BSB 966

Safe area spatial distribution evaluation in major cities of Anatoliki Makedonia and Thraki Region

Deliverable No: D.T3.5.2

GA T3 Implementation of REDA system (pilot studies)

Created by:
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1. BACKGROUND OF THE DOCUMENT

1.1. SCOPE AND OBJECTIVES

Selecting the location and spatial distribution of safe/refuge areas in a city, where people can find a shelter is of critical importance. The deliverable contains a pilot evaluation study of the distribution of State defined safe locations in major cities of the Anatoliki Makedonia & Thraki Region and their “accessibility” from different locations within a specified walking time of five (5) minutes, as it has been identified as a threshold by existing research. The study uses various methodologies to calculate the area around each safe location from where people can walk to in five minutes and presents the distribution of these areas in comparison to the respective city extend. The outputs provides essential information, which can be combined at a later stage with ancillary data (land use, population data, etc), to help Civil Protection authorities evaluate the current distribution and city coverage of the existing safe areas and plan for improvements.

Such a pilot implementation has not been foreseen in the initial project plan. It has emerged as a request by major stakeholders who recognized the potential of such a study to support their earthquake emergency plans. The study and the respective deliverable have been added to the project deliverables with the Addendum No.1 (December 2022). Considering that the REDACt project aims at improving the overall Resilience against Earthquakes, this deliverable is expected to positively contribute to the overall project targets (to improve the Operational Capacity of Competent Authorities at National and Regional levels and to improve Public safety), add value to project outputs and produce results.

1.2. RELATED DOCUMENTS

1.2.1. Input

Table 1. List of former deliverables acting as inputs to this document

Document ID	Descriptor
D.T.3.5.2	

1.2.2. Output

Table 2. List of other deliverables for which this document is an input.

Document ID	Descriptor
D.T3.2.	Safe area spatial distribution evaluation in major cities of Anatoliki Makedonia and Thraki Region

2. Safe locations for finding shelter after an earthquake

The following section provides an introduction to the subject of safe (refuge) locations where people can find shelter for at least a few hours after an earthquake (Fig.1).

Essential conditions and basic principles as defined by existing research and applied by the respective State Authorities are briefly presented and within this context, the role of the current deliverable is described.

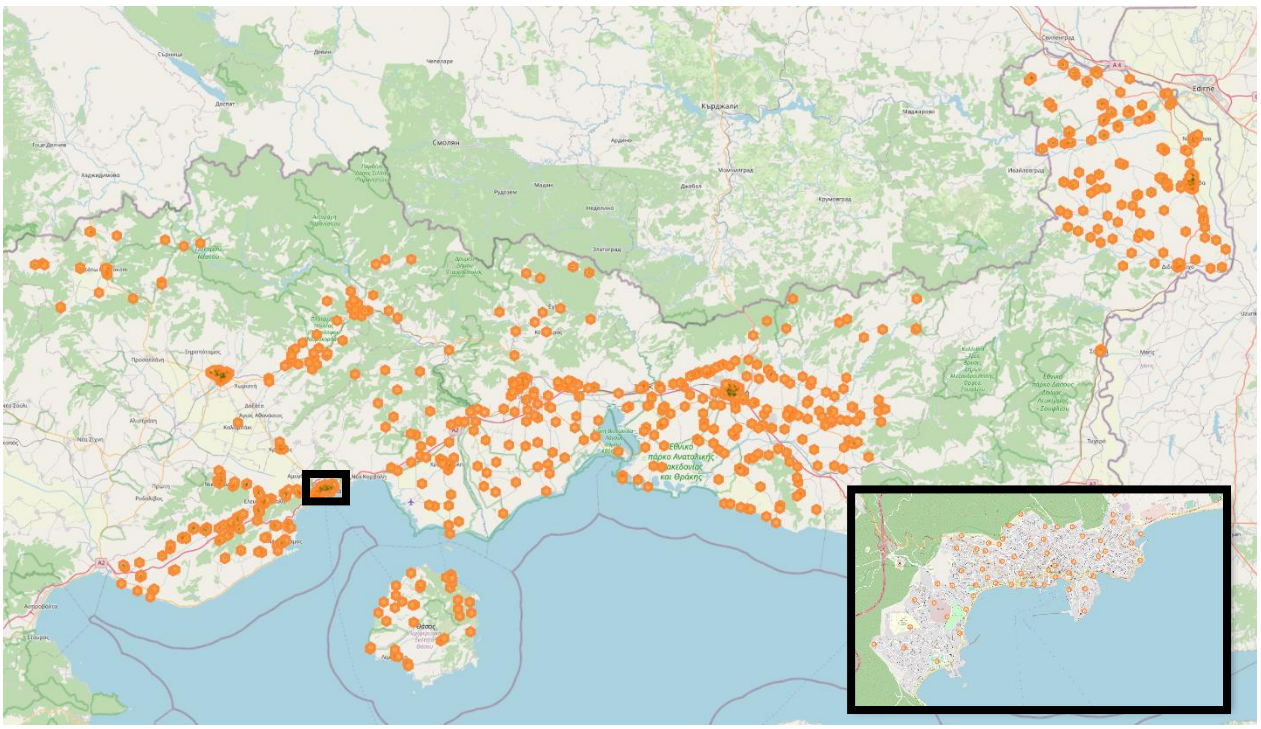

Figure 1. Safe areas in the Region of Anatoliki Makedonia & Thraki, Greece. Enlarged area shows the city of Kavala. Safe location data provided from the Regional Administration of Anatoliki Makedonia & Thraki.

2.1. Safe (refuge) locations

After a strong earthquake, the population seeks to find shelter where they can remain protected and wait for support to be provided by the competent state authorities. "Safe" or "refuge" areas are in general open space areas, located inside or outside urban areas, accessible on foot and by car respectively.

The process of moving towards a safe location as a critical part of the evacuation process and contributes significantly to successfully implementing emergency response actions and overall, to public safety.

Safe locations have been defined by Regional and/or State authorities based on a series of criteria including:

- Their distance from geologically hazardous areas (embankments, areas prone to landslides, existence of underground galleries etc.)
- Their minimum distance from surrounding buildings (at least half of their height).
- Their distance from large construction that may suffer serious damage.
- Their distance from power supply lines (electricity lines, poles, traffic lights, etc.)
- If near coastal areas, their location: they need to be in an elevated location to avoid possible tidal waves (Tsunamis).
- They have to be open spaces, freely accessible.
- Their accessibility. They have to be easily accessible by anyone and especially by elderly people and persons with kinetic difficulties. It is especially important to consider the conditions in the streets during the first minutes after a strong earthquake. Public transportation may not be available and using a car, may lead to causing traffic jams thus blocking streets and preventing State Services of quickly accessing parts of the city to provide help to those in need. Additionally, considering that pedestrians have to stay away from buildings so they have to use the streets to evacuate an area, car jammed streets pose an additional threat to them. For those reasons, transportation towards safe locations within the urban area is more efficient, safe and thus preferable on foot.
- The part of the city they serve, considering that for psychological and safety reasons, a safe area has to be accessed on foot in less than 5 minutes, therefore its distance from the starting point of any citizen has to be less than about 350-400m.

More detailed information (specifications and selection criteria) is provided by the competent at National and Regional levels Civil Protection Organizations as is the Hellenic Earthquake Planning Protection Organization-EPPO manual No. 3 "Evacuation of Buildings and population recourse to safe places after earthquake", available in Greek at *http://www.oasp.gr/sites/default/files/ ekkp.pdf* (last viewed on 21.04.2023).

2.2. Distance vs Walking time

Walking speed depends on body characteristics (mainly mass and lower limb length), on sex as males tend to have faster walking speed (Gills et.al, 2022) and on age. As a consequence, although mixed-sex and mixed-age people of varying body structure, physical condition, mass and sex present a variety of walking speeds, they usually adjust their walking speeds when walking together (Waghnild et.al, 2013).

Indicatively, the average walking speed and distance covered under normal conditions, as per gender and age are given in Table 1.

Table 3. Average walking speed and distance covered in 5 minutes walking time, by gender and age (after Gills et.al, 2022).

	m/sec		**Km/h**		**Distance walked (m) in 5 mins**	
Age	**Female**	Male	**Female**	Male	**Female**	Male
20-29	1.34	1.36	4.824	4.896	402	408
30-39	1.34	1.43	4.824	5.148	402	429
40-49	1.39	1.43	5.004	5.148	417	429
50-59	1.31	1.43	4.716	5.148	393	429
60-69	1.24	1.34	4.464	4.824	372	402
70-79	1.13	1.26	4.068	4.536	339	378
80-89	0.94	0.97	3.384	3.492	282	291
Average	**1.24**	**1.32**	**4.47**	**4.74**	**372.43**	**395.14**

Table 1 data indicate that under normal conditions, the walking distance covered by most of the population in five minutes, is around 380m but elderly people need more time to walk the same distance.

Additionally to those, ground morphology (slope) and even the available free space (ie a crowded street) or distracting events can also affect the walking speed of people. As walking speed is related to the time needed for a person to reach a safe area on foot in case of an emergency, additional parameters as the psychological condition of the individuals, could also be considered.

2.3. ISOCHRONES

The geographic area from which a person can walk in five minutes to a safe area, can be considered as a "catchment" area where transportation can only be done over the existing transportation network. "Seen" from a reverse perspective, this can also be considered as an area which can be accessed from a specified point, within a certain amount of time (Allen, 2018).

This kind of “catchments” have been used in urban planning (Barker, 2006), transportation planning (Grazer et.al, 2011; Guérois et.al, 2014; Sleszynski et.al, 2021), market analysis (Desai, 2006), hydrology (Bell, 1998; Al-Smadi, 1998), educational planning (Gagnon, 2020) in the form of **isochrone** maps.

An isochrone (in Greek, iso = equal, chronos = time) is defined as "a line drawn on a map connecting points at which something occurs or arrives at the same time". In a more general sense, isochrone maps can be used to show distance covered within a specified amount of time, using a specific mode of transportation which has a pre-defined speed, also considering in most cases, ground slope and existing traffic conditions and/or any other “speed cost” factors. They delineate, “catchment” areas which are accessible in a specified amount of time from departure from prespecified points, provided that time or distance conditions exist. In our case, each safe location is considered as the arrival point and the isochrone line is created by connecting the various departure points on the connected to the safe location, streets.

In the case of State defined safe locations (refuge areas), isochrone maps show (among other things) the area from which citizens can walk within a predefined amount of time to them (fig.2) and thus, they reflect the “reachability” (or accessibility) of these locations from various parts of a city, taking into consideration the maximum time limit of 5 minutes.

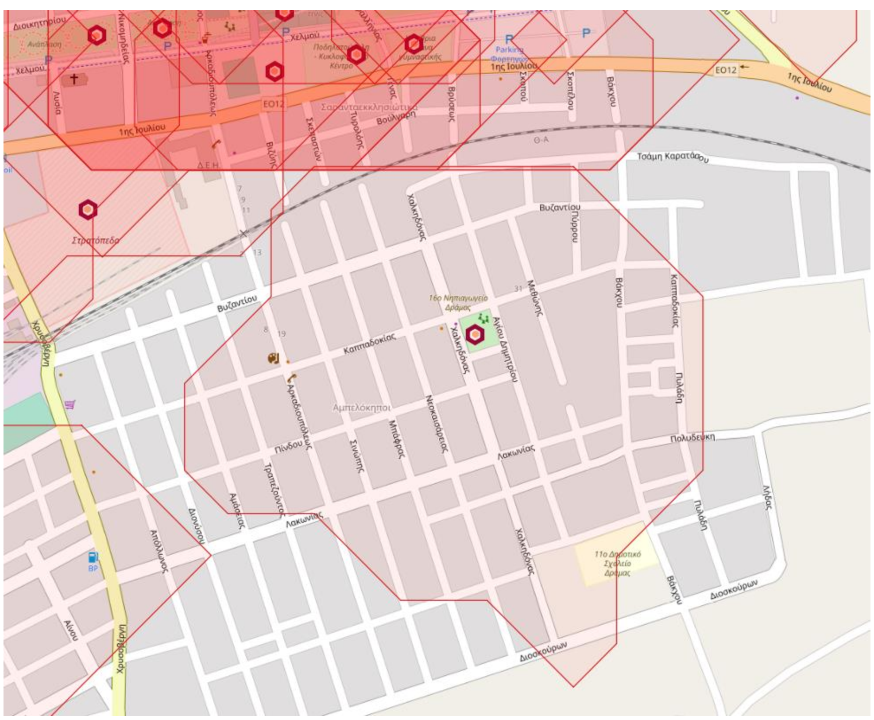

Figure 2. Isochrone area around a safe location (a park). Additional safe locations and the respective isochrone lines and “catchment” areas, can also be seen.

As is evident, the quality and accuracy of the road network used to delineate isochrones is of critical importance. The road network on which the assessment is made must be detailed, complete, up-to-date and accurate. Moreover, the existing morphological conditions must be taken into account to calculate the walking speed and therefore, the maximum walking distance in five minutes in order to precisely delineate the respective to a safe location, isochrone.

To the question if isochrone maps alone, can provide sufficient information to evaluate safe locations in terms of their efficiency, the answer is «NO!» There's a lot of additional information needed for this evaluation, including the capacity of each safe location to host persons in terms of available space and facilities, the ongoing activities in the vicinity at the time of the event and many more.

Having said that, isochrone maps in the sense already described, are related to the safe location coverage of an urban area so, they are an important first step which can provide useful insights about the coverage of urban areas by the defined safe locations, based on their spatial distribution and reachability in a predefined amount of time.

Combining at a later stage, the spatial distribution and urban area coverage of safe areas with additional information such as the existing population during various year-round periods (time of day, day of week depending on land uses) can provide important insights and thus help Civil Protection authorities optimize the selection of such areas in order to cover the population needs during an emergency and help plan for response actions.

2.3.1. Isochrone calculation models

Isochrones are typically delineated by using shortest path approach based on Dijkstra's algorithm (Dijkstra, 1959; Frana, 2010) to generate shortest-path trees between nodes of a network graph and by delineating a polygon around the nodes which can be accessed, only.

Isochrone maps help visualize the outermost limits than can be reached from a pre-defined point and even from set of points. Access time to those points is calculated taking into consideration the respective information (road maps, transportation networks, traffic conditions, local geography). This information is often being provided along with the respective isochrone calculation models by various providers as APIs and/or plugins, which can be incorporated into various GIS applications.

It must be noted that the shape and extend of isochrones, is totally dependent on the calculation model used and on the quality of the respective input data and information (e.g. base maps, traffic information, morphology etc). For those reasons, different approaches may provide outputs that vary, especially in terms of shape and extend of the developed "catchment areas" (Fig. 3).

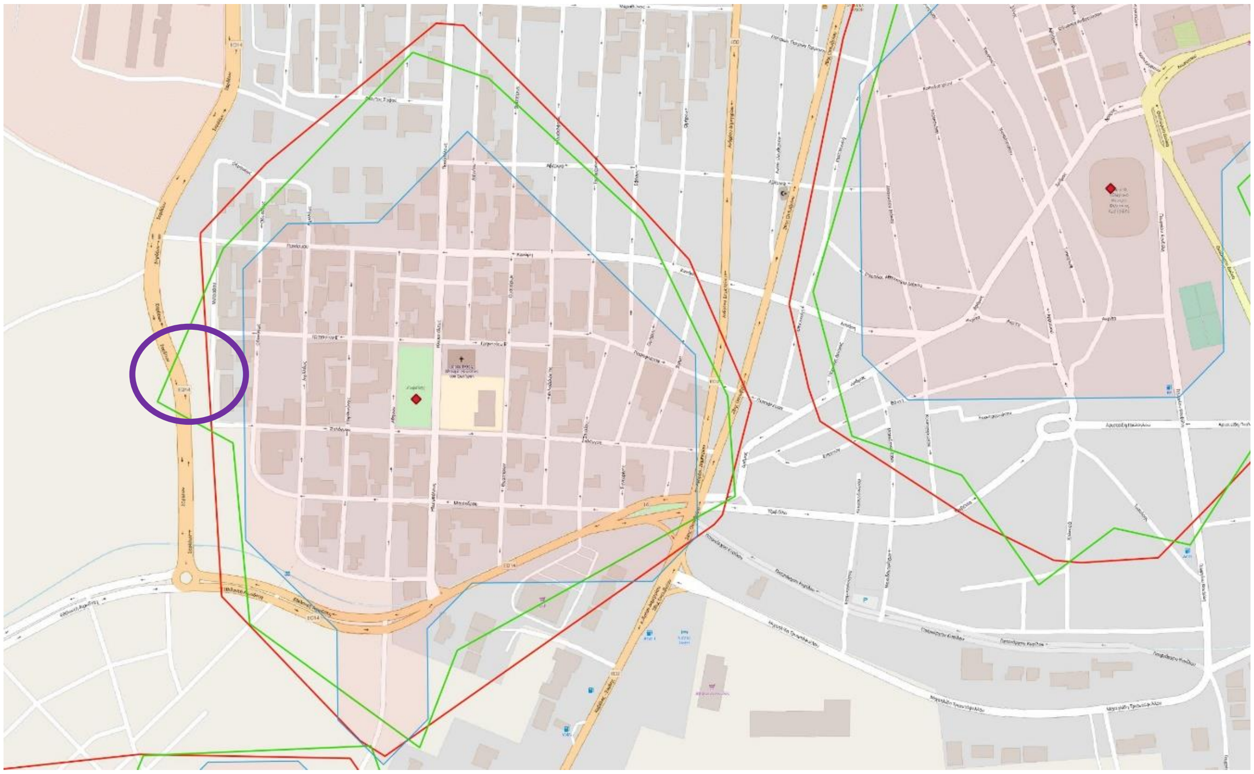

Figure 3. Isochrones created using different models: ORS (red line), Valhalla (green line) and TravelTime (blue line). The non-systematic differences that exist among them are evident as are mistakes in the delineation of the curves (the green line at the left side of the plan, covering part of the main street with NO direct access to the safe location (purple oval).

What should also be considered is that there’s a relatively high level of uncertainty of the final outputs, stemming from the numerous accessibility related factors affecting travel time, that exist (Fig.4). Factors affecting uncertainty are related to:

- **Land-use**: it’s related to the volume, spatial distribution and quality of facilities of any kind (jobs, shops, administrative, services, social facilities) and their specific requirements.
- **Transportation**: it relates to the effort needed to cover the distance between the departure point and the destination by any transportation means.
- **Time** is related to the availability of facilities at a specific point in time (working hours of Public services, opening hours of shops), their dynamic variability and the capacity or individuals to carry out or be engaged in those activities as they are affected by various conditions (weather, traffic).

- The individual component: it is related to the needs, capabilities and chances of any individual person. In other words, the individual component depends on the various properties and capabilities of each different person (age, physical condition and characteristics and even educational level and income).

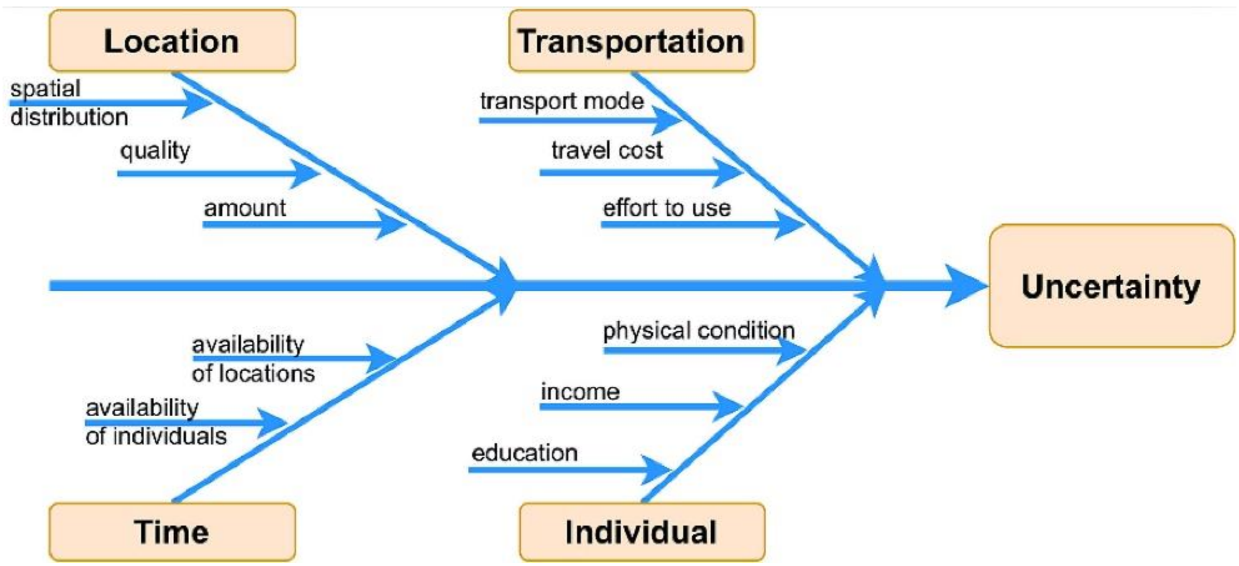

Figure 4. Sources of uncertainty in isochrone mapping (after Li et.al, 2021).

In addition to understanding the factors affecting uncertainty of isochrone maps, another aspect to consider is the acceptable level of uncertainty for **the specific application** isochrones maps have been developed. Different scenarios and research targets allow for a different level of acceptable uncertainty. When for instance planning for transportation in relation to recreation, a very different level of uncertainty can be accepted in comparison to when planning for travel times needed for the fire department to intervene in different parts of a city during an emergency.

To tackle the problem, research focuses on the dynamic factors involved in isochrone calculations, which affect uncertainty (Berg et.al, 2018).

There have also been attempts estimate the distribution of uncertainty in "static" isochrone maps using the Monte Carlo simulation. These have shown the distribution variability of uncertainty within a single time span (a day) and underline the necessity for more elaborate and in depth analyses regarding the development of isochrones (Li et.al, 2021).

For those reasons, some of the available models including Open Route providers (Valhalla, Graphhopper, HERE, TravelTime, ORS) have incorporated into their models and provided APIs, for isochrone mapping, information regarding dynamically changing components like traffic conditions and/or morphology (fig. 5).

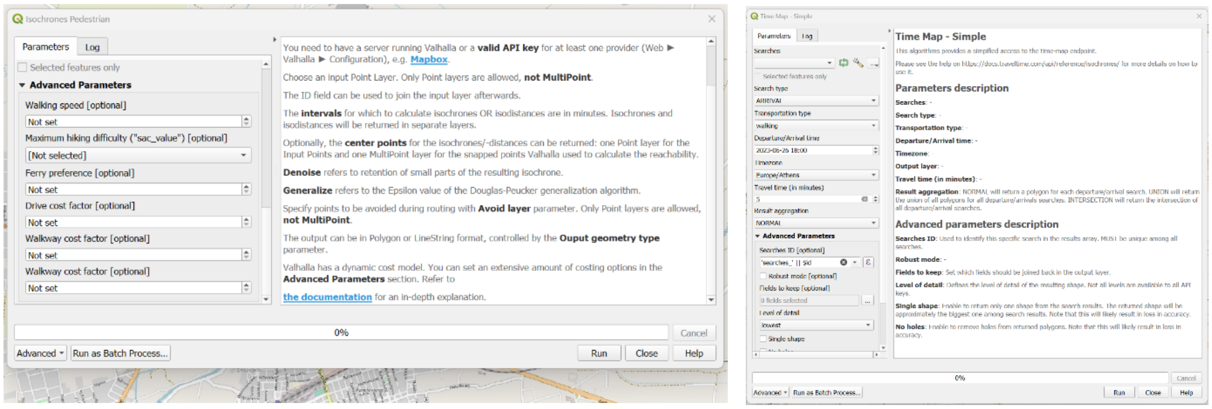

Figure 5. Isochrone creation using QGIS plugins. Left: Valhalla plugin and API, allowing control of various parameters affecting walking speed. Right: TravelTime plugin and API, which modifies distance for a predefined travel time by taking into consideration "traffic" conditions during the day by setting the corresponding date and time.

3. Safe area isochrone maps for major cities in the Region of Anatoliki Makedonia & Thraki

3.1. Materials and methods for data processing and isochrone map development

For the purposes of the present study, a number of different isochrone models (table 2) was used in order to evaluate their outputs before finally selecting the one to be adopted.

Opensource software and Open access data and services were preferred over commercial ones. Criteria considered include the data input requirements, the required parameters considered to delineate isochrones (eg. models considering dynamically changing parameters were preferred over "static" ones) and the suitability of outputs for the specific study.

Table 4. Isochrone models, APIs and QGIS plugin evaluated for developing isochrone maps of major cities in the Region of Anatoliki Makedonia & Thraki.

Nr	API / Plugin	More info

	GraphHopper Directions API Route Planning	https://www.graphhopper.com/
	Valhalla FOSSGIS	https://plugins.qgis.org/plugins/valhalla/ https://valhalla.github.io/valhalla/api/isochrone/api-reference/
	Open Route Service (ORS)	https://openrouteservice.org/
	HERE Maps Isoline, REST API, HQGIS plugin	https://developer.here.com/develop/rest-apis
	TravelTime	https://geoawesomeness.com/three-gis-based-travel-time-polygon-tools-compared/ https://traveltime.com/blog/here-isoline-api-traveltime-isochrone-api
	Location Lab Catchment QGIS plugin using HERE and OpenRouteservice APIs	http://gis-support.com/location-lab-qgis-plugin/

GraphHopper Directions API Route Planning, provides free routing but the isochrone API is commercial.

Valhalla is an open-source toolkit for multimodal transportation, powered by open data from OpenStreetMap. The respective APIs use the standard REST model. The route service provides guidance between points for various transportation means including car, bike, foot, and multimodal combinations involving walking and riding public transit. User apps can use the outputs of the routing service to plan journeys with routing and guidance. The Valhalla isochrone service computes areas that can be reached within specified time spans (periods) from one or more locations. Inputs to this process include the location of "departure" or "arrival" points (in our case the safe areas); costing parameters which are related to the means of transportation and can be adjusted to develop the route path, as well as for estimating time along the path; schedule related parameters (time of departure or arrival) and some filtering for shaping up the final outputs (denoise filters).

The **OpenRouteService (ORS)** provides a geocoding API which accesses global databases, OpenStreet Maps and can transform descriptions of locations (street addresses, postal codes and even place names), into a description of the location with a point geometry. Additionally the ORS geocoding service provides reverse geocoding service which transforms coordinates of points into meaningful descriptions (like addresses, nearby landmarks, known buildings etc). ORS provides an isochrone API for delineating reachable areas around points and vise versa.

Input can be either time or distance, transportation means, road type restrictions, vehicle (and transportation means characteristics) and more. It's free to use.

TravelTime API provides a way of searching and filtering data using time instead of distance. It is a RESTful web service or REST API, based on representational state transfer (REST), which is generally preferred over other similar technologies, because it uses less bandwidth, making it more efficient for internet applications. Required input data include the ID (unique identifier for the isochrone used as a reference in the subsequent API response), coordinates which define the departure or arrival locations, transportation type (driving, public transport, walking and cycling), departure or arrival time which must be in extended ISO-8601 format (e.g. 2021-09-27T08:00:00Z), travel time (duration of transportation in seconds).

The **HERE** (Maps) **Isoline Routing** API, enables user to find all destinations that can be reached in a specified amount of time or a maximum travel distance, or even the charge level available at the vehicle. The process results in an area polygon where each point can be reached within the provided time or distance limit. The API also works in the reverse and can calculate the isochrone by detecting all starting points from which a set center can be reached. Finally, the HERE Isoline Routing API can take into consideration both real-time and historical traffic information in its calculations.

Location Lab Catchment QGIS plugin offers a toolbox that allows for conducting location intelligence analysis using third-party APIs provided by HERE and by the Openrouteservice. The Catchment Area tool uses HERE or ORS to create isochrones.

As far as data is concerned, OpenStreetMaps -OSM (https://www.openstreetmap.org/copyright) was the choice for accessing transportation network data because it is openly accessible and free, allowing anyone to access, copy, distribute, transmit, and adapt the data.

Moreover, crowd sourcing makes sure that OpenStreetMaps data are continuously updated, which means that the data extracted when applying the method are always the most recent. It is a globally interoperable database, so the methodology adopted herein will be easily replicable to other locations regardless of the country. Additionally to those, the OSM database can be managed and analyzed with ease using a variety of technologies and tools including open source GIS software.

Safe location data used were provided by the Regional Administration of Anatoliki Makedonia & Thraki as .KML and .KMZ files which included as attributes (descriptive information), the Regional Administration Unit, the Location/City name, safe area coordinates (WGS84) and the name of the respective municipality (Fig.6).

Data were imported into QGIS and converted into a shapefile. As "address" is an attribute more easily recognizable and comprehensible than geographic coordinates, data were reverse geocoded in QGIS using the ORS plugin and based on Openstreet Maps, in order to produce address information which was attached to the file attributes (fig. 6).

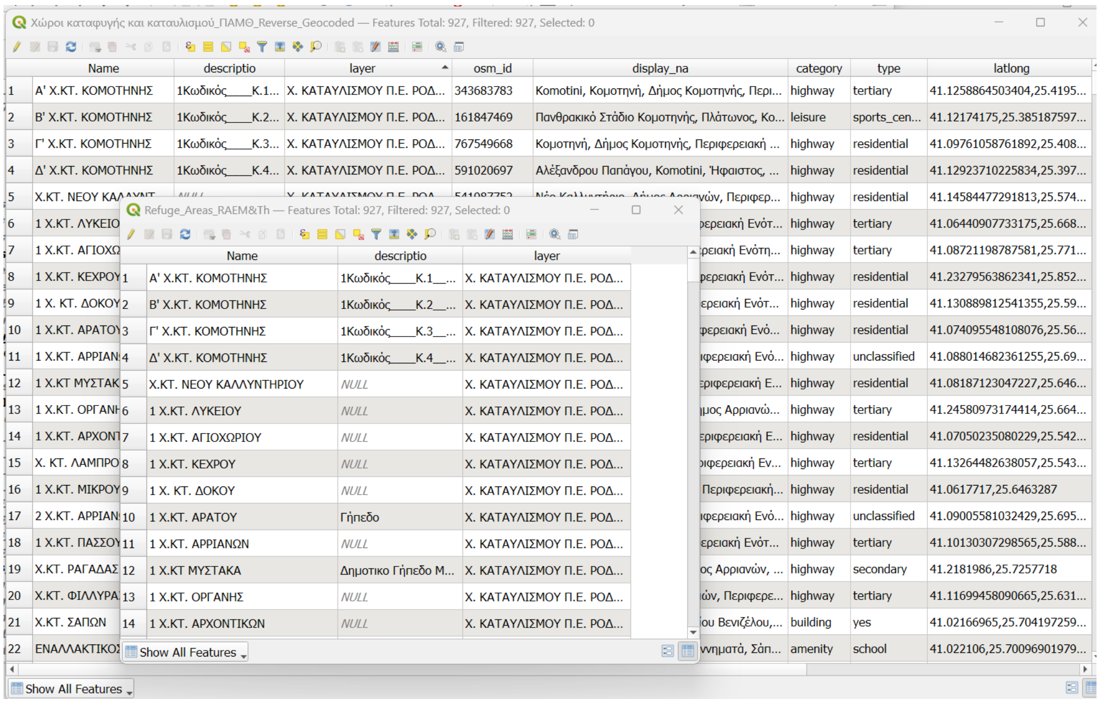

Figure 6. Safe areas attribute table. Input data table (table at front) and outputs of the reverse geocoding process (background table) where the "address" column (in Greek) and the coordinates can be seen along with various additional info created during the process.

A set of parameters were additionally considered based on the principles presented in previous paragraphs. These considerations included the uncertainty level incorporated by the use of various models as well as the differences in walking speed of people of different age and/or gender.

Since they take into consideration various parameters affecting walking speed, **dynamic isochrone creation models** were preferred over static ones. Additionally, multiple APIs invoking different dynamic models were used and their outputs compared in order to demonstrate the largest differences in calculating isochrones.

For the reasons explained in previous paragraphs, the APIs finally selected to be used include the ORS, Valhalla and TravelTime.

Additionally, and in order to provide an insight of how the walking speed of people of different age and/or gender (Gills et.al, 2022) affects the coverage of an urban area, maps of respective safe area isochrones, were created (Fig. 7).

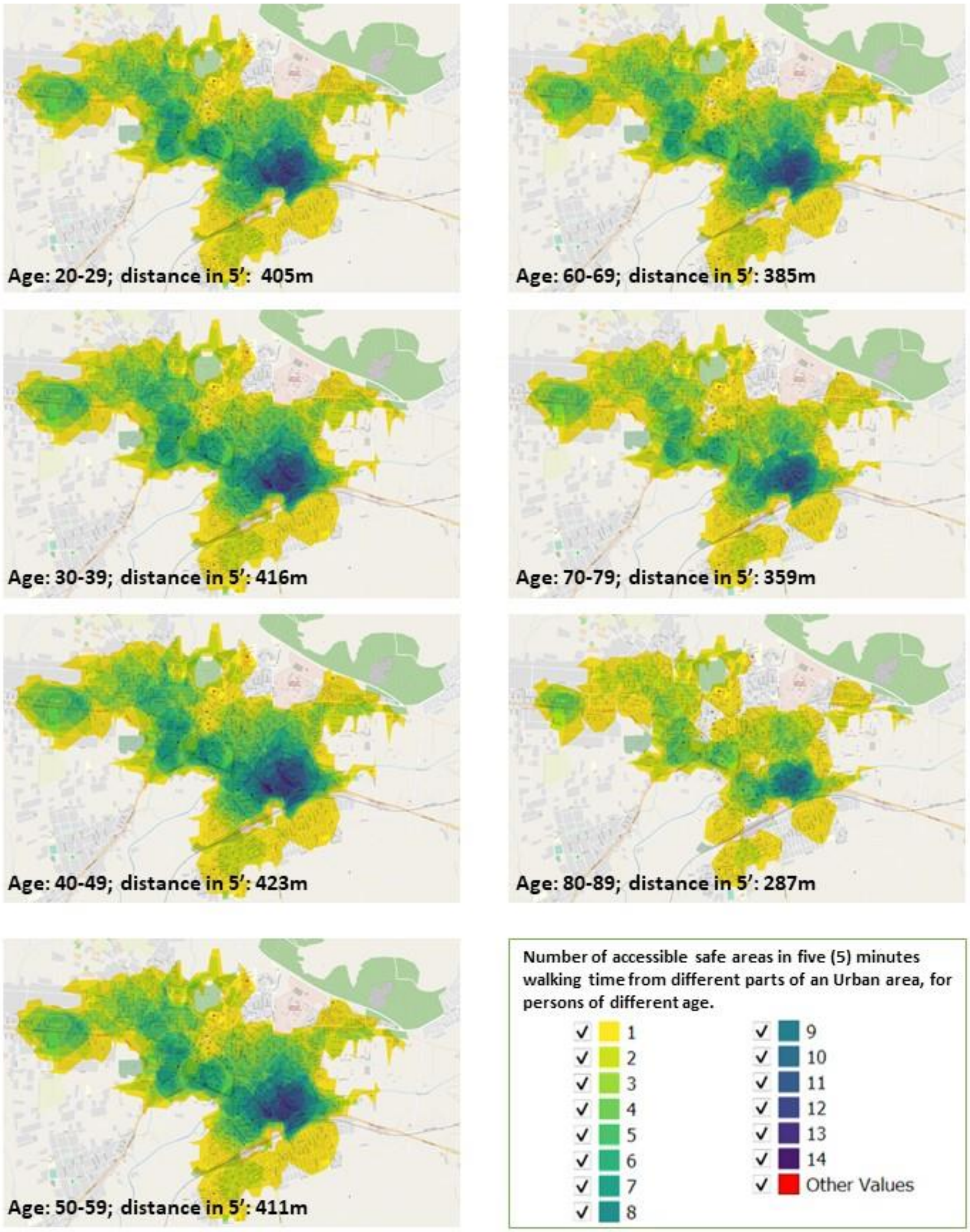

Figure 7. Safe area accessibility in five minute walking time, using isochrones created for people of different age.

Additional information produced during the processing phase includes population data linked to each safe area location (fig.8). These were based on the respective isochrone and the residential population estimates (5 years interval between 1975-2030).

Data have been derived from the raw global census data harmonized by CIESIN for the Gridded Population of the World (version 4.11), disaggregated from census or administrative units to grid cells and mapped per corresponding epoch (Freire S. et.al, 2022 and Schiavina M. et.al. 2022).

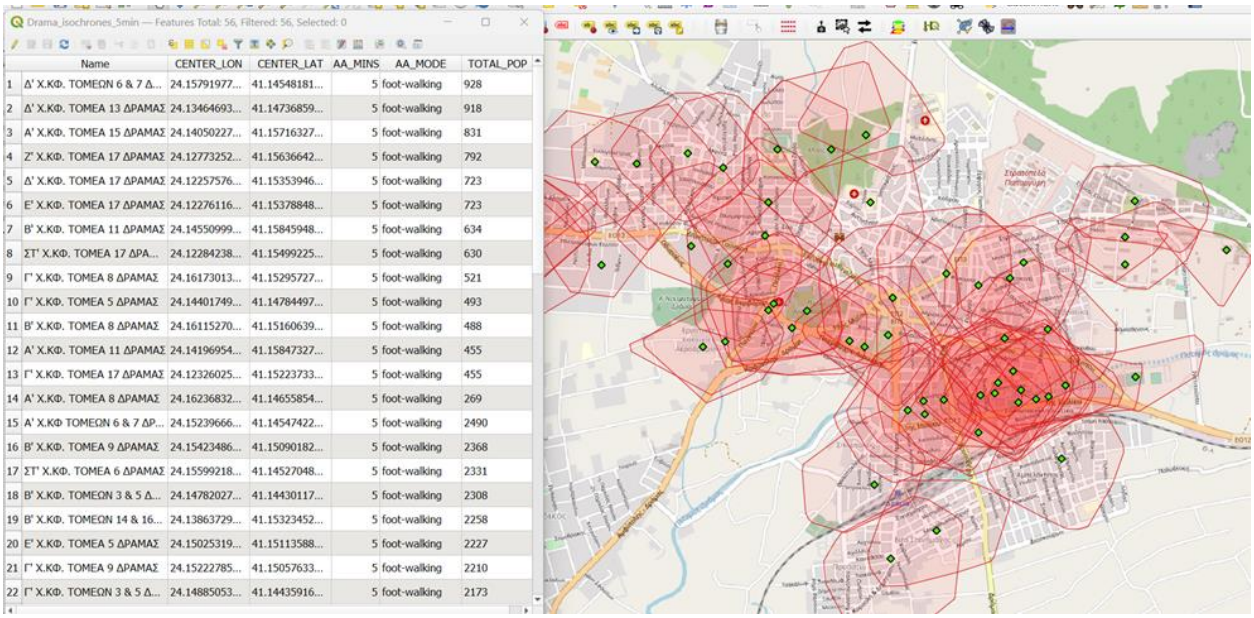

Figure 8. Safe area 5 minute isochrones and the respective population data seen at the attribute table

More accurate information retrieved from the Hellenic Statistical Authority can be used to depict the relationship between safe area distribution and population density (Fig.8).

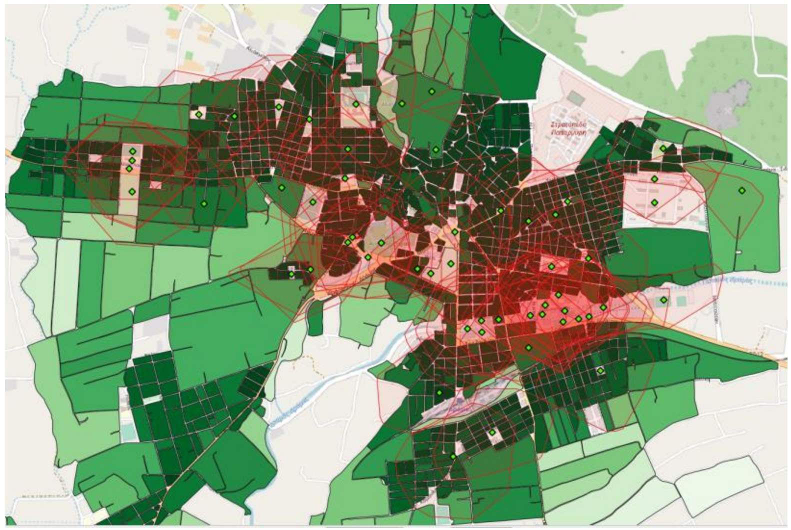

Figure 9. Safe location and their respective 5 minute isochrones, plotted against population density in m^2 per person (Data from the Hellenic Statistical Service). Darker colors correspond to greater population density.

Having said that, this information is **not** sufficient to model population needs in relation to available safe locations, because population concentration is related to land use (malls, schools, hospitals, public administration buildings etc) and moreover it changes temporarily (market open hours, market access during various times and days, school routine etc).

On the other hand, the capacity of the available safe locations to host people, needs also to be defined in terms of the number of people that can be safely hosted, the type and duration of "hosting" (residence time), the available facilities and more.

3.2. Access to safe locations in 5 minute walking time, of selected cities in the Region of Anatoliki Makedonia & Thraki

Considering the maximum walking time of 5 minutes, to access a safe area using the available transportation network (streets, paths), isochrone maps were developed for selected cities of the Region of Anatoliki Makedonia & Thraki. Cities investigated include (west to east): Drama, Kavala, Xanthi and Komotini.

Drama is located at the western part of the Region of Anatoliki Makedonia & Thraki. Its population reaches 55.593 according to the 2021 census. The city is the economic center of the surrounding area.

The city of Kavala is the principal seaport of eastern Macedonia and an important economic centre of Northern Greece with commerce, tourism, fishing and oil as the prominent activities.

The Municipal Unit host around 71.000 people (https://kavala.gov.gr/o-dimos/o-dimos-xthes-kai-simera/sintomi-perigrafi?lang=en-gb).

Xanthi is the capital of the respective regional unit and an economic center for commerce, tobacco business and farming products and tourism, especially during the recent period. The Polytechnic School with its five departments, is located in Xanthi. According to the 2021 census, the population of the city is around 59.000 (58.760) permanent residents who do not include the large number of university students.

Komotini is one of the main administrative, financial and cultural centers of northeastern Greece and a major agricultural and livestock farming centre. Democritus University of Thrace is based in Komotini with its administration and the Schools of Law, Classical and Humanity Studies, Social, Political and Economic Studies and the School of Physical Education and Sports. According to the 2021 census, Komotini has population of 65.107 citizens excluding the number of students who are regular residents of the city.

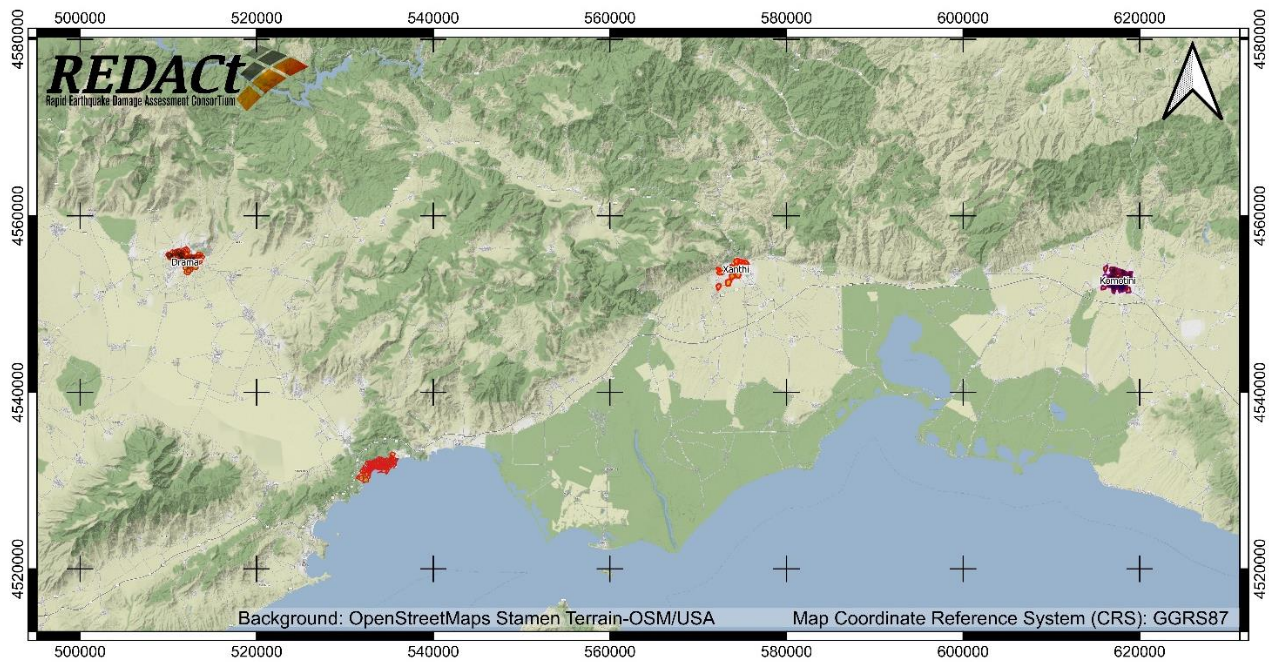

Figure 10. Major cities of the Region of Anatoliki Makedonia & Thraki investigated, considering the maximum walking time of 5 minutes to access a safe area using the available transportation network (streets, paths). Cities investigated include (west to east): Drama, Kavala, Xanthi and Komotini.

Traffic conditions and time of the day were not taken into consideration as walking speed is not significantly affected by those parameters. To calculate the distance travelled and to delineate the five-minute walking isochrones from each safe area, the average speed values as given in Table 3 by gender and age (Gills et.al, 2022) were calculated and used.

To make the adaptation of the developed maps by the stakeholders easier, and given that the maps cover only Greek territory, the Greek Geodetic Reference System of 1987 (GGRS87) was adopted. Having said that, all data and maps used and produced are also provided in digital format; therefore, their transformation in any desired coordinate reference system is very easy.

Each map includes a title where the city of reference and the methodology used to create the isochrones for each safe location are given.

The precision of the location of safe areas was found to be adequate for the intended use. Given the printing size selected (A4 page) for the deliverable, the design scale was 1/20.000.

Moreover, coordinates with units in meters (m) were used in the map frames to allow scaling the map and using them as reference (graphical scale). Having said that, the design scale only affects the analogy between the size of the map title and legend letters as compared to the map content because as already stated, data and maps are also available in digital format.

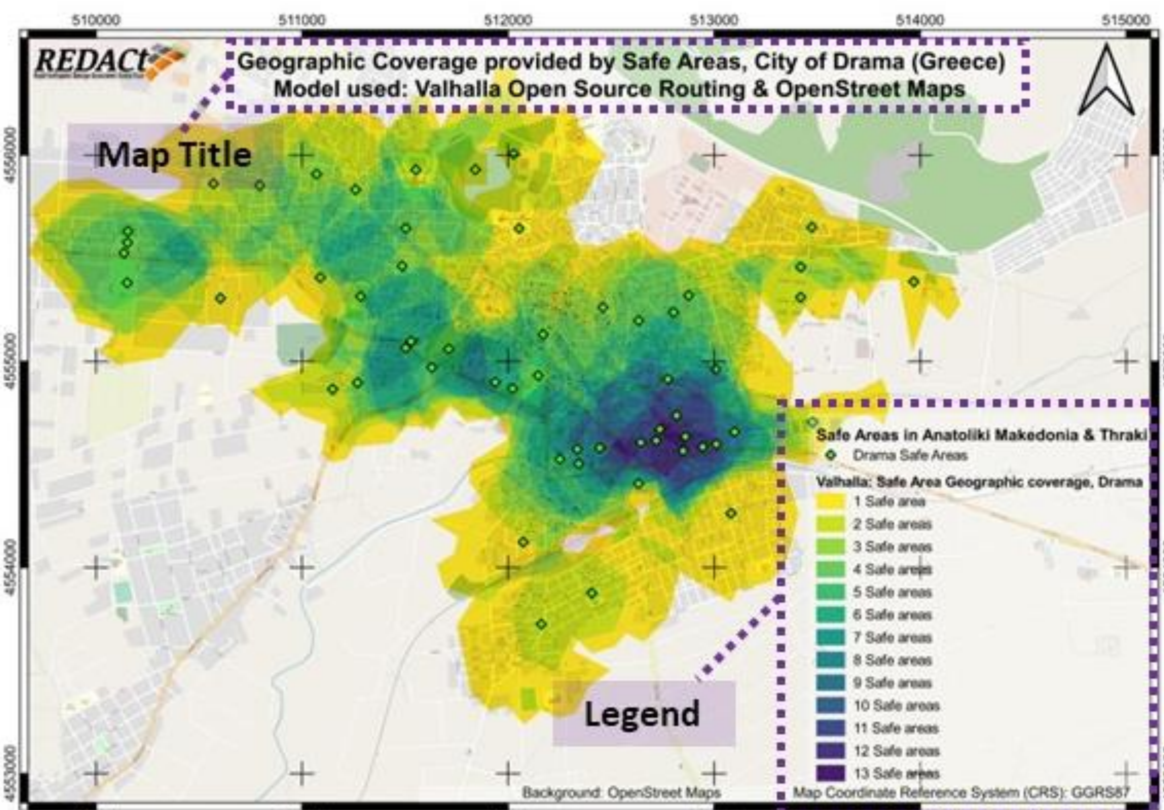

Figure 11. Accessibility of safe locations based on isochrones created using the Valhalla API for the city of Drama (info given in the map title). The number of safe locations accessible from different parts of the city, are given as colors in the map legend.

4. CONCLUSIONS

A set of maps depicting the capability (or the “coverage”) of safe areas to provide timely access to citizens from different parts of a city, given their spatial distribution and the maximum walking time of 5 minutes to reach a safe location, were developed.

These maps were based on safe location coordinate data, provided by the Regional Administration of Anatoliki Makedonia & Thraki, Greece (personal communication). Data were reverse geocoded, so that addresses and location descriptions that make easier for the user to understand and recognize, were added. OpenStreet maps were used as the necessary transportation and map background.

As the isochrone delineation depends on the model used, various isochrone delineation models were considered and evaluated for adoption in the present study. Models considering dynamically changing transportation parameters were preferred over static ones and Open source and free to use models were preferred over commercial ones. As a result of the evaluation process, the OpenRouteService (ORS), the Valhalla and the TravelTime models and respective APIs were used in Quantum GIS “environment” to develop the respective isochrone maps depicting the “coverage” of cities by the respective safe areas. Maps were developed for all the major cities for which data were available: Drama, Kavala, Xanthi and Komotini.

In most of the cases (with the exception of Xanthi), combining different cities and different isochrone creation models, it seems that the safe location spatial distribution can efficiently cover almost the entire city and people can reach any of them within 5 minutes walking time. It must be noted that the walking speed considered is the average walking speed for different genders and ages. This means that most but not all of the people can reach those safe locations in 5 minutes.

As the most influencing factor of walking speed seems to be age (over gender) and in order to provide an insight to the subject, isochrone considering walking speed of people of different age were also developed. They indicate the need for enhancing support to aged people and obviously to people with kinetic problems.

The present study provides an answer to the question if the defined safe locations are spatially distributed in a way that covers the essential necessity, as defined by state authorities, to be accessible in five-minute walking time. It can be considered as a first, important step towards improving the safety of the Public while supporting Civil Protection actions.

Future Research

To fully evaluate the capability of safe locations to fully provide the expected service to citizens, a number of additional parameters needs to be considered. Additional information that could be used includes the population density in different parts of the city, in different periods of the year, different times per day, the capacity of each location to host a number of people and the available in each safe location, facilities.

Additionally to those, both scenario based and real-time Rapid Earthquake Damage assessment outputs can provide valuable information regarding areas to be avoided during the response stage.

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APPENDIX I

1. Maps of Safe Locations of major cities in the Region of Anatoliki Makedonia & Thraki