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GeoWeightedModel : An R-Shiny package for Geographically Weighted Models

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ABSTRACT

This paper describes GeoWeightedModel, a R package, which provides a graphical user friendly web application to perform techniques from a subarea of spatial Statistics known as Geographically Weighted (GW) models, such as Geographically Weighted Regression (GWR) and its extensions: Robust GWR, Generalized GWR, Heteroskedastic GWR, Mixed GWR, and "Scalable GWR), Geographically Weighted Principal Component Analysis, and Geographically Weighted Discriminant analysis. It also allows calculating a basic and robust Geographically weighted summary. The main goal of GeoWeightedModel package was to make the workflow easier to use, especially for those who are not familiar with the R environment. With GeoWeightedModel, analyses can be performed interactively (point-and-click way) in a web browser, making the applications easier for many more researchers. In addition with this tool, the results of the analyses can be mapped providing a valuable tool for exploring the spatial heterogeneity of the data.

Code metadata

Current code version	*1.0.2*
Permanent link to code/repository used for this code version	https://github.com/ElsevierSoftwareX/SOFTX-D-22-00039
Permanent link to reproducible capsule	
Legal code license	*GPL-3.*
Code versioning system used	*git*
Software code languages, tools and services used	*R*
Compilation requirements, operating environments and dependencies	R ($\geq$ 4.1.2)
If available, link to developer documentation/manual	https://cran.r-project.org/web/packages/GeoWeightedModel/GeoWeightedModel.pdf
Support email for questions	jdelahozmaestre@gmail.com

1. Motivation and significance

Spatial statistics is useful for a wide range of fields including social, environmental, health sciences (among others), where georeferenced information is regularly gathered. Within spatial statistics there is a particular subarea called Geographically Weighted (GW) models. These models are designed for situations where spatial data is not well described by a global model, but where there are spatial regions where a properly located model calibration provides a better overview [1].

The GW modeling paradigm has expanded to include a variety of strategies that can be used when there is a suspicion of heterogeneity or non-stationarity in the study's spatial process. In most cases, the GW model's outputs or parameters are mapped to give a useful exploratory tool that can often precede (and direct) a more traditional or complex statistical investigation [1].

The GW models encompass the GW regression [2], the GW summary statistics [3], the GW generalized linear models [4,5], the GW Principal Component Analysis [6] and the GW discriminant analysis [7]. Some of these GW models are implemented in

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the open source environment R [8], namely spgwr [9], gwrr [10], McSpatial [11], gwer [12], gwfa [13], GWLelast [14], lctools [15], mgwrsar [16], scgwr [17], hgwrr [18], GWPR.light [19], gwpcormapper [20], GWpcor [21], GWnnegPCA [22]

However, when making a comparison of nine aspects (Weighting Matrix Specifications ; Functions GW summary statistics; Other GW regression functions ; Functions to Address Collinearity; Basic GW regression function; Generalized GW regression functions; Function for GWPCA ; Function for GWDA and Graphical user interface) (Appendix A, Table A.1), we found that GWmodel [1,23] is the package that provides the most comprehensive set of GW modeling tools, so GWmodel became the inspiration for the creation of GeoWeightedModel. It is important to note that since its first version published in CRAN (1.1-9) GWmodel has evolved and incorporated many routines for GW models, among which we can highlight: Robust Geographically Weighted Regression [24], Geographically weighted principal components analysis in its basic and robust forms [6], Geographically weighted regression with parameter-specific distance metrics [25], Scalable GWR [17], High-performance solutions of geographically weighted regression in R [26]. A full list of GWmodel package functions can be found on link https://CRAN.R-project.org/package=GWmodel.

It was proposed that the proposed application or package be accessible to as many users as possible, easy to distribute and install, and have a user-friendly graphical and functional environment. The environment of the R program meets the stated requirements: because through the Comprehensive R Archive Network (CRAN) infrastructure it can be distributed and be accessible by a large number of people. As an added value, R is a multiplatform environment, that is, the built program can be executed in the operating systems used by most personal computers such as Windows, Mac or Linux. Another requirement is that the package must be easy to install, since if we use elements external to the R software that need to be previously installed or compiled for the module to work, it is likely that the user will desist from using it, in our case the Installation does not require any external element.

Therefore, the main goal of GeoWeightedModel package was to make the workflow easier to use, especially for those who are not familiar with the R environment. With GeoWeightedModel, analyses can be performed interactively (point-and-click way) in a web browser, making the applications easier for many more researchers.

2. Software description

2.1. Software initialization

The *GeoWeightedModel* package (currently in version 1.0.1) is primarily written in R [8] and R shiny [27] framework.

The package is hosted on the Comprehensive R Archive Network (CRAN) repository and can be installed with the following command:

***Listing 1**: The code to install the GeoWeightedModel package*
```
R> install.packages ("GeoWeightedModel")
R> library (GeoWeightedModel)
```

After calling the following command, the application is launched in a web browser tab

***Listing 2**: The code to run the Shiny web application*
```
R> runGeoWeightedModel ()
```

2.2. Software architecture and functionalities

The implementation of the Shiny web application that incorporates all the functionalities of the package is based on the ui.R and server. R files that specify the front-end layout and backend logic of the app.

The Graphical User Interface (GUI) proposed in this work provides a menu that, from top to bottom, guides the user through the analysis, It consists of 7 main menus panels at the left of the page (Fig. 1). The "About" menu briefly summarizes the package functionalities (Fig. 1). The second menu, "Load data", contains two boxes, the first one allows us to upload the data file (where the variables and geographic location information of the samples should be housed), which must be in the format xls or xlsx, we load this file by clicking on the Browse button, then we select the worksheet and click the get data button. This file must have an area id column what should it must match the identifier of the shapefiles. The second box allows us to upload the map file that contains the areas of the study region. The map file must be in shapefile format (.shp, .dbf, .prj, shx, .xml) and can be loaded by clicking the "Browse" button and selecting all the files corresponding to the map. Additionally, we find a checkbox where we can load an example file.

The "Distance matrix" menu allow calculate a distance matrix (or vector if focus > 0) between any GW model calibration point(s) and the data points (Fig. 1). The output data can be downloaded in csv xls or pdf format or can be copied to the clipboard. At the top of the box we find a help button where the input parameters are specified and also a video explaining the use of the menu is shown (This same button is found in all the boxes present in the software).

The "Bandwidth selection" menu contains a pickerInput for automatic bandwidth selection to calibrate basic GW regression (bw.gwr), generalized GWR model (bw.ggwr), GW Principal Components Analysis (bw.gwpca), and GW Discriminant Analysis (bw.gwda) (Fig. 2). This menu returns the adaptive or fixed distance bandwidth. The main distinction between the fixed and adaptive approaches is that in the fixed approach, the kernel has the same spatial size regardless of the density of the data points. This could result in a variable number of weighted observations in the study area if the function has weights that are zero beyond a certain distance, while the adaptive adjusts the density of the data points using the number of observations. This results in a spatially larger kernel in areas with little information and a smaller kernel in areas with high data density [28].

Table 1 shows the input parameters for the bandwidth calculation.

The "Spatial autocorrelation" menu (Fig. 3) allow to calculates the Moran's I Index value and both a z-score and *p*-value to evaluate the significance of that Index. P-values are numerical approximations of the area under the curve for a known distribution, limited by the test statistic. This tests of spatial autocorrelation examine the independency of observed value in relation to values of that variable at neighboring locations. We use the spdep package [29], and this menu returns Moran I test under randomization, Monte-Carlo simulation of Moran I, Local Moran's I statistic summary, Monte-Carlo simulation of Local Moran's I statistic summary, the Local Moran's I statistic can be downloaded in csv xls or pdf format or can be copied to the clipboard. Moran's I results and their probability value can be mapped, customized and downloaded using the options in the plot tab (Fig. 3).

The" Geographically Weighted Summary Statistics" GWSS menu (Fig. 4) allow to calculates basic and robust Geographically weighted summary statistics. This includes geographically weighted means, standard deviations and skew. Robust alternatives include geographically weighted medians, interquartile

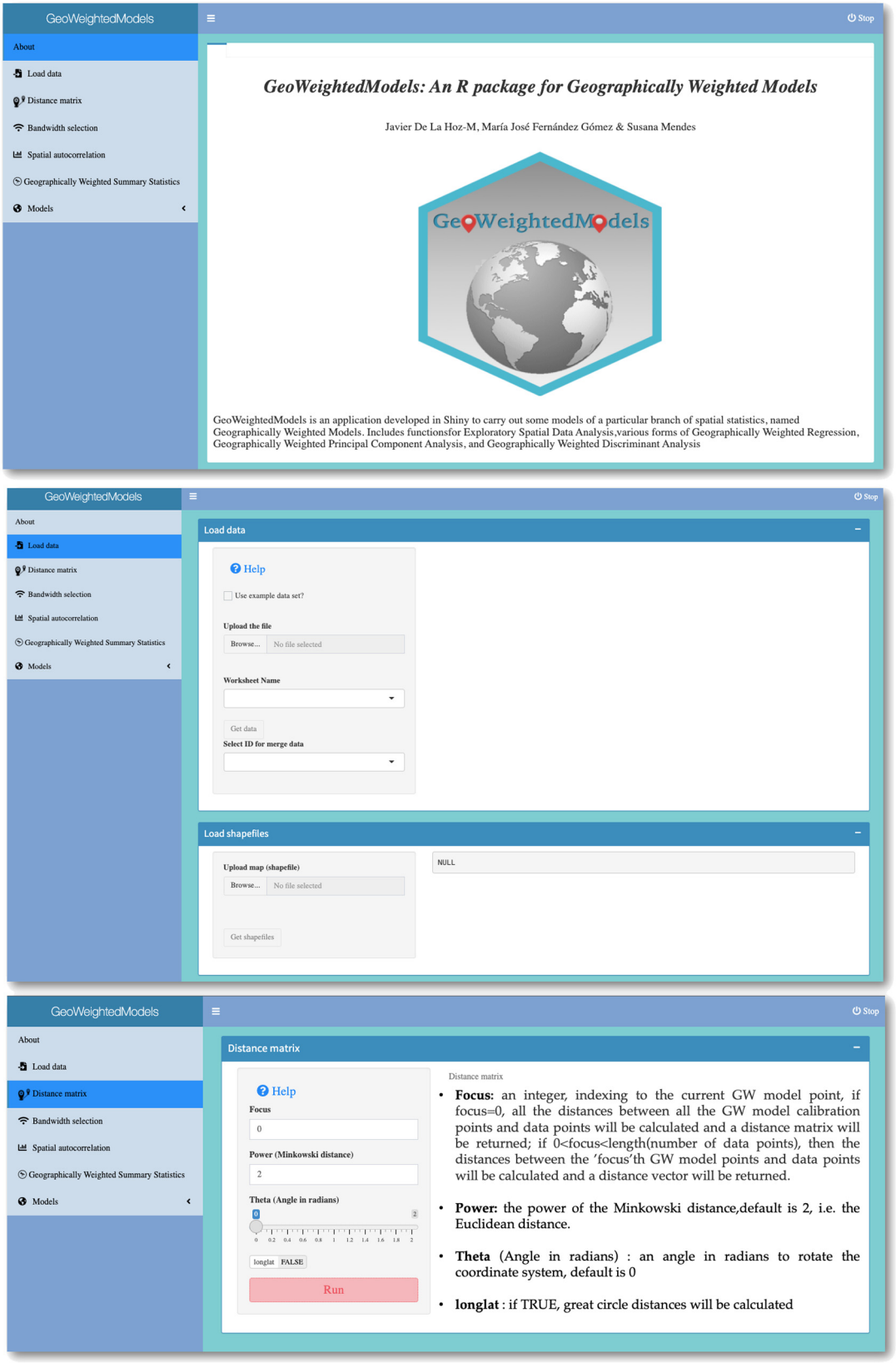


Fig. 1. Graphical User Interface for GeoWeightedModel package. From top to bottom the "About", "Load data" and "Distance matrix" menus are shown.

Table 1
Input parameters for bandwidth calculation.
Source: Gollini et al. [1].

Argument	Description	bw.gwr	bw.ggwr	bw.gwda	bw.gwpca
Dependient	Dependent variable of the regression model or grouping factor for discriminant analysis	✔	✔	✔	
Independient	Independent(s) variable(s) of the regression model or discriminant analysis.	✔	✔	✔	
Family	A description of the model's error distribution and link function, which can be "*Poisson*" or "*binomial*".		✔		
Approach	Specified by CV for cross-validation approach or by Akaike Information Criterion corrected (AICc) approach	✔	✔		
Kernel	A set of five commonly used kernel functions "gaussian", "exponential", "bisquare", "tricube", and "boxcar"	✔	✔	✔	✔
Power	the power of the Minkowski distance (p=1 is manhattan distance, p=2 is euclidean distance).	✔	✔	✔	✔
Theta	an angle in radians to rotate the coordinate system, default is 0	✔	✔	✔	✔
Longlat	if TRUE, great circle distances will be calculated	✔	✔	✔	✔
Adaptive	If TRUE, find an adaptive kernel with a bandwidth proportional to the number of nearest neighbors (i.e. adaptive distance); otherwise, find a fixed kernel (bandwidth is a fixed distance)	✔	✔	✔	✔
Cov.gw	if TRUE, localized variance–covariance matrix is used for GW discriminant analysis; otherwise, global variance–covariance matrix is used			✔	
Prior.gw	if TRUE, localized prior probability is used for GW discriminant analysis; otherwise, fixed prior probability is used			✔	
Mean.gw	if true, localized mean is used for GW discriminant analysis; otherwise, global mean is used			✔	
wqda	if TRUE, a weighted quadratic discriminant analysis will be applied; otherwise a weighted linear discriminant analysis will be applied			✔	
Variables	a vector of variable names to be evaluated				✔
Robust	if TRUE, robust GWPCA will be applied; otherwise basic GWPCA will be applied				✔

Table 2
List of GW summary statistics that are estimated by GeoWeightedModel. Note that X and Y are replaced in the output by the names of the variables being investigated.

Statistic	Bivariate or Univariate	Robust?	What it Measures
Mean (X_LM)	Univariate	No	Central tendency
Standard deviation (X_LSD)	Univariate	No	Spread
Variance(X_Lvar)	Univariate	No	Spread
Skewness (X_LSKe)	Univariate	No	Asymmetry
Coefficient of variation X_LCV	Univariate	No	Spread
Covariance (Cov_X.Y)	Bivariate	No	Spread
Pearson correlation (Corr_X.Y)	Bivariate	No	Association
Spearman Correlation (Spearman_rho_X.Y)	Bivariate	Yes	Association
Median(X_Median)	Univariate	Yes	Central tendency
Interquartile Range (X_IQR)	Univariate	Yes	Spread
Quantile Imbalance (X_QI)	Univariate	Yes	Asymmetry

ranges and quantile imbalances. This function also calculates basic geographically weighted covariances together with basic and robust geographically weighted correlations. The geographically weighted summary statistics that can be estimated in the application are listed in Table 2.

In the tab "*Summary*" all the information generated can be downloaded in csv xls or pdf format or can be copied to the clipboard. On the other hand, in the "*Plot*" tab, you can customize and download graphs using the options available for this purpose, among these options we have "*Select variable*", "*Main title*", "*Select pallete*" (16 color palettes available), "*North arrow position (latitude and longitude)*", "*Select the Option* (png or pdf format)", and a *download button* (Fig. 4).

Finally, the menu " Models ", contains three submenus, "GW Regression", "*GW Principal Component Analysis*", and GW Discriminant Analysis". From the first submenu you can select in addition to the basic model " *Basic GWR model*" [2] another five "*Robust GWR*" [4], "*Generalized GWR*" [4,5], "*Heteroskedastic GWR*" [4], "*Mixed GWR*" [30], and "*Scalable GWR*" [17] (Fig. 5), also Local collinearity diagnostics. Table 3 shows the input parameters for the calculation of all available GWR models. Additionally, Spatial Points Data Frame (SDF) object integrated with fit.points, GWR coefficient estimates, *y* value, predicted values, coefficient standard errors and t-values in its "data" slot generated can be downloaded csv xls or pdf format. While In the plot tab, the values obtained in the summary can be plotted, customized and downloaded in .pdf or .png format.

The submenu "*GW Principal Component Analysis*" allow to calculates basic or robust GW Principal Component Analysis (Fig. 6). Within the outputs or results are included the model fitting parameters to generate the report that populates the localized loads, an integrated SDF with local proportions of variance for each principal component, cumulative proportion and winning variable for the first principal component in its slot of data".

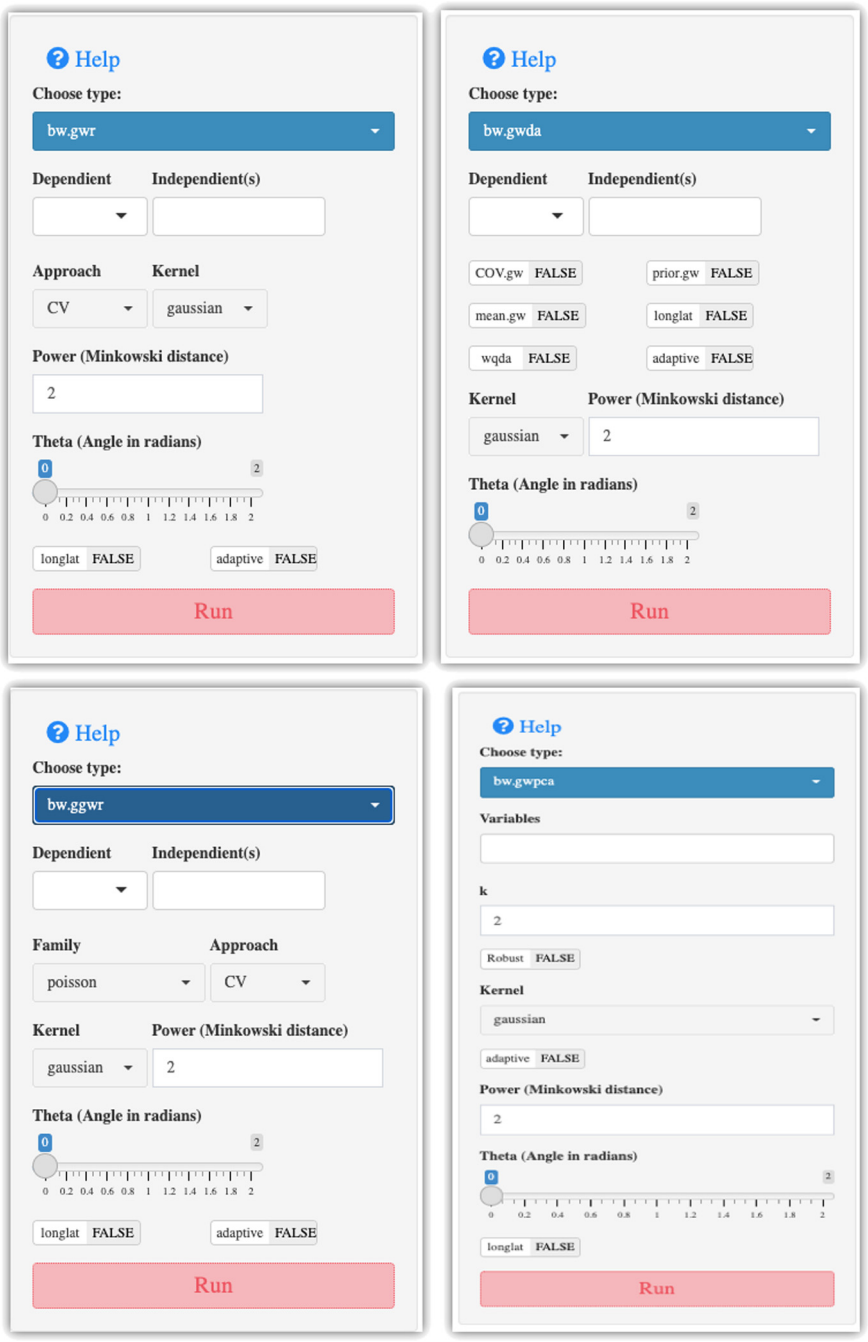


Fig. 2. Bandwidth selection menu. The options of each type of Bandwidth available in the package are shown.

We can visualize how each of the variables locally influence a given component, in tab "*winning variable*" by mapping the winning variable with the highest absolute loading, also how data dimensionality varies spatially and how the original variables influence the components in the tab "*Percent Total Variation*".

The submenu "*GW Discriminant Analysis*" (Fig. 6) enables geographically weighted discriminant analysis to be performed, including the calculation of the probabilities and entropy of the location. The input parameter are : Within the outputs, an SDF object is included with the probabilities for each level, the highest probability and the entropy of the probabilities in its "data" slot. . On the other hand, in the "Plot" tab, you can customize and download graphs using the options available for this purpose.

3. Illustrative examples

A general presentation is available in the video provided in the supplementary material (Appendix B), while the data used in the different analyses and can be downloaded from the link https://github.com/JavierDeLaHoz/GeoWeightedModel. Alternatively, you can use an example dataset which can be accessed by clicking the checkbox (Use example data set?) located in the load data box. The example dataset is named USelect and contains the results of

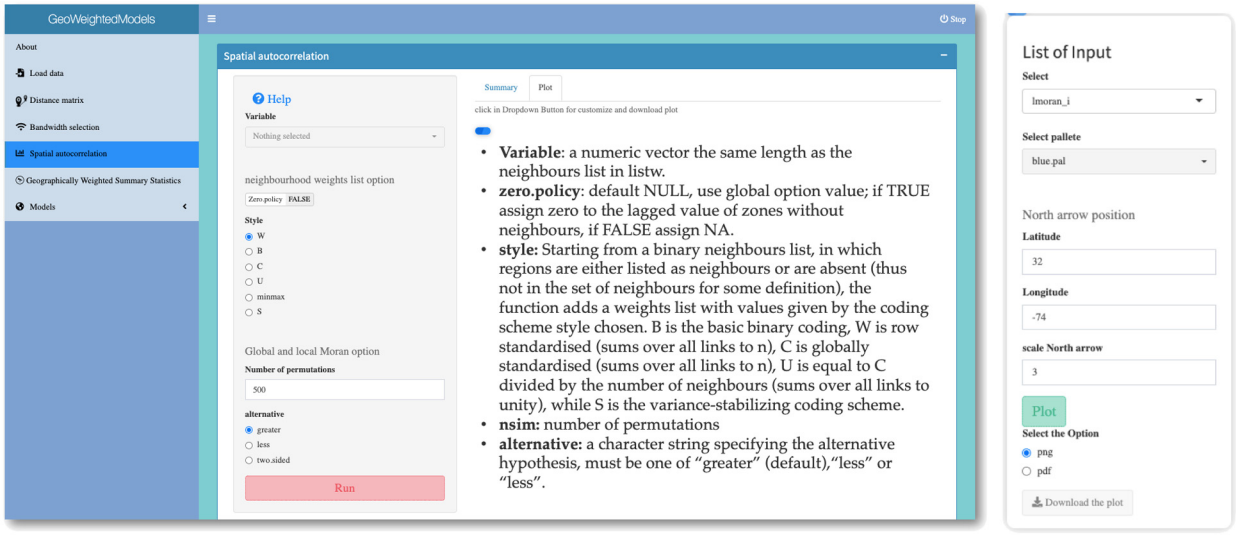


Fig. 3. Spatial autocorrelation menu. The options input are shown.

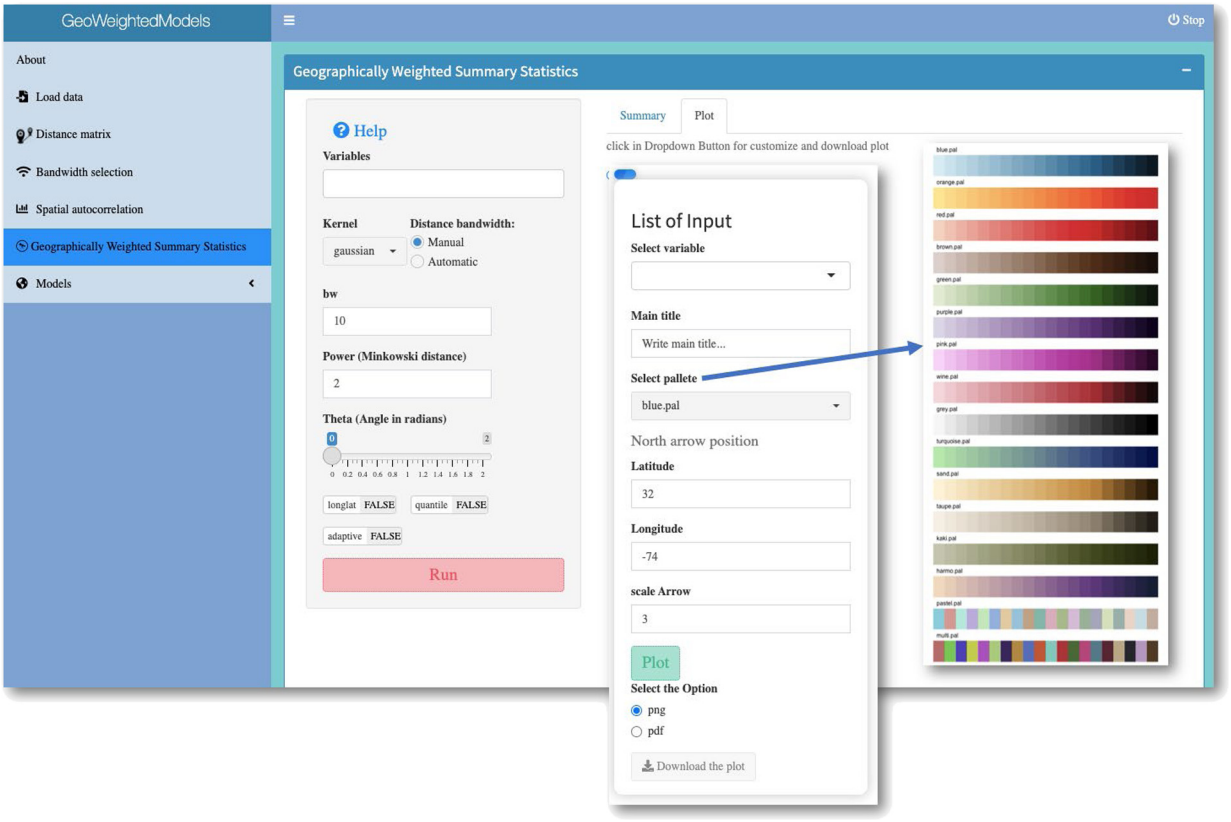


Fig. 4. Geographically weighted summary statistics menu. Customization options and color palettes available for graphics are displayed.

the 2004 US presidential election at the county level, along with five socioeconomic variables. These data are also integrated into the GWmodel package, where they are used for GW discriminant analysis.

In Appendix C you can find an example of the outputs of each of the models.

4. Impact

The models implemented in the software, such as the GWR and its extensions, have been widely used in various areas, as described by [31], who found that more than 1588 scientific articles were published between 1996 and 2019, indicating that

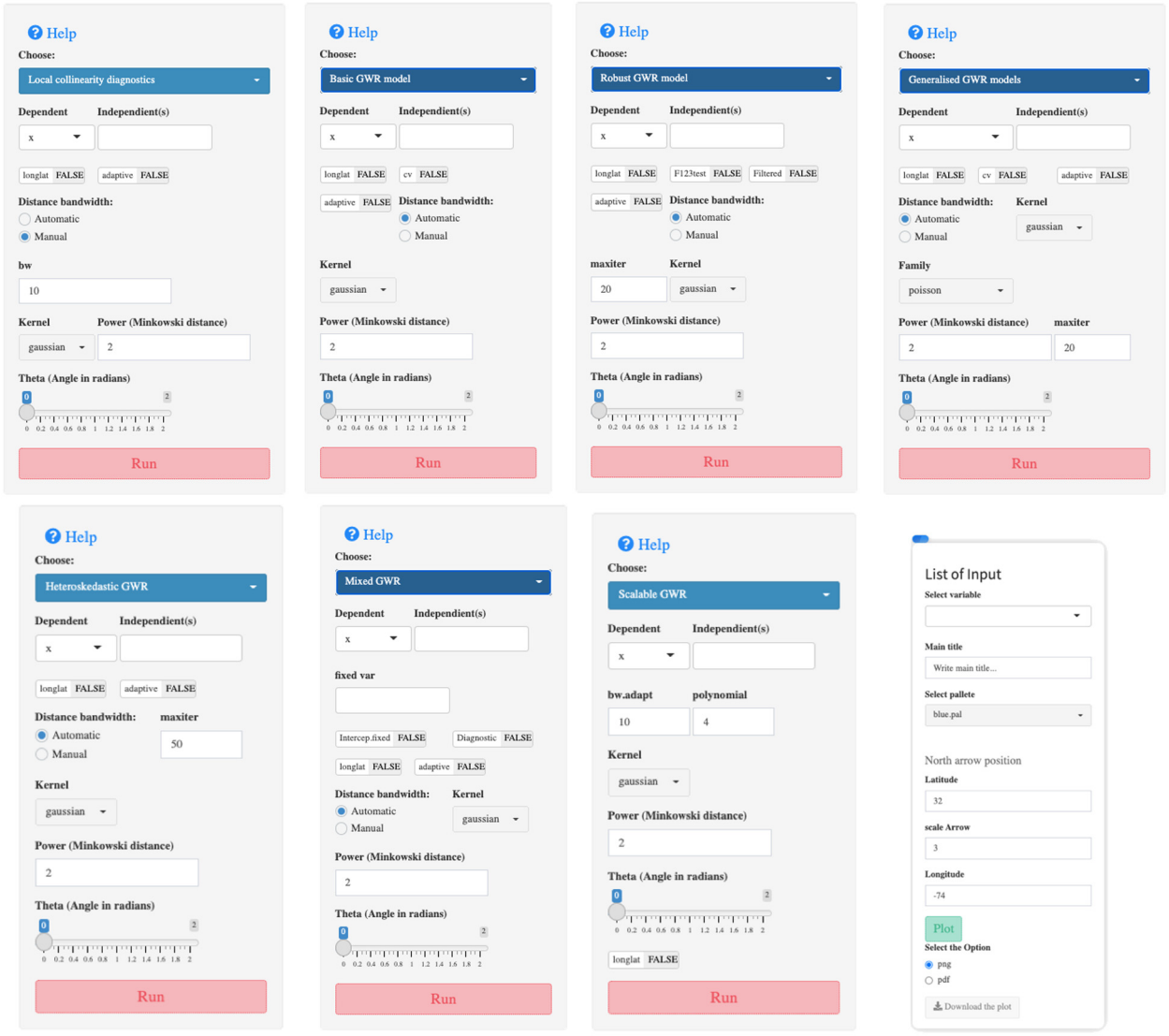


Fig. 5. GW Regression options available in the GeoWeightedModel package.

GWR is widely used and has attracted a lot of attention from scholars from different disciplines.

It is clear that the *GeoWeightedModel* package was not created with the intention of answering new research questions. Rather, the reasoning In particular, "GeoWeightedModel objectives are: To present a free and easy to use tool to perform techniques from a branch of spatial statistics known as geographically weighted (GW) models; Open source, open to the possibility of implementing and incorporating new features from new developments related to GW models. Also, as it is freely available to the scientific community, the impact of the software on that community is expected to be significant.

Since the software is freely available from the CRAN repository, it is possible to monitor downloads. *GeoWeightedModel* had recorded 2606 (https://cranlogs.r-pkg.org/badges/grand-total/GeoWeightedModel) downloads since its initial use, in January 2022, however this number of downloads is expected to increase significantly over time

5. Conclusions

In this paper the GeoWeightedModel package was presented. This was designed with ease of use in mind, it is aimed at researchers and students in various fields who are interested in the application of spatial statistics in situations where the spatial data is not well described by some universal or global model, but where there is spatial data or regions where a correctly located model calibration provides a better description of your data.

Only with few clicks, users can analyze the data in a variety of ways including results in both tabular form (which can be downloaded in various formats) and graphical form. The generated graphs can be customized by the user and can be downloaded in png or pdf format.

Declaration of competing interest

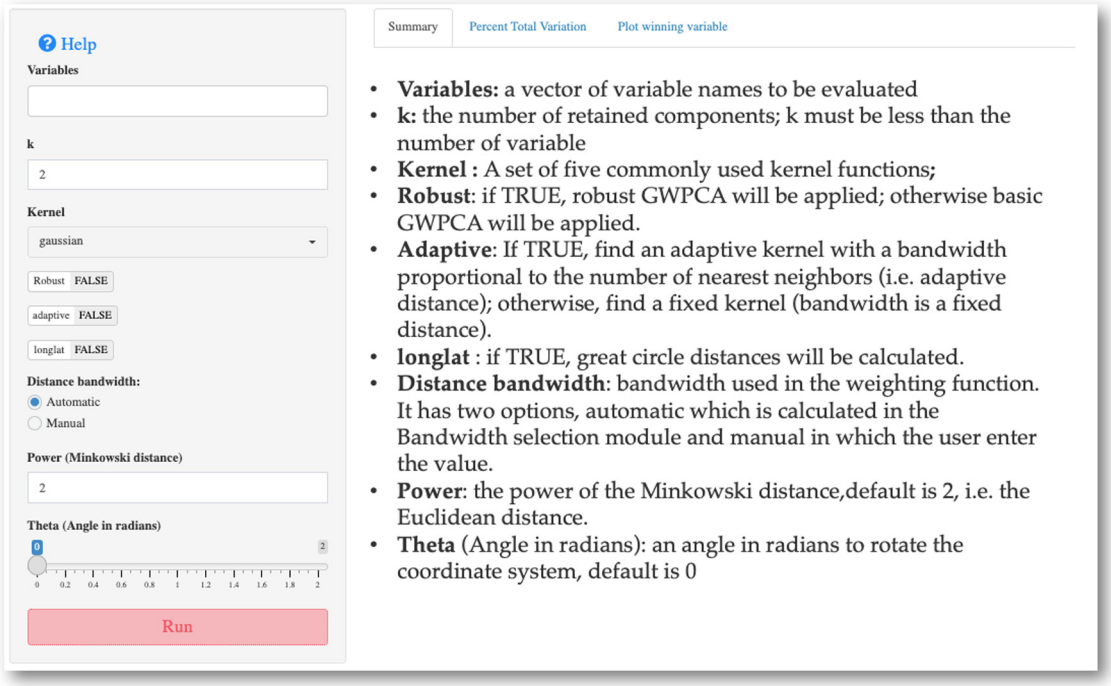
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.softx.2022.101250.



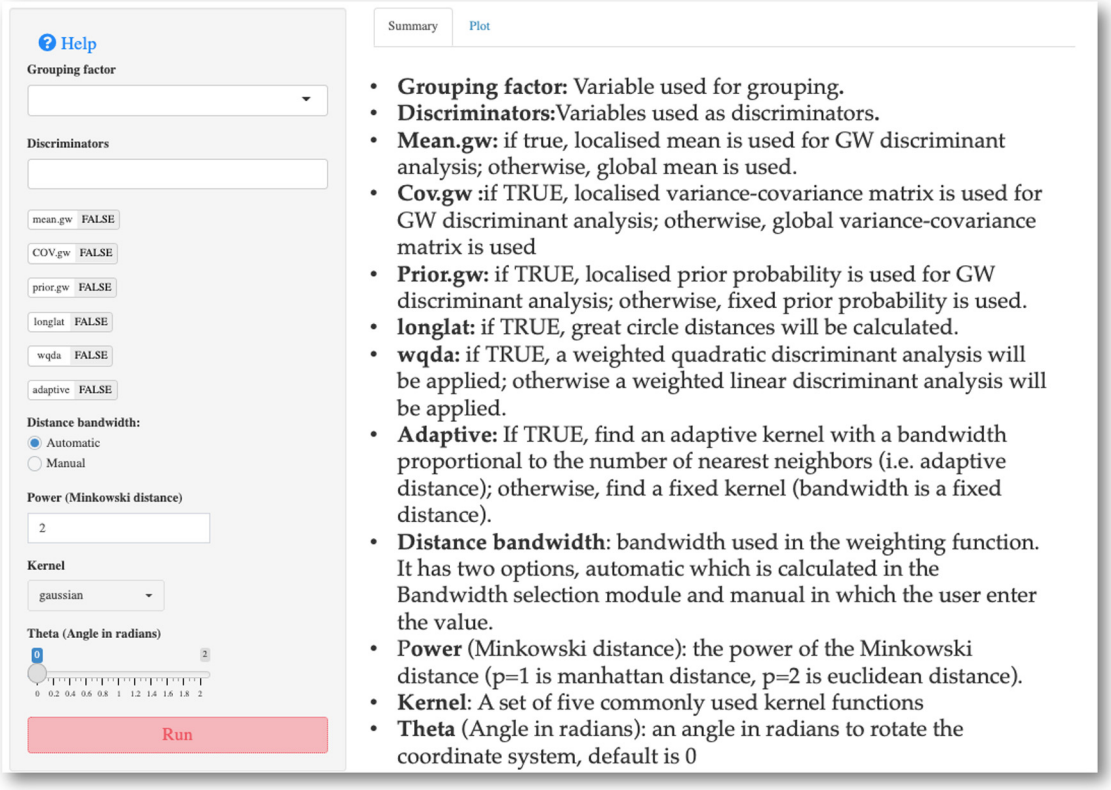


Fig. 6. GW Principal Component Analysis and GW Discriminant Analysis menu. The options input are shown.

Table 3
Input parameters for Geographically Weighted Regression.
Source: Gollini et al. [1].

Argument	Description	Local collinearity diagnostics	Basic	Robust	Generalized	Heteroskedastic	Mixed	Scalable
Dependent	Dependent variable of the regression model	✔	✔	✔	✔	✔	✔	✔
Independent	Independent(s) variable(s) of the regression model	✔	✔	✔	✔	✔	✔	✔
Cv	If TRUE, cross-validation data will be calculated	✔	✔		✔			
Family	a description of the model's error distribution and link function, which can be "Poisson" or "binomial".				✔			
Kernel	A set of five commonly used kernel functions "gaussian", "exponential", "bisquare", "tricube", and "boxcar"	✔	✔	✔	✔	✔	✔	✔
Power	the power of the Minkowski distance (p=1 is manhattan distance, p=2 is euclidean distance).	✔	✔	✔	✔	✔	✔	✔
Theta	an angle in radians to rotate the coordinate system, default is 0	✔	✔	✔	✔	✔	✔	✔
Longlat	if TRUE, great circle distances will be calculated	✔	✔	✔	✔	✔	✔	✔
Adaptive	If TRUE, find an adaptive kernel with a bandwidth proportional to the number of nearest neighbors (i.e. adaptive distance); otherwise, find a fixed kernel (bandwidth is a fixed distance)	✔	✔	✔	✔	✔	✔	
Distance bandwidth	Bandwidth used in the weighting function. It has two options, automatic which is calculated in the Bandwidth selection module and manual in which the user enter the value.	✔	✔	✔	✔	✔	✔	
Max. iter	If TRUE, localized prior probability is used for GW discriminant analysis; otherwise, fixed prior probability is used			✔		✔		
Fixed	Independent variables that appeared in the formula that are to be treated as global						✔	
Intercept fixed	If TRUE the intercept will be treated as global						✔	
Diagnostic	If TRUE the diagnostics will be calculated						✔	
F123	Default FALSE, otherwise calculate F-test results			✔				
Filtered	Default FALSE, the automatic approach is used, if TRUE the filtered data approach is employed, as that described in [4]			✔				
bw.adapt	Adaptive bandwidth (i.e. number of nearest neighbors) used for geographically weighting							✔
Polynomial	degree of the polynomial to approximate the kernel function							✔

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