# Chapter 9
# Basics on Mapping Solar Radiation Gridded Data

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**Abstract** There is a lot of gridded information on meteorological variables elsewhere. Numerical weather prediction models and satellite-derived models deliver time series and aggregates of main meteorological variables with global coverage that can be finally used to create maps offering information on the spatial variability of those magnitudes. This chapter intends to give a very simple overview of mapping solar radiation data or any other gridded variable using QGIS open-source Geographic Information System.

## 1 Spatial Data and Geographic Information Systems

Spatial data is nowadays used in many disciplines of very different nature from social sciences to engineering. Basically, spatial data is information geographically referenced on some specific variables with the associated spatial reference; that is, spatial data needs to have geographic coordinates (latitude and longitude or UTM coordinates) and a system of reference. Spatial information can be found in several data types: point (single location of a city), line (border of a country), polygon (area of a country) and grid (rectangular matrix of points). Points, lines and polygons are denoted as vector data, and the gridded information is named raster data. Systems of reference are structures used to define unique positions in the space. The coordinate system that is most commonly used to define locations on the three-dimensional earth is called the geographic coordinate system (GCS), and it is based on a sphere or spheroid. Locations in the GCS are defined by their respective latitude and

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longitude within the GCS. One of the most used systems of reference is the WGS84 projection (World Geodetic Survey 1984) which uses the centre of the earth as the origin of the GCS and is used for defining locations across the globe.

Spatial data is conveniently exploited through the Geographic Information Systems (GIS). A GIS is a collection of computer tools for visualization, handling, processing and analysis of spatial data. GIS can be presented in a commercial or free software tool, or as a toolbox (collection of functions and methods) in programming packages frequently used in engineering like MATLAB®, R or Phyton (Bivand et al. 2008; Trauth 2010). The latter is the case of the Mapping Toolbox of MATLAB®, the sp package in R or the GeoPandas package in Python.

The most well-known commercial GIS software is probably ArcGIS, professional software containing the state of the art in geographic information systems (https://www.arcgis.com/index.html). Nevertheless, there is open-source alternative software that can be useful for many applications. One of the most widely used is QGIS (https://qgis.org/es/site/), whose community is actively and continuously developing new features and updating the program. QGIS was developed as a project of the Open Source Geospatial Foundation (OSGeo), a non-profit organization for fostering and supporting broader open geospatial technologies (https://www.osgeo.org/). Figure 1 shows the QGIS 3.2 Desktop.

Very basically the spatial data is presented in a GIS as a set of layers. Each layer can be a vector or a raster layer, and the GIS software usually provides specific methods that operate with vector or with raster layers. A GIS is able to show in one single map multiple layers of information. This requires that all the layers use the same system of reference in order to be visualized together. In addition, there are also methods for data restructuration and conversion into different formats, such as raster-to-vector translation. The layer has also attributes and metadata associated.

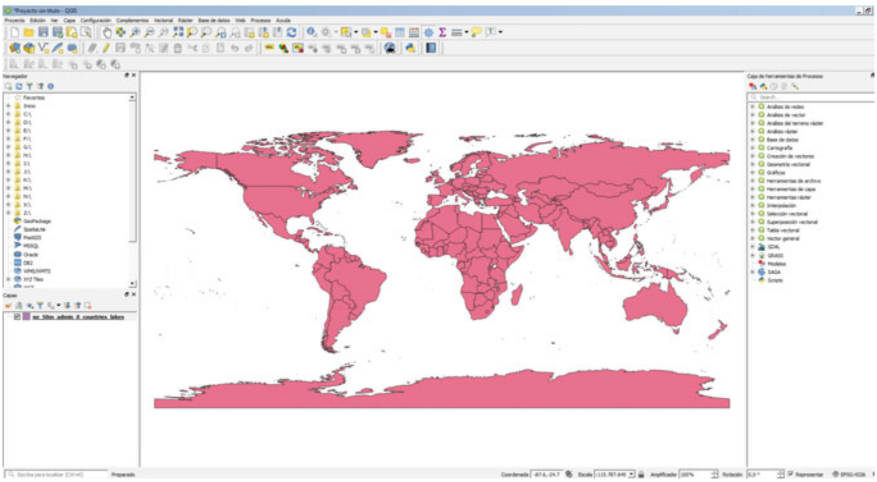

**Fig. 1** QGIS Bonn desktop

Every analysis, visualization or mapping activity to be done in a GIS requires of the availability of several basic spatial data (world, countries borders, coastline, etc.) that usually act as a background layer or map. There is a lot of free available spatial data on the Internet that can be used for mapping gridded solar radiation and other meteorological gridded data. Natural Earth is a good example of public domain with vector and raster data for being used with GIS software (https://www.naturalearthdata.com/). Data themes are available at three levels of detail (scales 1:10, 1:50 and 1:110 m).

## 1.1 Shapefiles

The shapefile is very common and widely used format for vector data that was developed by Esri (ESRI 1998). A shapefile consists actually of three files with the extension .shp, .shx and.dbf. The first one stores the geometry of the digital features as a set of vector coordinates. The second one contains an index for allowing quick access to the spatial features. The third required file stores attribute data. All of them must present in the same folder in order to be usable by a GIS. For instance, Natural Earth is a public domain offering free shapefiles of the countries, boundary lines, coastlines and polygons of the world with at least first-order administrative attributes (names of countries, provinces, states, etc.) that can be very useful in mapping gridded information. Figure 2 shows several shapefiles (administrative level 1, roads and water areas and labels on provinces) of east Spain obtained from the DIVA-GIS free spatial data repository (http://diva-gis.org/Data). This figure was created with QGIS 3.2 loading three shapefiles and selecting the attributes to be shown of each layer. GADM is also a free repository with spatial data for all countries and their subdivisions (https://gadm.org/).

Shapefiles can contain also polygons that represent specific geographic areas that share a common characteristic not only countries boundaries and regions. For instance, Fig. 3 shows an updated version of the Köppen–Geiger climatic zones attending exclusively to precipitation criterion (Peel et al. 2007). In addition, QGIS can be used to convert categorized raster information (land cover classification) into shapefile.

## 1.2 Raster Data

Raster data is information on a specific feature represented as a rectangular surface divided into a regular grid of cells. In a raster file, every cell or pixel is associated with a particular latitude and longitude. Therefore, raster data is made up of pixels (also referred to as grid cells) and although they are usually regularly spaced and square, they can also be irregular. Satellite image and satellite-derived meteorological information are the most typical examples of raster spatial data. Raster files


**Fig. 2** Illustration of basic vector data

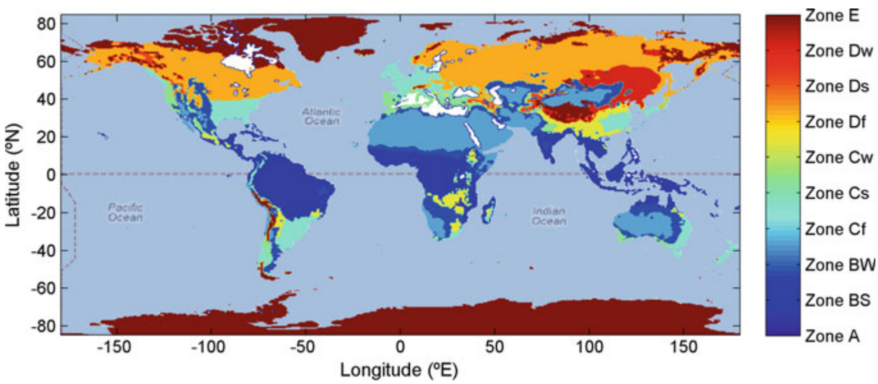


**Fig. 3** Köppen–Geiger climatic zones considering only precipitation

contain basically a 2D matrix of data, and thus, map algebra can be easily performed with any raster file in most of the GIS tools. Raster data may be discrete data as occurs in land-use maps or continuous data as elevation maps (DEM—digital elevation map). QGIS uses the GDAL library to read and write raster data formats and is compatible with most common raster formats (ArcInfo ASCII, GeoTIFF, EDRAS, etc.).

Typical raster datasets include remote sensing data, such as aerial photography or satellite imagery data. Unlike vector data, raster data is geocoded by pixel resolution and the x/y-coordinate of a corner pixel of the raster layer. This allows QGIS or any other GIS to position the data correctly in the map canvas. Figure 4 shows an image of the elevation map of Spain from the raster information available from DIVA-GIS website.

QGIS includes most of the common methods for raster data incorporating procedures from GDAL, GRASS and SAGA libraries. In mapping solar radiation and in particular solar potential, it is required frequently to deal with the slope of the terrain. Loading a DEM raster in QGIS, the slope can be estimated directly by the slope process of GDAL or *r.slope* method in GRASS. In solar potential, estimation is very common to establish a threshold for the slope that makes null the solar potential; one of the most widely used criteria of slope considers that terrains with a slope beyond 3% are not available for solar power deployment (Navarro et al. 2016). The estimation of the slope can be used to generate a raster mask or exclusion layer that multiplies the raster of solar irradiation to generate the corresponding solar potential. A raster mask or exclusion layer is a raster of the same size and resolution than the target which contains only 1 or 0 values according to the exclusion criteria specified. Figure 5 illustrates the process of generating an exclusion map for the slope criteria of the 3% used in the determination of the solar potential for Vietnam (Polo et al. 2015a, b). Different exclusion criteria are used depending on the solar power technology for determining the availability of a geographic area for deployment solar energy systems (Omitaomu et al. 2012; Martín-Chivelet 2016). Every exclusion criteria can be determined by binary exclusion masks that result in the final solar potential map using raster algebra.

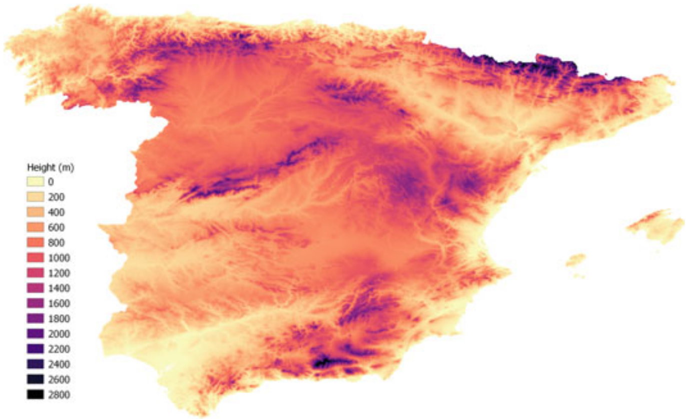


**Fig. 4** Elevation map of Spain

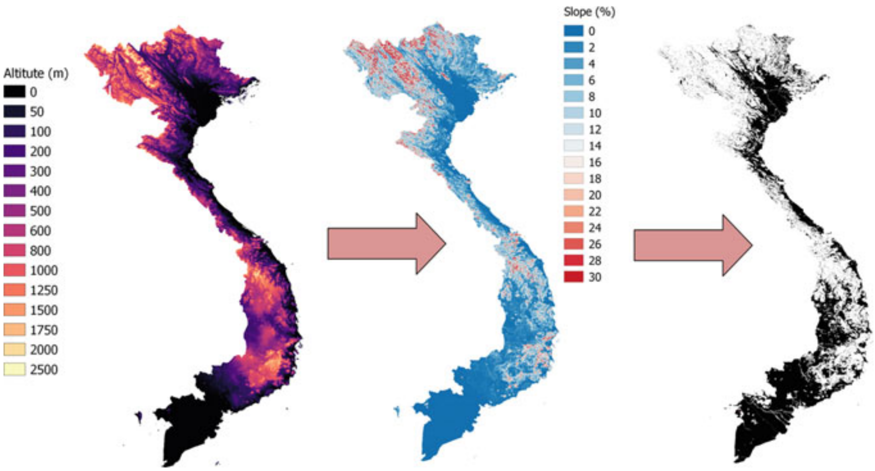


**Fig. 5** Process for the slope exclusion mask; left, elevation map; middle, slope map; right, exclusion mask

## 2 Simple Exercise of Solar Radiation Mapping

In this section, a simple step-by-step procedure for creating a solar radiation map with QGIS is described. Let us start with the rectangular raster data, a regular matrix of daily mean solar global irradiation for the month of February derived from Meteosat satellite imagery from 10 years. The matrix consists of 300 columns and 150 rows of data that represent the domain covering −10–5°E longitude and 35–44°N latitude at a spatial resolution of 0.05° (Polo 2015).

The raster data is stored in an ASCII file in the ESRI ASCII format which allows a very easy handling a transformation of the data. ESRI ASCII format is basically a matrix of data in ASCII file with a header as follows:

NCOLS 300
NROWS 180
XLLCORNER-10
YLLCORNER 35
CELLSIZE 0.05
NODATA_VALUE-9999.

The header gives information on the number of rows and columns of the matrix, the spatial resolution, the geographic coordinates of the lower left corner and the flag used in those cells where there is no data.

The second step is to download the geographic boundary of the region that is going to be mapped. In this case, the Iberian Peninsula and Balearic Islands can be obtained from Natural Earth free spatial data as a shapefile.

Finally, the raster must be cut to fit the boundaries of the selected region. QGIS has a method for intersecting and clipping operations with at least two layers: a raster layer and a vector layer. In QGIS Bonn version, this can be found in the *Raster/Extract/Cut* menu. Figure 6 illustrates all the process and shows the final map.

The raster data is commonly used also in Web services through what is named as geoportal. A geoportal is a Web-based geospatial resource that allows users to access geospatial information and services through the Internet. For that purpose, it is needed a Web map, a Web server for publishing the map online and a set of methods (java-script, PHP, etc.) for interacting with the map. QGIS includes a plugin for creating a Web visor map in a very straightforward way, called *qgis2map*. Figure 7 shows a very simple example of a Web map where uses *OpenStreetMap* as a background map for showing the solar radiation map of February in Spain.

There are many examples of solar radiation Web maps and services through the Internet provided by both public and private organizations. As illustrative mention of a few of them, some of the most well-known and used free services are:

- PVGIS, developed and supplied by the European Commission—Joint Research Centre (JRC), focused on the performance of the photovoltaic technology. PVGIS offers Web-based maps and information covering Europe, Africa and Asia based on Meteosat satellite imagery (http://re.jrc.ec.europa.eu/pvgis_v2.html)
- IRENA Global Atlas 3.0 is a browser that compiles Web maps from several suppliers on renewable energy resources including solar radiation data (https://irena.masdar.ac.ae/gallery/#gallery).
- National Solar Radiation Database viewer from NREL offering solar radiation maps for USA, Central America, part of South America and part of Asia (https://maps.nrel.gov/nsrdb-viewer).

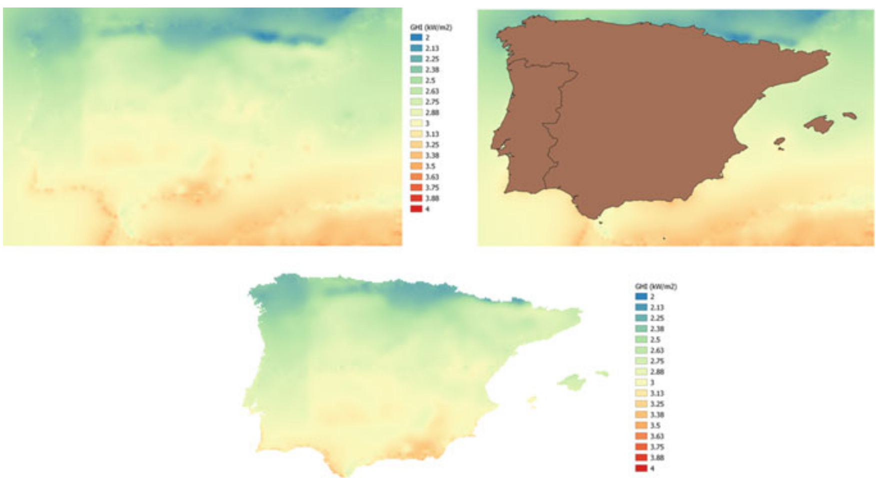

**Fig. 6** Illustration of the intersection between a regular raster of gridded data and a vector shapefile to generate a map of solar radiation


Fig. 7 Illustration of Web map visor using *OpenStreetMap* as background

– The "Solar Atlas for the Mediterranean" is a portal for global horizontal and direct normal irradiance data for the southern and eastern Mediterranean region (http://www.solar-med-atlas.org/solarmed-atlas).

## 3 Interpolating Tables of Gridded Data

In some cases, the gridded information of solar radiation data can be regularly distributed with a coarser spatial resolution or can be formed by a discrete set of points. Interpolation is then a commonly used GIS technique to create a continuous surface. Interpolation of solar radiation is described in detail in Chap. 8. Therefore, this section illustrates a few examples of interpolation of discrete points using QGIS tools.

Let us consider as an example monthly means of global solar irradiation in three Morocco regions that were derived from satellite imagery at a spatial resolution of $0.1° \times 0.1°$. The data was stored in a simple ASCII or .csv file containing three columns of data: longitude, latitude and GHI in kW m$^{-2}$. QGIS can load a layer of delimited text data that is viewed in QGIS canvas as a regular grid of discrete points. Interpolation of this regular grid can be done in QGIS using the GDAL library, which contains around twenty interpolation methods. The list can range from methods that do not perform interpolation or smoothing, like the nearest neighbour, to interpolation techniques like inverse distance weighted, ordinary or

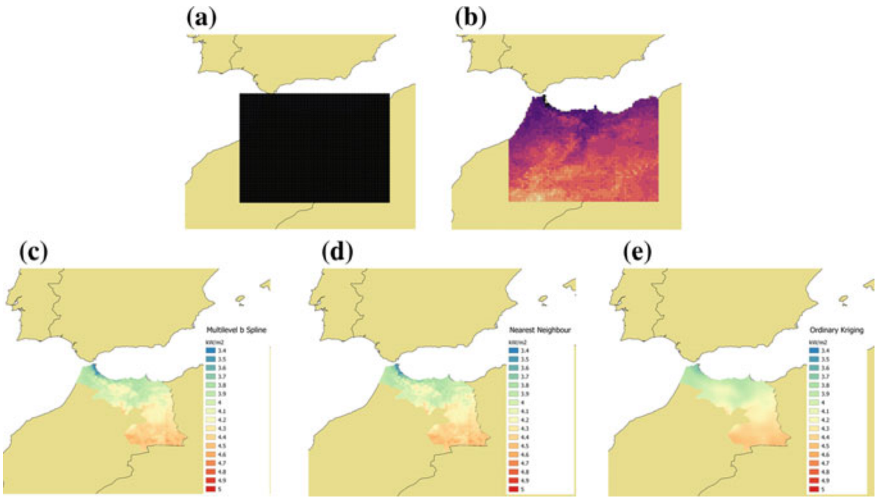


**Fig. 8** Examples of spatial interpolation of discrete points of solar radiation data. **a** Regular grid of satellite-derived discrete points, **b** regular grid of categorized discrete points, **c** Interpolation with multilevel B Spline, **d** Nearest neighbour method for creating a continuous surface, **e** Ordinary kriging interpolation

regression-kriging. Figure 8 illustrates some examples of interpolation. The choice of one or another interpolation method depends on the purpose or visualizing needs and on the characteristics of the discrete point set as well (Chelbi et al. 2015; Hofierka et al. 2017):

- Nearest neighbour consists in assigning to each cell the value of the nearest cell in the original grid; it can be used for categorical data or for classifying data.
- Spline interpolation is a method for smoothing the data, since estimate values using a mathematical function that minimizes the surface curvature among points.
- Kriging is an advanced geostatistical procedure that uses the semivariogram to express the spatial continuity (autocorrelation). The semivariogram measures the strength of the statistical correlation as a function of distance.

## 4 Sharing Geospatial Data

Nowadays, it is very common to find geospatial information that is being shared through the Internet. GeoServer (http://geoserver.org/) is an open-source code, written in Java, that allows to display and share spatial data using open standards set by the Open Geospatial Consortium (OGC). GeoServer has become an easy method to connect Web maps such as OpenLayers, Google maps or Bing Maps. There are two basic service sets—the Web Feature Services (WFS) and the Web Map Services (WMS). The WFS is concerned with direct access to data—reading, writing and updating features. The WMS is concerned with transforming your data into a map (image). QGIS versions 2.x are compatible with a plugin called GeoServer Explorer that makes rather easy to share a QGIS project or maps through GeoServer. Likewise, QGIS allows loading easily WMS and WFS services available on the Internet.

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