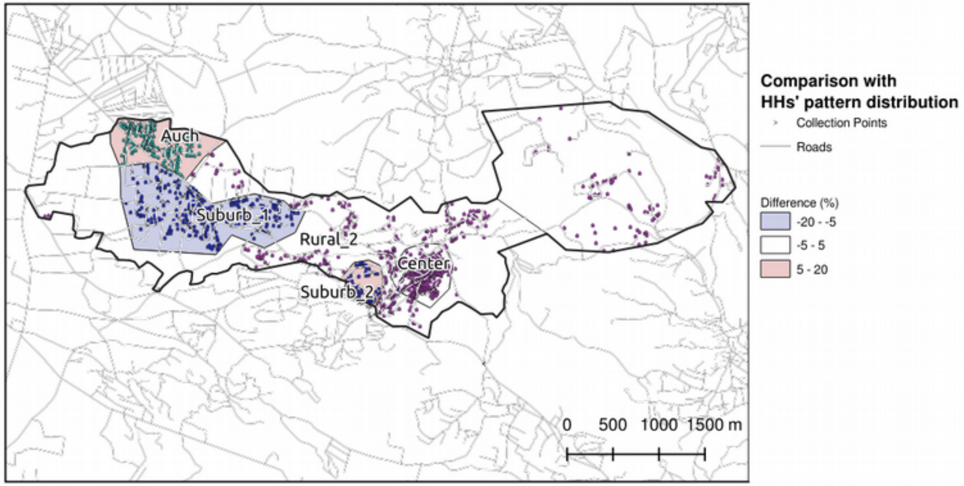
RESULTS: Waste generation – simulating urban patterns

Validation: simulated vs. assessed waste distribution

HHs' simple distribution→ differences ≥15% (max ±40%)

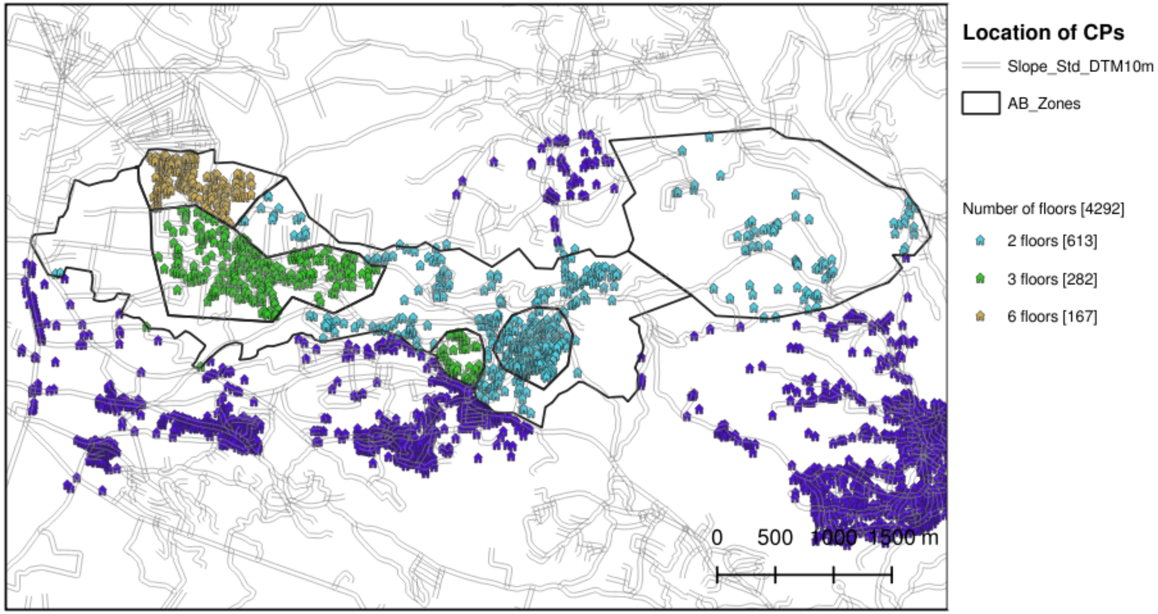
- HHs' pattern distribution → differences ≥1% (max ±15%)
  - good results at the scale of neighborhoods
  - not working at the scale of the single collection point
  - requires local knowledge





RESULTS: Location of collection points

Input



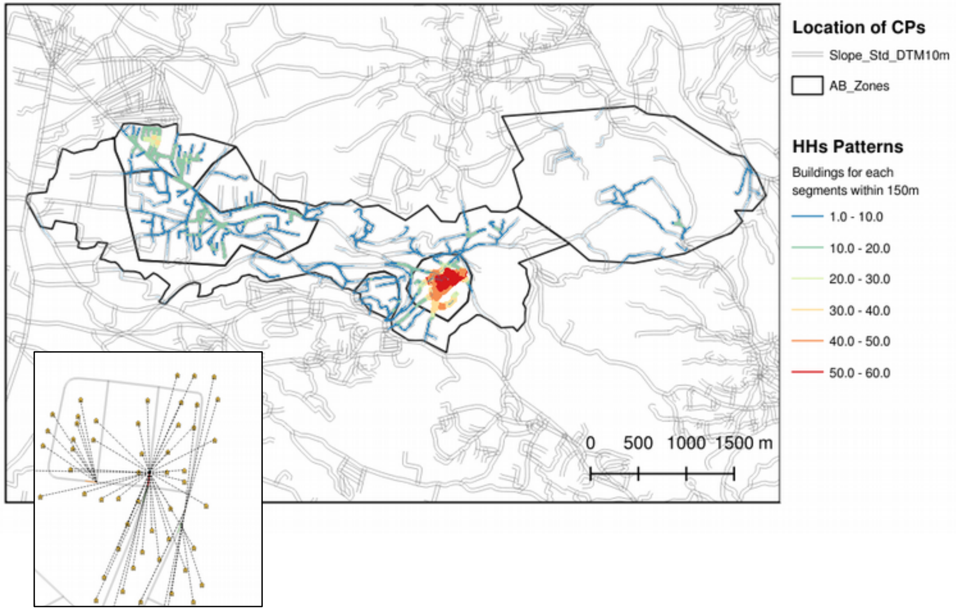
Input:
- Administrative boundary
- Buildings & roads

Sequential application of modules:
1) Service area for a given zone
2) Suitable location of collection points
3) Storage volume for SW (single fraction)
4) Collection points
5) Change number of bins given the frequency

Village:
Ain Baal

RESULTS: Location of collection points

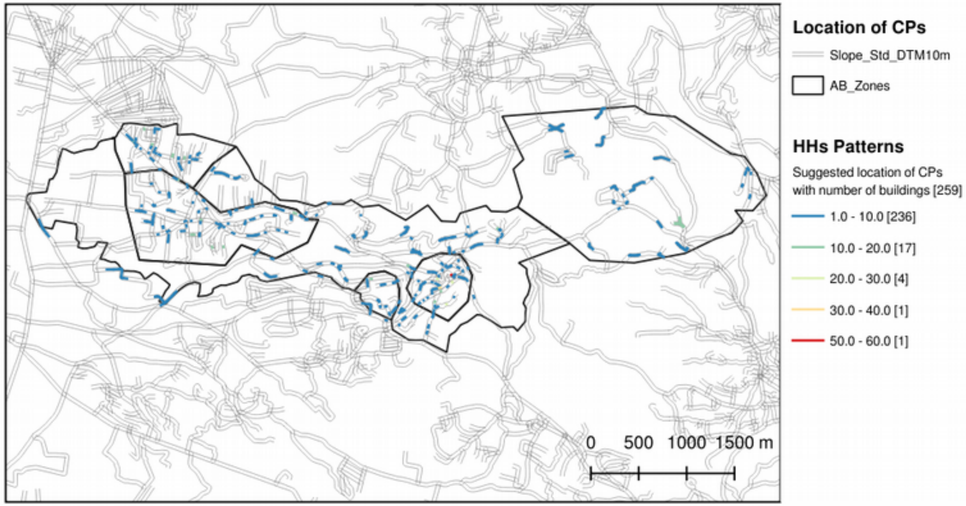
Module 1: Service area for a given zone



Village: Ain Baal

(1) Service area: 150 m
(2) Buildings: 16

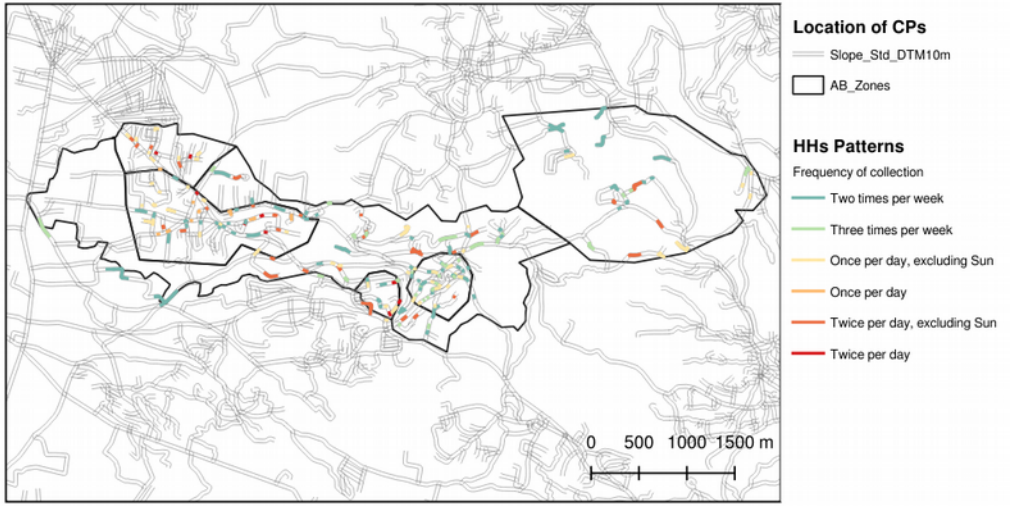
Module 2: Suitable locations of collection points



- validation: 202 CP (GPS) vs. 259 (simulated)
  the distance of 150 m is probably not respected in the real situation

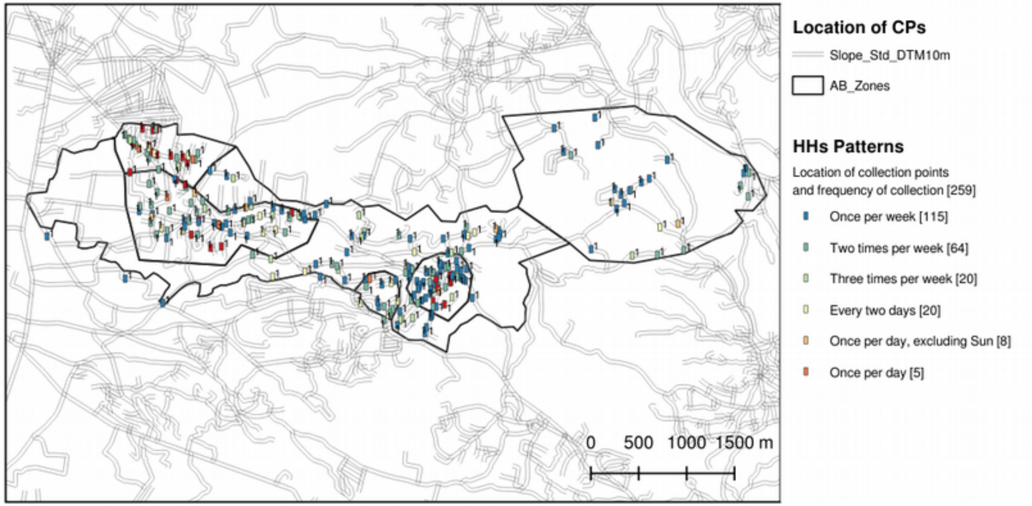
RESULTS: Location of collection points

Module 3: Storage volume for SW (single fraction)



- not “points” but “locations”
- storage volume is calculated on characteristics of the chosen fraction of waste (HH waste, organic, etc.)

Module 4: Collection points



- number of bins: 259

Village: Ain Baal

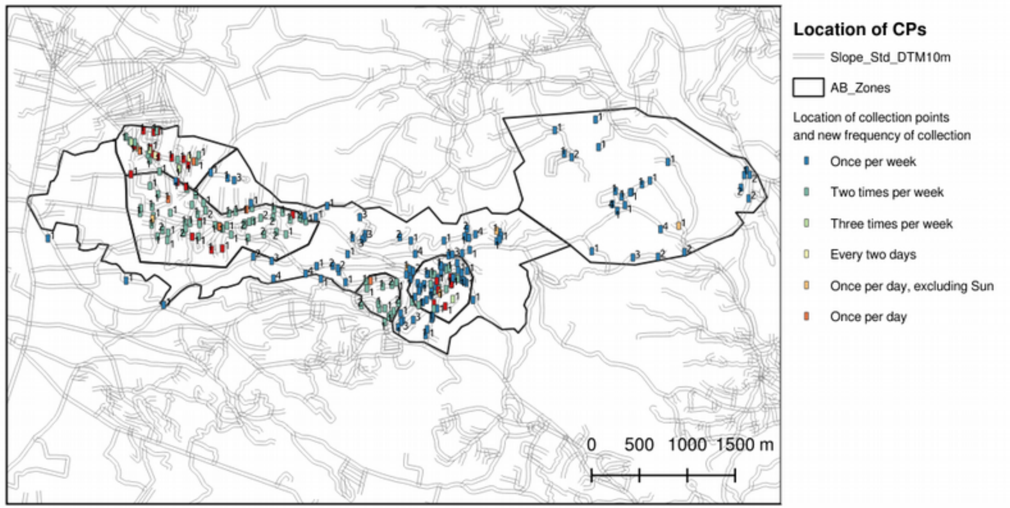
(1) Service area: 150 m
(2) Buildings: 16

(3) Waste prod.: 0.94 kg/hab/day
100% HH waste, 200 kg/m³
Bins: 0.8 m^3, 60%

(4) Frequency: automatic, 1 bin

RESULTS: Location of collection points

Module 5: Change number of bins given the frequency



- number of bins: 335

Once collection points have been located (Mod.4), manual analysis is required:

- Identifiy target areas for each route depending on the capacity of trucks
- Assign to each target area a desired frequency of collection (also depending on the capacity of trucks)

Module 5 is run on resulting map:

- given the frequency
- calculates the number of bins

Village: Ain Baal

(1) Service area: 150 m
(2) Buildings: 16

(3) Waste prod.: 0.94 kg/hab/day
100% HH waste, 200 kg/m³
Bins: 0.8 m^3, 60%

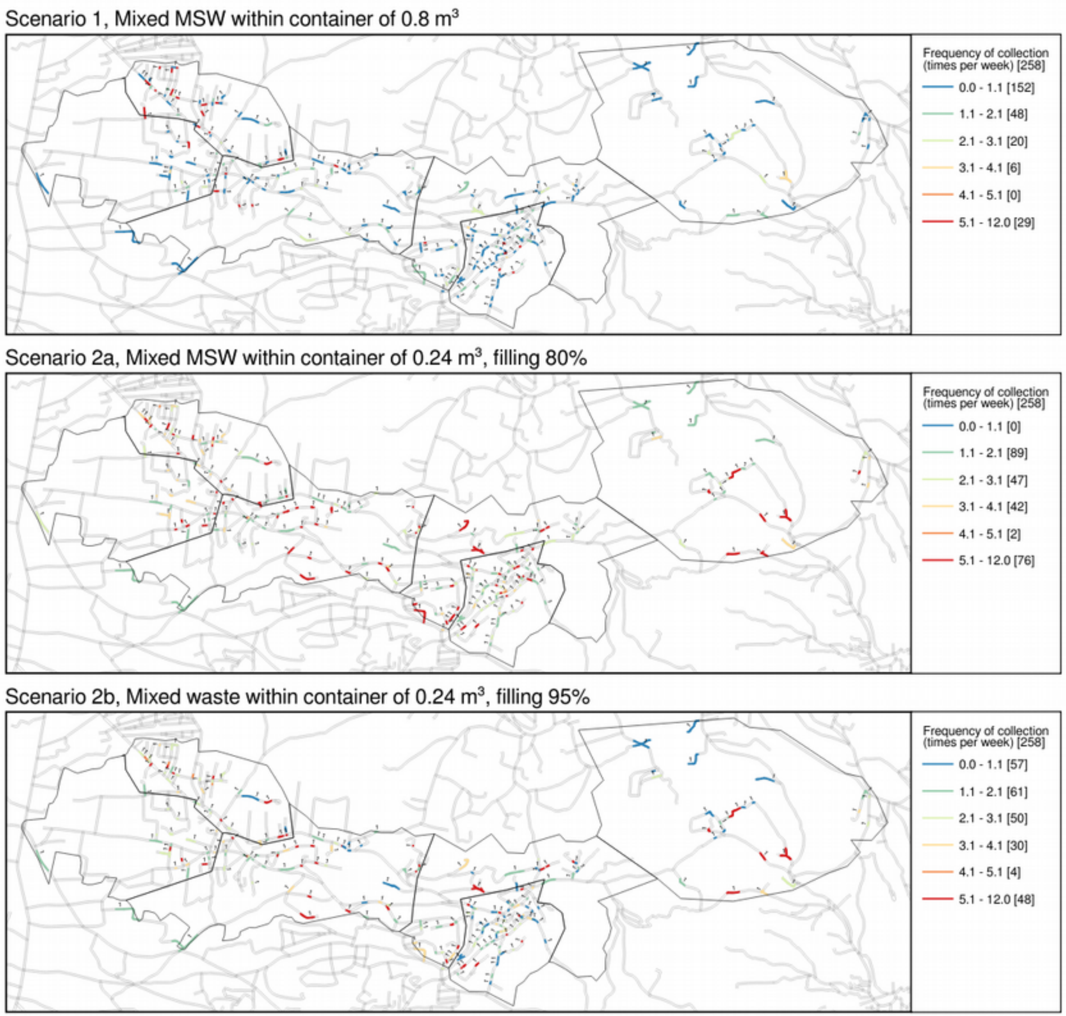
(4) Frequency: automatic, 1 bin
(5) Frequency: manual

RESULTS: Waste C&T - Collection

Collection: closed routes within villages

Different scenarios:

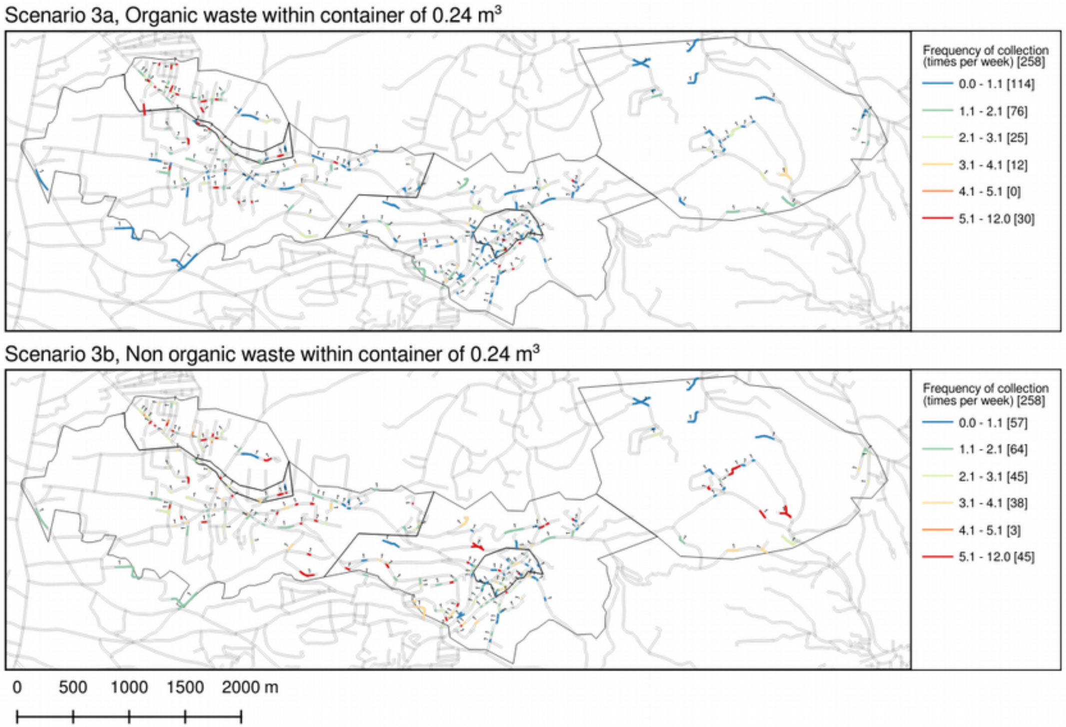
- S0 – Current situation
- Optimization:
  - S1 – Mixed MSW (0.8 m³) (60 t/week)
  - S2a – Mixed MSW (0.24 m³, 80%)
  - S2b – Mixed MSW (0.24 m³, 95%)
  - S3 – Separate collection:
    - Organic (0.24 m³, 60%)(36 t/week)
    - Non organic (0.24 m³, 80%)(24 t/week)



RESULTS: Waste C&T - Collection

For each Scenario:

- Procedure for the *Location of collection points
- Manual definition of collection routes: depending on:
  - volume of vehicles
  - desired frequency
  - type of waste (embedded in *Location)
- Module *Shorter route for the collection
- Preparation of the timetable
  - N. of route
  - Hours
  - Days

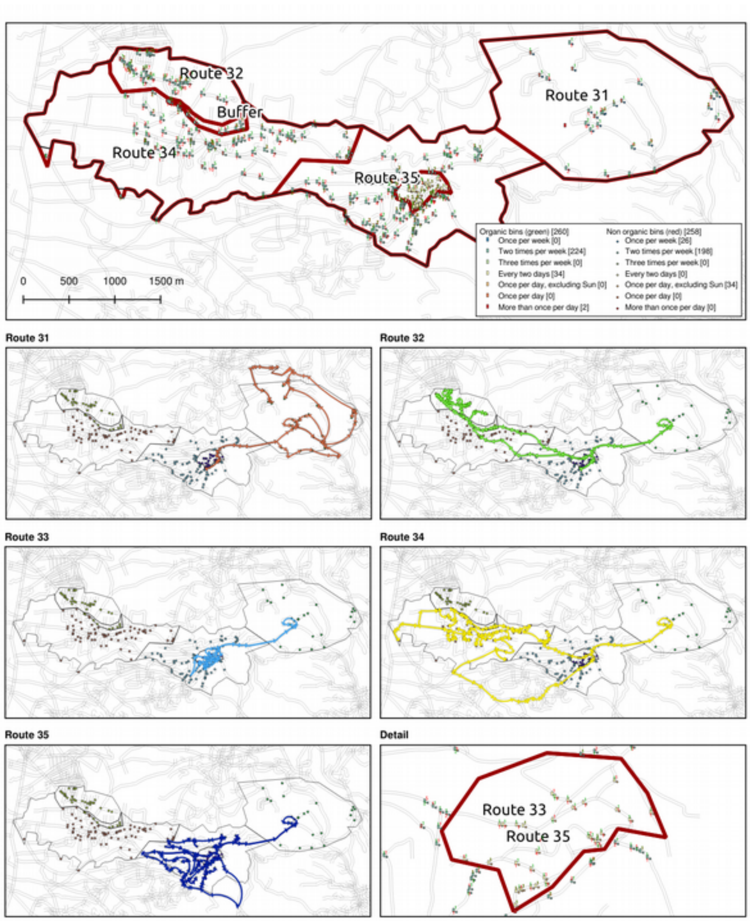


RESULTS: Waste C&T - Collection

Introduction of Separate collection (S.3) with reference to baseline (S.0):

- Fuel consumption is slightly increasing
- Relevant increase in the number of bins (smaller increase in installed volume)(within the project, about 1000 bins are provided)
- Slight increase in required man-hours (labour costs)

Scenario	S.0	S.1	S.2a	S.2b	S.3
Cost for fuel consumption (LBP/month)	980’000	-12%	(as per Scenario 1)		6%
Number of bins (total)	245	50%	229%	179%	355%
Installed volume (m^3)	130	126%	49%	26%	106%
Required man-hours (hours/week)	162	-32%	8%	0%	5%



RESULTS: Waste C&T - Transfer

Transfer:

- from villages to SWTF Ain Baal
- and back (gradient change)

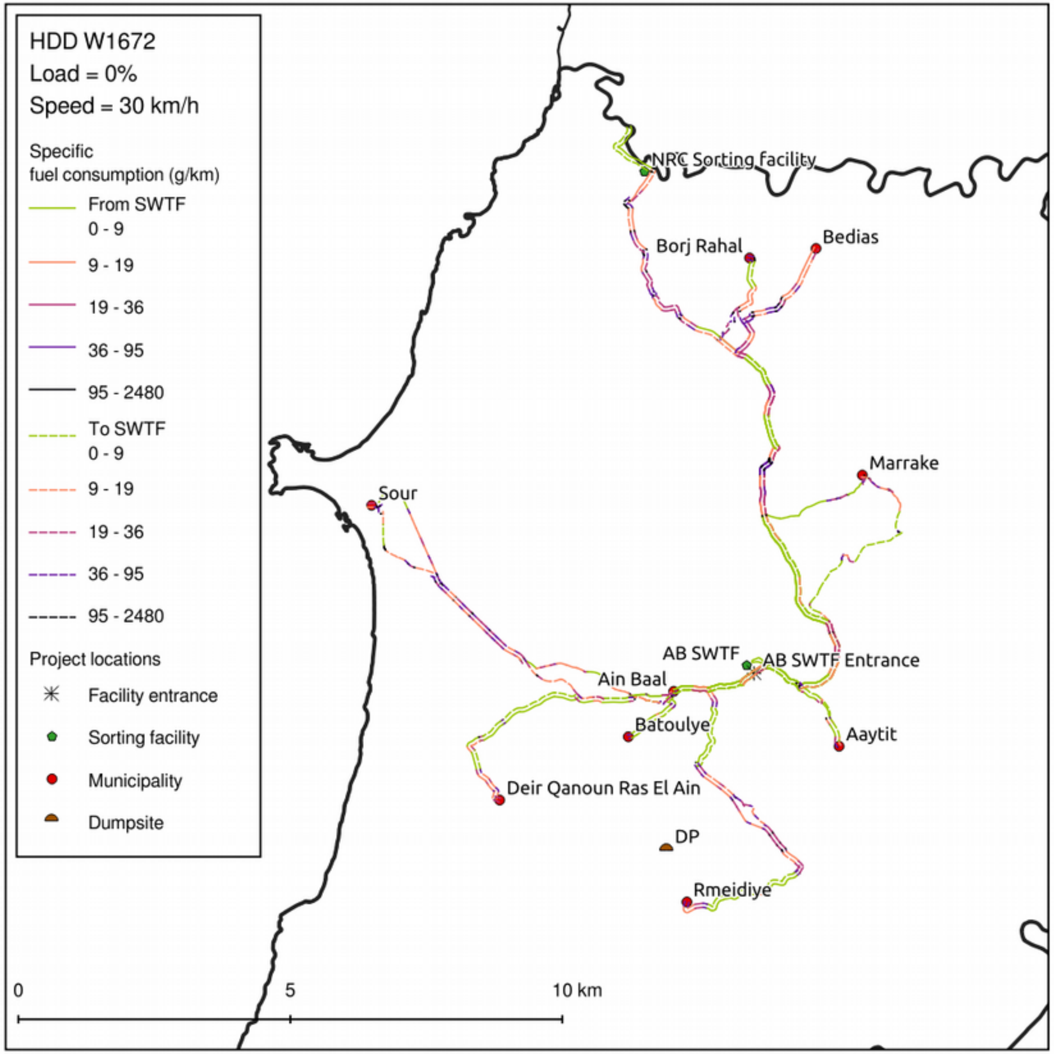
For all the Municipalities:

- Inventory of collection vehicles
- Starting/ending point

Comparison in terms of FC, time and length of the route for:

- Different categories of vehicles (2 LCV, 3 HD)
- Different load (only for HD)(0 – 50 -100 % del carico)
- Different speed (30 – 50 – 70 km/h)

(33 simulations)

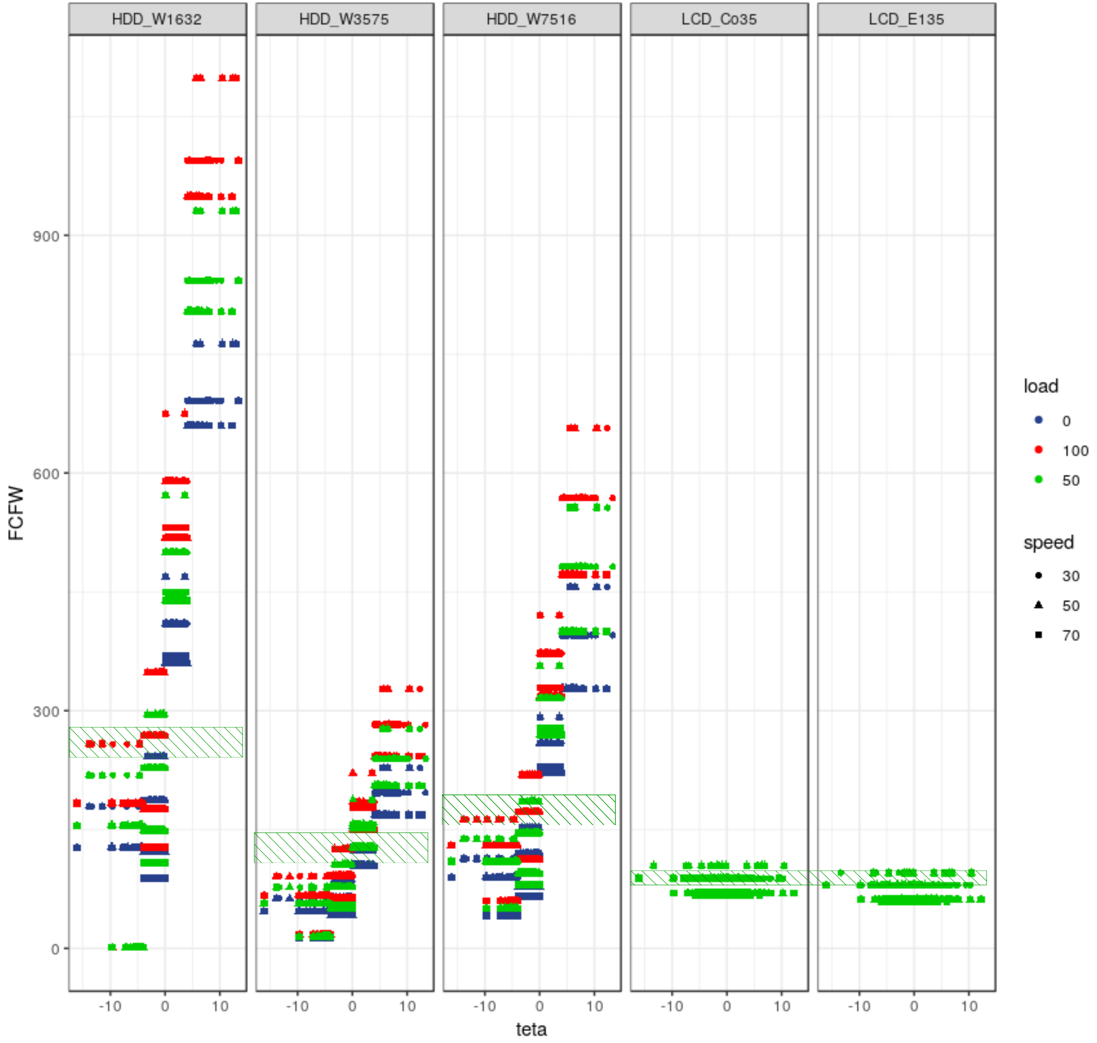


RESULTS: Waste C&T - Transfer

Results:

- Gradient vs. specific fuel consumption:
  - LCV not influenced by gradient
  - HD increase with size & load
  - relevant variation with gradient (plateaux)
  - fuel consumption in flat conditions is comparable with reference values (EEA, 2018)

- Economic impacts:
  - fuel consumption of full load (100%) round trip is about 10% higher than fuel consumption of half load (50%)
  - full load operation of vehicles is suggested



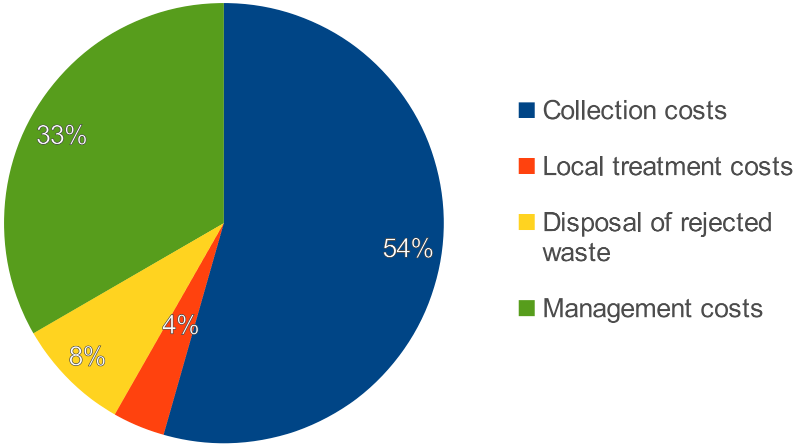
RESULTS: Economic analysis

Stakeholders:

Municipalities, Union of Tyre Municipalities, private operator for Ain I

Results:

- Total cost for SWM – 97,000 LBP/t
  - 27-83% of Municipal budgets
  - 1-6% of the annual income for a household (5 people, 1 salary)
- Sale of recyclables:
  revenues 10,000 LBP/t of mixed MSW waste
- Impact of improvements:
  - Ain Baal SWTF correct operation from +1.5% to −6%
  - Introduction of separate collection +2%



Note:

due to the economic crisis, these figures may be reviewed
(in Sep. 2020, 1$ = 1500 LBP,
currently 1$ = 8500 LBP on the black market)

RESULTS: Dissemination and appropriateness

Are developed QGIS tools (modules & procedures) appropriate?

$\rightarrow$ evaluation of IT skills and user capabilities

$\rightarrow$ trainings

Proposal:

- Group 1 (technicians, environmental committees…), Group 2 (students of a Lebanese university)
- Learning agreement (trainer, participants)
- 4 lessons, 4 hours per lesson
- Basic documentation: “Introduction to basic GIS and spatial analysis using QGIS: Applications in Bangladesh” (Ahmed et al., 2018)
- Questionnaires/semi-structured interviews to evaluate trainings

Note: Implementation blocked by COVID-19 and socio-political crisis in Lebanon

CONCLUSIONS

Main research question

Development of a simple procedure which integrates data collection and spatial analyses in order to provide a practical support to local administrations charged with waste management.

→ **Modules have been developed in a QGIS environment, and procedures have been created in order to tackle different aspects of SWM**

Secondary research questions

- *Evaluation of the level of accurateness of the procedure depending on the availability of data*

→ **A comparison between the results of GIS tools and real data has been done.**

- Evaluation of the level of appropriateness of the developed procedure considering its implementation through a free open source GIS (QGIS) (training + evaluation by trained people)

→ **Not achieved, since no field visits were organized after COVID-19 lockdown**

(1) Analysis of the current situation

- Assessment of existing routes, fuel consumption, monthly cost, location of collection points, frequency and time for emptying bins
- GPS data are fundamental
- Proper recording of consumption and budget by Municipalities should be implemented

CONCLUSIONS

(2) Functioning of tools

- **Development:** time expensive, lack of documentation and "trial-and-error" approach; topological inconsistencies of maps may be an obstacle.
- **Application:**
  - High potential in planning, design, optimization of the collection
  - Fast analysis, remote application
- **Tools:**
  - **Waste generation:** identification of buildings is a fast task for small areas, inventory of patterns required for large areas; Households' pattern distribution more appropriate in simulate the distribution of waste; distribution is reliable.
  - **Route optimization:** OSM is appropriated for a first application; inconsistencies with GPS should be considered.
  - **Fuel consumption:** results comparable with reference values in flat conditions, higher values for local routes; important support in estimating costs; validation is required.
  - **Location of collection points:** smooth operation, mass balance guarantee, modeled location is realistic and coherent.

(3) Economic analysis

- Impact of improvements has been evaluated:
  - Optimization of Ain Baal SWTF may lead to savings
  - Introduction of SC has a small economic relevance, with positive impacts on hygiene, comfort and environmental impact

CONCLUSIONS: Follow-up

Support:

- Maps and analysis will be incorporated within Municipal SWM plans and discussed with local authorities [ON-GOING]
- GIS training for local authorities (Webinar) [EXPECTED ON AUGUST 2020]

Testing and sharing:

- Improvement and test of models, a trainee is working on this topic [ON-GOING]
- Upload of developed models and reference data on sharing platform such as GitHUB and involvement of the community.

Indicators: Identification of geographical indicators (e.g. slope of roads, density of urban areas, presence of agricoltural / degraded area) influencing SW management

Conferences & papers

Conferences

- “WasteSafe – 6th International Conference on Integrated Solid Waste & Faecal Sludge Management in South Asian Countries” (23-24 febbraio 2019, Khulna – Bangladesh):
    - Villa F., Dias S.M., Grosso M., **Social aspects in the pathway towards the closure of a dumpsite: the case of Ngong (Kenya)**
    - Villa F., Arcidiacono A., Causone F., Masera G., Tadi M., Grosso M., **Entering Rocinha: a study on solid waste management in a slum of Rio de Janeiro (Brazil)**
- “CUCS – IV conference: Citizenship and collective goods. University and international cooperation for safety, environment and sustainable development” (19-20-21 settembre 2019, Trento – Italia):
    - Villa F., Vaccari M., Grosso M., **Open source GIS and solid waste management in low and middle-income countries: an application for Lebanon**
- “Sardinia Symposium – 16th International Waste Management and Landfill Symposium” (30/09-4/10/2019, Cagliari – Italia):
    - Villa F., Vinti G., Vaccari M., **Appropriate Solid Waste Management System In Quelimane (Mozambique) - Study And Design Of A Small Scale Center For Plastic Sorting With Wastewater Treatment**, Sessione E1 - Circular economy in Developing Countries, 30/09/2019

Papers

- Villa F., Vaccari M., Gibellini S., **Separate collection of organic waste and cardboard: assessing the impact of a development cooperation project in Tulkarem, West Bank**, Environmental Engineering & Management Journal (EEMJ), Vol. 17, N.10 (Pubblicato: 01/10/2018)
- Domini M., Gibellini S., Villa F., Vidoni A., Difrancesco L., Sorlini S., Vaccari M., **The challenge of sharing data in cooperation projects: cause for reflection**, Journal of UNiversities and international development Cooperation (JUNCO), Vol.1, N.1 (Pubblicato: 19/09/2019)
- Causone F., Grosso M., Tatti A., Villa F., **Energia e rifiuti in favela: da problema a risorsa**, Presentato per la pubblicazione sulla rivista “Territorio”
- Villa F., Arcidiacono A., Causone F., Masera G., Tadi M., Grosso M., **Entering Rocinha: a GIS approach for the improvement of solid waste management in a slum in Rio de Janeiro (Brazil)**, Presentato per la pubblicazione sulla rivista “Detritus Journal”

Thank you!