# Automated modeling of geographical accessibility using the AccessMod framework

**Yaniss Guigoz**
yaniss.guigoz@unige.ch
University of Geneva
**Nicolas Ray**
University of Geneva
**Pierre Lacroix**
University of Geneva
**Frederic Moser**
University of Geneva
**Pablo Timoner**
University of Geneva
**Mattia Santoro**
National Research Council of Italy (CNR)
**Paolo Mazzetti**
National Research Council of Italy (CNR)
**Gregory Giuliani**
University of Geneva

---

**Research Article**

**Keywords:** AccessMod, Virtual Laboratory, physical accessibility, OpenStreetMap, Docker, urban accessibility

**Posted Date:** October 18th, 2025

**DOI:** https://doi.org/10.21203/rs.3.rs-7820101/v1



**Additional Declarations:** No competing interests reported.

---

# Abstract

This paper describes the chaining of several existing components to measure geographic accessibility to services into a single automated framework called the “AccessMod framework”. It then explains how this framework is exposed on the Internet thanks to the use of a virtual laboratory that transforms it into an integrated and transparent service.

To demonstrate the capabilities of this service, a use case allowing to model geographic accessibility to green spaces in specific cities has been implemented in a virtual laboratory using Docker images. An execution of this geographic accessibility modeling to green spaces is done for the city of Yerevan, Armenia. Three ways of running the model are demonstrated: (1) in command line; (2) through the virtual laboratory interface and (3) through the GEOSS portal.

The outputs are described, and the advantages, issues, limitations and perspectives are discussed. The possibility to reduce the technical complexity of geographic accessibility modeling thanks to its exposition on a web browser represents an undeniable step towards a wider adoption of this accessibility parameter for various thematics. This paper raises the importance of the availability of global renown datasets (e.g. OpenStreetMap, Worldpop, Copernicus land cover, etc.) for automated workflows, but also highlights the limitations of global models, that need to be customized (e.g. for the travel scenarios that are different among cities).

Several perspectives are finally proposed to improve the automatic modelling of geographic accessibility through this framework.


# Highlights

- Chaining of separate components into a single framework to compute geographic accessibility
- Framework’s exposition on the Internet through a virtual laboratory to lower usability barriers
- Use case for accessibility to green spaces in urban environments, using the city of Yerevan , Armenia, as an example
- Advantages of simplified access to geographic accessibility modelling through a single framework over the Internet

# 1. Introduction

Our societies are increasingly shaped around the concept of efficiency at all levels, which is the case for accessibility to services. Although the concept of accessibility can be approached from several angles (e.g. financial, social, geographical) [1], we focus in this paper on the geographic aspect of accessibility, that allows to measure the share of a target population covered by a given service (e.g. healthcare, education, recreational areas, etc.). Being able to measure geographic accessibility to a service is important in terms of planning, be it for population well-being [2, 3] or for more critical health emergencies where accessibility time is of vital importance [4–7].

Various approaches exist for measuring spatial accessibility. [8] describes the six following ones:

- **Provider-to-population ratio**, that calculates accessibility as a ratio between some relevant variables (number of beds, of doctors, of health facilities, etc.) and the population of a given area;
- **Euclidian distance**, that measures accessibility as a distance in straight-line from a residence to the health facility;
- **Gravity models** that combine availability and accessibility of facilities;
- **Kernel density**, that defines a sphere of influence around a health service provider by interpolation;
- **Network analysis**, that calculate optimized travel time or distance to the nearest service provider by considering the roads and transportation network;
- **Cost distance analyses**, that computes a “cost surface” based on input data layers (roads, elevation, land cover, etc.) for a given area, that is combined in turn with a layer of health facilities to obtain a least-cost path layer from any part of the surface to the facilities.

Among these different approaches, the cost distance has several advantages: by considering travel time rather than distance, it is more representative of the reality; it allows to consider travel not only in a network but on any type of land cover over the studied surface, which is often the case in sub-saharan Africa; using regularly updated input datasets (e.g. roads, facilities) allows to regularly re-assess geographical accessibility of the studied area.

Several tools exist to support the calculation of geographic accessibility to a given service. As a non-exhaustive list, we can distinguish in a first category the leading Geographic Information System (GIS) Software such as ArcGIS and QGIS, that give access to specific tools or plugins such as ArcGIS Network Analyst, ArcGIS Urban, TravelTime, QNEAT3. We can mention as a second category some specialized tools (generally desktop) for accessibility analysis such as AccessMod[1] and NetworkX. Finally, a third category consists in Application Programming Interfaces (APIs) such as Google Maps API, OpenRouteService, HERE API, that provide online accessibility analyses services.

Among these various tools allowing to analyze accessibility, AccessMod[1] has the following advantages: (1) it is an official WHO tool, (2) it can be run on all operating systems as a standalone application, (3) it is a free and open source software with a user manual and tutorial[2], (4) it uses a travel-time cost-distance approach. Moreover, it has already been successfully applied in several health domains such as maternal health [5, 6], immunization [9], and snakebite vulnerability [10], but also in other areas such as accessibility to schools [11], drinking water [12], accessibility pressure due to natural hazards [13], or accessibility to green spaces [3, 14].

Geographic accessibility modeling tools are a key support to decision-making, but several sequential steps are typically required to obtain the results: data pre-processing; data upload into the tool; accessibility; visualization and export of the results. In certain cases, it is often necessary to compute geographic accessibility regularly over the same area or across various countries for global assessments. This is for example the case for calculating the target4 indicator of the “Ending Preventable Maternal Mortality” [15], where the threshold of two hours travel time to the nearest health facility has become an international standard to be calculated for each country. For the computation of such repetitive steps, an automated workflow would simplify the procedure and reduce the necessary time and resources needed for calculating geographical accessibility. Furthermore, quality relevant input data can increase the accuracy of the analysis. The selected datasets will have a direct impact on the analysis results (see for example [16] for population), meaning that the input datasets choice should therefore be carefully assessed.

In a first effort towards automation, a dedicated R package called "inAccessMod" [17] has been developed to simplify AccessMod input data selection and pre-processing. To further simplify and automatize the use of AccessMod, the "AMRemote" tool[3] has been developed to implement the AccessMod "Replay" function, that allows to use AccessMod in command line with an AccessMod project file as input. Such command line analyses can be run on local machines, regular servers or cluster servers, making it possible for AccessMod to compute large datasets and to run many analyses by changing parameter values.

Through the elements described so far in link with AccessMod, we have different blocks existing for performing geographic accessibility analyses: (1) the inAccessMod R package for data preparation and homogenization; (2) the AccessMod tool for performing accessibility analysis (and several other types of analyses out of scope here); (3) the AccessMod replay function implemented through the AMRemote tool for command line use of AccessMod.

The combination of these different blocks into a single easy-to-use interface would

allow to take advantage of all the automation efforts done in the inAccessMod package and the AccessMod replay function, opening up the geographic accessibility computation to a larger public.

The objective of this paper is to describe the workflow that assembles these different pieces to provide a unique entry point for automatizing the calculation of geographic accessibility to a given service. We call it the AccessMod framework in the sense of an "integrated collection of components that collaborate to produce a reusable architecture for a family of related applications" [18] since the framework chains independent components of AccessMod, each having their own technical specificities and libraries, to form a new integrated product beyond a simple workflow. This paper also proposes a use case to show the benefit of this workflow for other users. To support this objective and to reach the widest audience possible, an entire data value chain from data to knowledge is implemented through the Global Earth Observation System of Systems (GEOSS) [19]. GEOSS is a global coordinated network of EO data providers, designed to provide comprehensive, timely, and reliable information about the Earth with the aim to improve decision-making across various. Through the Virtual Laboratory (VLab)[20], it allows: (1) a harmonized discovery and access to heterogenous EO data sources; (2) publishing the AccessMod model and related scientific workflow connecting data and model; (3) executing the implemented workflow; and finally (4) publishing the workflow results using different interfaces (e.g., static download; webservices). To ensure that the implemented approach is replicable and re-usable, all the Knowledge resources (e.g., data, model, documentation, computing resources results …) are freely and openly shared, curated and organized into a Knowledge package discoverable and accessible from the GEO Knowledge Hub [21] (GKH –

https://gkhub.earthobservations.org), an open-source digital repository of open authoritative and reproducible knowledge created and operated by the Group on Earth

Observations (GEO).

The concept of geographic accessibility plays an important role in the achievement of some Sustainable Development Goals (SDG) targets. It is for example the case for SDG targets 3.8 (accessibility to health services), 4.1 (accessibility to schools), 6.1 (accessibility to clean drinking water), 9.1 (accessibility necessary for efficient infrastructures), 11.2 (accessibility to public transportation in urban areas), and 11.7 (accessibility to green and public spaces) where geographic accessibility plays a key role. The theme of accessibility to urban green spaces for some selected cities has been chosen to demonstrate the feasibility of an automatic workflow allowing to calculate accessibility by simply selecting a city. We will first describe the methodology used by: (1) detailing the separate elements that were existing before our intervention; (2) explaining the elements developed during our intervention, to chain the various separate elements; (3) indicate the issues faced during this development and mention the choices made. We will then present the outputs obtained and discuss the advantages, issues, limitations and perspectives opened by the implemented workflow.

## 2. Methods

The AccessMod framework is made of existing but separate elements that have been assembled into a single framework. This framework is then exposed on the Internet thanks to the use of a virtual laboratory that transforms it into an integrated and transparent service.

# 2.1 Software components available separately

The following tools exist separately:

1.The **inAccessMod** R package[4] [17] supports automatic data download and pre-processing for use in AccessMod, through R commands. R functions[5] enable automatic download of several geospatial data sets for a user-defined area (country, region): administrative boundaries (source: geoBoundaries[22]), Digital Elevation Model (source: srtm [23]), population distribution (source: Worldpop[24]), landcover (source: Copernicus Global Land Service[6]), roads network (source: OpenStreetMap[7]), rivers (source: OpenStreetMap[8]), water bodies (source: OpenStreetMap[9]) and other potential barriers to movement. It also resamples raster data, aligns rasters, and reprojects all data sets to a common projection.
In case the user prefers other data sources not available in the proposed sources, the input can be manually downloaded and subsequently transferred to the project’s corresponding directory using a dedicated function from the package prior to processing.
inAccessMod outputs are made of a consistent set of ready-to-use input layers for AccessMod, with same projections and same resolution for rasters.
For this use case demonstration, a private fork of the inAccessMod repository has been created and modified allowing analyses to focus specifically on urban areas rather than entire countries. We used the ESRI World Urban Areas dataset [25] as a vector dataset containing city footprints and names. To our

knowledge, it is the only publicly available dataset of this type. When focusing on a specific city, a city extent shapefile is generated by applying an approximate 5 km buffer to the city's boundary. This buffered extent serves as the reference for the project extent, accommodating potential movements outside official city limits, which is pertinent in cases of irregular or extended boundaries. The city shapefile remains applicable for computing population statistics.

2. AccessMod[10] [1] is distributed through three bundles: AccessMod Desktop, AccessMod VirtualBox, and AccessMod Docker. It provides both a graphical user interface and a command-line tool for modeling geographic accessibility. Its core component is a Docker image based on Alpine Linux, which integrates all required dependencies.

3. AccessMod comprises five main analysis modules: (1) Geographic accessibility; (2) Geographic coverage; (3) Referral analysis; (4) Zonal statistics; (5) Scaling-up. In addition to its main analysis modules, AccessMod includes a set of essential tools for preparing and managing data inputs. The landcover merge tool combines land cover, roads, and natural barriers such as rivers and lakes into a single raster layer, while the population alignment tool ensures spatial consistency across demographic and geographic datasets. Other built-in utilities include dataset management, import/export functions, and an interactive facility relocation tool.

4. The analytical workflow begins with the merged landcover layer, which forms the basis for calculating accessibility to or from selected service locations. These calculations rely on one or more travel scenarios that assign transport modes and speeds to each road type or land cover category. The model is implemented through a multi-modal extension of GRASS GIS's r.walk module (r.walk.accessmod). For non-motorized travel modes, slope effects are incorporated using correction functions: Tobler's hiking function for walking [1, 26], and a cycling function derived from BikeCalculator.com [27].

The output of the geographic accessibility module is a raster surface in which each pixel represents travel time to the nearest service location (e.g., a health facility, school, or other point of interest). Based on this "travel time" layer, further analyses can be conducted, such as zonal statistics, which overlay the population distribution to estimate the proportion of people able to reach a service within a specified time threshold.

AccessMod also provides a "replay" function, which enables analyses to be executed from the command line once all datasets have been loaded into a project. This function relies on two files: the project archive (.am5p), and the config.json, a parameter file that is updated after each analysis to ensure reproducibility. The configuration file can also be edited programmatically to fine-tune analyses or enable batch execution. Both files can be extracted from a previous analysis through the graphical interface. A companion tool, AMRemote[11], further streamlines use of the replay function by allowing users to easily call and run analyses.

In order to share scientific models over the Internet towards open knowledge, the concept of **virtual laboratories** that allow to run workflows of scientific models, offer several advantages such as efficiency, reproducibility and collaboration[28]. Among the existing virtual laboratories, the Virtual Earth Laboratory (VLab)[12] was developed [20] [29] in the framework of several European projects. The VLab "provides functionalities for [13]:

- Harmonized discovery of and access to heterogeneous resources from multiple systems
- Publication of scientific workflows developed on heterogenous programming environments

- Run of scientific workflows developed on heterogenous programming environments
- Publication of workflow results

5. The Group on Earth Observations (GEO), coordinating the global effort of Earth Observations of co-producing user-driven Earth Intelligence solutions, has been working for a long time on developing a unique access point to environmental data (the GEOSS platform) and more recently to environmental knowledge through the **GEO Knowledge Hub**[14]. It is then legitimate to contribute to this global coordinate effort by using the GEO Knowledge Hub [21] as the unique entry point for running models linked to accessibility.

# 2.2 Integration of the software components into a framework

The various existing elements described in the previous section have been merged into a single framework called "AccessMod framework" for chaining the operations described here above, which results in a much easier interaction needed from the end user. This also required additional developments that are described in this section.

## 2.2.1 Creation of the AccessMod[15] framework from existing separate software components

The elements encompassed in the new framework follow a logical order:

1. **01_get_data**: The inAccessMod R package is being used to first get the required data[16] and process it automatically into suitable input data (projection, resolution) for AccessMod analysis. The roads, rivers and lakes are downloaded from OpenStreetMap by default[17].
2. **02_build_merged_landcover**: the "landcover merged" layer, essential for further analyses using AccessMod, is automatically created. The source files necessary for the creation of the merged landcover layer are the landcover, the roads, and any barrier to movement (e.g., water bodies).
   A new unique identifier is applied to OpenStreetMap roads categories, all layers are rasterized at the same resolution (100 meters by default). The input layers are then merged into one in the following sequence from top to bottom: roads, water lines, water polygons, landcover.
3. **03_create_start_points**: as the thematic for this pilot is the accessibility to green spaces in cities, it is necessary to obtain the features corresponding to green areas of a given area (city selected), to which accessibility will be analyzed. The request[18] consists in extracting from OpenStreetMap the polygons corresponding to parks, natural reserves, grasslands, woods and forests. To comply with AccessMod current limitation to calculate accessibility to points only, each polygon is then represented by a single point corresponding to its centroid. This centroid is calculated by using the k-means algorithm [30] on the cluster of points forming the polygons.
   It should be noted that such an automatic function for extracting the start points did not exist so far in AccessMod, as a point shapefile needs to be manually uploaded into AccessMod.
4. **04_travel_time**: once the input data is available (previous steps 01 and 03) and the merged landcover is produced (step 02), the next step consists in creating an AccessMod project[19] and to perform the

travel time to nearest point analysis[20] using the available data. This is automatically done for a given city in this step, and various outputs are created, that illustrate accessibility.

### 2.2.2 AccessMod framework API

In addition to the new AccessMod framework Docker image, an **AccessMod API** has also been developed for using this application. It means that the AccessMod framework can not only be launched through the shell script, but can also be used through the API either by:

- Using curl commands that allow to directly interact with the API
- Or using a **Docker curl wrapper** that provides a convenient way to interact with the API, especially for environments where curl might not be readily available, or if a consistent behavior across different systems is needed.

The innovative aspects of AccessMod framework vs the existing AccessMod separate elements are then the following:

- The standalone elements (inAccessMod, AccessMod, AMRemote and isolated scripts) have been combined into a single AccessMod framework, allowing to perform geographic accessibility analysis through a single tool
- An AccessMod API has been developed, that allows to interact with the AccessMod API using curl commands or a Docker wrapper
- An automated polygon types extraction from OpenStreetMap and transformation to points has been implemented

### 2.2.3 Porting of AccessMod on the Virtual Laboratory

The Virtual Earth Laboratory (VLab) [20, 29] is a software framework developed to facilitate scientific workflows implementation for supporting knowledge generation and evidence-based decision-making. The main functionalities of VLab include: (i) harmonized discovery of and access to heterogeneous resources from multiple systems, (ii) publication and sharing of scientific models developed on heterogenous programming environments, (iii) execution of scientific workflows developed on heterogenous execution environments (e.g. different cloud platforms, different software libraries, etc.), and (iv) publication and sharing of execution results. VLab functionalities are all available through Web Application Programming Interfaces (APIs), making it possible for the end-users to develop their own applications. When a model is published on VLab, the framework can trigger its execution on a variety of cloud platforms, allowing to seamlessly move the code to the cloud platform where the required input data is hosted. Several tests were executed on different cloud platforms including the European Open Science Cloud (EOSC), the commercial Amazon Web Services (AWS) cloud and most Copernicus DIAS platforms (Creodias, ONDA, Sobloo).

VLab was utilized to share the AccessMod framework so that it can ultimately be utilized through VLab Web APIs and run from the GEO Knowledge Hub as a knowledge package. A procedure is described[21] that explains the different steps. As the necessary data and tools are wrapped in a Docker machine, all necessary elements become available in the virtual laboratory for performing the accessibility analysis.

The AccessMod model is available in two different Docker modes:

1. Two different Docker images (one for data ingestion and one for model execution) can be utilized to run the entire workflow of the AccessMod model.
2. A wrapper Docker image which acts as a bridge towards a remote server where the AccessMod workflow is executed.

Currently, VLab requires one single docker image to be utilized as the computational environment for a model. Unfortunately, the two Docker images (mode 1) are incompatible and it was not possible to build a single Docker image, therefore this modality was discarded and AccessMod was published on VLab utilizing the wrapper Docker image.

It is worth noting that this way of sharing the model does not fully exploit VLab functionalities, i.e., the model is not actually executed on different cloud platforms, only the wrapper is. However, this still allowed AccessMod to be executable via VLab Web APIs, facilitating the development of the web application described in [20], and the re-use of the existing GEO Web Portal framework which utilizes VLab Web APIs for model execution. Besides, once the two Docker images (mode 1) will be merged solving their incompatibilities, it will be possible to update the VLab version of AccessMod (with the new single Docker image) and fully exploit VLab functionalities without the need of any other changes/developments of the other system components.

# 3. Results

### 3.1 AccessMod framework github

The AccesssMod framework application is available on GitHub[22] and can be run:

- locally in command line through the bash shell by the users if Docker is installed and running on their computer
- on a remote server
- on a cluster

After installing the Accessmod framework image (by cloning the repository from github), the user can run the “start.sh” script.  When running the script, the user is asked three main questions: (1) the city for which accessibility to green spaces should be run; (2) if the script should be run in development mode or not; (3) the part of the analysis that should be run, in a logical order. The illustrations shown below use as an example the city of Yerevan in Armenia.

Once the various parts have been run, the outputs become available in the “output” folder corresponding to the city selected, contained in the “data/location” folder of the “accessmod_gpp” folder that has been created when installing the accessmod_gpp image.

The following outputs are created:

1. a travel time raster, available in several formats (.tif, .img, .png), where each cell contains the time (in minutes) to the nearest point in terms of travel time.

2. the population coverage in a given travel time (minutes), both as a table (pop_vs_traveltime.csv) and as a graph (pop_vs_traveltime.pdf)
3. a raster (raster_cost_allocation_pr.img) that contains for each cell the unique ID of the point that is the closest in terms of travel time. This allows to allocate for each point feature (centroid of each green space in our use case) the area it covers. When crossing this information with population, it allows for example to understand which population is served by each green space, which might be useful for city green spaces planning.
4. a raster (raster_speed_pr.img) that contains the road or landuse category for each pixel
5. a compressed .json file (travel_time_output.json)

### 3.2 VLab interface

Instead of launching the accessibility analysis in command line, it is also possible to launch it through the Virtual Earth Laboratory (VLab) [20], which has the advantage of only using a familiar internet browser interface. This interface requires to be logged in, either through a google account or through a specific login to the VLab. The analysis is performed on the VLab central cluster. This is the cluster, deployed on AWS cloud platform, which hosts the latest version of the VLab framework. Taking advantage of the underlying cloud platform, the cluster is configured to allow executions of models with varying requirements in terms of CPU/RAM (as defined by the modelers when publishing a model on VLab).

The “Workflows”[23] menu exposes the various models available through the VLab, and the one called “SDG 11.7 Urban Green Spaces” allows to run accessibility analysis.

Once the analysis is finalized, the various outputs can directly be downloaded by clicking on the blue hyperlink buttons. Additionally, the model can be shared via email directly through the interface.

### 3.3 Integration into the GEO infrastructure

Once the AccessMod model published into the VLab, it becomes available through its Application Programming Interface (API) allowing any other client application to interact with the model. Therefore, it facilitates its integration with the GEOSS portal[24] enabling users to search for any analytical services available in the VLab (figure 9).

Once discovered, then users can inspect the model and the necessary data inputs directly within the portal, searching for relevant data sources as input for the service and selecting the cloud platform of preference to execute the model (figure 11). In this experimental setup, the cloud costs associated with cloud utilization (where present) are covered by VLab operators for demonstration purposes. Therefore, computational availability might not always be present.

Once a workflow is run, a message indicates it is saved in the “saved runs” section, where its status can be checked. Once the run is finished, outputs are available for download (statistics as CSV file, maps as geotiff) or could be visualized using the Web Map Service (WMS) interface enabling an interoperable access to the outputs. In addition, it is possible to create a dashboard to share the results in a simple and effective way with text, graphs and maps.

To facilitate the replicability and re-use of the proposed approach all resources are made available as a Knowledge package in the GEO Knowledge Hub (GKH: https://gkhub.earthobservations.org/packages/xx3rj-6zp63). The record (Figure 12) provides essential information like the title, description, keywords, and contributors. Each resource includes detailed metadata, such as the resource type, description, license, and publication date. Once the package is complete, it can be published or submitted for review, making it accessible to the global Earth observation community.

# 4. Discussion

## 4.1. General advantages

The AccessMod software offers the possibility to perform accessibility analysis but requires some pre-processing and processing steps that might represent a barrier for non-GIS experts who would have an interest in performing such analyses. The innovative AccessMod framework, by hiding the complexity in the back end, considerably lowers the entry barriers to perform accessibility analyses, in this case to green spaces in urban environments. Such integrated approach could widen the use of accessibility analyses for the benefit of evidence-based decisions in various domains where accessibility plays a significant role.

Although the execution of the AccessMod framework through bash command line might still represent an obstacle for some people, the availability of the AccessMod framework in a virtual laboratory represents an additional advantage. It means that third party applications such as the GEOSS Platform Plus can directly call the workflow and ask the user a single information (i.e. the city for which accessibility needs to be computed) and wait for the result that will become available when ready in a personalized workspace (accessible when logged in). This reduces the complexity of accessibility analysis for the user at its maximum and allows non-experts to obtain scientifically relevant data.

Moreover, the availability of the AccessMod framework workflow among other environmentally relevant workflows in the same environment (the GEOSS portal) with global visibility is an advantage for the user. The user can indeed easily access various scientific workflows in the same interface without needing to take care of the input data availability that is automatically downloaded and processed. As an example, combining the results of geographic accessibility to green spaces in a city with urban heat islands analysis in a same user interface might be relevant in the context of climate change adaptation.

## 4.2. Data issues

Input data play a crucial role in accessibility modeling, [16] and it is necessary to make informed comparisons and choices before making any new analysis. The AccessMod framework uses by default well known global authoritative data sources that have been proven suitable for accessibility modeling: Shuttle Radar Topography Mission (SRTM)[23] for Digital Elevation Model; Copernicus Global Land Cover[31] for land cover; Worldpop[24] for population distribution; OpenStreetMap (OSM)[32] for rivers, lakes, roads and green spaces; ESRI urban areas [25] for cities delineation. As the travel scenario needs to attribute a specific speed on each road and landcover category, a default scenario[25] is used for any town and corresponds to OSM roads categories.

Although these are well-known and trustful datasets, other datasets might be added in the future, for example to use alternative population distribution layer or urban areas.

This workflow shows not only the benefits of open data used here, but also the importance of citizen science projects such as OSM that provide the grounds towards urban assessment and planning (in this case accessibility to urban green spaces). The chaining of such open data, its combination with citizen science and global exposition through open workflows available on a Global Earth Observations platform is a step towards more open and replicable/reusable science for public benefits.

## 4.3. Limitations

Several limitations need to be taken into consideration in the current version of the AccessMod framework:

- AccessMod is a raster-based tool that has been developed in contexts where the population travels mostly off roads. In urban contexts, a vector approach (e.g. network analyst) would be more appropriate but raises other challenges such as a network perfectly connected. The AccessMod framework approach presented here simplifies the travel network but allows travel off-roads, which is relevant for analyzing the geographical accessibility to urban green spaces.
- The analysis is currently restricted to a limited number of cities worldwide[26]. This is mainly due to the lack of computational resources required if the workflow should be run on-the-fly further to users' demand.
- Currently, the user cannot change many parameters, and it might be useful in certain cases to modify either some input data (e.g. the population layer used) or the travel scenario. The possibility to work with several scenarios might be of particular importance for cities subject to specific climate conditions such as rainy season, where accessibility can be totally different from dry season.
- The least-cost path algorithm presumes that an individual will systematically reach the nearest green space from his/her location. This might not necessarily be the reality as one might prefer a big park with recreational features to a small not welcoming green space.

## 4.4 Perspectives

Inclusion of the AccessMod framework in the GEOSS Platform Plus is a first attempt to chain several independent components into a user interface simplified to the extreme for the user. This pilot demonstrates that the concept is feasible, although many improvements can be foreseen.

First, a bigger number of cities should become available for accessibility analysis in the AccessMod framework analysis.

Although this pilot focused on accessibility to green spaces in urban environments, the same concept can be extended to many other service points that would greatly benefit from easy modeling of accessibility in a given country/region, such as: accessibility to water points in a given country/region; accessibility to schools; accessibility to health services, etc. If most of the input data will be identical when using AccessMod (DEM, landcover, population distribution, rivers, lakes, roads), only the target service distribution layer (e.g. schools, water points, health services instead of green spaces) and travel scenario(s) should be differentiated, but the workflow remains identical.

The inclusion of vector analysis possibilities into the AccessMod framework would be an added-value to keep the advantages of the off-roads travel consideration currently available in AccessMod, while adding more precision for travel in urban environments. This would however represent an additional challenge in terms of input data quality necessary for network analysis, which is a bottleneck in many countries.

Finally, having the flexibility to modify some parameters (e.g. running the analysis with other travel scenarios, choosing alternative input layers) would allow us to better consider the reality of the ground. This flexibility could also enhance the workflow's usefulness for policy-making, for example by simulating accessibility improvements under different development scenarios, such as adding new green spaces, modifying transport networks, or adjusting travel modes. Such "what-if" analyses would provide decision-makers with evidence-based insights on how specific interventions could improve accessibility, while maintaining the advantages of pre-processed input data and automated computation. Implementing these capabilities, however, requires on-demand processing infrastructure, as it is not feasible to pre-process all possible scenarios for every thematic or geography.

# 5. Conclusions

This paper describes a first innovative attempt to have a complete workflow to quantify accessibility to given features (in this example to urban green spaces in urban environments) using an extremely simple interface. Despite limitations, this approach opens the way to a wider use of such tools by non-expert people for evidence-based decisions such as urban planning. This same approach can be used for many other thematics (e.g. geographic accessibility to health services in a given country).

However, this highlights the importance of the availability of widely recognized datasets (e.g. OpenStreetMap, WorldPop, Copernicus land cover, etc.) for automated workflows, but also highlights the limitations of global models, that need to be customized (e.g. for the travel scenarios that are different among cities or countries regions).

This successful use case is an encouragement to overcome the barriers mentioned and to further improve the workflow by adding additional interaction possibilities, possibly through other thematics and geographies to confront the diversity of realities as much as possible.

# Declarations

### Acknowledgements

The authors would like to acknowledge the European Commission "Horizon 2020" that funded the GEOSS Platform Plus project (Grant Agreement no. 101039118) and the European Space Agency (ESA).

### Author contributions: CRediT

YG: Conceptualization, Methodology, Formal analysis, Writing–original draft, Writing - Review & Editing, Visualization. NR: Writing - Review & Editing, Supervision. PL: Writing - Review & Editing, Resources. FM: Software, Resources, Visualization. PT: Software, Resources, data curation. MS: Software, Resources. PM: Resources. GG: Conceptualization, Methodology, Formal analysis, Writing - Review & Editing, Supervision, Project administration, Funding acquisition.

### Funding sources

European Commission "Horizon 2020"; GEOSS Platform Plus project (Grant Agreement no. 101039118).

### Data availability statements

All data supporting the findings of this work are freely and openly available through the URLs indicated in the paper.

### Disclosure statement

No potential conflict of interest was reported by the author(s).

# References

1. Ray, N. and S. Ebener, *AccessMod 3.0: computing geographic coverage and accessibility to health care services using anisotropic movement of patients*. International journal of health geographics, 2008. 7(1): p. 63.
2. Organization, W.H., *Assessing the value of urban green and blue spaces for health and well-being*. 2023, World Health Organization. Regional Office for Europe.
3. Giuliani, G., et al., *Modelling Accessibility to Urban Green Areas Using Open Earth Observations Data: A Novel Approach to Support the Urban SDG in Four European Cities*. Remote Sensing, 2021. 13(3): p. 422.
4. Wigley, A.S., et al., *Measuring the availability and geographical accessibility of maternal health services across sub-Saharan Africa*. BMC Medicine, 2020. 18(1): p. 237.
5. Sy, Z., et al., *Optimization of the emergency obstetric and neonatal care network in Benin through expert-based sub-national prioritizations*. Frontiers in Global Women's Health, 2024. 5.
6. Macharia, P.M., et al., *Measuring geographic access to emergency obstetric care: a comparison of travel time estimates modelled using Google Maps Directions API and AccessMod in three Nigerian conurbations*. Geospatial Health, 2024. 19(1).

7. Banke-Thomas, A., et al., *Inequalities in geographical access to emergency obstetric and newborn care*. Bull World Health Organ, 2024. 102(11): p. 837–839.
8. Ouma, P., et al., *Methods of measuring spatial accessibility to health care in Uganda*, in *Practicing health geography: The african context*. 2021, Springer. p. 77–90.
9. Joseph, N.K., et al., *Spatial access inequities and childhood immunisation uptake in Kenya*. BMC Public Health, 2020. 20(1): p. 1407.
10. Ochoa, C., et al., *Vulnerability to snakebite envenoming and access to healthcare in the Terai region of Nepal: a geospatial analysis*. The Lancet Regional Health - Southeast Asia, 2023. 9: p. 100103.
11. Macharia, P.M., et al., *Modelling geographic access and school catchment areas across public primary schools to support subnational planning in Kenya*. Children's Geographies, 2023. 21(5): p. 832–848.
12. Simonin, V., et al., *Present and Future Drinking Water Security and Its Impacts on Maternities: A Multi-Scale Assessment of Sudan. LID – 10.3390/ijerph20032204 [doi] LID – 2204.* (1660–4601 (Electronic)).
13. Hierink, F., et al., *Modelling geographical accessibility to support disaster response and rehabilitation of a healthcare system: an impact analysis of Cyclones Idai and Kenneth in Mozambique*. BMJ Open, 2020. 10(11): p. e039138.
14. Chênes, C., G. Giuliani, and N. Ray, *Modelling physical accessibility to public green spaces in Switzerland to support the SDG11*. Geomatics, 2021. 1(4): p. 383–398.
15. Organization, W.H., *Ending preventable maternal mortality (EPMM): a renewed focus for improving maternal and newborn health and well-being*, in *Ending preventable maternal mortality (EPMM): a renewed focus for improving maternal and newborn health and well-being*. 2021.
16. Hierink, F., et al., *Differences between gridded population data impact measures of geographic access to healthcare in sub-Saharan Africa*. Communications Medicine, 2022. 2(1): p. 117.
17. Timoner, P., et al., *inAccessMod: An R package to automate data downloading and processing for AccessMod*. Journal of Open Source Software, 2024. 9(93): p. 5879.
18. Edwin, N.M., *Software frameworks, architectural and design patterns*. Journal of Software Engineering and Applications, 2014. 7(8): p. 670–678.
19. Giuliani, G., et al., *Knowledge generation using satellite earth observations to support sustainable development goals (SDG): A use case on Land degradation*. International Journal of Applied Earth Observation and Geoinformation, 2020. 88: p. 102068.
20. Santoro, M., P. Mazzetti, and S. Nativi *The VLab Framework: An Orchestrator Component to Support Data to Knowledge Transition*. Remote Sensing, 2020. 12, DOI: 10.3390/rs12111795.
21. *GEO* Knowledge *Hub*. Available from: https://gkhub.earthobservations.org/
22. Runfola, D., et al., *geoBoundaries: A global database of political administrative boundaries*. PLOS ONE, 2020. 15(4): p. e0231866.
23. USGS. *Shuttle Radar Topography Mission*. 2010 [cited 2014 2014-11-15]; Available from: http://srtm.usgs.gov/.
24. Tatem, A.J., *WorldPop, open data for spatial demography*. Scientific data, 2017. 4(1): p. 1–4.

25. ESRI, *World Urban Areas dataset*, ESRI, Editor. 2021, ESRI.
26. Tobler, W., *Three presentations on geographical analysis and modeling: Non-isotropic geographic modeling; speculations on the geometry of geography; and global spatial analysis (93 – 1).* 1993.
27. Austin, C. *Bike calculator*. 2012 [cited 2025; Available from: www.BikeCalculator.com
28. Ceola, S., et al., *Virtual laboratories: new opportunities for collaborative water science*. Hydrol. Earth Syst. Sci., 2015. 19(4): p. 2101–2117.
29. Nativi, S., P. Mazzetti, and M. Santoro. *FROM DATA TO KNOWLEDGE: THE VIRTUAL LABORATORY*. in *CONFERENCE PROCEEDINGS OF THE CNR-INSTITUTE OF ATMOSPHERIC POLLUTION RESEARCH*. 2018.
30. Ahmed, M., R. Seraj, and S.M. Islam *The k-means Algorithm: A Comprehensive Survey and Performance Evaluation*. Electronics, 2020. 9, DOI: 10.3390/electronics9081295.
31. Buchhorn, M., et al. *Copernicus Global Land Cover Layers—Collection 2*. Remote Sensing, 2020. 12, DOI: 10.3390/rs12061044.
32. Haklay, M. and P. Weber, *Openstreetmap: User-generated street maps*. IEEE Pervasive computing, 2008. 7(4): p. 12–18.

## Footnotes

[1] https://github.com/unige-geohealth/accessmod

[2] https://www.accessmod.org/

[3] https://github.com/ptimoner/AMRemote/tree/main

[4] https://github.com/unige-geohealth/inAccessMod

[5] https://github.com/unige-geohealth/inAccessMod/blob/main/vignettes/Tutorial.Rmd

[6] https://land.copernicus.eu/

[7] https://www.openstreetmap.org/

[8] https://www.openstreetmap.org/

[9] https://www.openstreetmap.org/

[10] https://github.com/unige-geohealth/accessmod/releases

[11] https://github.com/ptimoner/AMRemote/tree/main

[12] https://vlab.geodab.org/

[13] https://essilab.atlassian.net/wiki/spaces/VTD/overview

[14] https://gkhub.earthobservations.org/

[15] https://github.com/unige-geohealth/accessmod_gpp

[16] https://github.com/unige-geohealth/accessmod_gpp/blob/main/01_get_data/main.R

[17] https://github.com/unige-geohealth/inAccessMod/tree/main/R

[18] https://github.com/unige-geohealth/accessmod_gpp/blob/main/03_create_start_points/get_osm_data.R

[19] https://github.com/unige-geohealth/accessmod_gpp/blob/main/04_travel_time/project_create.R

[20] https://github.com/unige-geohealth/accessmod_gpp/blob/main/04_travel_time/travel_time.R

[21] https://essilab.atlassian.net/wiki/spaces/VLAB/pages/5701839/Publish+a+model+from+a+Git+repository

[22] https://github.com/unige-geohealth/accessmod_gpp

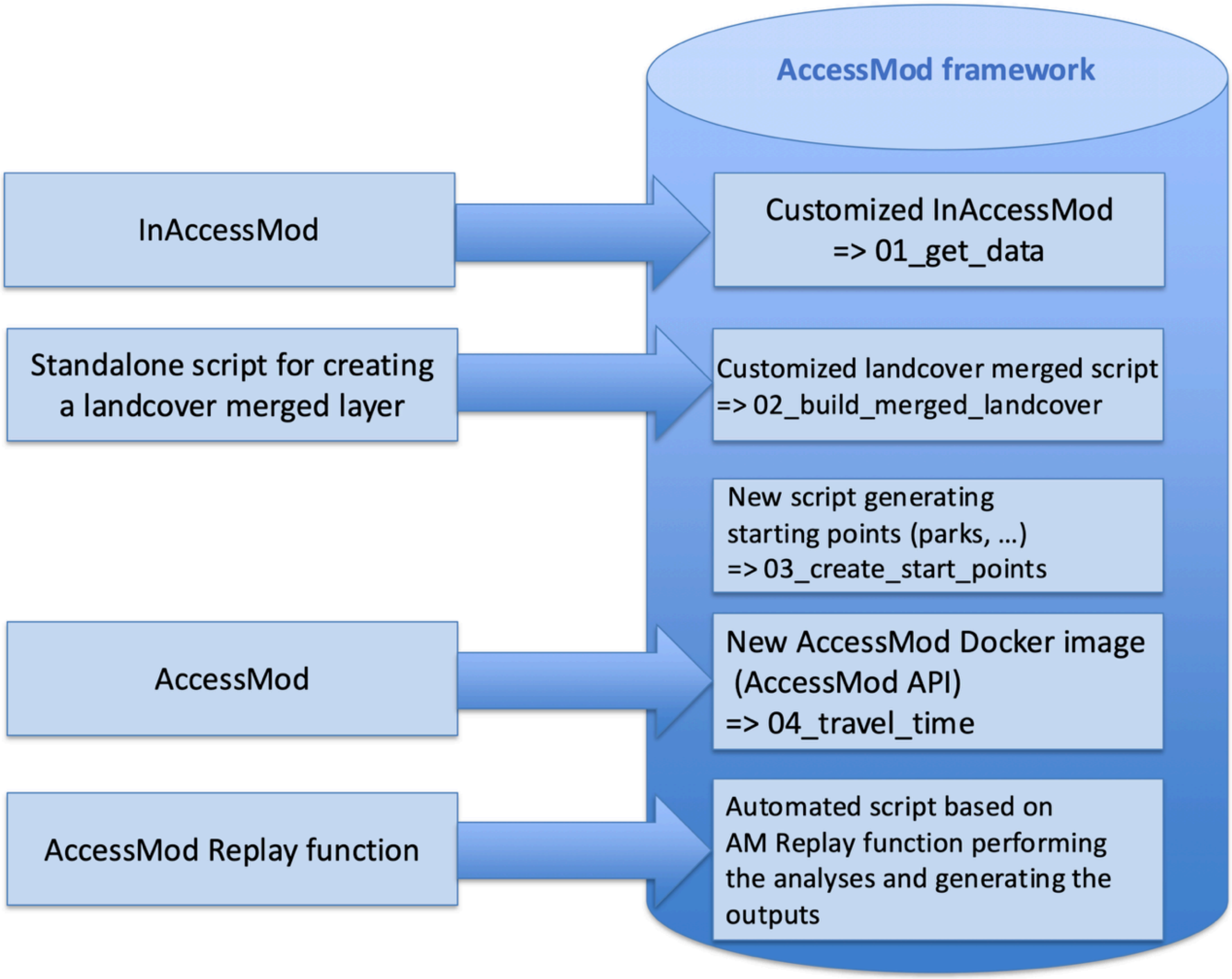
[23] https://vlab.geodab.org/workflows

[24] https://gpp.uat.esaportal.eu/

[25] https://github.com/unige-geohealth/accessmod_gpp/blob/main/assets/scenario_default.json

[26] https://accessmod.mapx.org/get_list_locations

# Figures




## Figure 1

summary of the assemblage of existing software components into a single framework

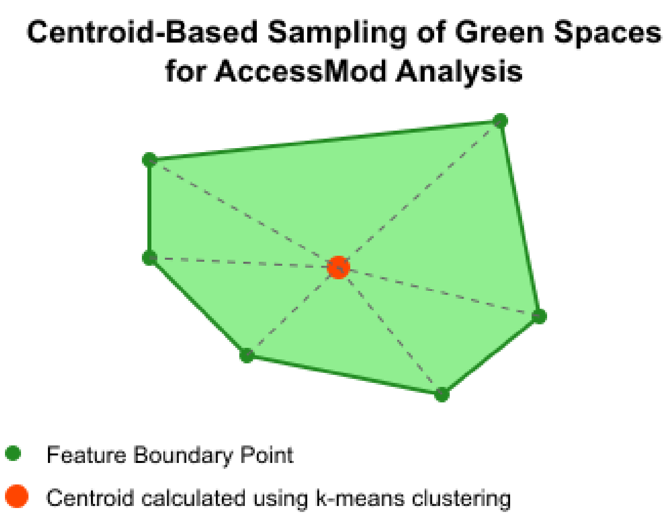


**Figure 2**

features' centroids creation for use as accessibility starting points

```
Enter the city name (default is Geneva): Yerevan
Do you want to develop? (y/N): n
[ City Yerevan ]
[ Dev mode false ]
Select the part to load:
1) 01_get_data
2) 02_build_merged_landcover
3) 03_create_start_points
4) 04_travel_time
5) Exit
Enter your choice [1-5]:
```

**Figure 3**

basic screen of the ./start.sh script of the AccessMod frameworkapplication

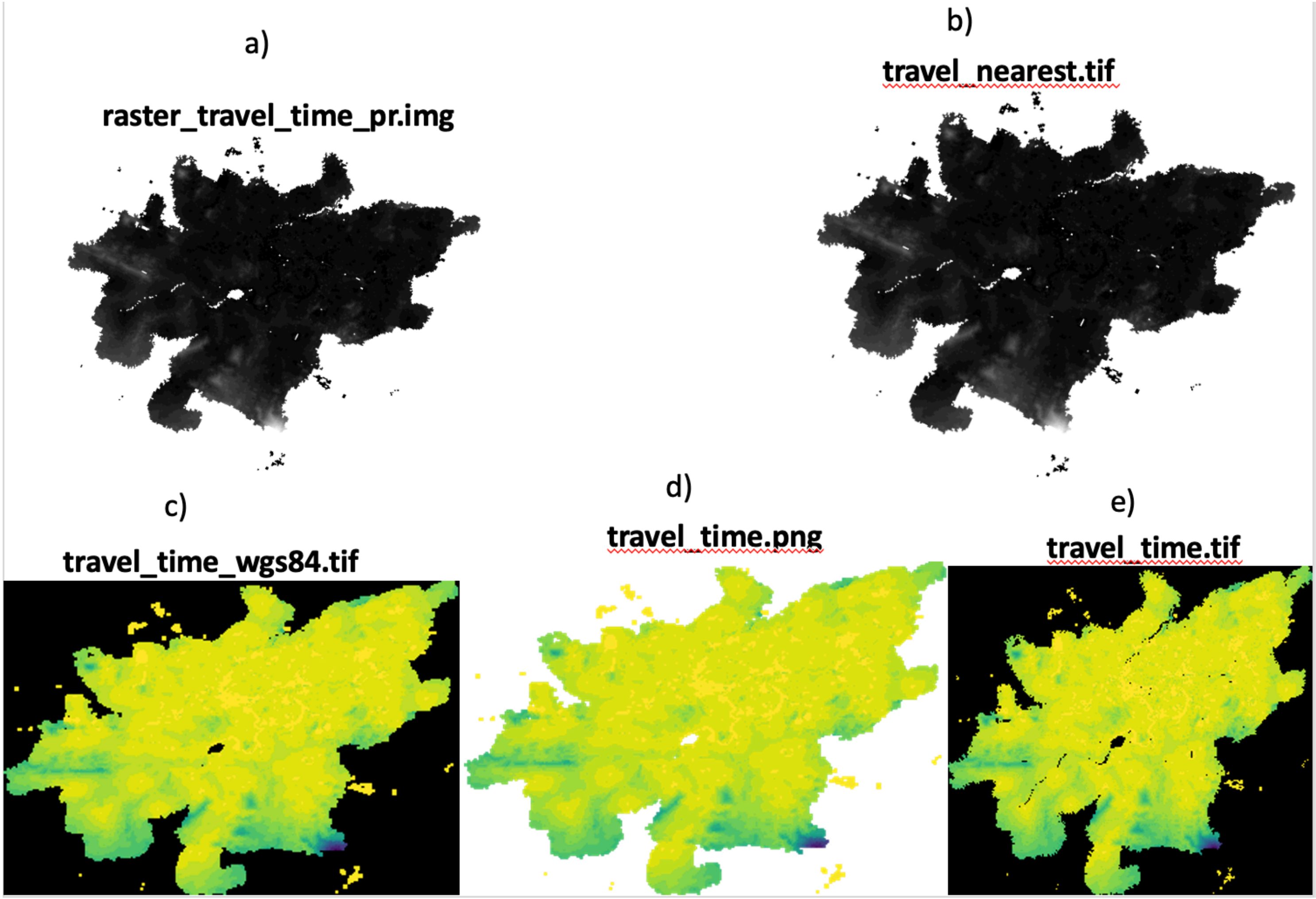
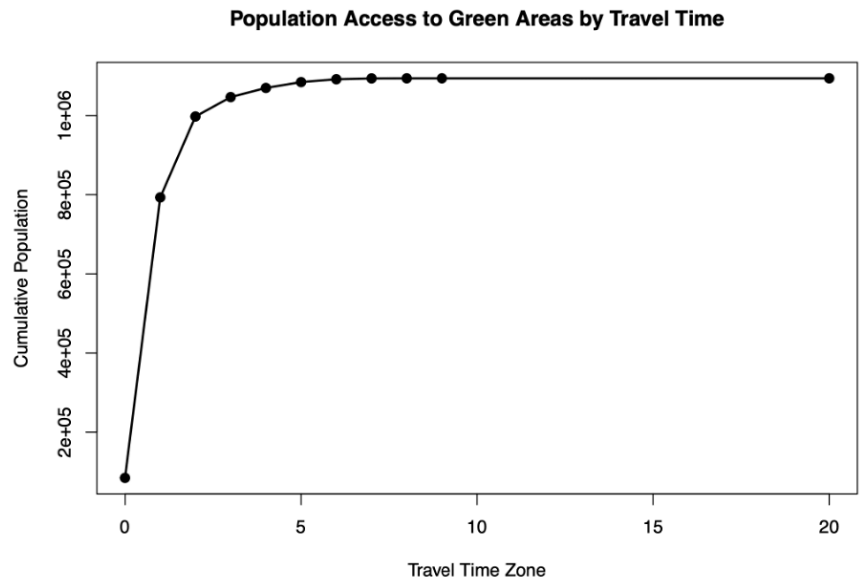



**Figure 4**

Various formats of the resulting travel time raster: a) and b) showing respectively .img and .tif black and white versions of the travel time (minutes) from each cell to the nearest point; c), d) and e) showing the same information in colored version but in .png format (d) or in .tif format non-projected (c) or projected (e) pop_vs_traveltime

| | zone | sum | cumSum |
|---|---|---|---|
| 1 | 0 | 84544.3594427109 | 84544.3594427109 |
| 2 | 1 | 708687.320531607 | 793231.679974318 |
| 3 | 2 | 204373.179625273 | 997604.859599591 |
| 4 | 3 | 49006.9450275898 | 1046611.80462718 |
| 5 | 4 | 23136.3408370018 | 1069748.14546418 |
| 6 | 5 | 14807.7286586761 | 1084555.87412286 |
| 7 | 6 | 7205.11797714233 | 1091760.9921 |
| 8 | 7 | 2108.56631231308 | 1093869.55841231 |
| 9 | 8 | 178.237766265869 | 1094047.79617858 |
| 10 | 9 | 13.7744045257568 | 1094061.57058311 |
| 21 | 20 | 24.2645244598389 | 1094085.83510757 |




## Figure 5

the population coverage having access to green areas in a given city by travel time (minutes). In the table, the “zone” column corresponds to the number of minutes; the “sum” column corresponds to the population number covered in the given time (zone); the “cumSum” column shows the addition of population covered for each time (zone) threshold. The graph is a visual representation of this same information.

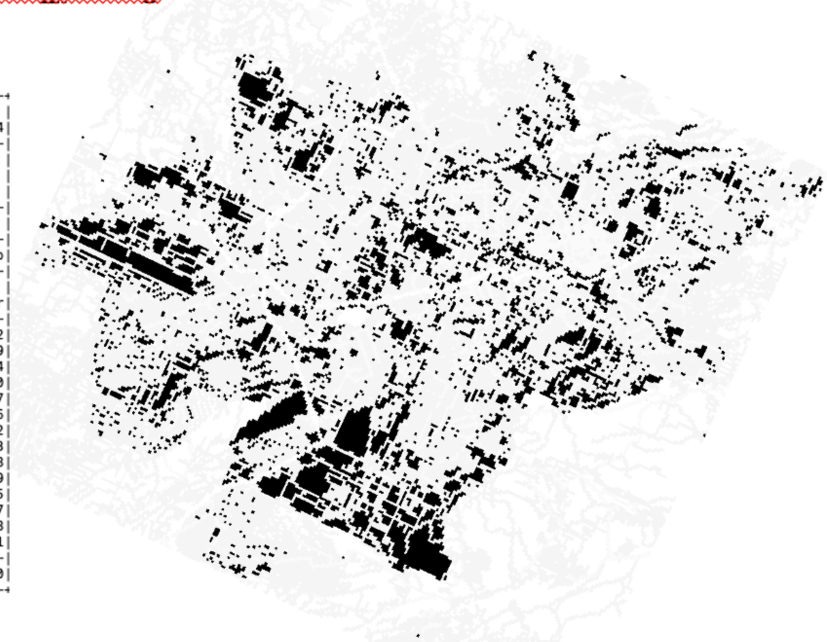
**raster_cost_allocation_pr.img**

**Figure 6**

the raster cost allocation layer

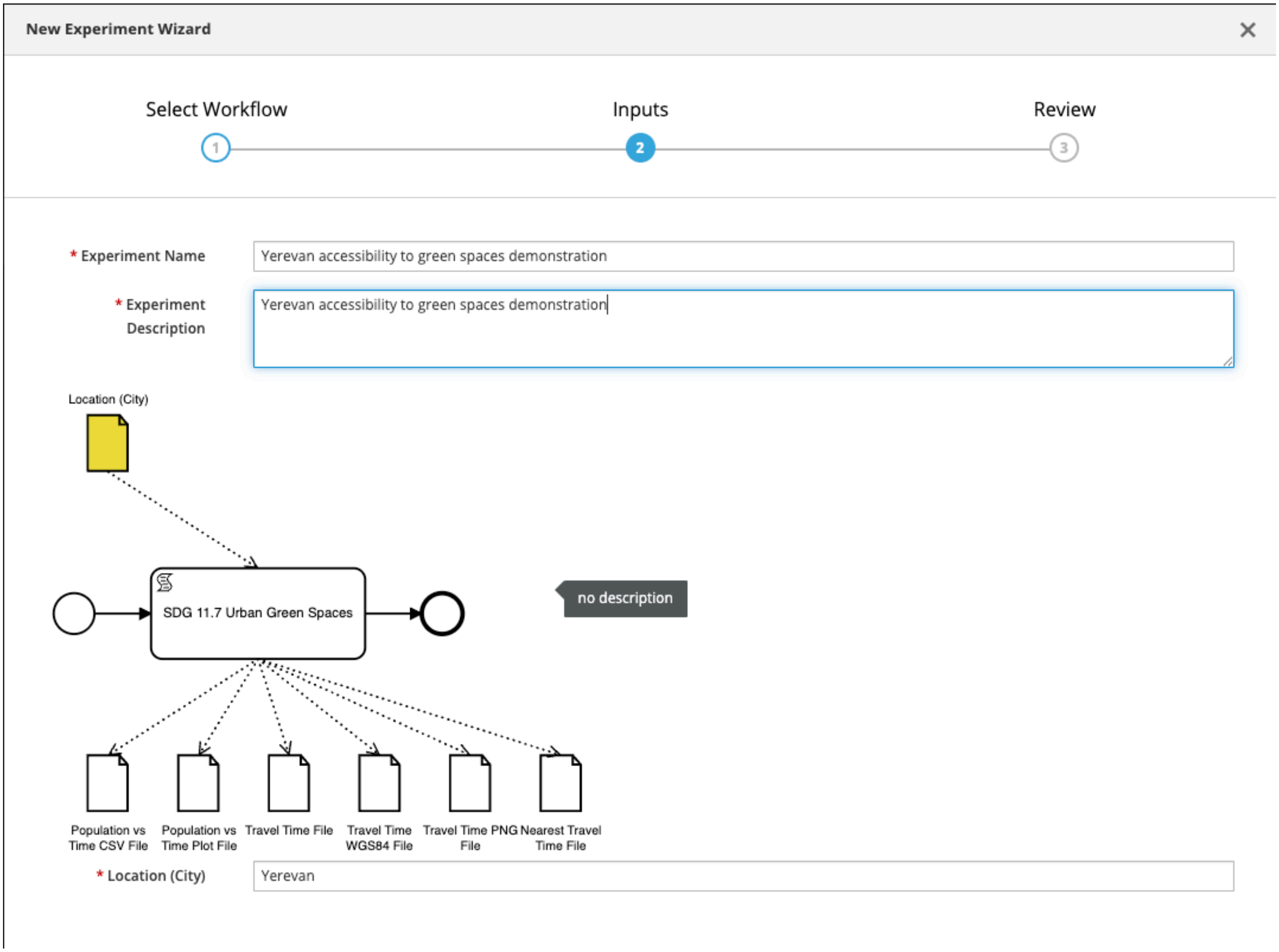
## raster_speed_pr.img

```
+----------------------------------------------------------------------------+
|                        RASTER MAP CATEGORY REPORT                          |
|LOCATION: project_gpp_Geneva                        Mon Aug 19 15:38:19 2024|
|----------------------------------------------------------------------------|
|          north: 5124711.40462896    east: 284909.77843155                 |
|REGION     south: 5115457.14104188    west:  274774.1564076                 |
|           res:        73.44653641    res:       73.44653641               |
|----------------------------------------------------------------------------|
|MASK: none                                                                  |
|----------------------------------------------------------------------------|
|MAP: Reclass of rLandCoverMerged__pr in project_gpp_Geneva (rSpeed__pr in pro|
|----------------------------------------------------------------------------|
|                   Category Information                      |  square  |  % |
|      #|description                                          |kilometers| cover|
|----------------------------------------------------------------------------|
|1002000|WALKING:2. . . . . . . . . . . . . . . . . . . . . . |  4.142894|  4.42|
|1003000|WALKING:3. . . . . . . . . . . . . . . . . . . . . . |  0.647327|  0.69|
|1004000|WALKING:4. . . . . . . . . . . . . . . . . . . . . . |  4.822588|  5.14|
|1005000|WALKING:5. . . . . . . . . . . . . . . . . . . . . . |  4.784827|  5.10|
|2005000|BICYCLING:5. . . . . . . . . . . . . . . . . . . . . |  0.161832|  0.17|
|3020000|MOTORIZED:20 . . . . . . . . . . . . . . . . . . . . |  7.838054|  8.36|
|3030000|MOTORIZED:30 . . . . . . . . . . . . . . . . . . . . | 37.631291| 40.12|
|3040000|MOTORIZED:40 . . . . . . . . . . . . . . . . . . . . |  5.184012|  5.53|
|3050000|MOTORIZED:50 . . . . . . . . . . . . . . . . . . . . |  9.267568|  9.88|
|3060000|MOTORIZED:60 . . . . . . . . . . . . . . . . . . . . |  0.933230|  0.99|
|3070000|MOTORIZED:70 . . . . . . . . . . . . . . . . . . . . |  0.512467|  0.55|
|3080000|MOTORIZED:80 . . . . . . . . . . . . . . . . . . . . |  0.253537|  0.27|
|3120000|MOTORIZED:120. . . . . . . . . . . . . . . . . . . . |  0.258931|  0.28|
|      *|no data. . . . . . . . . . . . . . . . . . . . . . . | 17.359159| 18.51|
|----------------------------------------------------------------------------|
|TOTAL                                                       | 93.797718|100.00|
+----------------------------------------------------------------------------+
```



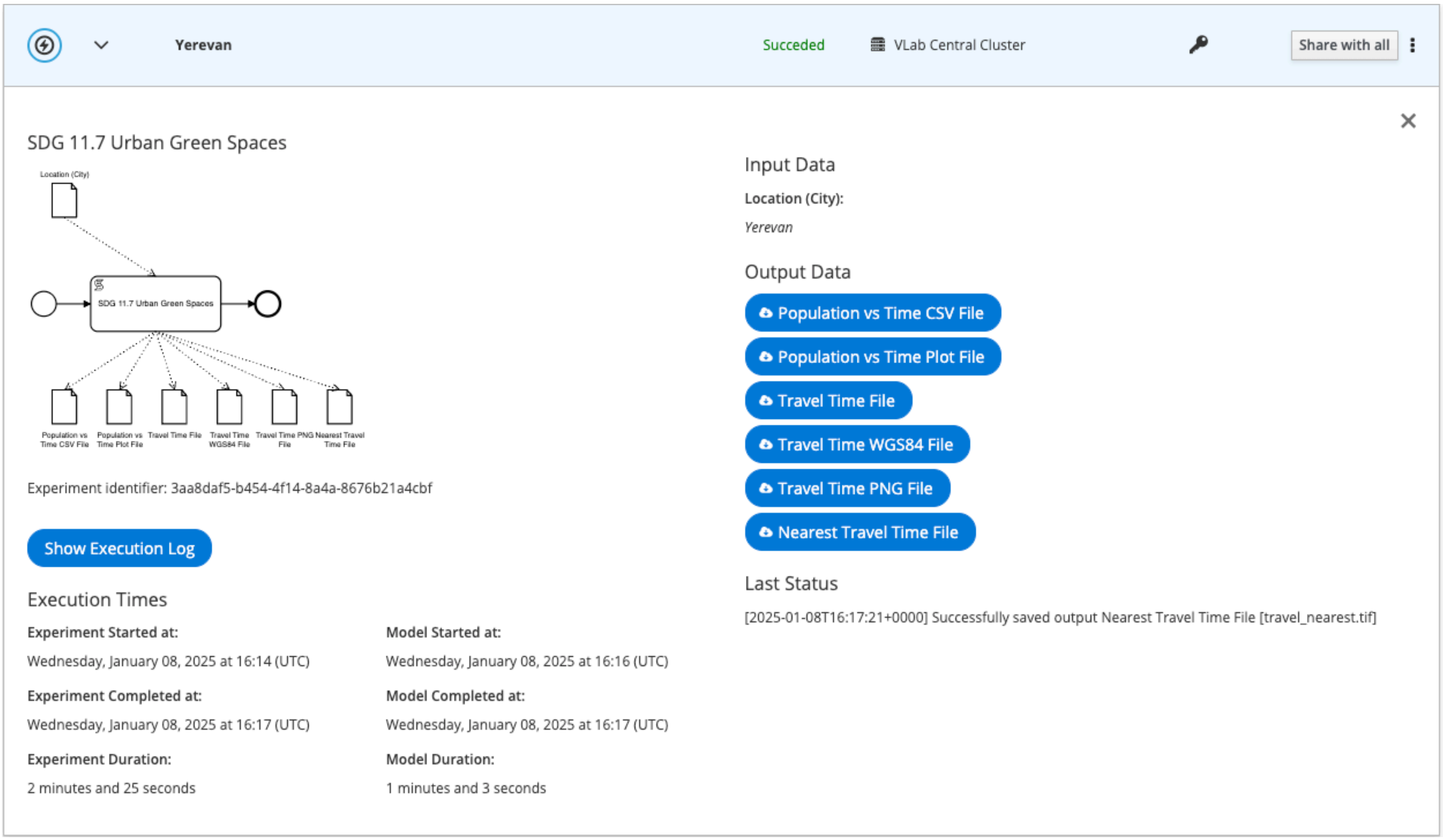
### Figure 7

the raster showing the roads categories



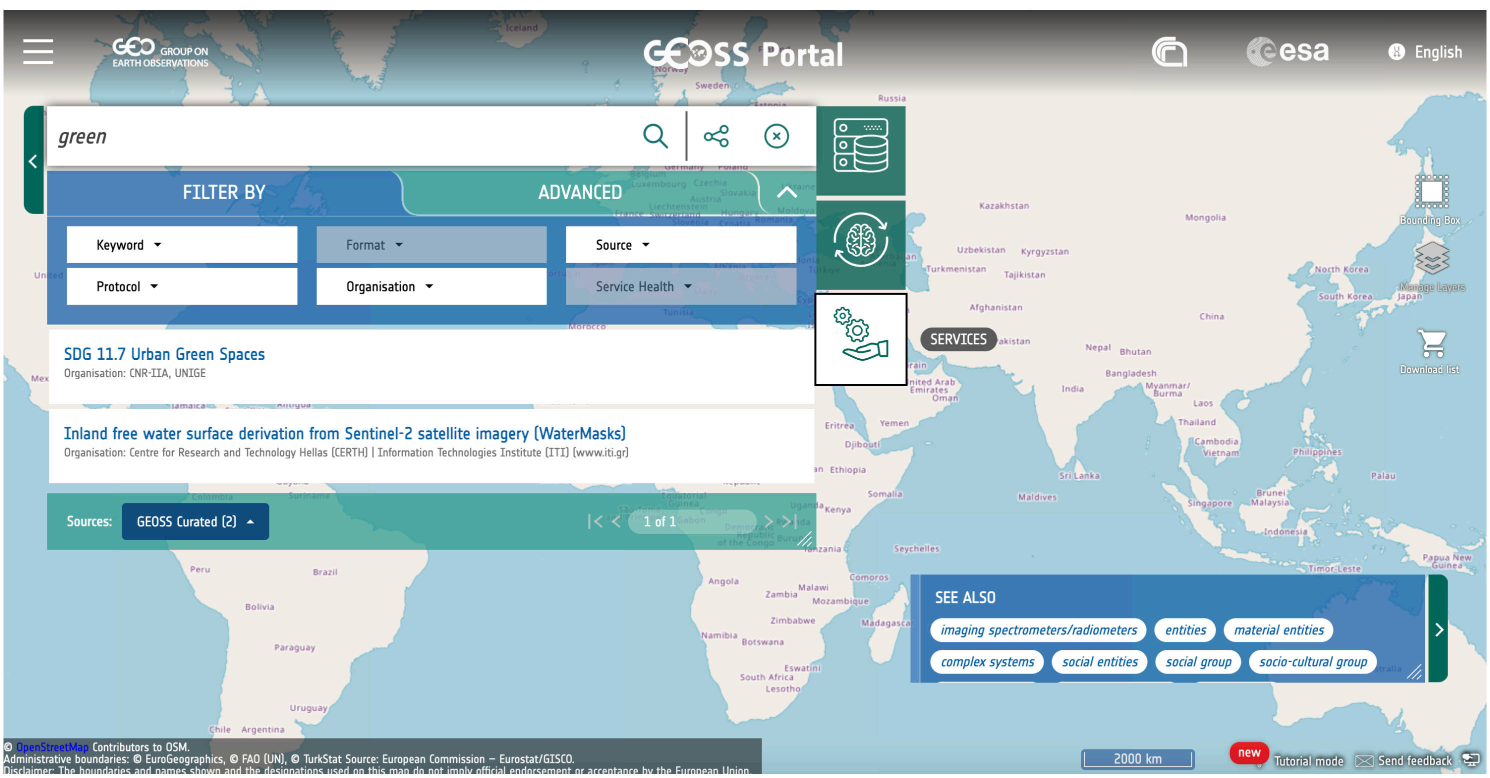

## Figure 8

Accessibility analysis launch window in the Vlab




## Figure 9

Accessibility analysis result window in the VLab




## Figure 10

The GEOSS portal interface allowing to search for the term “green” and resulting with a service “SDG11.7 Urban Green Spaces”

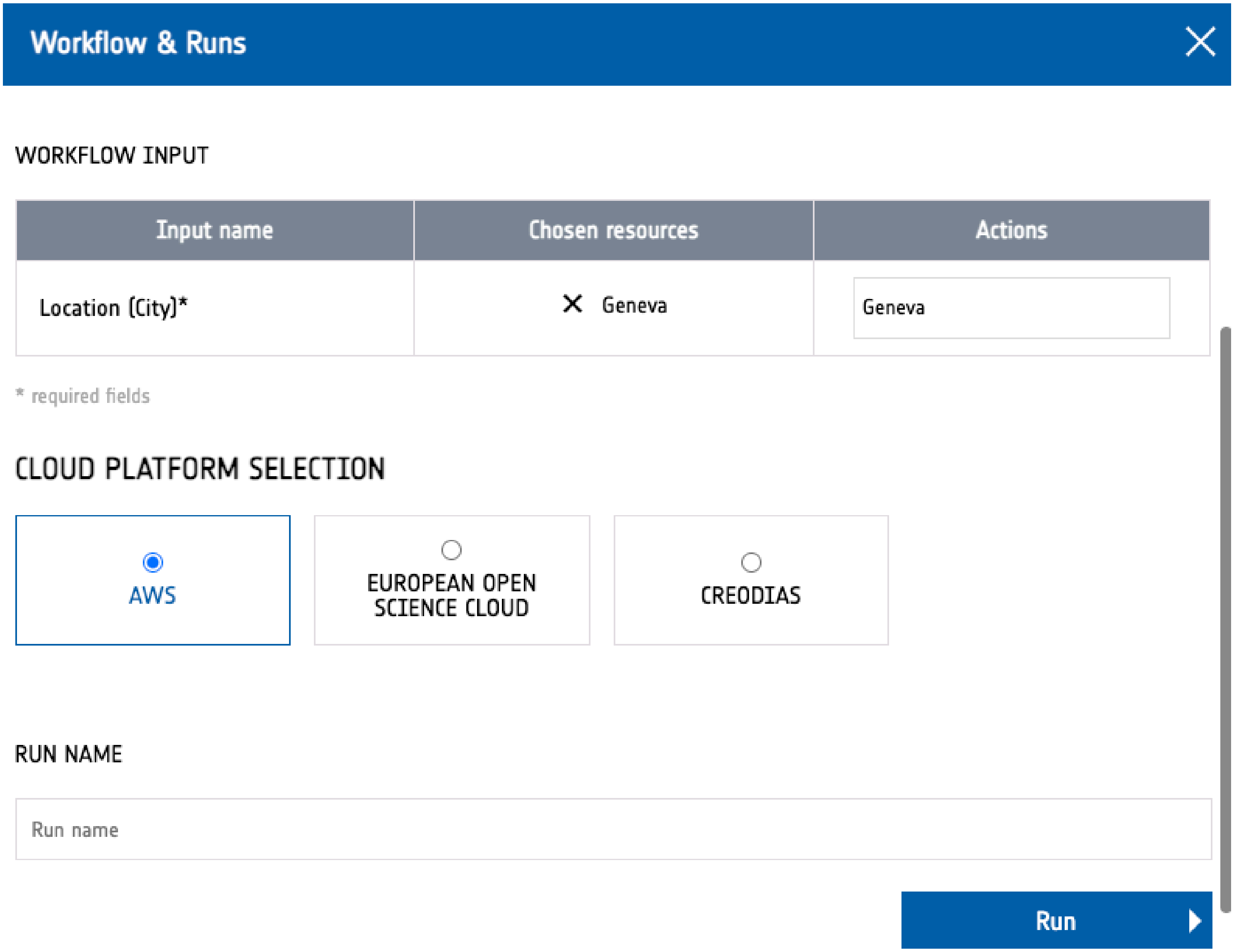



**Figure 11**

the workflow analysis launch

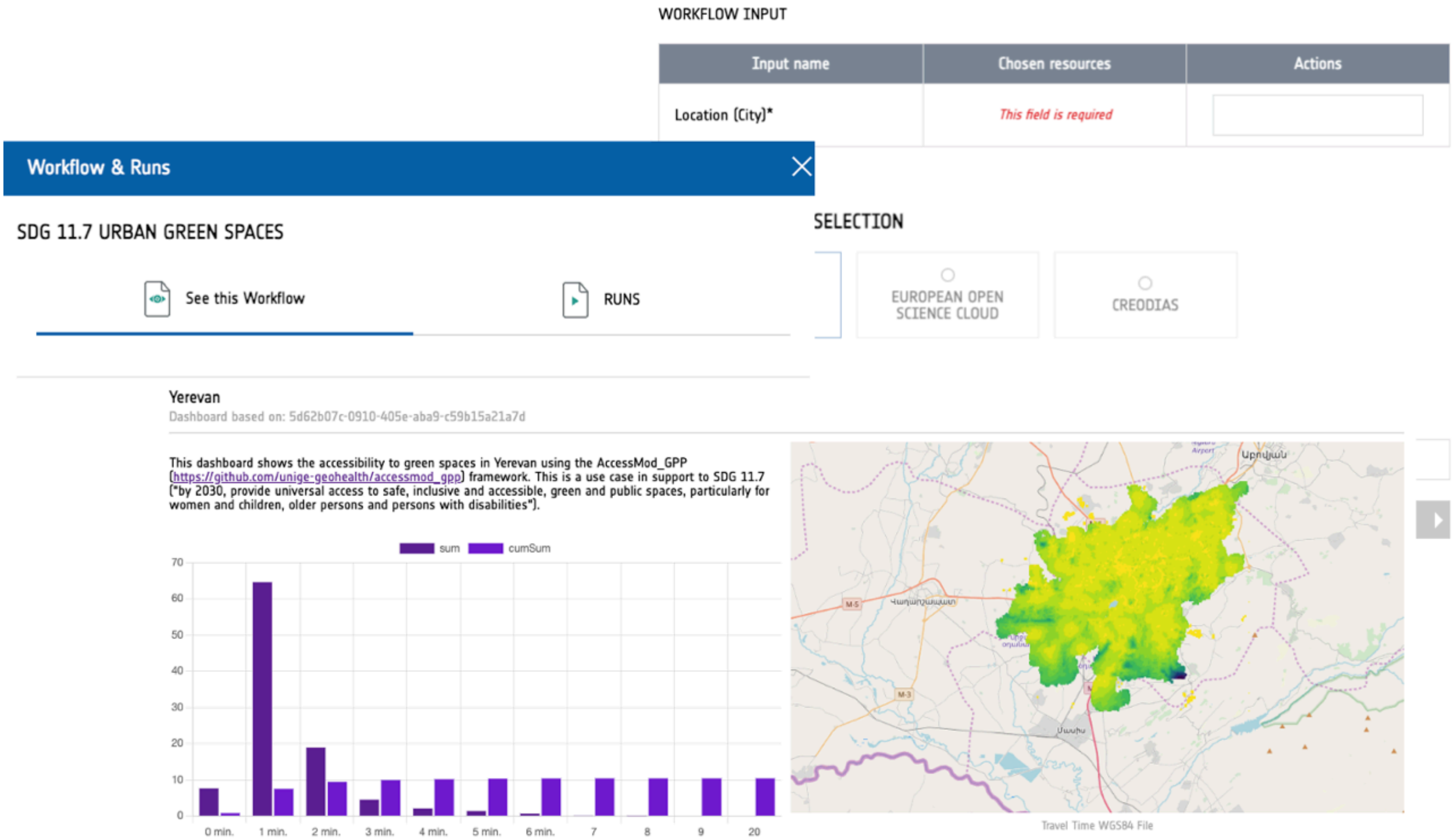
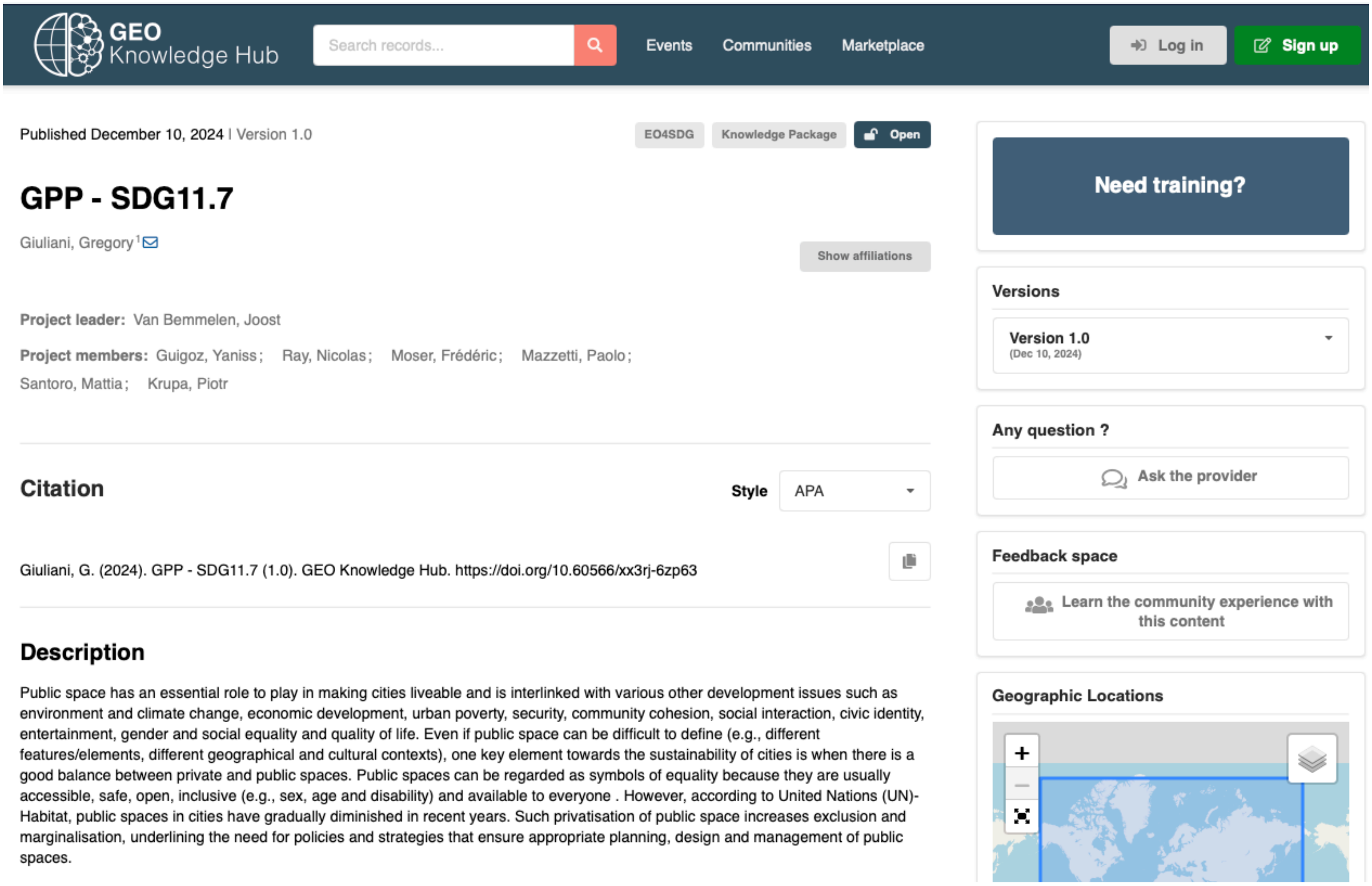



**Figure 12**

Dashboard showing the accessibility analysis result in the GEOSS platform




## Figure 13

AccessMod framework available as a knowledge package in the GEO Knowledge Hub