CoCA：Population-Economy-Land Multifactor Coordinated Development Prediction Model 1.1.0

Instructions for Use

November 2023

HPSCIL

目录

1. Product Introduction

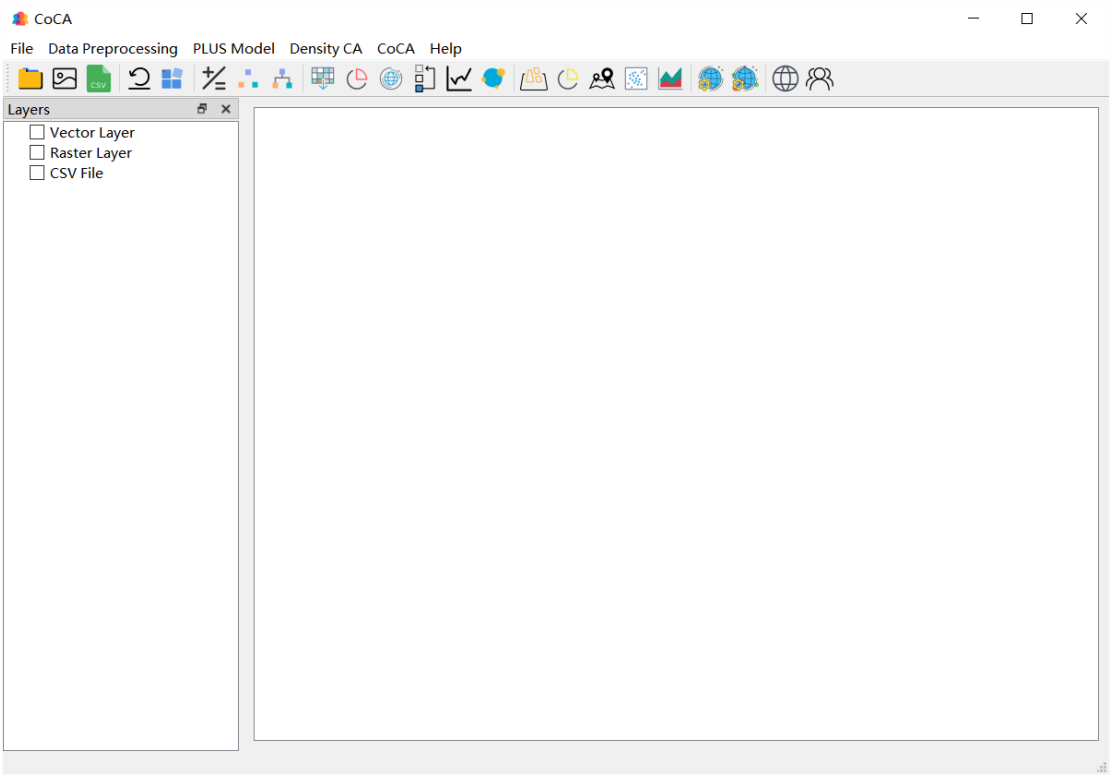
Target Audience

Geographic Information、Urban Planning Practitioners、and Researchers.

1.1. Installation Method

To extract the compressed file, open the extracted folder and simply click on the CoCA.exe file to run it directly.

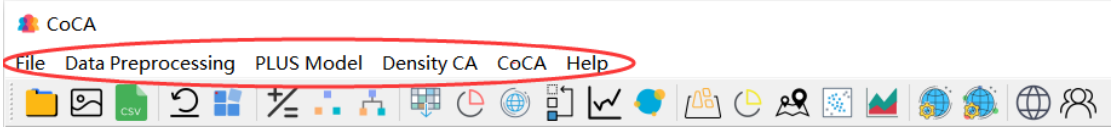
1.2. Interface display effect



1.3. Software control description

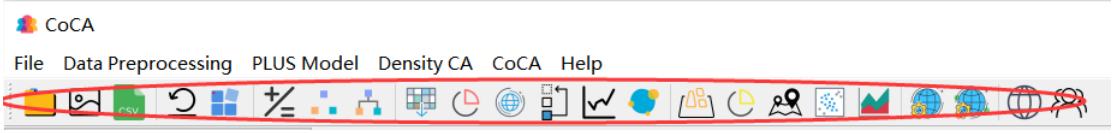
1.3.1. Menu bar

The content consists of several sections: "Documents", "Data Processing", "PLUS Model", "Density Cellular Automata", "Collaborative Cellular Automata", and "Assistance".



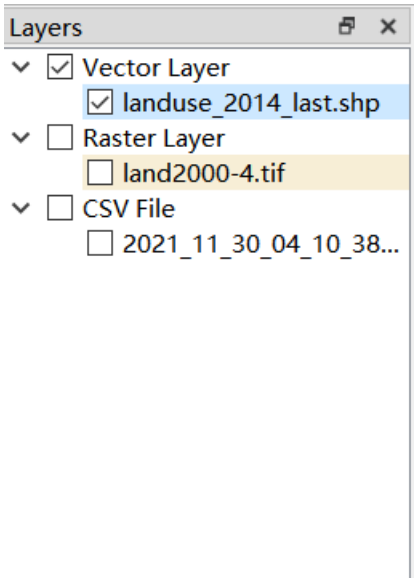
1.3.2. Toolbar

The content is divided into several sections: "Open Vector File", "Open Raster File", "Open CSV File", "Open Project File", "Save Project File", "Raster Calculator", "Image Supervised Classification", "Image Unsupervised Classification", "Extract Land Expansion Area using PLUS Model", "Calculate Overall Development Probability using PLUS Model", "Adaptive Cellular Automata Simulation using PLUS Model", "Calculate Markov Chain using PLUS Model", "Accuracy Assessment using PLUS Model", "Calculate Initial Density State for Urban Development using Density CA", "Calculate Overall Density Development State for Urban Development using Density CA", "Extract Urban Centers using Density CA", "Simulate Continuity Change in Urban Features using Density CA", "Accuracy Assessment using Density CA", "Simulate Collaborative Change in Single Urban Feature", "Simulate Collaborative Change in Multiple Urban Features", and "About Us".

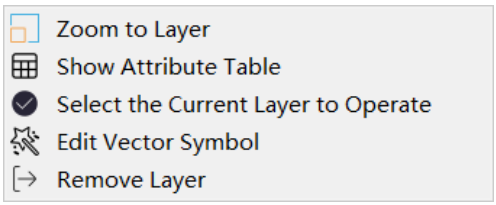


1.3.3. Data management module

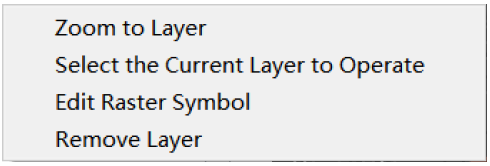
This area is used to display the opened data and perform some basic GIS functionalities. The data consists of "vector data," "raster data," and "CSV file data." Each module shows the data that has been imported into the system.



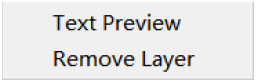
By right-clicking on the data that needs to be processed, you can open the toolbar for basic GIS functionalities. The vector data includes five options: "Zoom to Layer," "Open Attribute Table," "Select as Current Operational Layer," "Symbolize," and "Remove Layer."



The raster data includes four options: "Zoom to Layer," "Select as Current Operational Layer," "Raster Symbolization," and "Remove Layer."

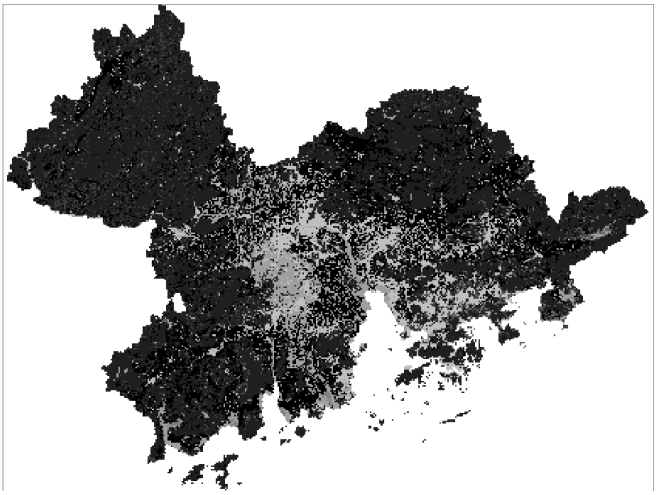


The CSV file includes two options: "Text Preview" and "Remove Layer."



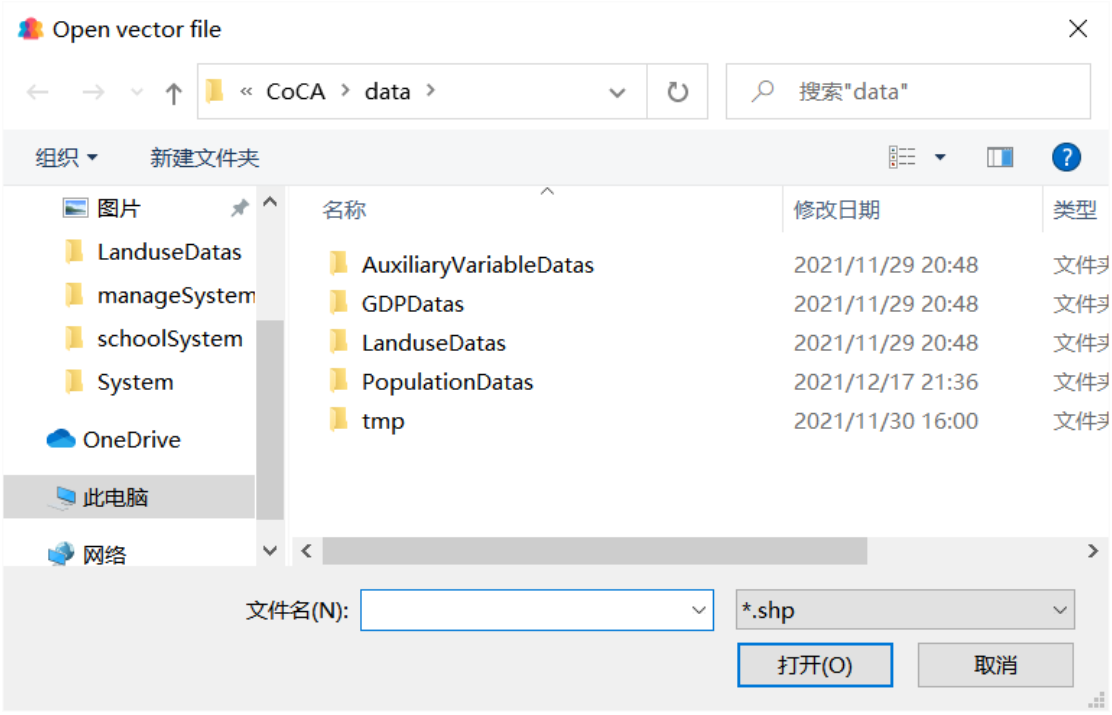
1.3.4. Data visualization area

This area is used to display imported vector and raster files, supporting the display of data after operations such as classification.



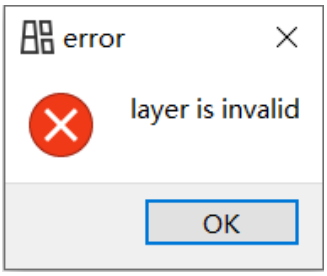
1.3.5. Function dialog box

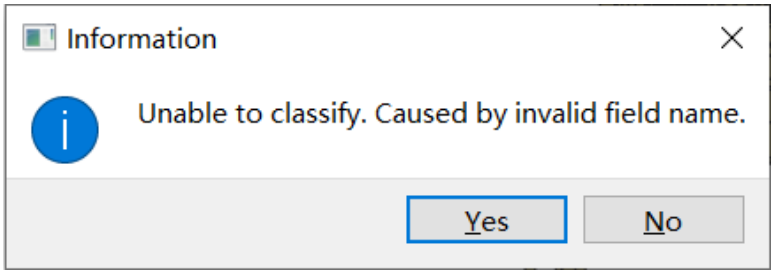
This dialog box is utilized for the selection of the import and save file locations.

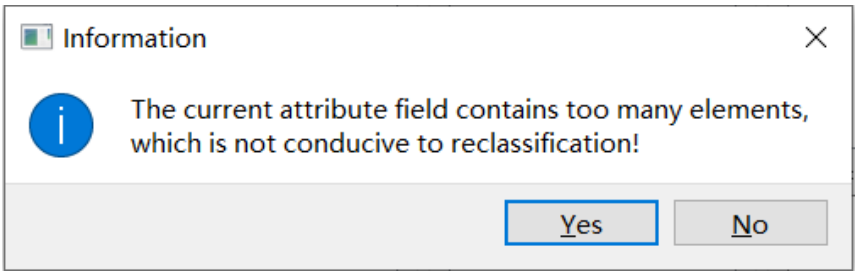


1.3.6. Exception prompt dialog box

This dialog box is used to prompt the user about the current abnormal state and the reason for the operation in the system.





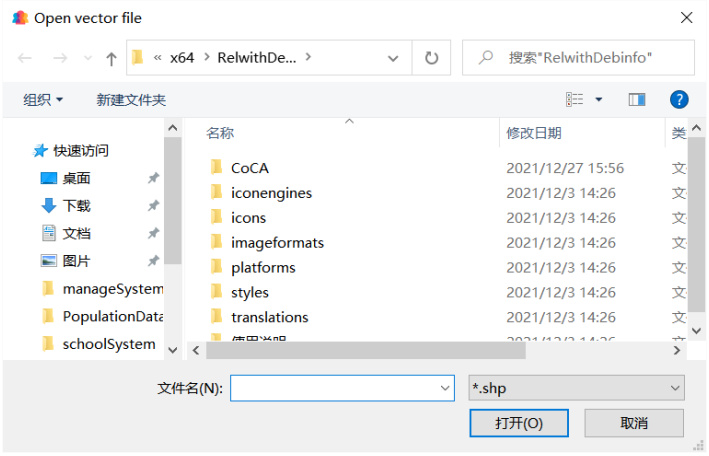


2. Data display function

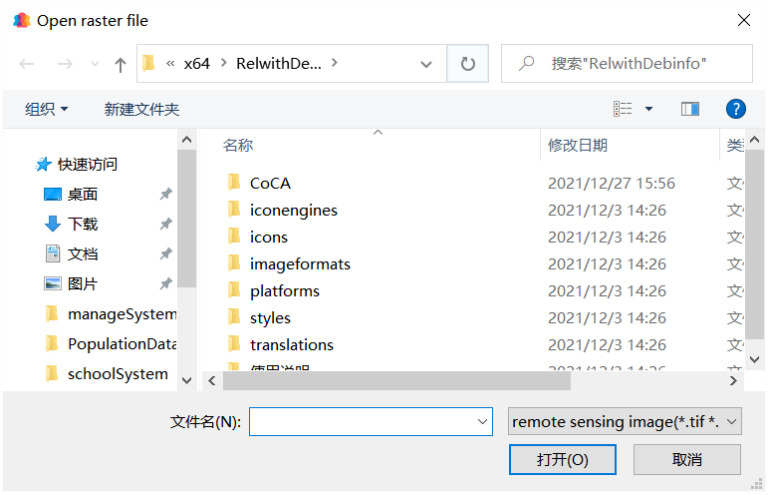
2.1. Basic functions

2.1.1. Data file import

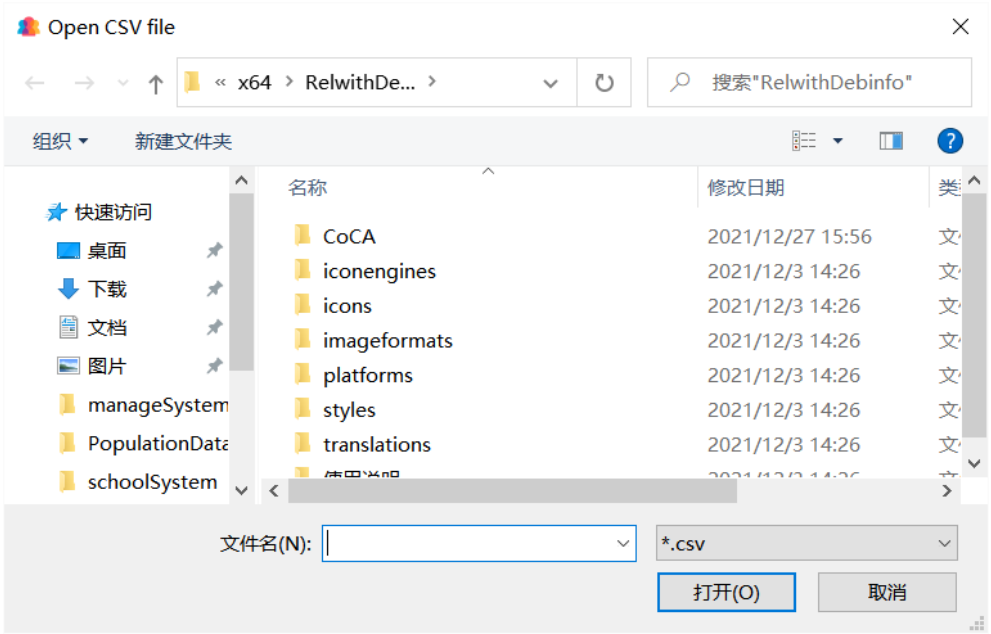
Click on "Open Vector Layer" under the File directory or the icon in the menu bar  Open the dialog box for selecting vector files，用 Users can choose the desired vector files to be added to the main interface for visualization. Import the selected vector file into the system for subsequent operations.



Please click on "Open Raster Layer" under the "File" directory or the corresponding icon on the menu bar to open the "Select Raster File" dialog box. Users can choose the desired raster file and add it to the main interface for visualization. By selecting the raster file to be opened, it can be imported into this system for subsequent operations.

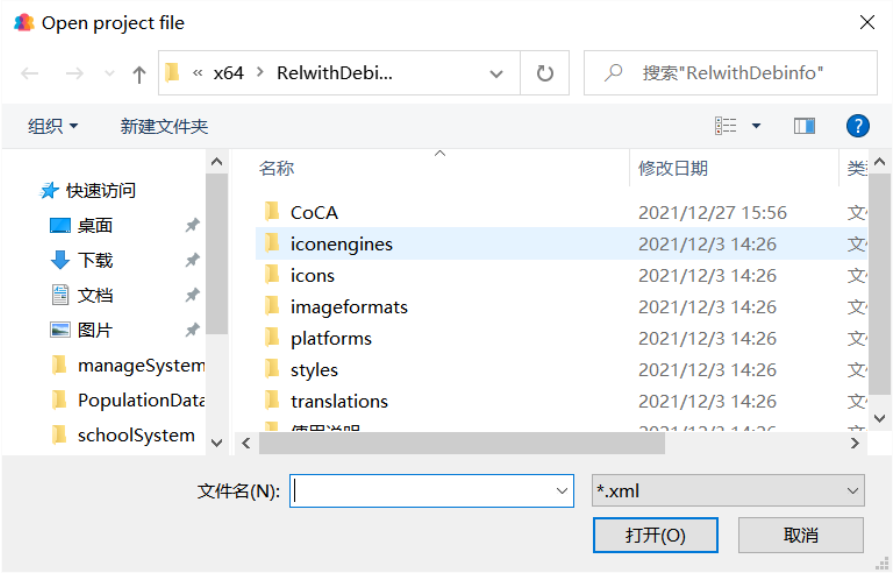


Please click on "Open CSV File" under the "File" directory or the corresponding icon on the menu bar  Open the "Select CSV File" dialog box, where users can choose the desired CSV file to add it to the main interface. By selecting the text file to be opened, it can be imported into this system for subsequent operations.

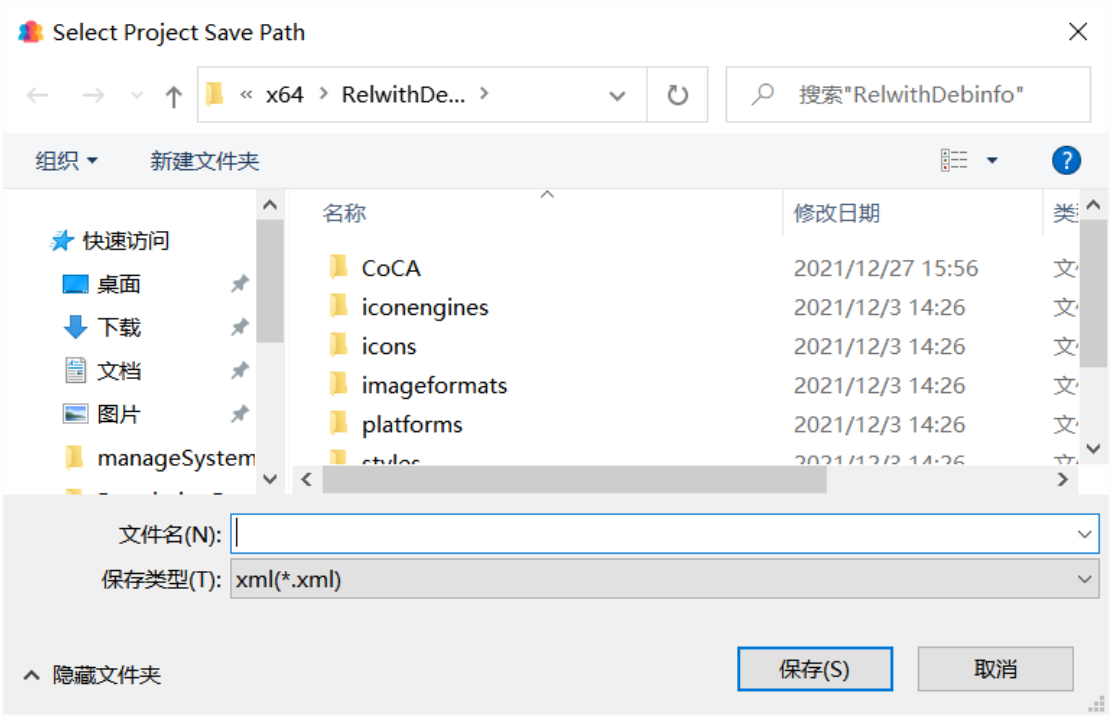


2.1.2. Importing and saving project files

Please click on "Open Project File" under the "File" directory or the corresponding icon on the menu bar  Open the "Select Project File" dialog box, where users can choose the desired project file and apply it.



Please click on "Save Project File" under the "File" directory or the corresponding icon on the menu bar  Open the "Save Project File" dialog box, where users can save the current project at a specified location.

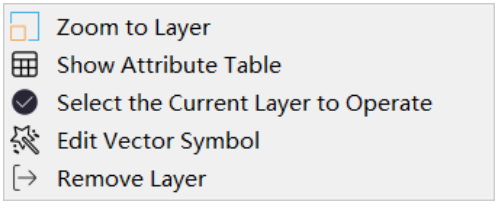


2.1.3. Exit

Clicking on "Exit" under the File directory will close the application.

2.1.4. Basic GIS function selection for raster data

Right-click on the raster data layer that needs to be operated, and after clicking the right mouse button, the following interface will appear：



2.1.4.1.Zoom to layer

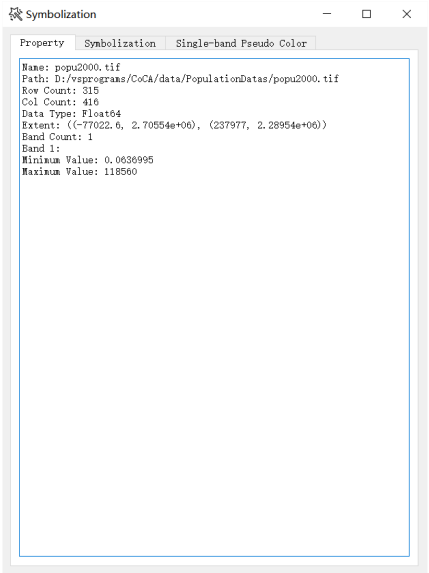
Click on the "Zoom to Layer" option to display the selected vector data layer in its entirety within the data visualization area.

2.1.4.2.Select the current working layer

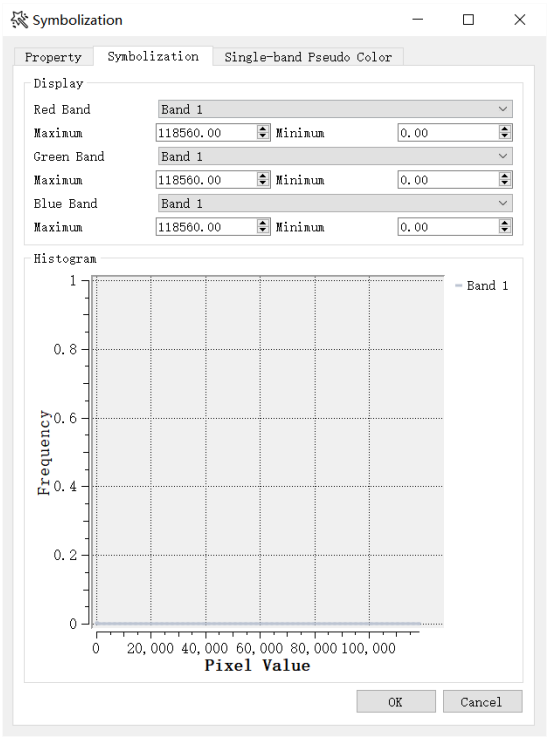
By clicking on the "Select Current Working Layer" option, you can edit the selected data.

2.1.4.3.Symbolize

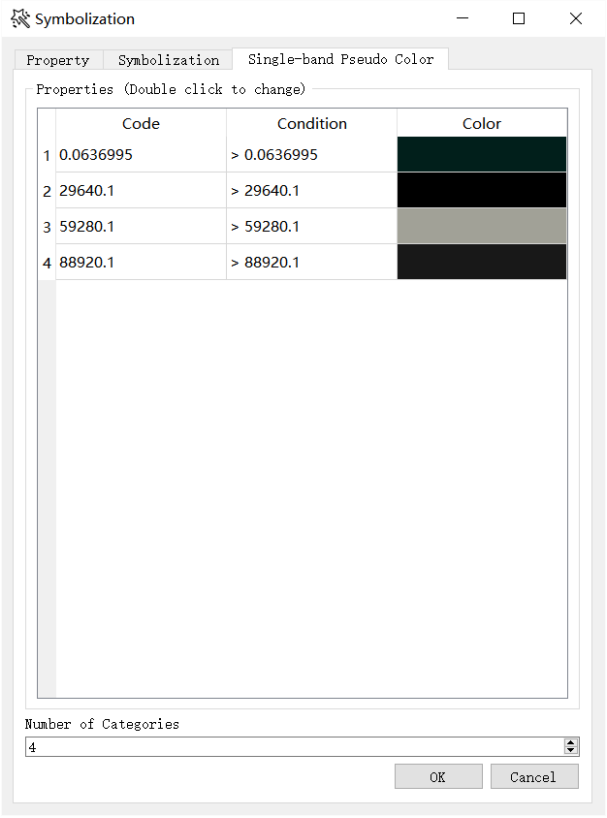
If the data in the current working layer is raster data, click on the "Edit Raster Symbol" option to open the interface for raster layer symbology.



The "Properties" page displays the basic parameters of the selected layer, including the layer name, path, resolution, data storage type, extent, number of bands, and the maximum and minimum pixel values for each band.

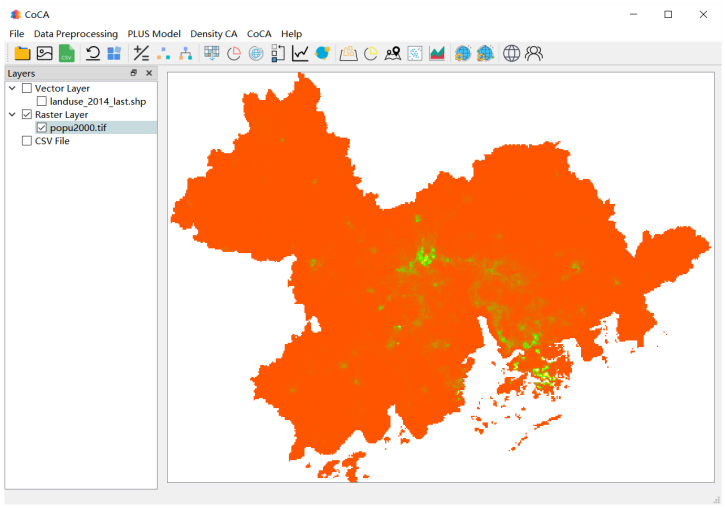


The "Symbolization" page can compute the frequency of different bands within a user-specified pixel range.



The "Single-band Pseudo Color" page allows the user to display a single band in pseudo-color. Users can set the number of categories in the "Number of Categories"

field and click on "Color" to change the color. The effect is as follows：

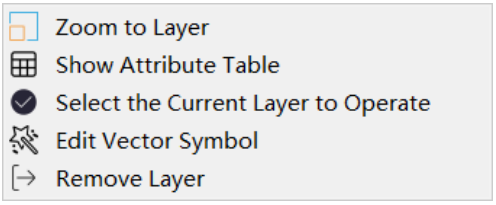


2.1.4.4.Remove layer

Click on the "Remove Layer" option to remove the selected raster data.

2.1.5. Basic GIS function selection for vector data

Click on "Exit" under the "File" directory to close the application：

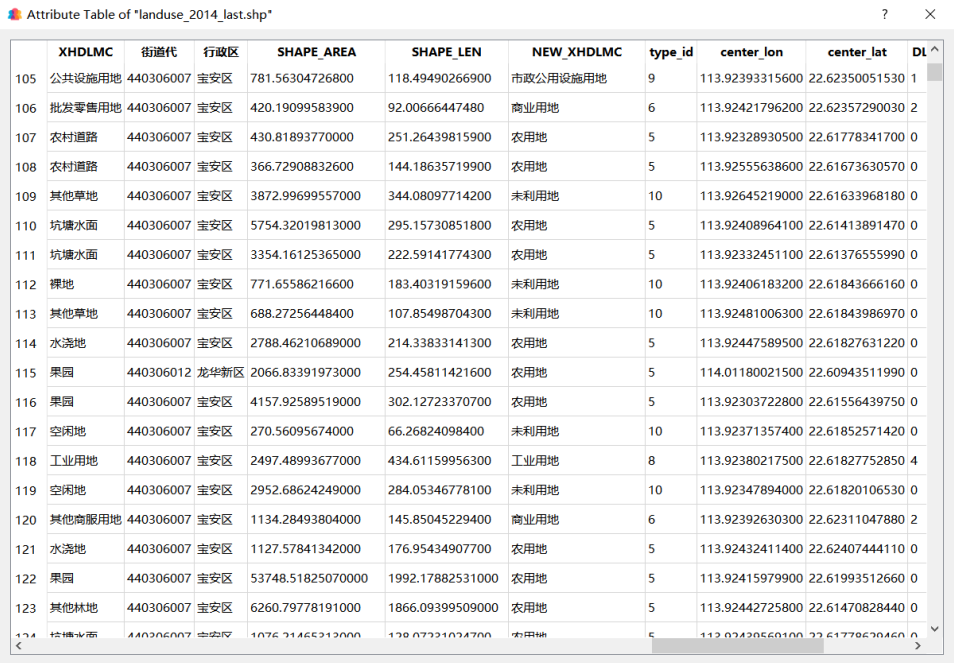


2.1.5.1.Zoom to layer

Click on the "Zoom to Layer" option to display the selected vector data layer in its entirety within the data visualization area.

2.1.5.2.Open attribute table

Clicking on the 'Open Attribute Table' option will take you to the attribute table interface, where the attribute table of the selected data will be displayed. We can also edit the attribute table by selecting specific entries. Please refer to the example below：


Attribute Table of "landuse_2014_last.shp"

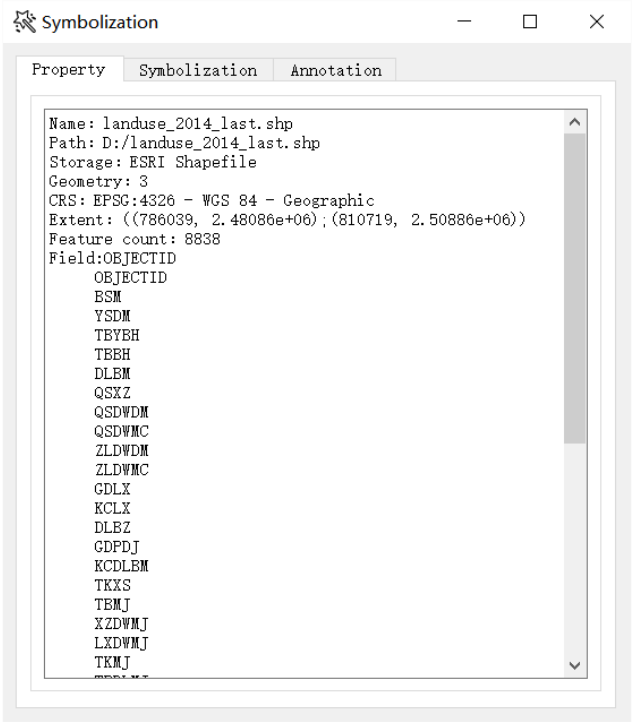
	XHDLMC	街道代	行政区	SHAPE_AREA	SHAPE_LEN	NEW_XHDLMC	type_id	center_lon	center_lat	DL
105	公共设施用地	440306007	宝安区	781.56304726800	118.49490266900	市政公用设施用地	9	113.92393315600	22.62350051530	1
106	批发零售用地	440306007	宝安区	420.19099583900	92.00666447480	商业用地	6	113.92421796200	22.62357290030	2
107	农村道路	440306007	宝安区	430.81893770000	251.26439815900	农用地	5	113.92328930500	22.61778341700	0
108	农村道路	440306007	宝安区	366.72908832600	144.18635719900	农用地	5	113.92555638600	22.61673630570	0
109	其他草地	440306007	宝安区	3872.99699557000	344.08097714200	未利用地	10	113.92645219000	22.61633968180	0
110	坑塘水面	440306007	宝安区	5754.32019813000	295.15730851800	农用地	5	113.92408964100	22.61413891470	0
111	坑塘水面	440306007	宝安区	3354.16125365000	222.59141774300	农用地	5	113.92332451100	22.61376555990	0
112	裸地	440306007	宝安区	771.65586216600	183.40319159600	未利用地	10	113.92406183200	22.61843666160	0
113	其他草地	440306007	宝安区	688.27256448400	107.85498704300	未利用地	10	113.92481006300	22.61843986970	0
114	水浇地	440306007	宝安区	2788.46210689000	214.33833141300	农用地	5	113.92447589500	22.61827631220	0
115	果园	440306012	龙华新区	2066.83391973000	254.45811421600	农用地	5	114.01180021500	22.60943511990	0
116	果园	440306007	宝安区	4157.92589519000	302.12723370700	农用地	5	113.92303722800	22.61556439750	0
117	空闲地	440306007	宝安区	270.56095674000	66.26824098400	未利用地	10	113.92371357400	22.61852571420	0
118	工业用地	440306007	宝安区	2497.48993677000	434.61159956300	工业用地	8	113.92380217500	22.61827752850	4
119	空闲地	440306007	宝安区	2952.68624249000	284.05346778100	未利用地	10	113.92347894000	22.61820106530	0
120	其他商服用地	440306007	宝安区	1134.28493804000	145.85045229400	商业用地	6	113.92392630300	22.62311047880	2
121	水浇地	440306007	宝安区	1127.57841342000	176.95434907700	农用地	5	113.92432411400	22.62407444110	0
122	果园	440306007	宝安区	53748.51825070000	1992.17882531000	农用地	5	113.92415979900	22.61993512660	0
123	其他林地	440306007	宝安区	6260.79778191000	1866.09399509000	农用地	5	113.92442725800	22.61470828440	0

2.1.5.3.Select the current working layer.

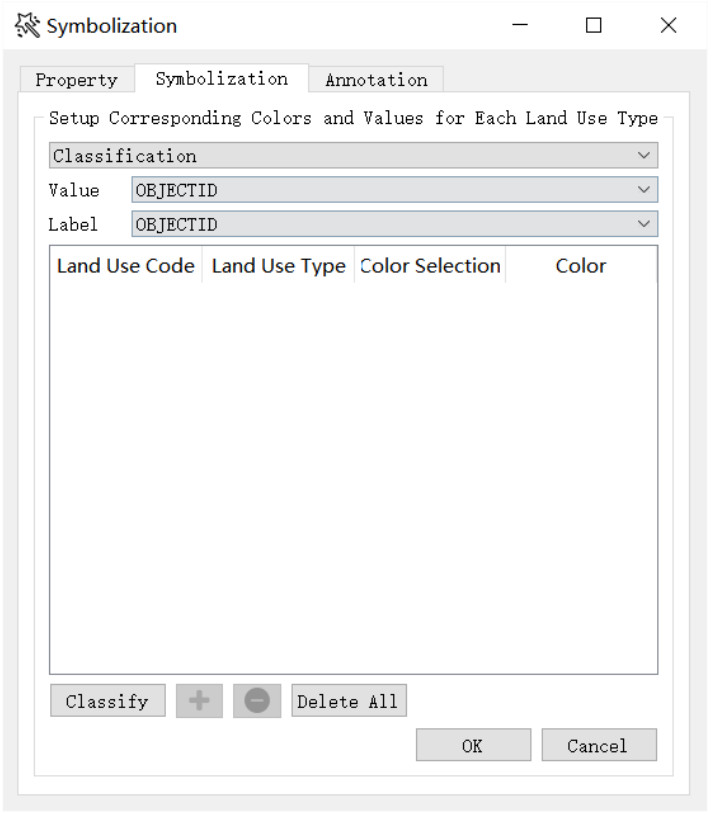
Click on the "Select Current Operating Layer" option to modify the symbology or adjust other parameters of the selected data.

2.1.5.4.Symbolize

If the data of the current operating layer is vector data, click on the "Edit Vector Symbols" option to open the vector layer symbology interface.



The "Properties" page displays the basic parameters of the selected layer, including the layer name, path, storage method, geographic feature type, reference system, coordinate range, number of features, and all attribute field names.

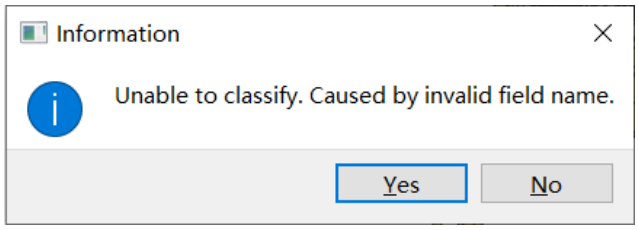


Symbolization page allows you to classify and render features of vector layers. In the "Classification" dropdown menu 

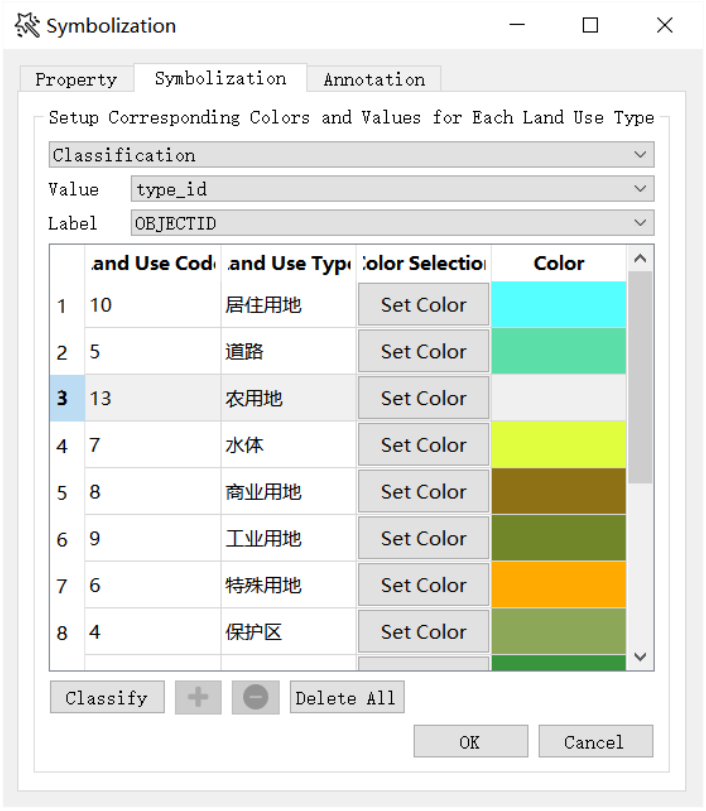
You can choose the method for symbolizing the current operating data, and the "Field Value" dropdown menu allows you to select the field value for symbolization

You can choose the field name that will be used for classification of the current layer. Additionally, the "Label" dropdown menu allows you to specify the labeling option for the classified features.

If a non-numeric field is selected in the "Field Value" dropdown menu, an error popup will appear, requesting the user to select a valid field value again：



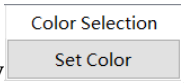
After adjusting the parameters, click the "Classify" button Classify , The classification symbolization will be performed based on the current parameters. The classification results will be displayed as shown in the following image：

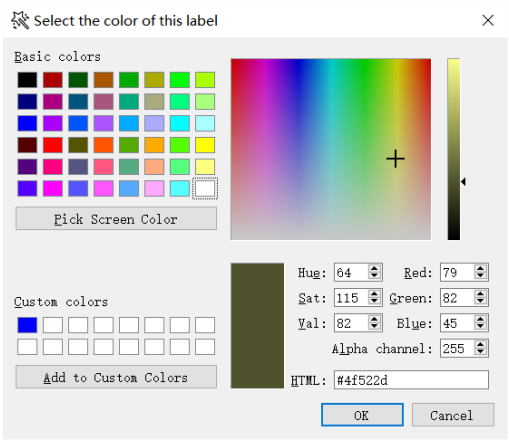


In addition, click the "Add a Class" button A new class can be automatically added by clicking the "Add a Class" button, as shown in the image below：

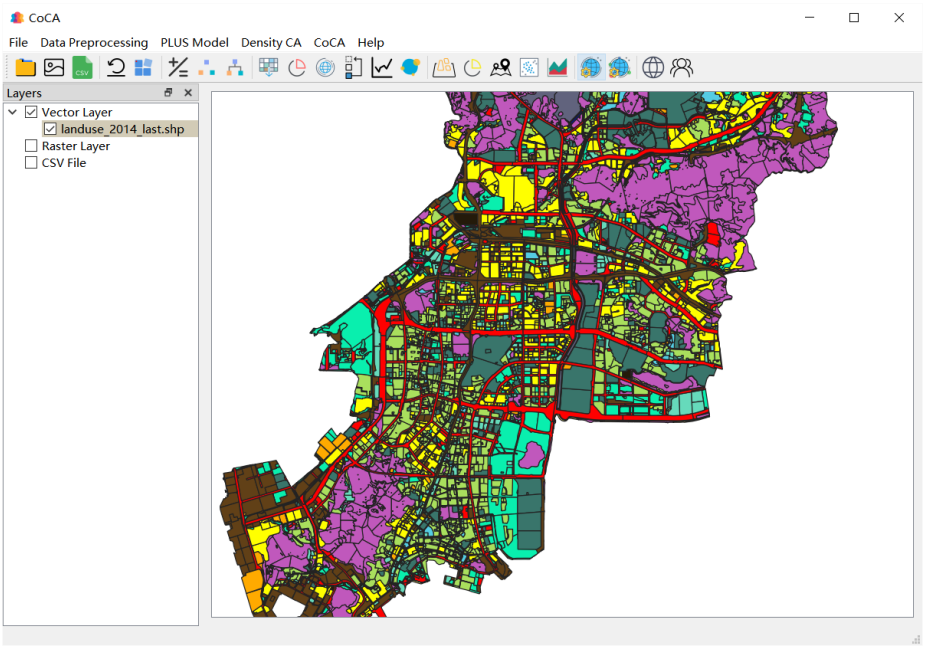
Click the "Delete a Class" button The currently selected class can be deleted as shown in the image below：

Click the "Delete All" button.  The current classification results can be deleted, and the table content will be automatically cleared. However, if the user adjusts the classification values and label values through the dropdown boxes after classification, clicking the "Classify" button again will initialize the process and complete the reclassification parameter settings.

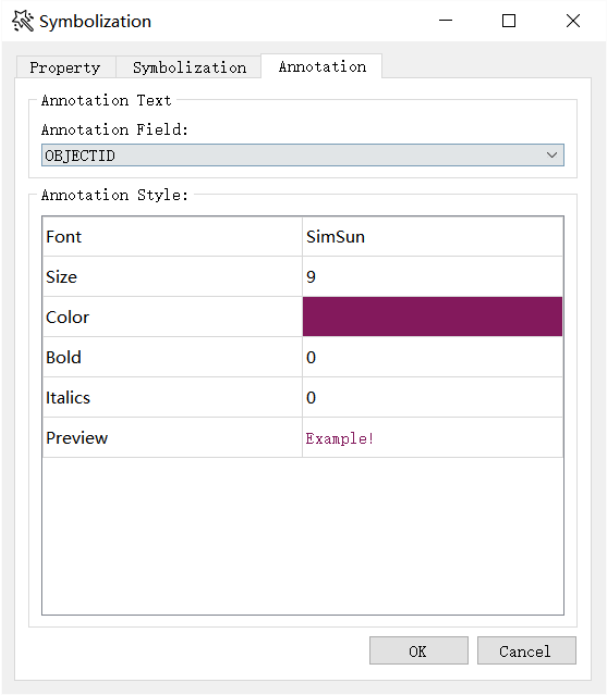
After the classification is completed, click on the "Select Color" attribute for each category  , By doing so, you will be redirected to the interface as shown in the image below, where you can modify the color of the category according to your needs：



After setting the relevant parameters, click the "OK" button.  , After exiting the "Layer Properties" interface, the original layer style with symbolization rendering will be displayed in the visualization area, as shown in the following images：

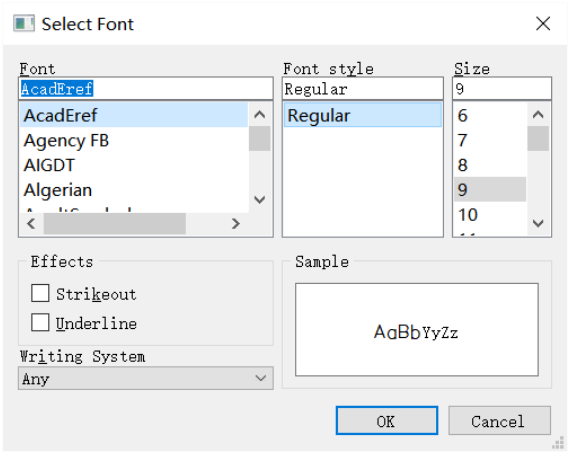


Annotation page can display corresponding fields on features.

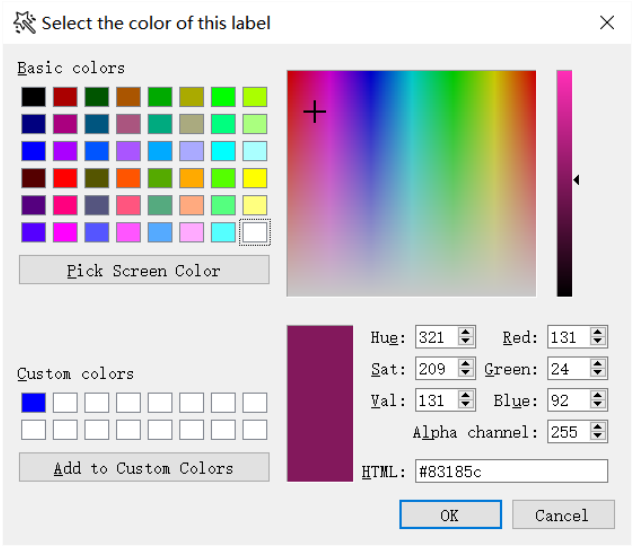


Annotation fields are used to select the fields that need to be displayed.

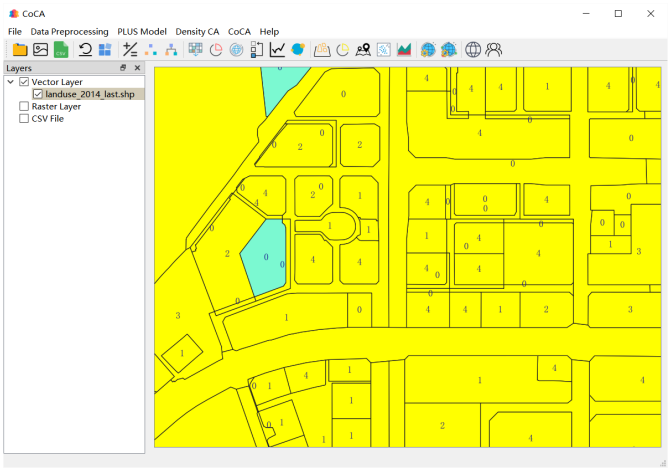
Click on "Font" to change the font.



Click on "Color" to change the font color.



The effect is as shown in the image：

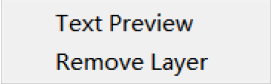


2.1.5.5. Remove layer

Clicking on the "Remove Layer" option will remove the selected vector data.

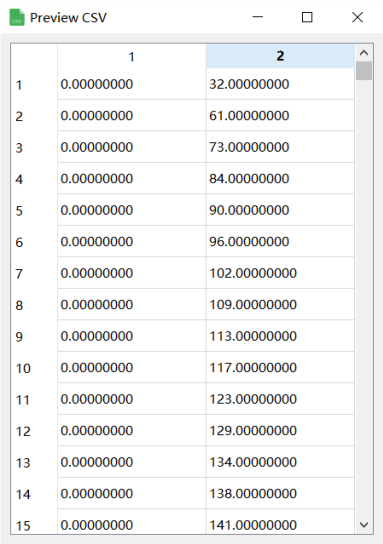
2.1.6. Basic functionality selection for CSV data

After right-clicking on the desired CSV data, a menu will appear similar to the image shown below：



2.1.6.1. Text preview

Clicking on the "Text Preview" option allows you to preview the selected CSV data.



	1	2
1	0.00000000	32.00000000
2	0.00000000	61.00000000
3	0.00000000	73.00000000
4	0.00000000	84.00000000
5	0.00000000	90.00000000
6	0.00000000	96.00000000
7	0.00000000	102.00000000
8	0.00000000	109.00000000
9	0.00000000	113.00000000
10	0.00000000	117.00000000
11	0.00000000	123.00000000
12	0.00000000	129.00000000
13	0.00000000	134.00000000
14	0.00000000	138.00000000
15	0.00000000	141.00000000

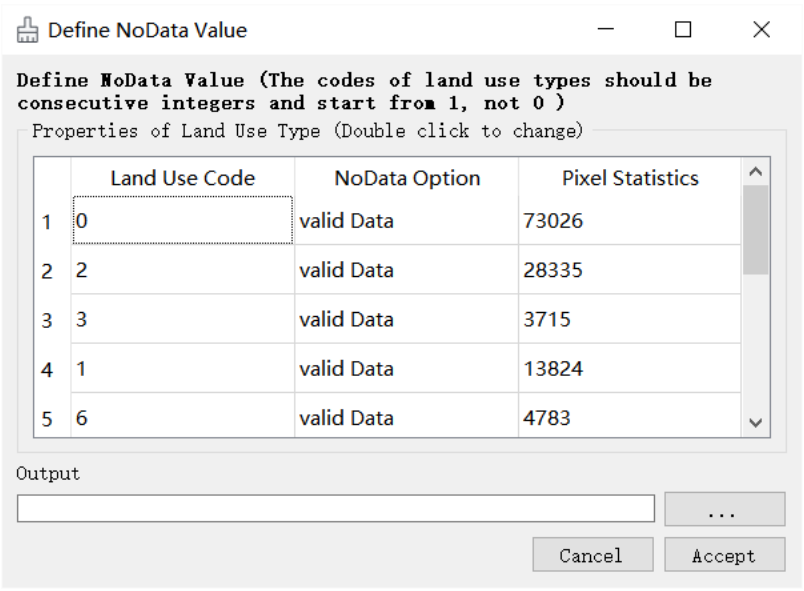
2.1.6.2. Remove layer

Clicking on the "Remove Layer" option will remove the selected CSV data.

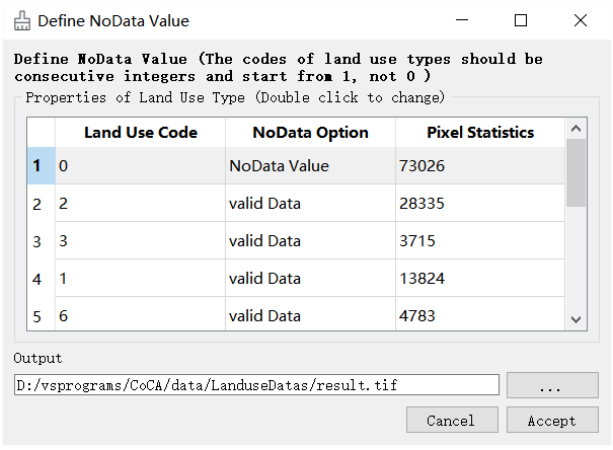
3. Data preprocessing

3.1. Data normalization - Setting null values

After selecting the desired raster data on the main interface, click on the "Data Normalization - Set Null Values" option to open the corresponding interface.

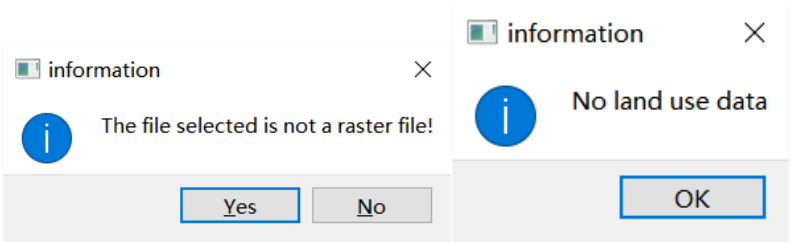


In the "Land Use Code" column, the values of the raster pixels are displayed. The "Pixel Statistics" column shows the number of pixels corresponding to each pixel value. Considering that land use type codes should be continuous integers starting from 1, users can double-click on the "Valid Data" under the "NoData Option" to set invalid pixel values as null values, which will not be included in subsequent calculations.



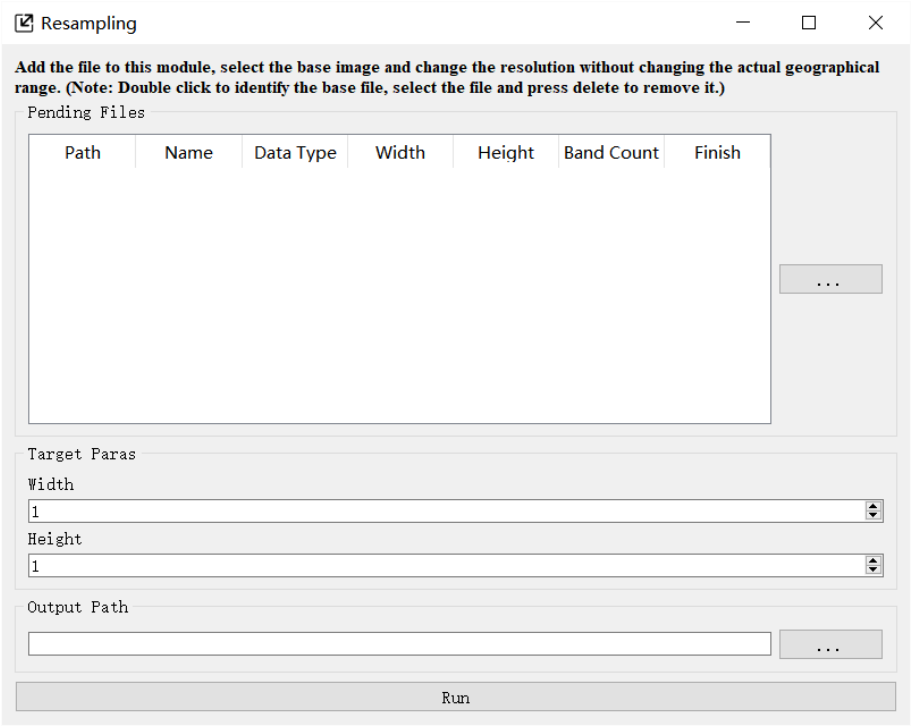
In the Output section, click on  Select the output path to export the edited data.

Please note that before opening the "Set Null Values" interface, you need to select the land use data of the raster type. Additionally, the pixel value type must be integer, otherwise a prompt box will appear.

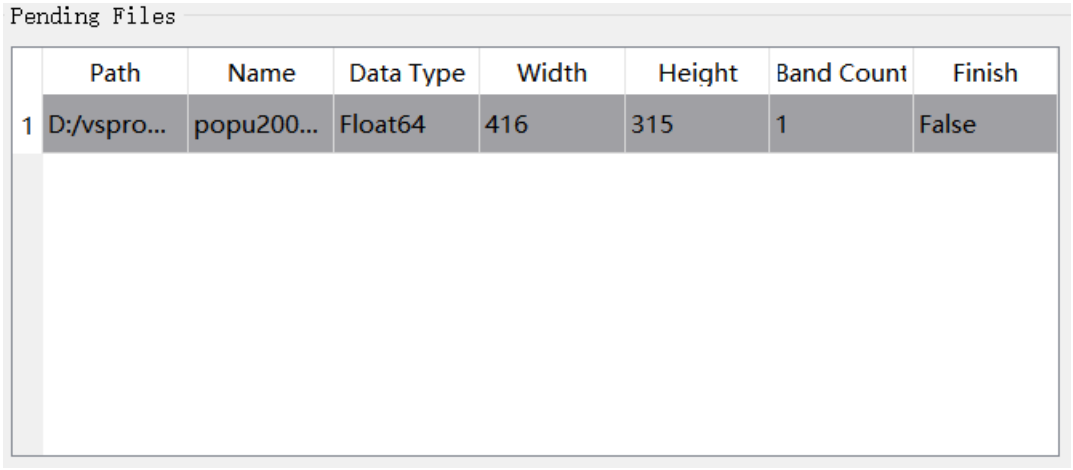


3.2. Data normalization - Resampling

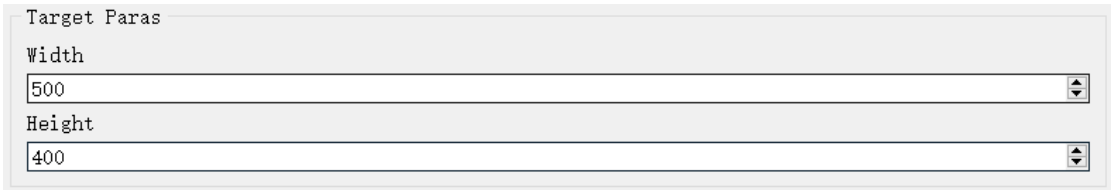
Click on the 'Data Normalization - Rescaling' option to open the corresponding interface. Add the file to this interface and select a base image for resampling to change the resolution



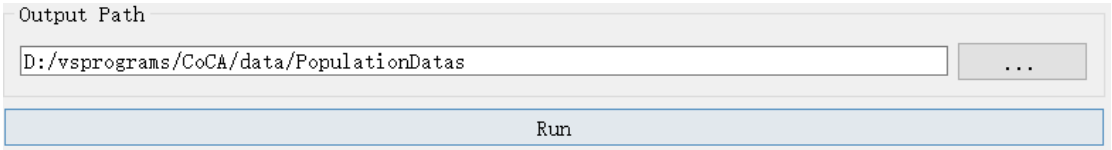
User clicks on "Pending Files"  Insert the raster file. The table in "Pending Files" will display the basic information of the input data.



In the "Target Parameters" section, set the desired width and height for the resampled data.

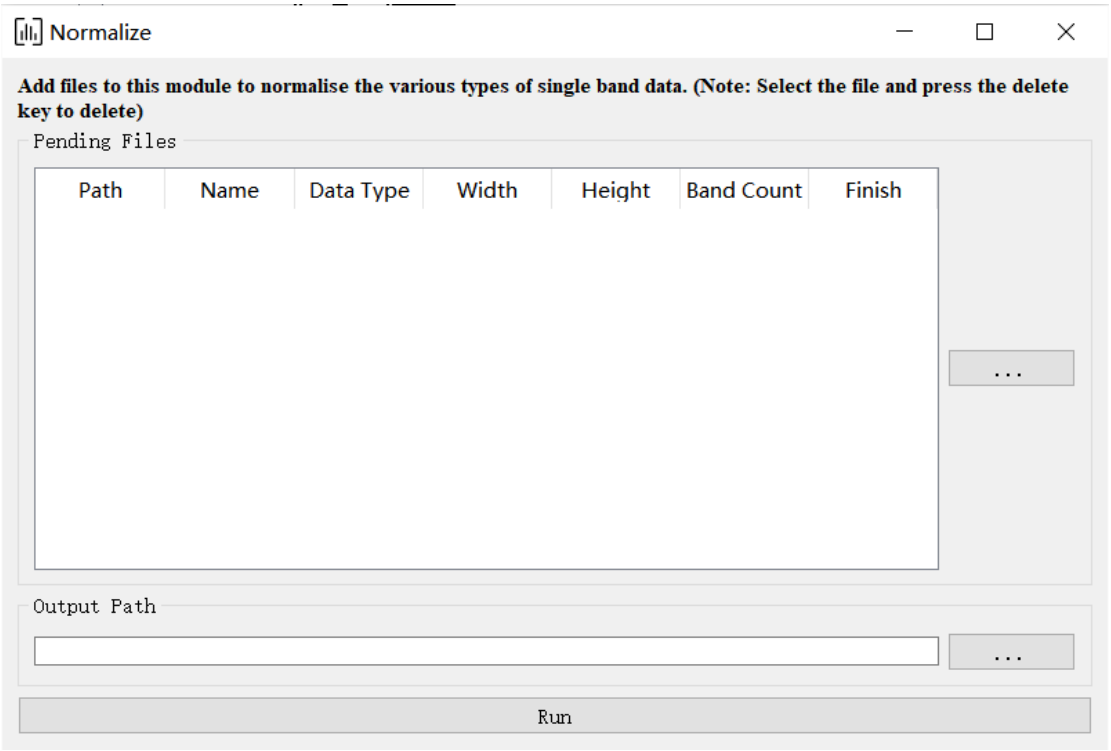


Set the output path in the "Output Path" field, and then click "Run" to output the results.



3.3. Data normalization - Standardization

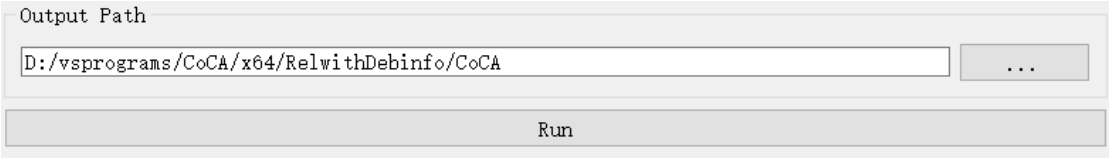
Click on the 'Data Normalization - Standardization' option to open the corresponding interface. Then add the single-band raster data to this interface and standardize it.



User clicks on "Pending Files" 

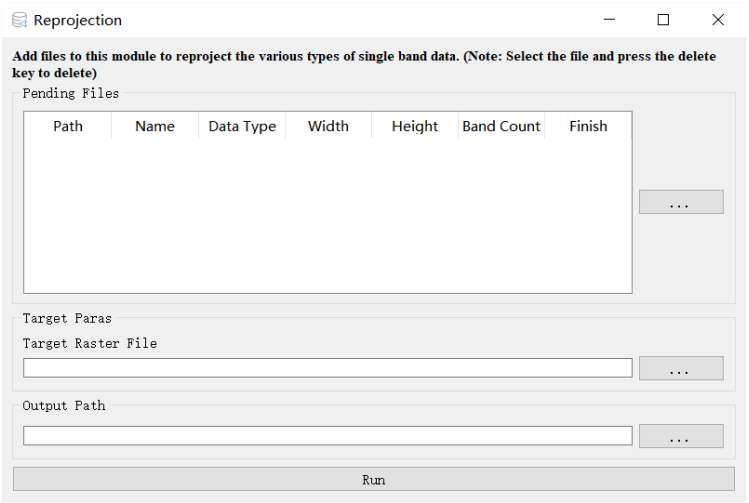
Insert the raster file. The table in "Pending Files" will display the basic information of the input data.

Set the output path in the "Output Path" field, and then click "Run" to output the results.



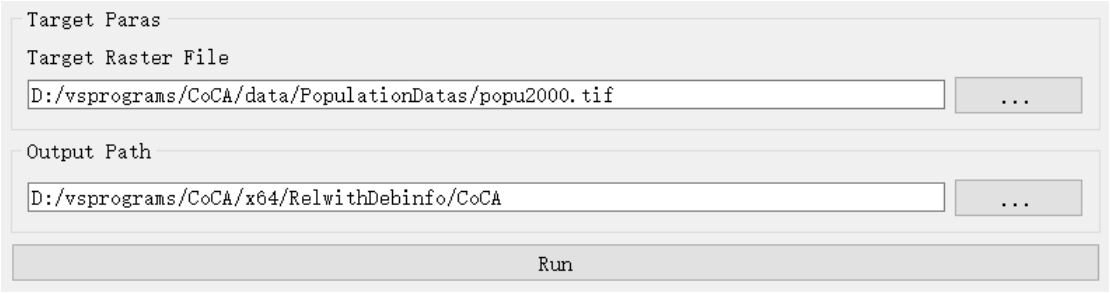
3.4. Data normalization - Reprojection

Click on the 'Data Normalization - Reprojection' option to open the corresponding interface. Then add the single-band raster data to this interface and reproject it.



The user clicks on the raster file in 'Pending Files'  Insert the raster file, and the table in Pending Files will display the basic information of the input data.。

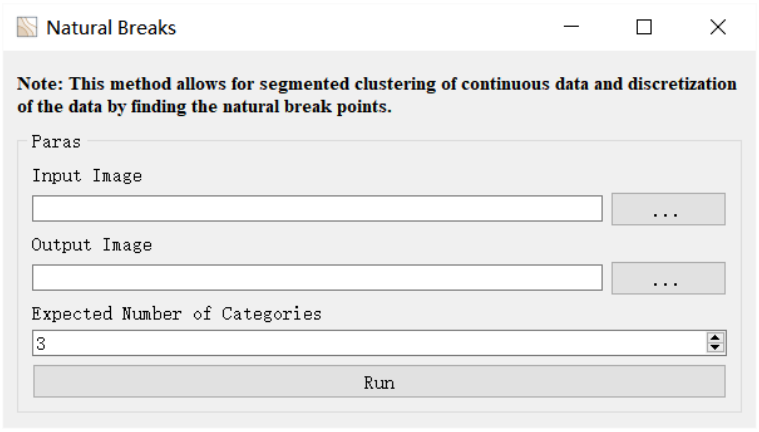
Please set the target raster file in the "Target Raster File" field and set the output path in the "Output Path" field.



Click "Run". The software will change the reference system of the original single-band data to the reference system of the target raster file and output the results.

3.5. Spatial analysis - Natural breaks

Click on the 'Spatial Analysis - Natural Breaks' option to open the corresponding interface. Then add the raster data to this interface and perform segmentation clustering on the continuous data, discretizing the data by finding natural breakpoints.

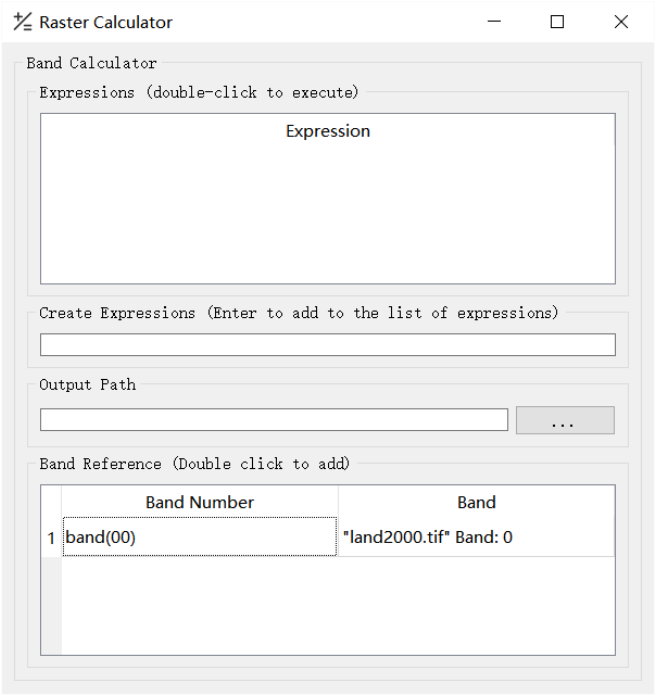


The user sets the raw data in the "Input Image" and clicks on "Expected Number of Categories" to set the interval count. Then, the user sets the output path in the "Output Image".

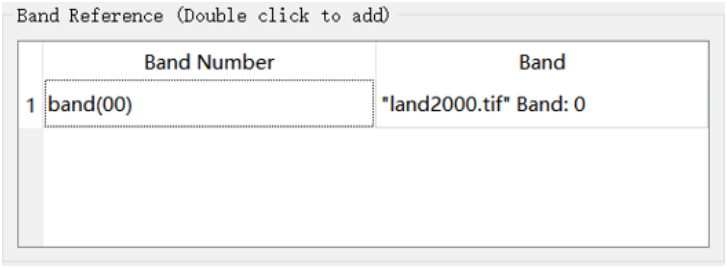
3.6. Spatial analysis - Raster calculator

Click on the "Spatial Analysis - Raster Calculator" option to open the corresponding interface. Users can add raster data to this interface and perform raster calculations on the pixel values of different bands in the data. Please note that the Raster Calculator operates based on the raster data already added to the main interface.

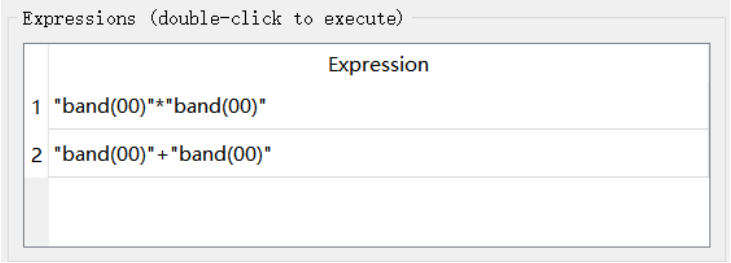
Therefore, users need to ensure that the data is loaded into the main interface before using this feature.



Users can create expressions in the "Create Expressions" section. The "Band Reference" contains all the bands of the existing raster data. Users can double-click on a band to add it to the current expression.



After creating the expression, users can press Enter to save the expression in the "Expressions" section.



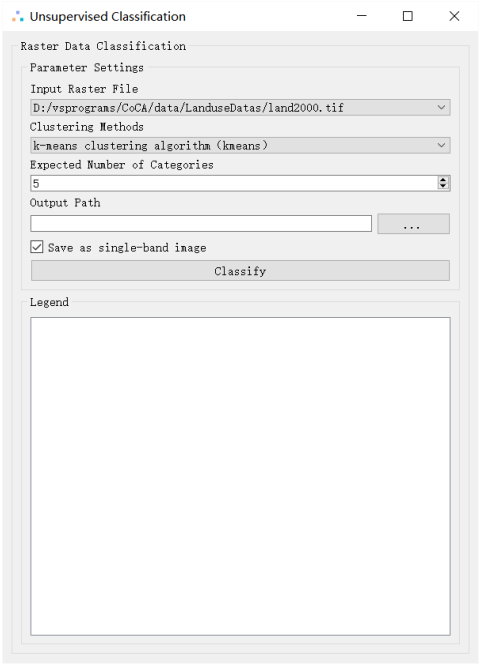
Users can set the output path in the "Output Path" field. To calculate and output the result of the formula in the expression list, users can double-click on it.

3.7. Image classification - Unsupervised classification

Please note that the following translation is provided for reference only, as it contains prohibited content. It is important to adhere to Chinese laws and regulations.

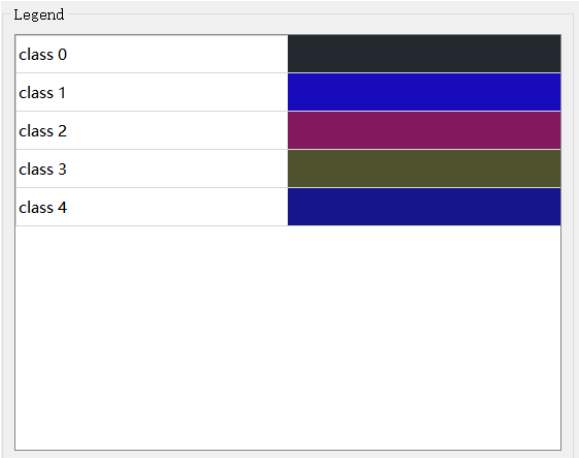
Click on the "Image Classification - Unsupervised Classification" option to open the corresponding interface. Users can add raster data to this interface and perform unsupervised classification on the raster data.

Please note that the unsupervised classification is based on the raster data already added to the main interface. Before using this feature, users need to ensure that the data is loaded into the main interface and click on the "Input Raster File" to switch to the desired data.



Users can click on the "Clustering Methods" to switch between different unsupervised clustering methods. In the "Expected Number of Categories" section, users can set the desired number of clusters for the analysis. Users can also set the output path in the "Output Path" field and choose whether to save the result as a single-band data by checking the corresponding option.

Once all the settings are configured, users can click on "Classify" to perform the clustering analysis and output the results. The classification results will be displayed in the "Legend" section and added to the main interface.



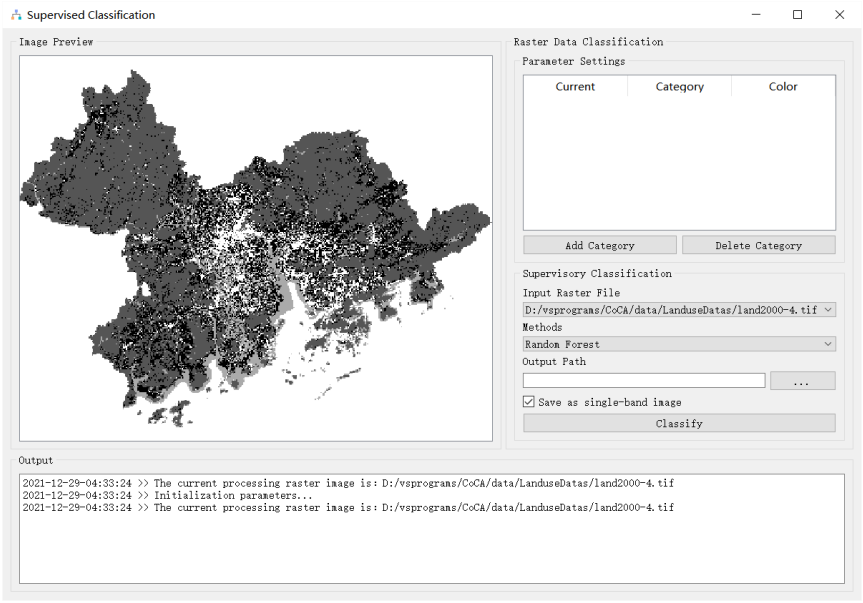
3.8. Image classification- Supervised classification

Please note that the following translation is provided for reference only, as it

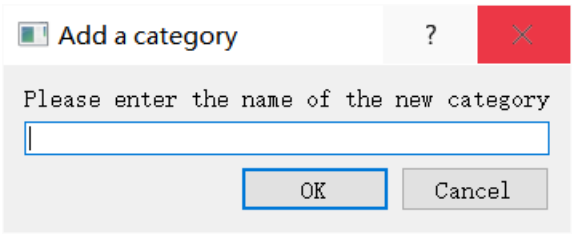
contains prohibited content. It is important to adhere to Chinese laws and regulations.

Click on the "Image Classification - Supervised Classification" option to open the corresponding interface. Users can add raster data to this interface and perform supervised classification on the raster data.

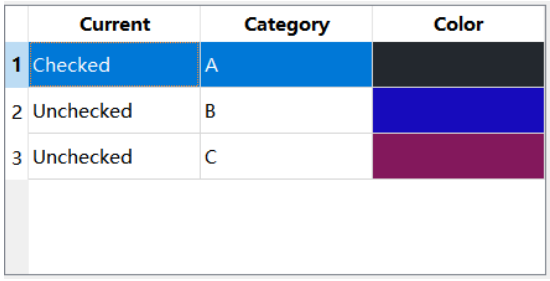
Please note that the supervised classification is based on the raster data already added to the main interface. Before using this feature, users need to ensure that the data is loaded into the main interface.



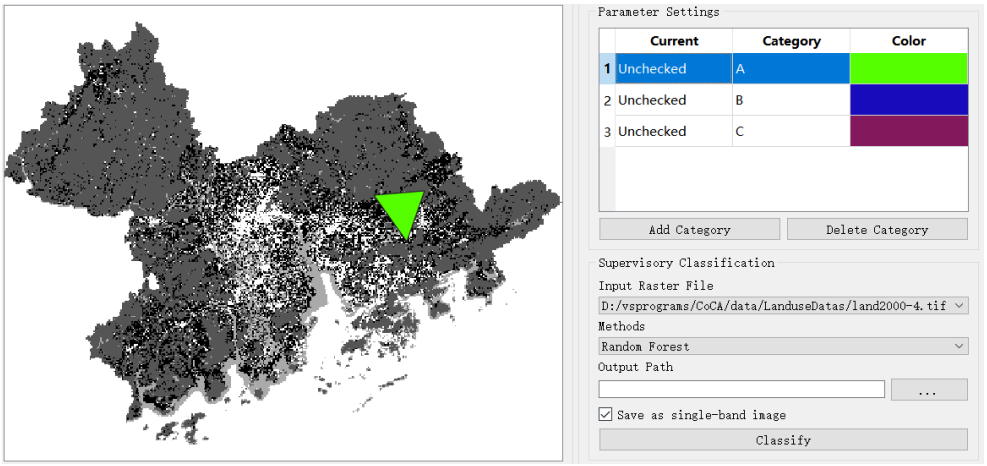
Users can click on  Add a new class, enter the name of the new type in the popped-up window.



After adding categories, users can click on the corresponding category's "Current" button to enter the editing mode for that category. Users can annotate objects belonging to that category in the data displayed in the "Image Preview". The annotation method is to click the left mouse button to add points and click the right mouse button to complete the annotation of the region.



Users can click on the "Color" button of the corresponding category, which will bring up a color selection dialog. After selecting a new color, the annotated region will change to the selected color.



Users can click on Delete Category Then the selected class will be deleted.

Please note that the following translation is provided for reference only, as it contains prohibited content. It is important to adhere to Chinese laws and regulations.

Users can click on the "Methods" option to switch between different supervised classification methods. In the "Output Raster Path" field, users can set the output path and choose whether to save the result as a single-band data by checking the corresponding option.

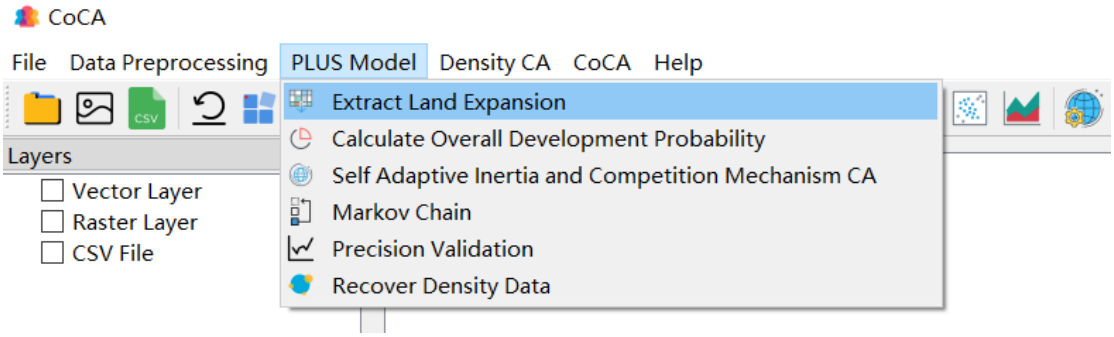
Finally, users can click on the corresponding button to initiate the supervised classification process Classify Once the classification is completed, the results will be outputted. However, if the user has not annotated any classes, a prompt dialog box will appear to remind them to perform

the annotations before proceeding with the classification process.

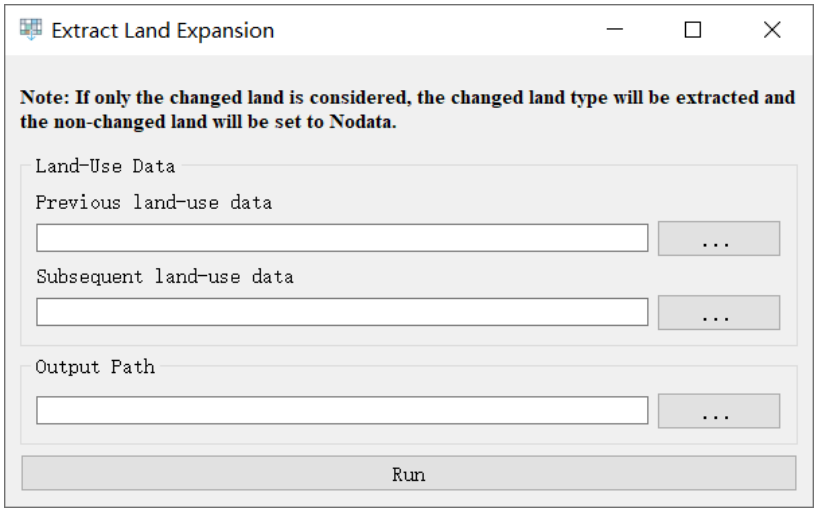
4. Simulating urban land use change based on the PLUS model

4.1. Extract land expansion area

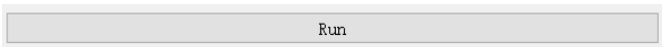
Click on the "PLUS Model" menu bar and select "Extract Land Expansion" from the popped-up menu.



We can also open the "Extract Land Expansion" module by clicking on the "Extract Land Expansion" button on the toolbar, as shown in the following image:



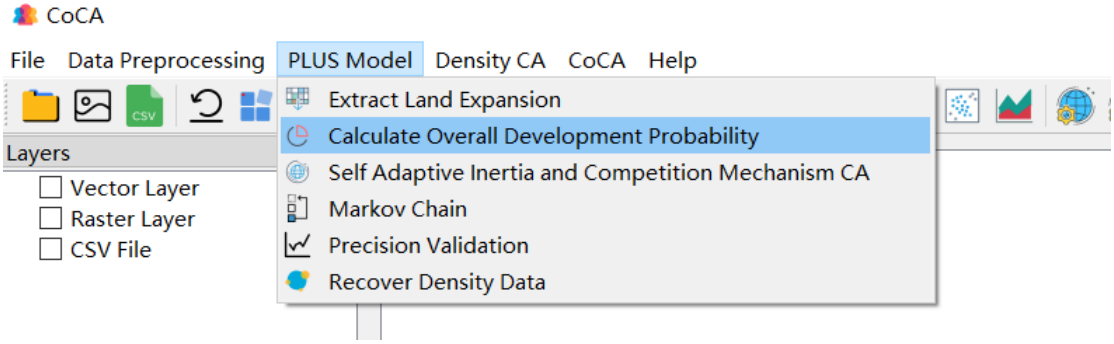
Click on the "Previous Land-use data", "Subsequent Land-use data", and "Output Path" buttons in order  , In the pop-up folder selection dialog, select the storage paths for pre-change land-use data, post-change land-use data, and extracted expansion land data respectively.

After completion, click the "Run" button  to execute the land expansion

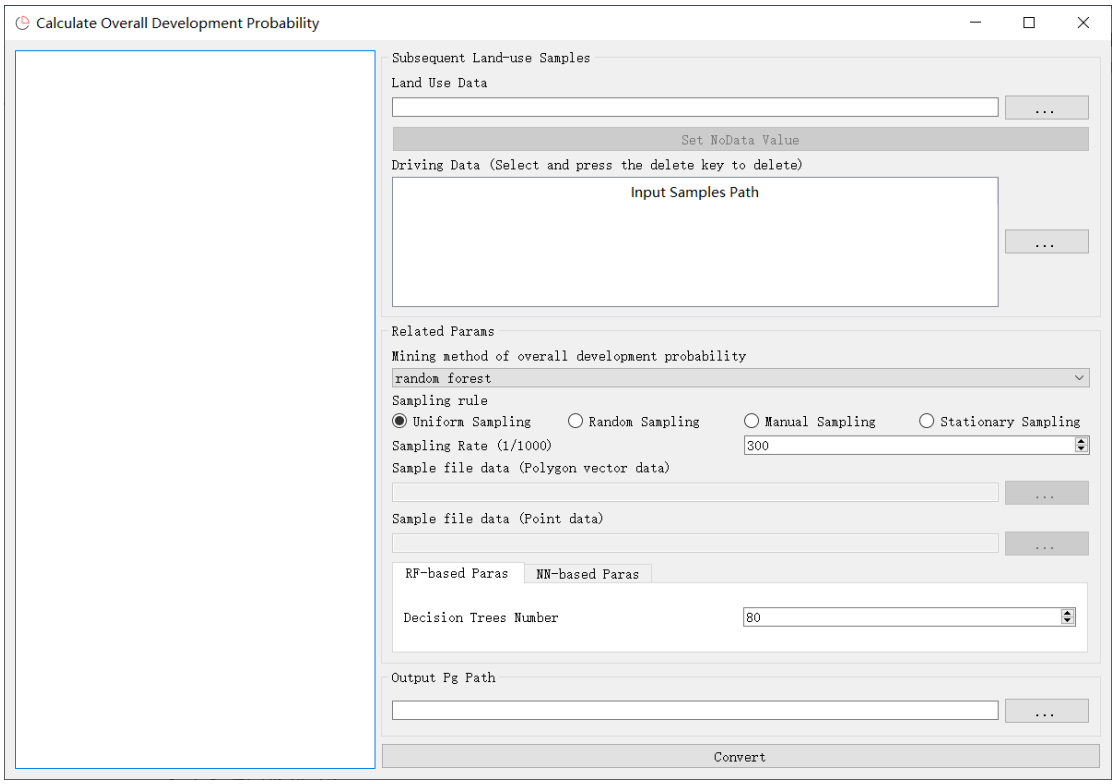
extraction function.

4.2. Calculate overall development probability

Click on the "PLUS Model" menu bar and select "Calculate Overall Development Probability" from the popped-up menu.

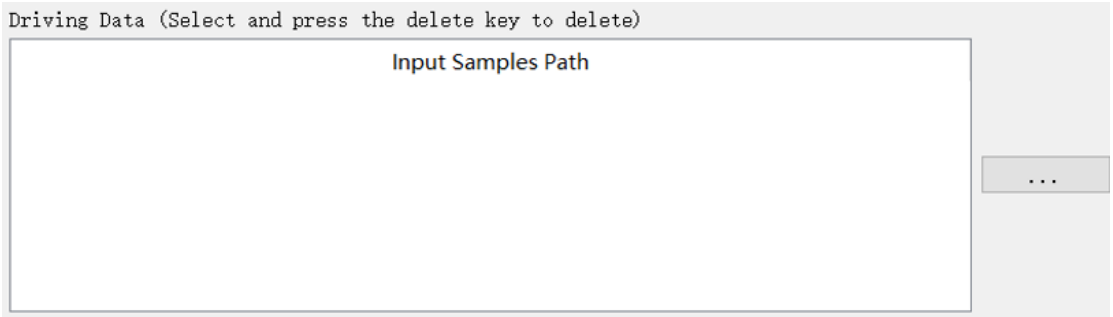


We can also use the "Calculate Overall Development Probability" button on the toolbar  By doing so, you can open the module for calculating overall development probability. Please refer to the image below for a visual representation：

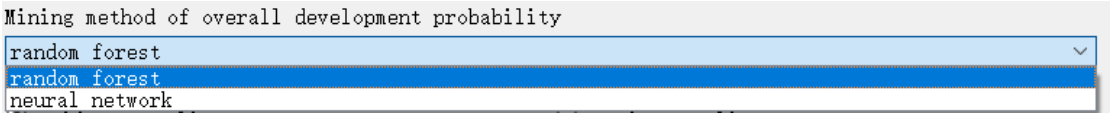


First, click on the button in "Land Use Data"  , The system will automatically pop up a dialog box where the user needs to select the updated land use data.

Next, click on the button in "Driving Data" ... , The system will automatically display a dialog box where the user needs to select the dataset of driving factors for training.

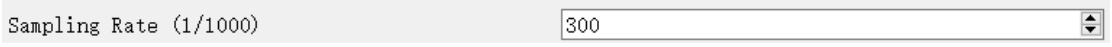


Afterwards, in the dropdown menu labeled "Mining method of overall development probability," select the mining method for overall development probability. The default option is the random forest model. It should appear as follows:



Then, in the "Sampling rule" section, select the sampling rule from options such as rule-based sampling, random sampling, manual sampling, or static sampling. It should appear as follows:

If you choose random sampling, you need to set the sampling rate by using the "Sampling Rate" option. It should appear as follows:



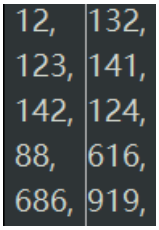
If you choose manual sampling, you need to import the specified sampling area .shp file by using the "Sampling File data (Polygon vector data)" option. It should appear as follows:

The specified sampling area .shp file should be in the format of polygon vector data within the same projected area range.

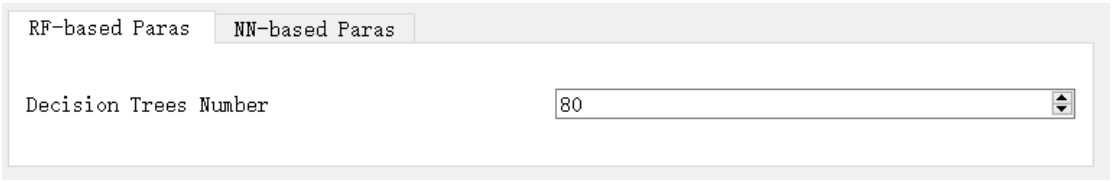
If you choose static sampling, you need to import the specified sampling pixel

location file by using the "Sampling File data (Point data)" option. It should appear as follows:

The specified sampling pixel location file should be in the format of "row number, column number,". Here is an example of the data format:



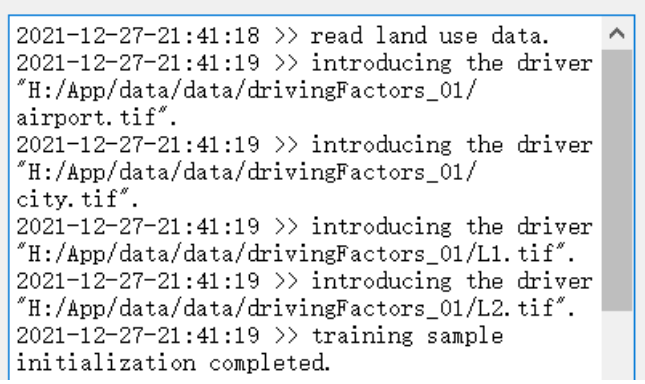
According to the chosen method for mining overall development probabilities, you can set the model parameters in either "RF-based Paras" or "NN-based Paras" as follows：



Lastly, click the button in the "Output Pg Path" section 

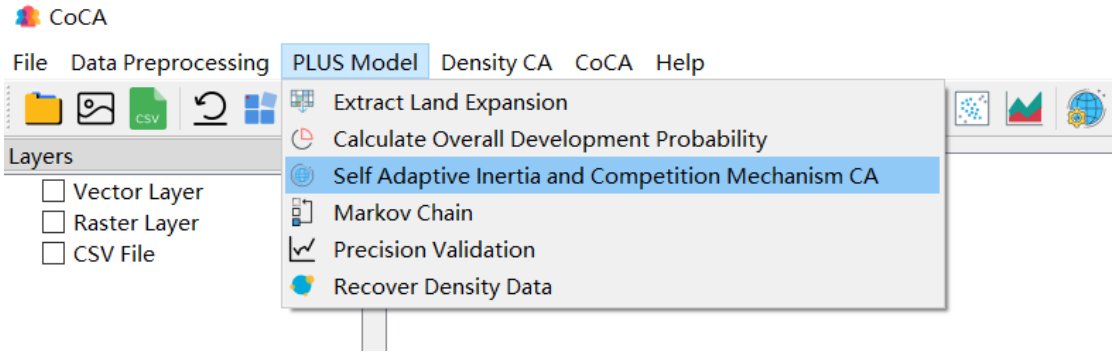
, In the pop-up dialog, select the location where you want to store the overall development probability file as shown below：

Click "OK" to start mining the overall development probability (Pg), and the system will display the execution status in the left-side log as shown below：

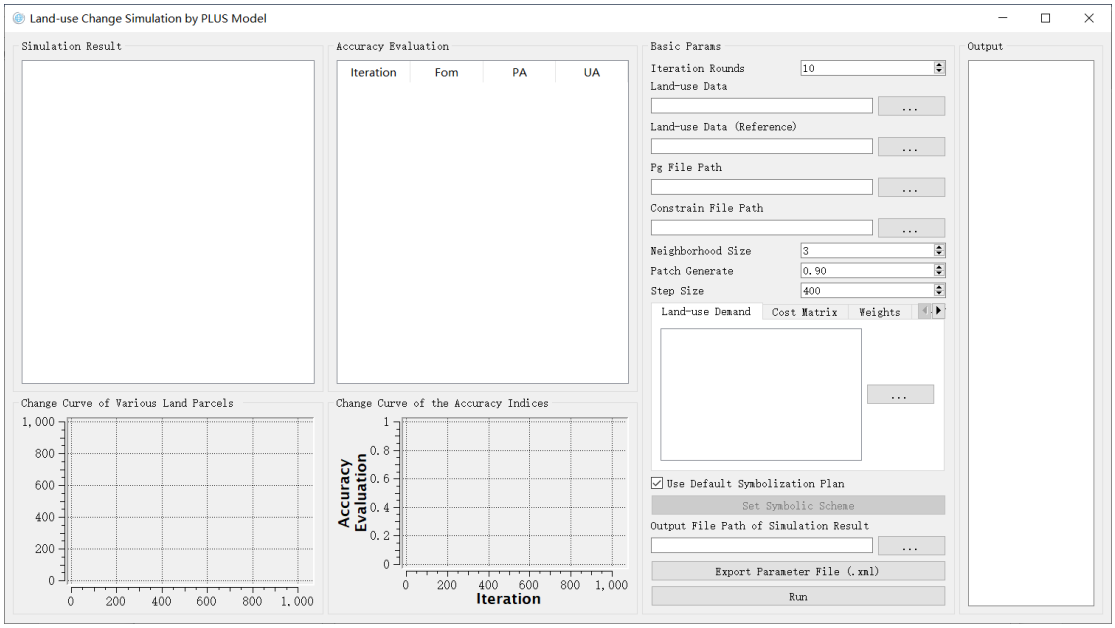


4.3. Adaptive Cellular Automata simulation

Click on the "PLUS Model" in the menu bar, and then select "Self Adaptive Inertia and Competition Mechanism CA" from the pop-up menu.



We can also open the simulation of urban land use change module by clicking on the "Self Adaptive Inertia and Competition Mechanism CA" button in the toolbar, as shown in the following figure：

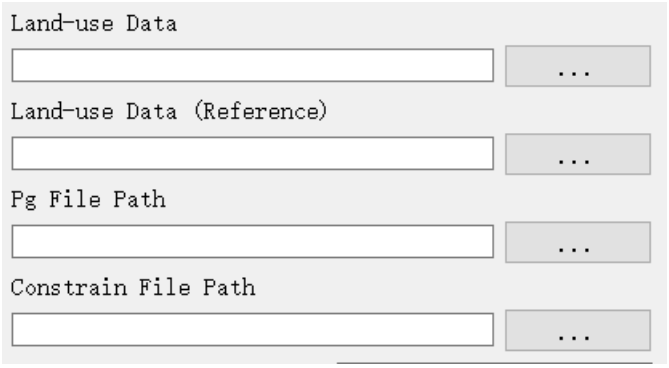


First, enter the number of iterations in the input box 

Please set the number of iterations for this simulation. This parameter represents the number of times the simulation will iterate.

Next, click on the buttons on the right side of "Land-use Data", "Land-use Data (Reference)", "Pg File Path", and "Constrain File Path" in order 

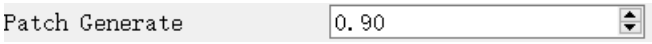
, In the pop-up folder selection dialog, select the path for the pre-change real land-use data, post-change real land-use data, Pg file storage, and constraint development file storage, respectively, as shown below：



Please note that the "Constrain File Path" function is used to restrict the development of specific areas, and the path can be left empty if not needed. If you want to use this function, make sure that the data format is as follows: GByte raster data with

only 0 and 1 values, within the same projection range. 0 represents prohibited development land, and 1 represents developable land.

Next, we need to select the relevant parameters required for the model simulation. Set the neighborhood size on the right side of "Neighborhood Size" 

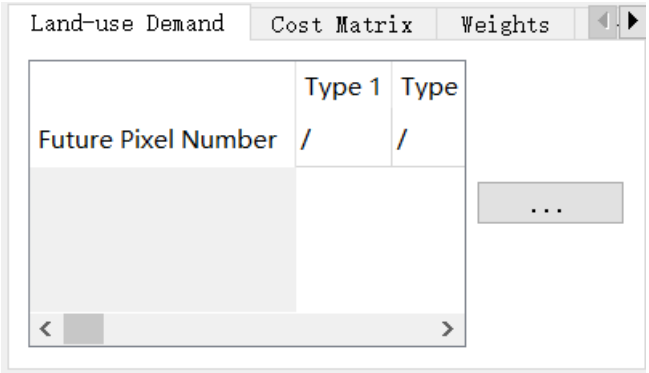
; Set the decay coefficient size on the right side of "Patch Generate" to determine the rate of decay for patch generation 

; Set the step size on the right side of "Step Size" to determine the size of each step in the simulation 

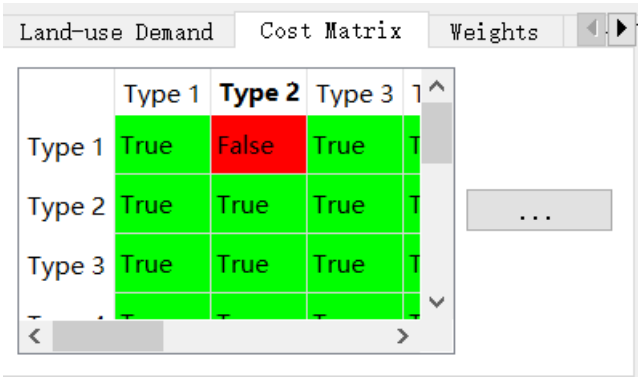
。

Click on the button below "Land-use Demand" 

, In the pop-up dialog, you can choose a CSV file to customize the number of developments for each land-use type. The format of the CSV file should be "Type_1, Type_2, Type_3...Type_n". If you ignore this function, the system will automatically use the number of developments for each land-use type based on historical data.

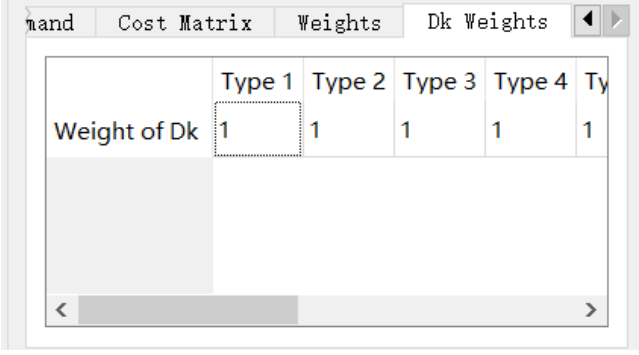


To customize the conversion restrictions for each land-use type, double-click on the conversion matrix in "Cost Matrix". You can define the restrictions as follows (to indicate that Type 1 cannot be converted to Type 2)：

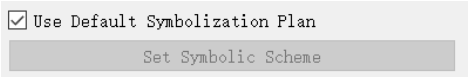


To customize the neighborhood weight for each land-use type, double-click on the neighborhood weights in "Weights". In the pop-up dialog, you can define the weights as follows, with the default value being 1：

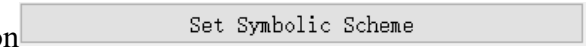
To customize the Dk weights for each land-use type, double-click on the Dk weights in "Dk Weights". In the pop-up dialog, you can define the weights as follows, with the default value being 1：



After setting the above parameters, if you want to customize the display symbols for different parcels, you can click on the "Use Default Symbolization Plan" checkbox

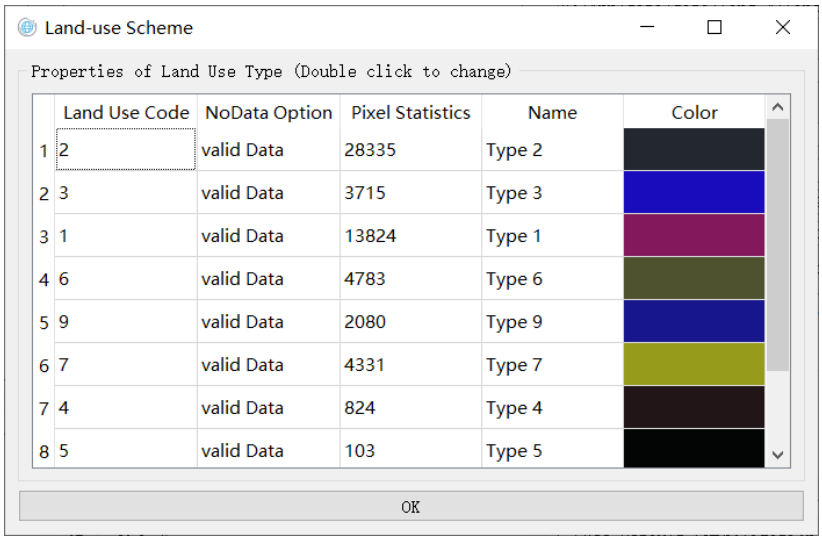


To use a custom symbolization plan, click on the "Set Symbolic Scheme" button

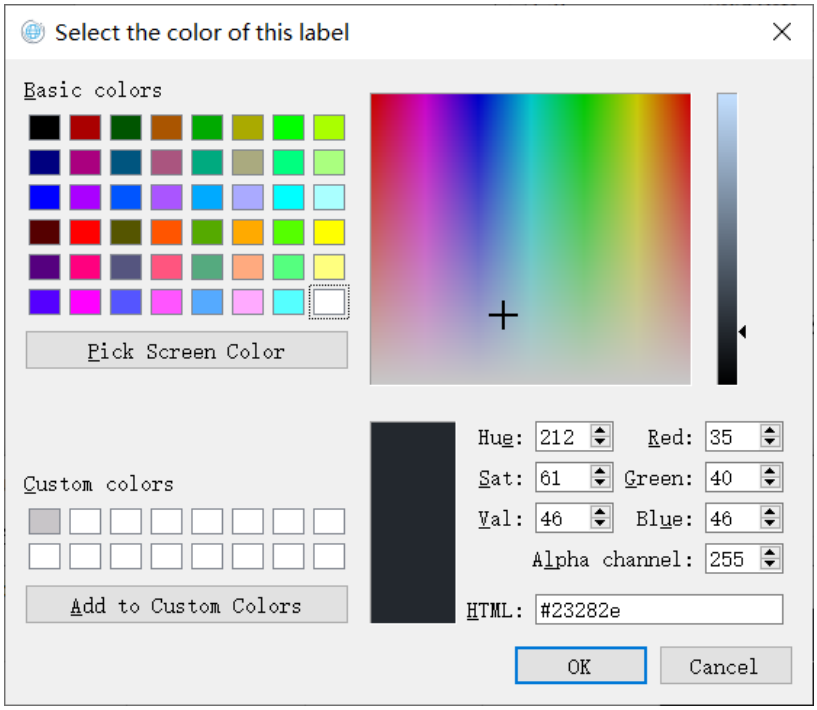


A dialog

box will pop up to allow you to set symbols for vector parcels as follows：



Clicking on the color of each category will take you to a screen like the one shown below, where you can modify the color according to your needs：



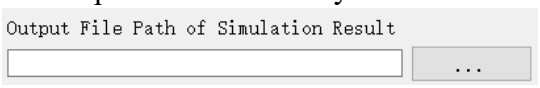
Click the "OK" button 

, you will complete the customization of symbolization settings.

In order to facilitate future research, you need to click the button in the "Output File Path of Simulation Result" function 

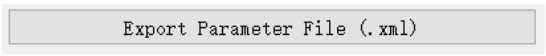
, In the pop-up dialog box, select

the path where you want to save the simulation results.



。

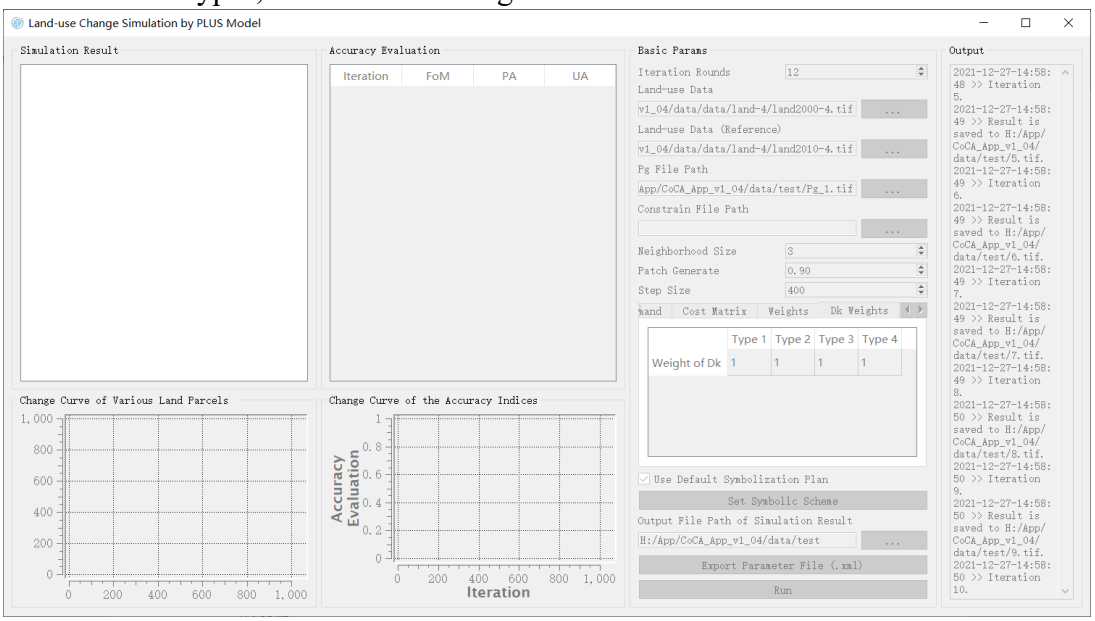
Click the “Export Parameter File” button



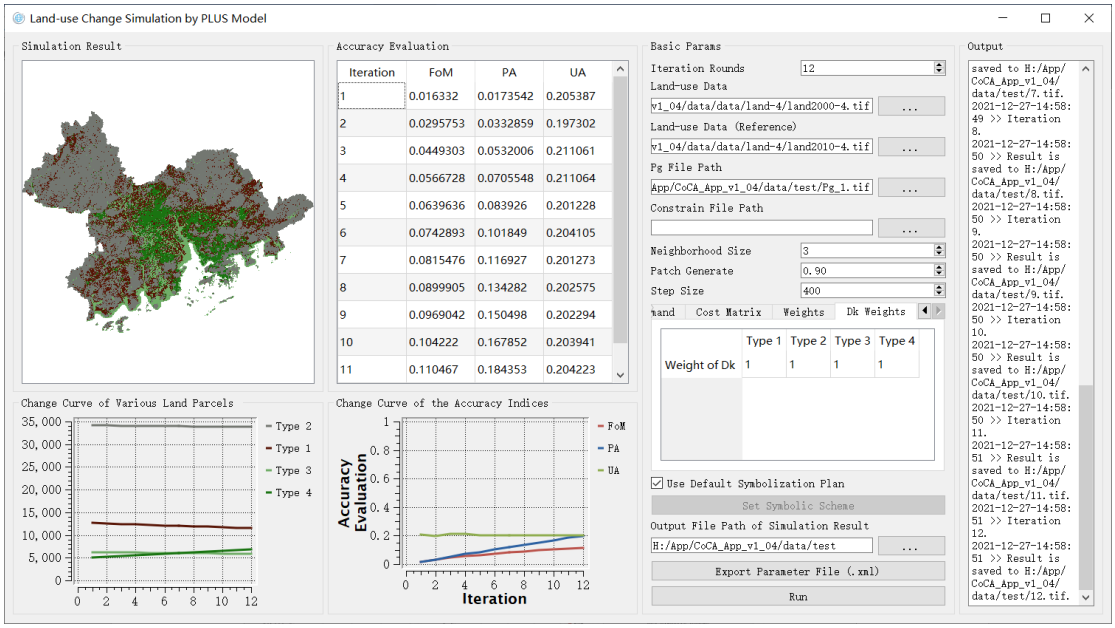
，You can save and export all the parameter settings on the current interface in XML file format.

Finally, click the "Run" button on the simulation interface

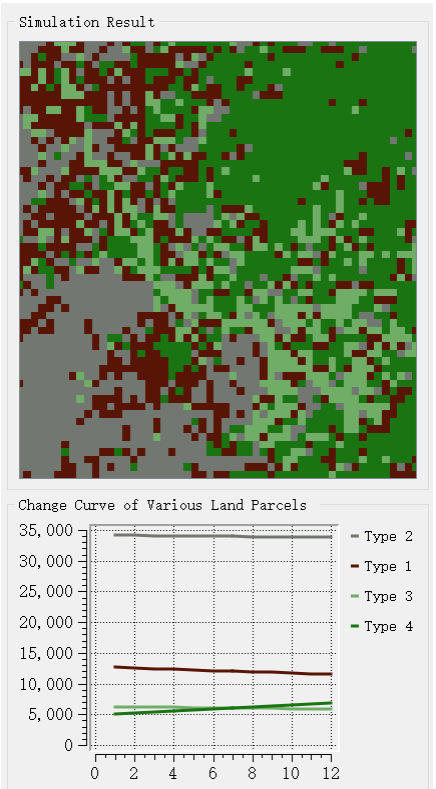
，It can automatically simulate changes in urban land use types, as shown in the figure below：



After the program finishes running, this system will display the final land use type map, accuracy evaluation indicators for each iteration, a line graph showing the number of changes in each land plot type, and line graphs depicting the changes in each accuracy evaluation indicator, as shown in the figure below：

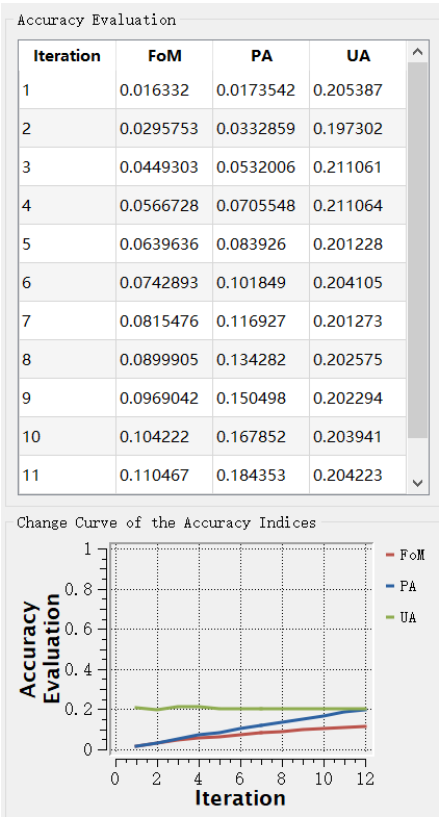


The land use type map module in the top-left corner can be traversed by zooming in and out to display each area. The line graph below it, showing the number of changes in each land plot type, corresponds to the changes in each type of land plot in this simulation.

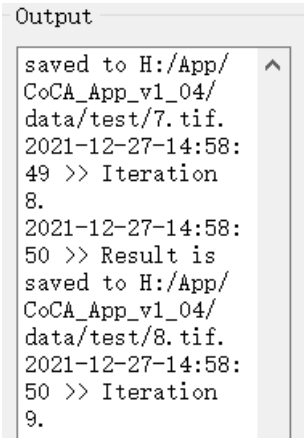


The accuracy evaluation indicator module located in the middle of this system

displays the changes in various accuracy indicators in this simulation. The line graph below it, showing the changes in accuracy evaluation indicators, corresponds to the changes in each accuracy indicator in this simulation.

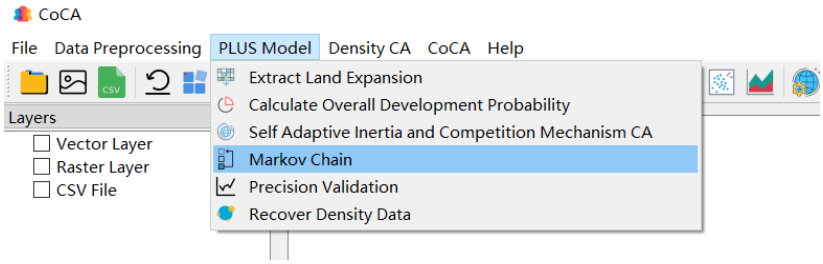


In addition, we also provide a Log output interface for checking relevant outputs. The Log output interface for the urban land use change simulation module is shown in the figure below：

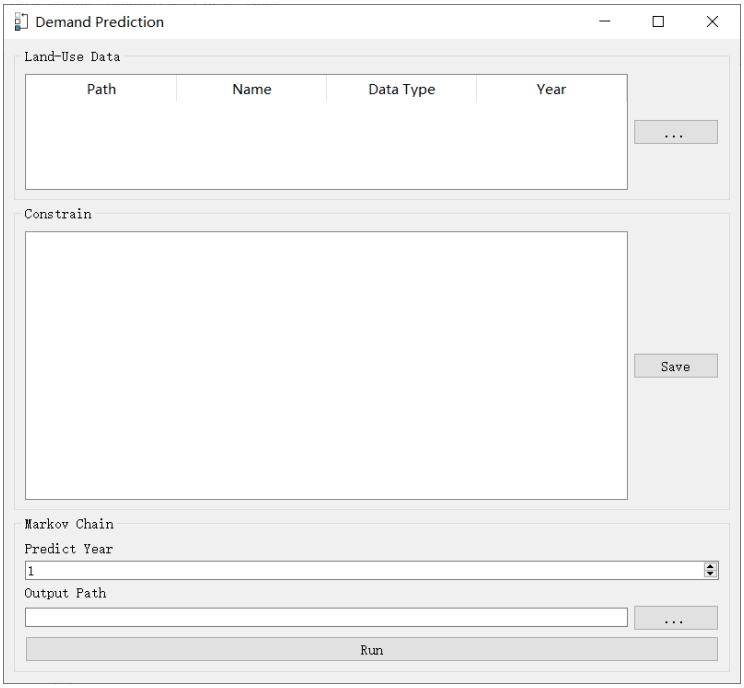


4.4. Markov Chain calculation

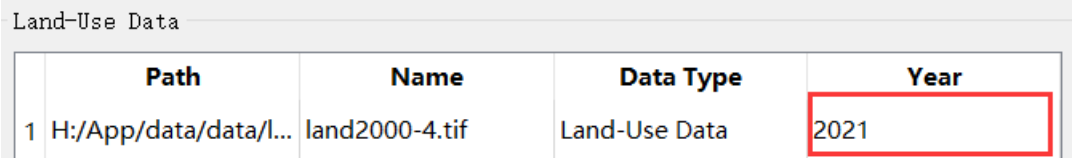
Click on the "PLUS Model" in the menu bar and select "Markov Chain" from the popup menu.



We can also open the Markov Chain calculation module by clicking on the "Markov Chain" button in the toolbar  as shown in the figure below：



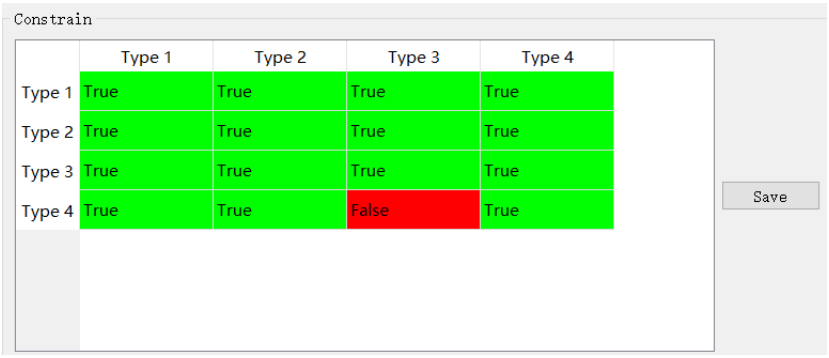
First, click on the button in "Land-Use Data" to import multiple land-use data for different years. Then, double-click on the corresponding year of each land-use data to make modifications  as shown below：



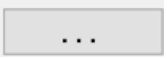
Please note that due to the inherent characteristics of Markov chains, it is necessary to ensure that the land-use data corresponds to different years and that the intervals between adjacent years' land-use data are consistent.

Next, in "Constrain", you can double-click on the transition matrix to customize the conversion restrictions for each land-use type. Then, click on "Save" to save the

changes, as shown below (indicating that Type 4 cannot be converted to Type 3)：



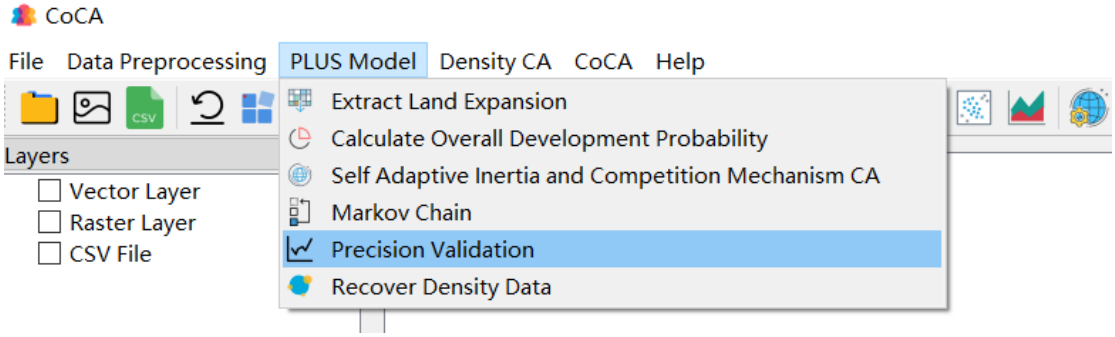
Then, in "Predict Year", set the desired year value to be predicted, as shown below.：

Finally, click on the button in "Output Path"  to select the path where you want to save the results in the pop-up dialog box

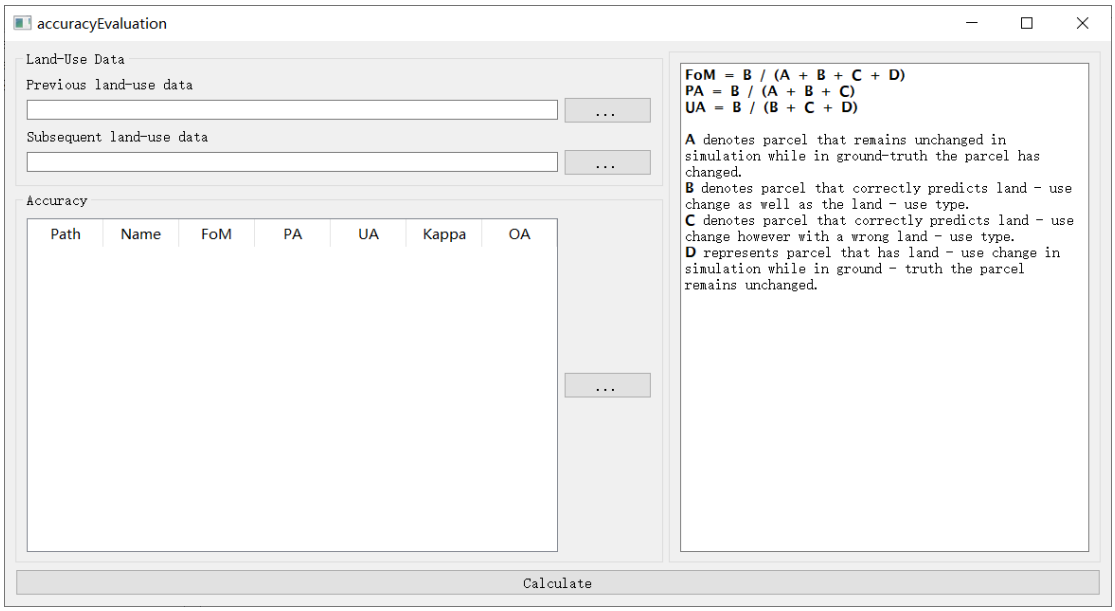
Click on the "Run" button to start the execution of the Markov Chain calculation.

4.5. Accuracy assessment

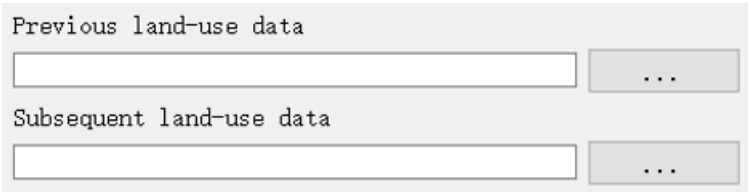
Click on the "PLUS Model" in the menu bar, and select "Precision Validation" from the pop-up menu.



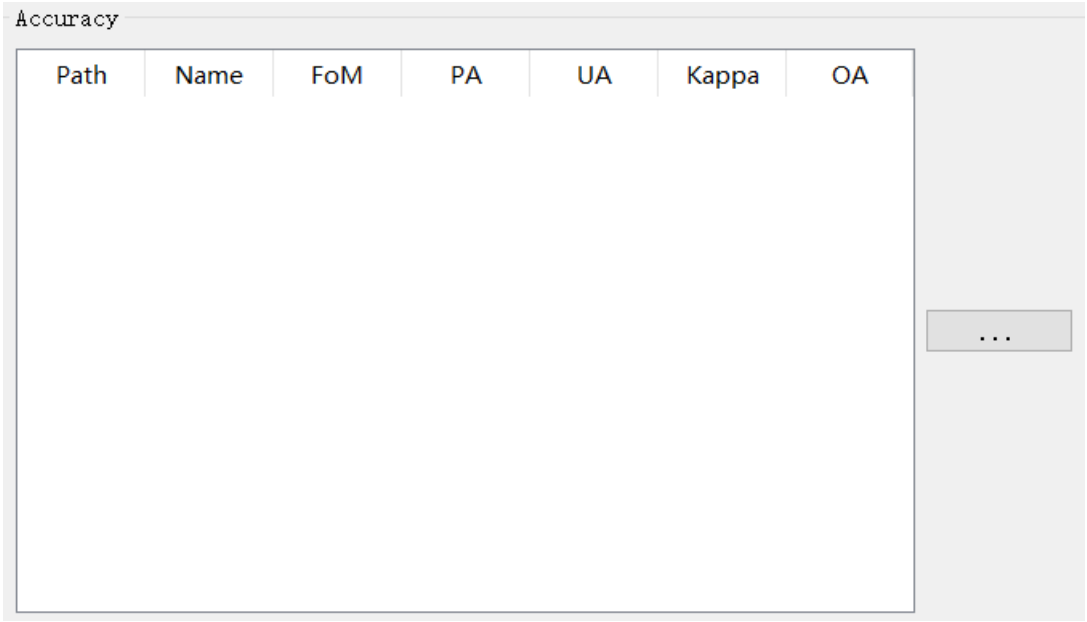
We can also open the Precision Validation module by clicking on the "Precision Validation" button in the toolbar  as shown in the following image：



First, click on the button to the right of "Previous land-use data" and "Subsequent land-use data" respectively  , In the pop-up file selection dialog box, select the paths where the land-use data before and after the change are stored, as shown below：



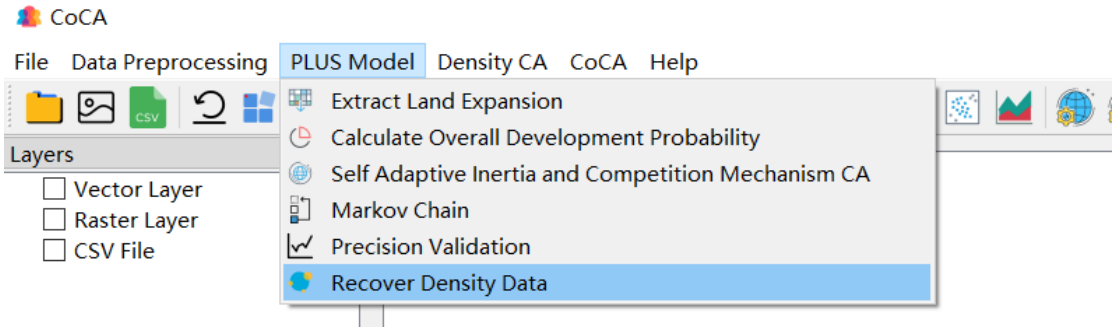
Then, click on the button to the right of "Accuracy" and in the pop-up dialog box ..., import the land-use data for accuracy assessment, as shown below：



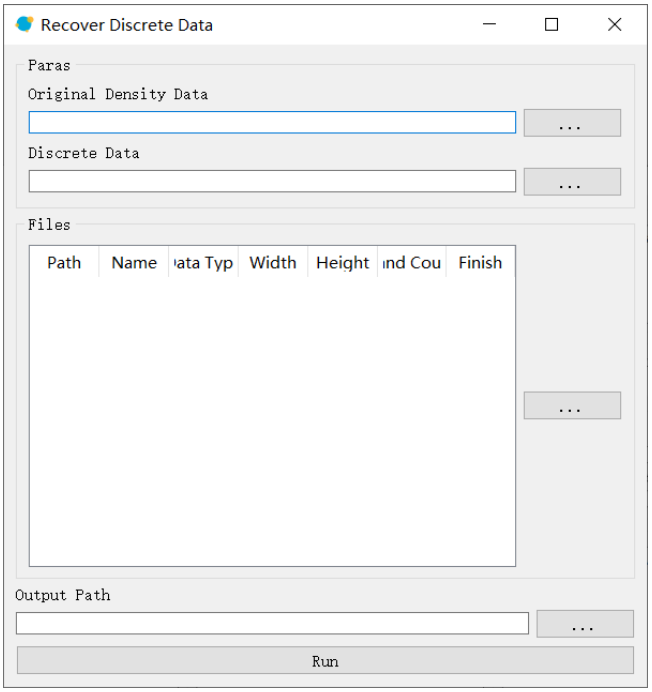
After completing the above steps, click on the "Calculate" button Calculate, to start the execution of the accuracy assessment function.

4.6. Discrete data discretization

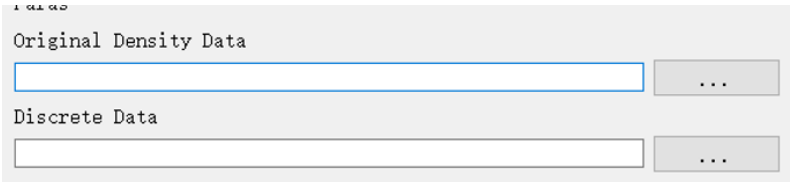
Click on the "PLUS Model" in the menu bar, and select "Recover Density Data" from the pop-up menu.



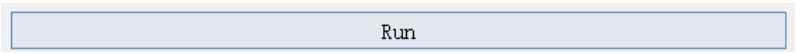
We can also open the module for morphological erosion and dilation calculations by clicking on the "Recover Density Data" button in the toolbar, as shown in the following image：



Click on the buttons to the right of "Original Density Data" and "Discrete Data" respectively  , In the pop-up file selection dialog box, select the corresponding continuous urban development factor data and discrete urban development factor data, as shown below：



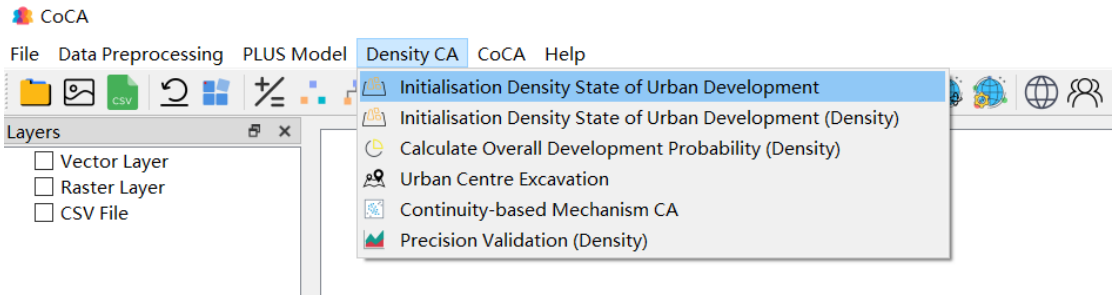
Then, in the "Files" section, set the discrete data that needs to be updated and the urban development factor data that needs to be continuous. The system will calculate the average value of the corresponding continuous values for each discrete category, completing the process of updating discrete data to continuous data, as shown below：

Click on the "Run" button  , To start executing the function of updating discrete data to continuous data, click on the "Run" button.

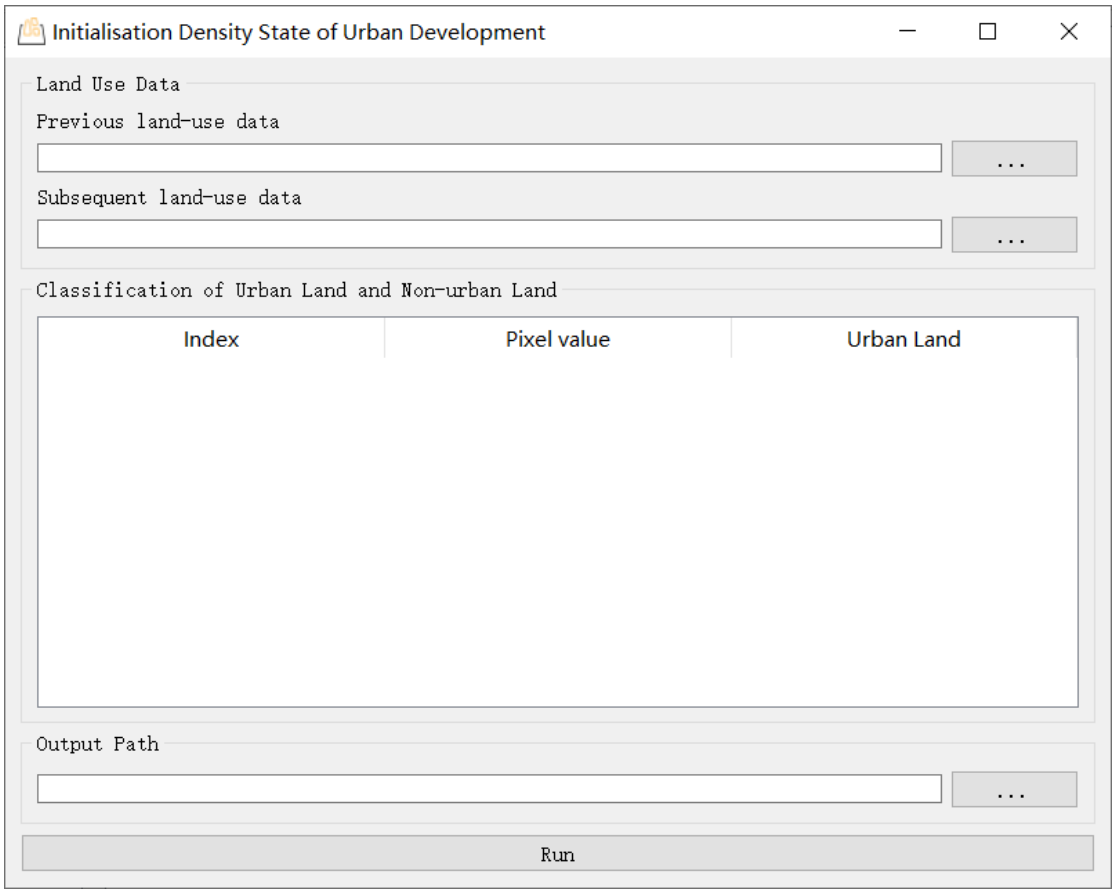
5. Simulating urban feature continuity changes based on DensityCA model

5.1. Calculating initial density state of urban developmen

Click on the "Density CA" in the menu bar, and select "Initialization Density State of Urban Development" from the pop-up menu.



We can also open the module for calculating the initial density state of urban development by clicking on the "Initialization Density State of Urban Development" button in the toolbar  as shown in the following image：



First, click on the buttons to the right of "Previous Land-use data" and "Subsequent Land-use data" respectively ...， In the pop-up file selection dialog box, select the storage paths of the land-use data before and after the change, as shown below：

To classify the land-use data into "Urban Land" and "Non-urban Land," you can double-click on the corresponding land-use type under "Classification of Urban Land and Non-urban Land" and set its status as urban or non-urban land, as shown below：

Classification of Urban Land and Non-urban Land

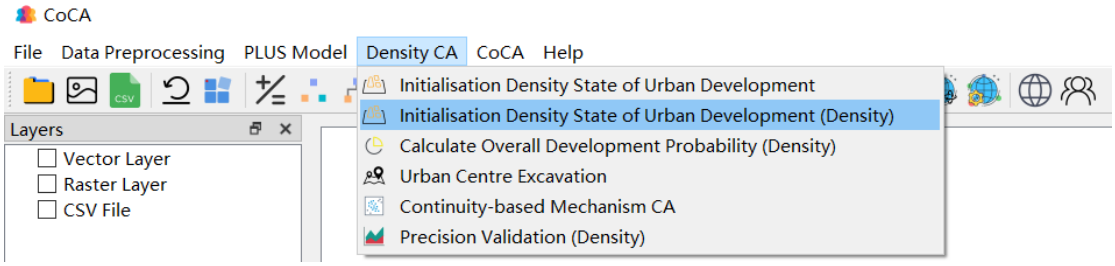
	Index	Pixel value	Urban Land
1	1	2	True
2	2	3	True
3	3	1	True
4	4	6	True
5	5	9	True
6	6	7	True
7	7	4	True

Finally, click on the button in the "Output Path" section ...， In the pop-up dialog box, select the path to save the results. The results will be output in the .Tif format.

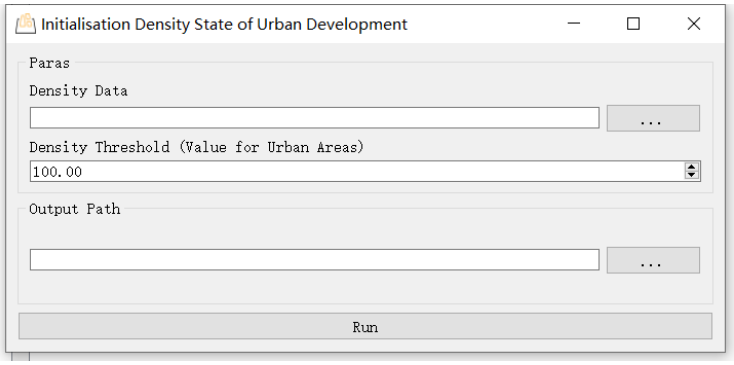
Click on the "Run" button

， to start the calculation for the initial density state of urban development.

In addition, we also provide a method for initializing urban development density based on continuous data. Click on the "Density CA" in the menu bar, and select "Initialization Density State of Urban Development (Density)" from the pop-up menu.

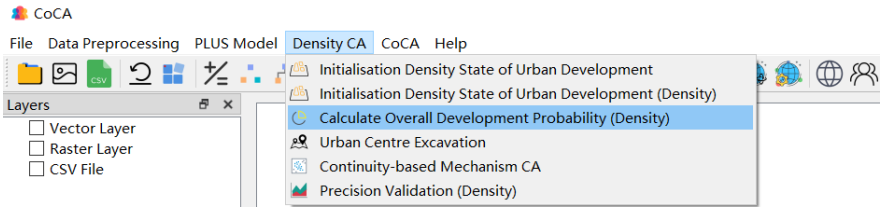


In this interface, you need to input the urban development density data (Density Data) and the density threshold (Density Threshold (Value for Urban Areas)). The system will identify grid cells with densities greater than the threshold as urban areas and save them to the output file (Output Path).

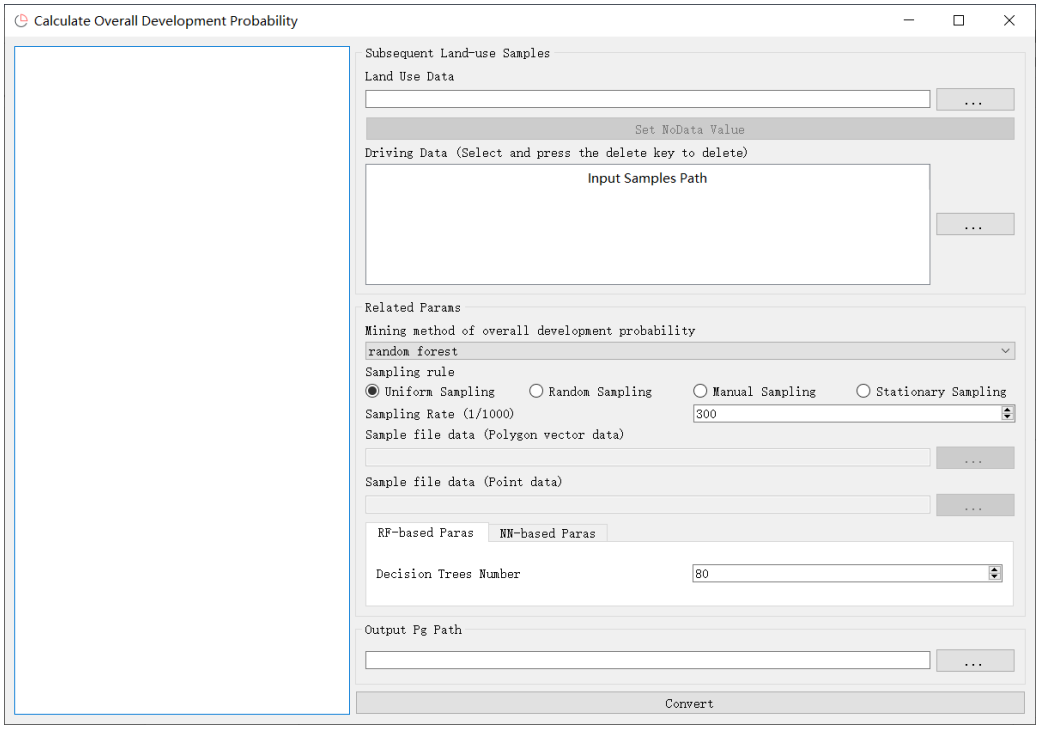


5.2. Calculating overall density development probability of the city

Click on the "Density CA" in the menu bar, and select "Calculate Overall Development Probability (Density)" from the pop-up menu.

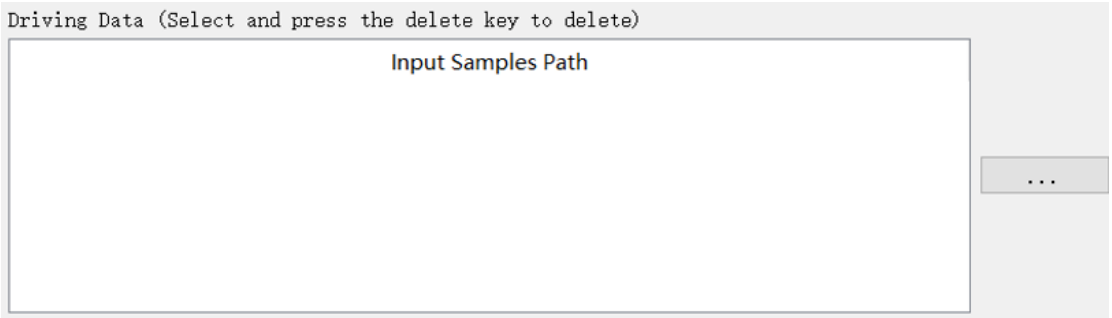


We can also open the module for calculating the overall development probability by clicking on the "Calculate Overall Development Probability (Density)" button in the toolbar , as shown in the following figure :

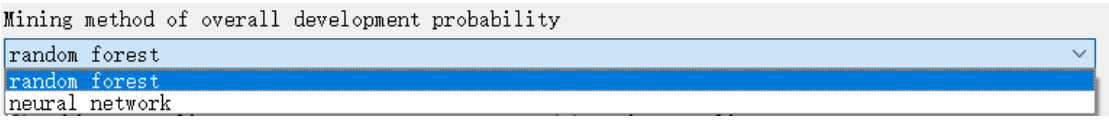


First, click on the button in the "Land Use Data" section ...， The system will automatically open a dialog box, and you need to select the updated land use data.

Next, click on the button in the "Driving Data" section ...， The system will automatically open a dialog box, and you need to select the dataset of driving factors for training.



After completion, select the mining method for the overall development probability from the dropdown menu under "Mining method of overall development probability". The default option is the Random Forest model, as shown below：



Next, select the sampling rule from "Sampling rule" section. The options include

Rule-based sampling, Random sampling, Manual sampling, and Static sampling, as shown below：

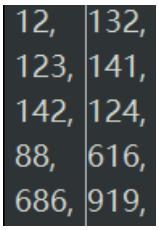
If you choose Random sampling, you need to set the sampling rate using the "Sampling Rate" option, as shown below：

If you choose Manual sampling, you need to import the specified sampling area .shp file using the "Sampling File data (Polygon vector data)" option, as shown below：

The specified sampling area .shp file should be in the format of polygon vector data within the same projected area range.

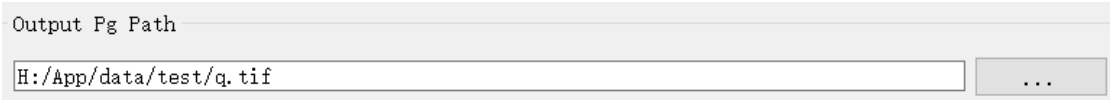
If you choose Static sampling, you need to import the specified sampling pixel location file using the "Sampling File data (Point data)" option, as shown below：

The specified sampling pixel location file should be in the format of "row number, column number,". Here is an example of the data：

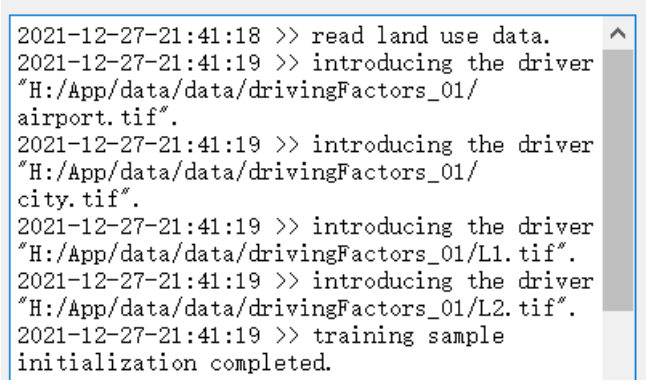


Next, based on the selected mining method for overall development probability, set the model parameters in either "RF-based Paras" or "NN-based Paras", as shown below：

Finally, click on the button in "Output Pg Path" ... , and select the storage location for the overall development probability file in the dialog box that appears, as shown below：

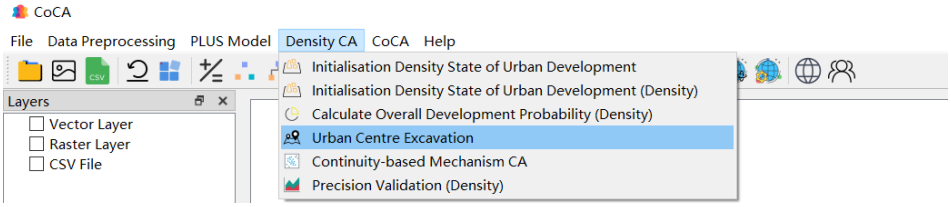


After clicking "OK", the system will start mining the overall development probability (Pg), and the execution status will be displayed in the left-side log, as shown below：

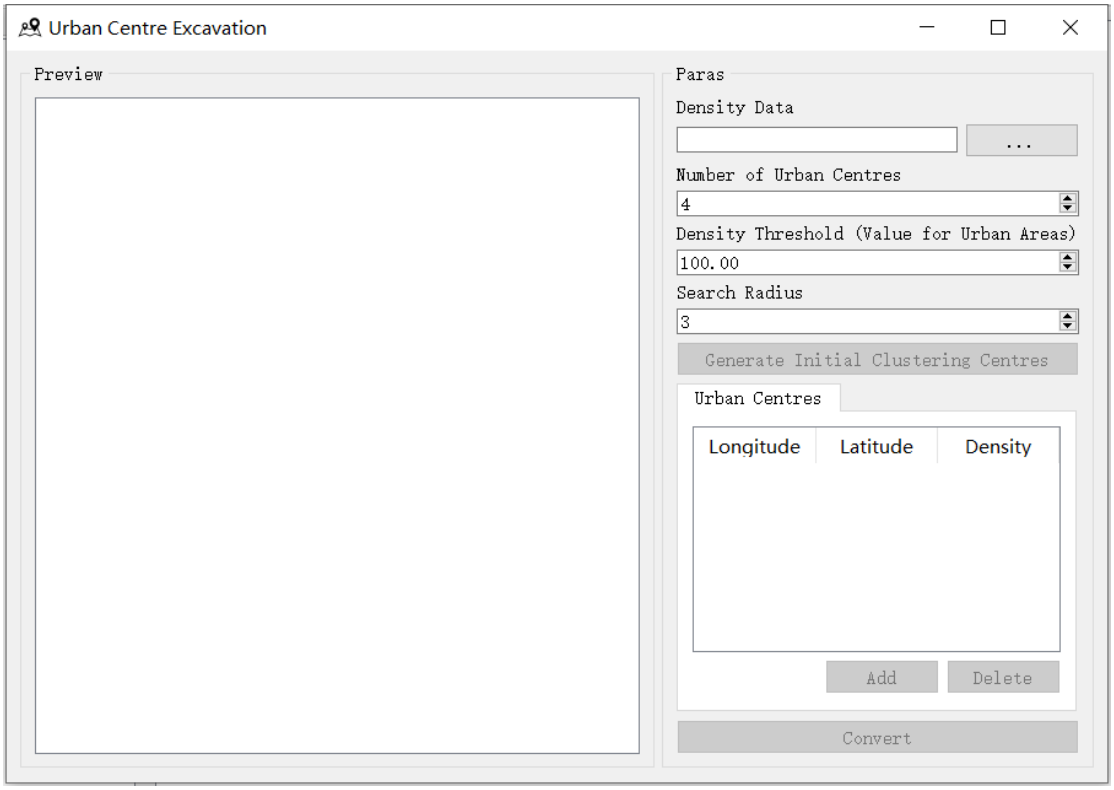


5.3. Extracting urban centers

Click on the menu bar "Density CA" and select "Urban Centre Excavation" from the pop-up menu.

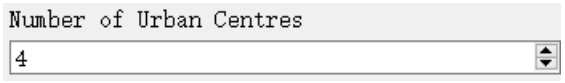


Alternatively, you can open the Urban Centre Excavation module by clicking on the "Urban Centre Excavation" button in the toolbar, as shown in the image below：

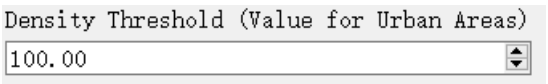


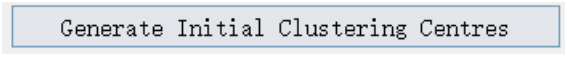
First, click on the button to the right of "Density Data"  , to select the folder where the urban development density data is stored, as shown below：

Next, click on "Number of Urban Centres" to set the desired number of urban centers to be extracted, as demonstrated below：

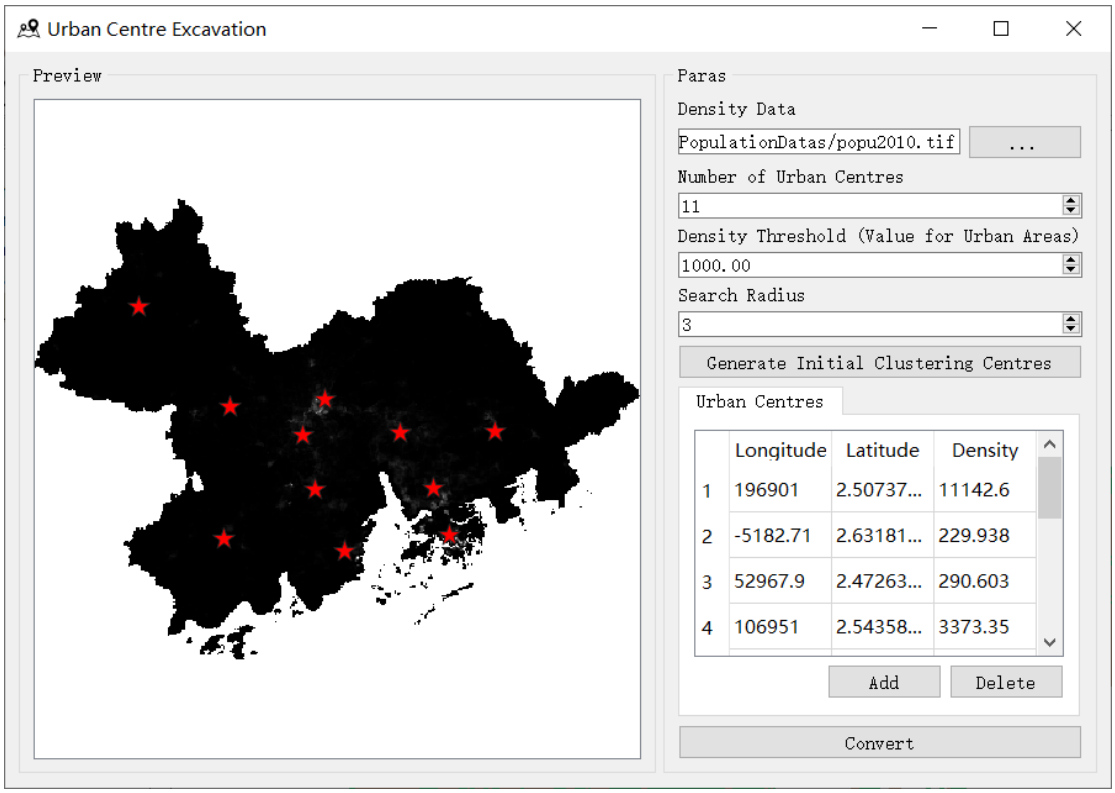


After that, click on the "Density Threshold (Value for Urban Areas)" to set the threshold value for identifying urban areas in raster units, as depicted below：



Click the button  to start the extraction of urban centers. Once the extraction is complete, you can view them in the "Urban Centres" section. Additionally, you can manually modify the "Density" of each urban center by double-clicking on it. To delete a selected urban center, click on "Delete"

After clicking on the "Add" function, you can simply click on the desired location on the map area to add a point .

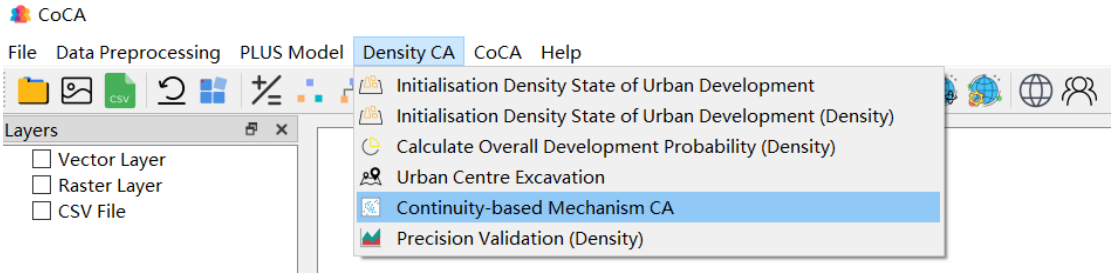


Finally, click the button 

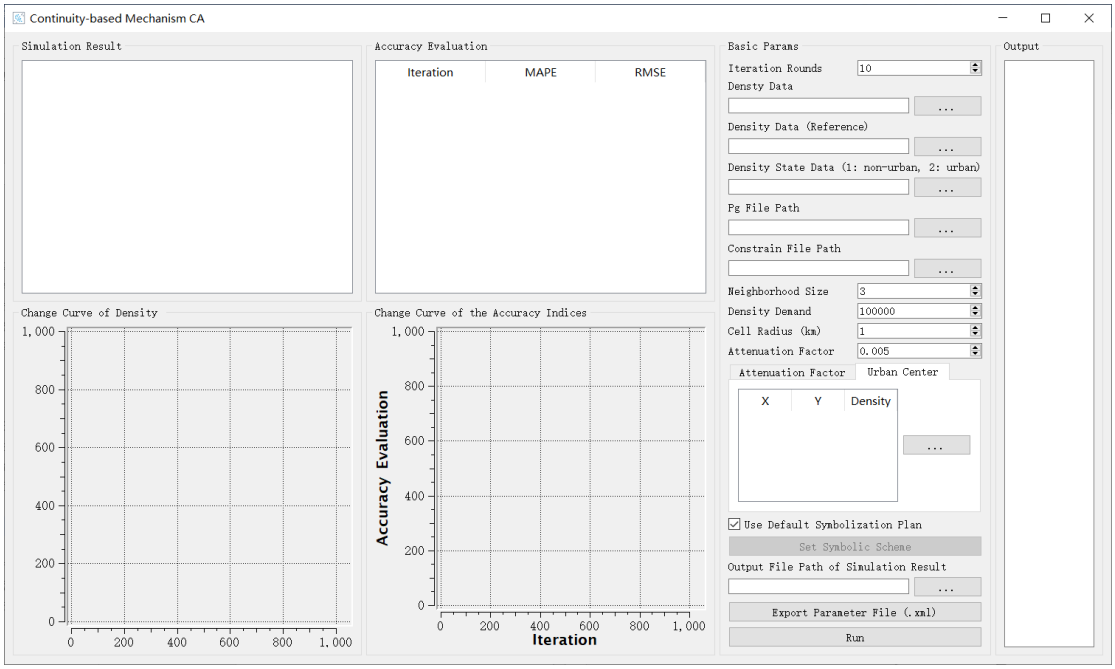
to export the calculated urban center data in .CSV format. In the dialog box that appears, select the storage location for the urban center data.

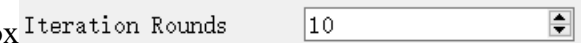
5.4. Simulating the continuity changes of urban features

Click on the menu bar "Density CA" and select "Continuity-based Mechanism CA" from the pop-up menu.



Alternatively, you can open the Continuity-based Mechanism CA module by clicking on the "Continuity-based Mechanism CA" button in the toolbar  as shown in the image below：



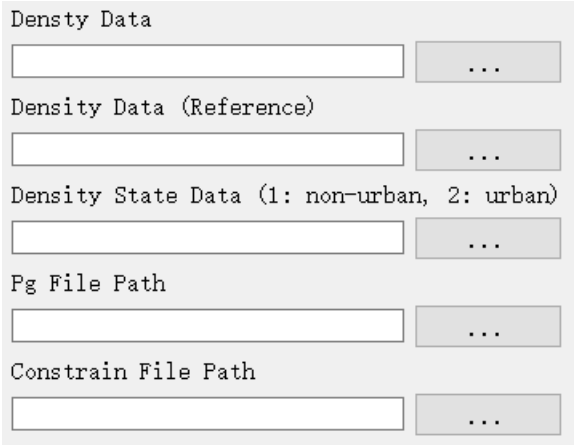
First, set the number of iterations for this simulation in the iteration rounds input box 

This parameter represents the number of iterations for the simulation.

Then, click on the buttons to the right of "Density Data", "Density Data (Reference)", "Density State Data", "Pg File Path", and "Constrain File Path" respectively 

, In the dialog box that appears, select the folder paths for

the pre-change real density data, post-change real land-use data, initial density data before urban change, Pg file path, and constraint development file path, as shown below：

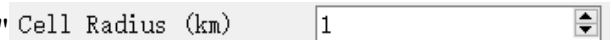


Note that the "Constrain File Path" function is used to restrict development in specific areas, and the path can be left empty. If you want to use this function, make sure the data format is a GByte raster, within the same projection range, containing only 0 and 1. 0 represents prohibited development, and 1 represents permissible development.

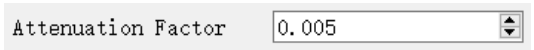
Next, we need to select the relevant parameters required for the model simulation. Set the neighborhood size on the right side of "Neighborhood Size,"

； set the desired density demand size on the right side of "Density Demand,"

； set the cell radius size on the right side of "Cell Radius,"

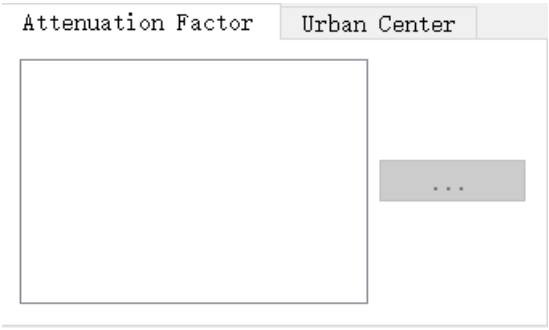


。and set the attenuation factor size on the right side of "Attenuation Factor."



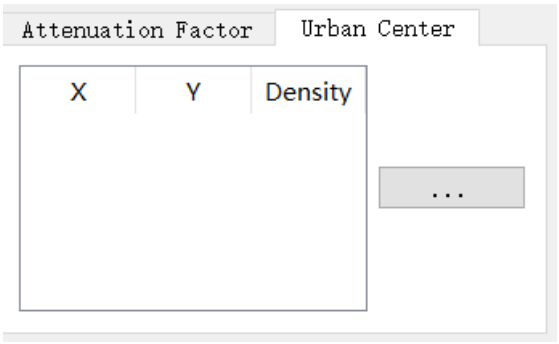
。

The "Attenuation Factor" will automatically lock based on the above parameters.

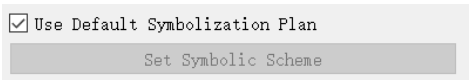


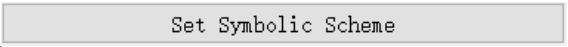
In "Urban Center," click the button 

, to import a city center .CSV data file in the popup dialog box, and the system will automatically read the file information.

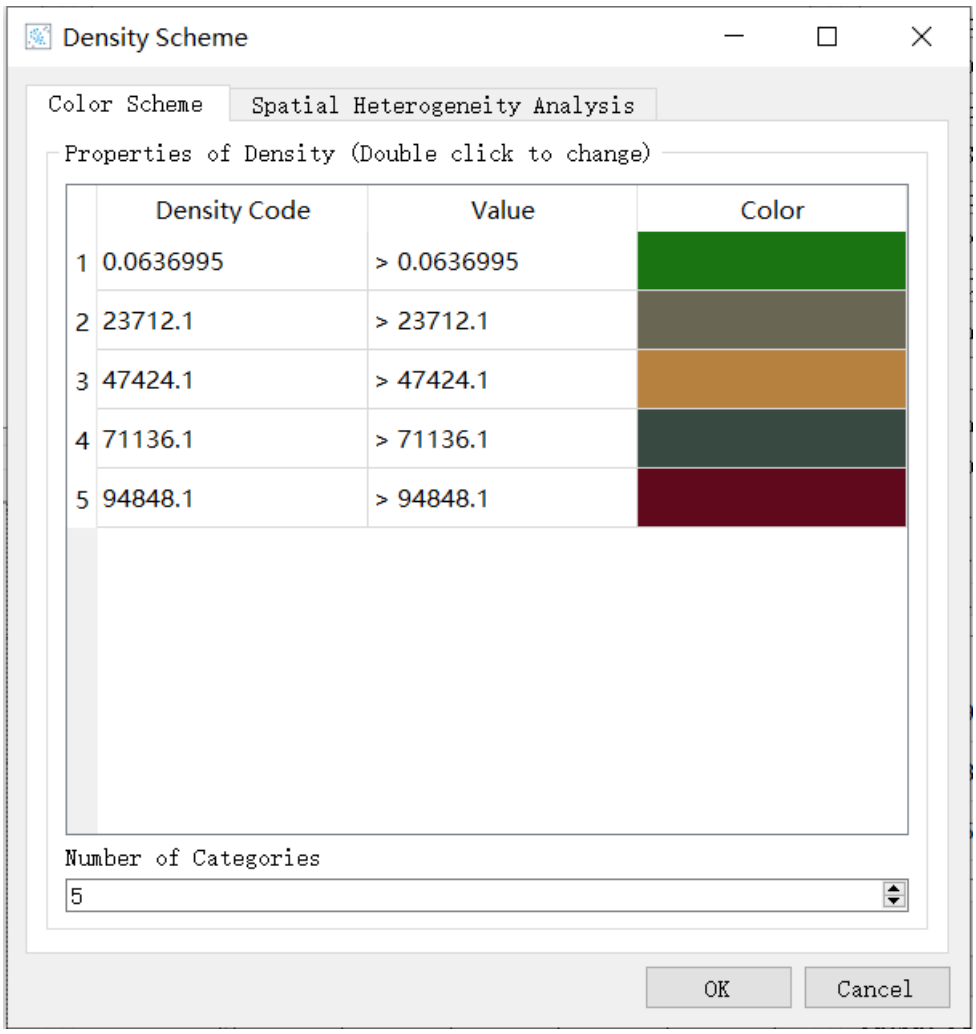


After setting the parameters above, if you need to customize the display symbols for different land parcels, you can click the checkbox "Use Default Symbolization Plan"

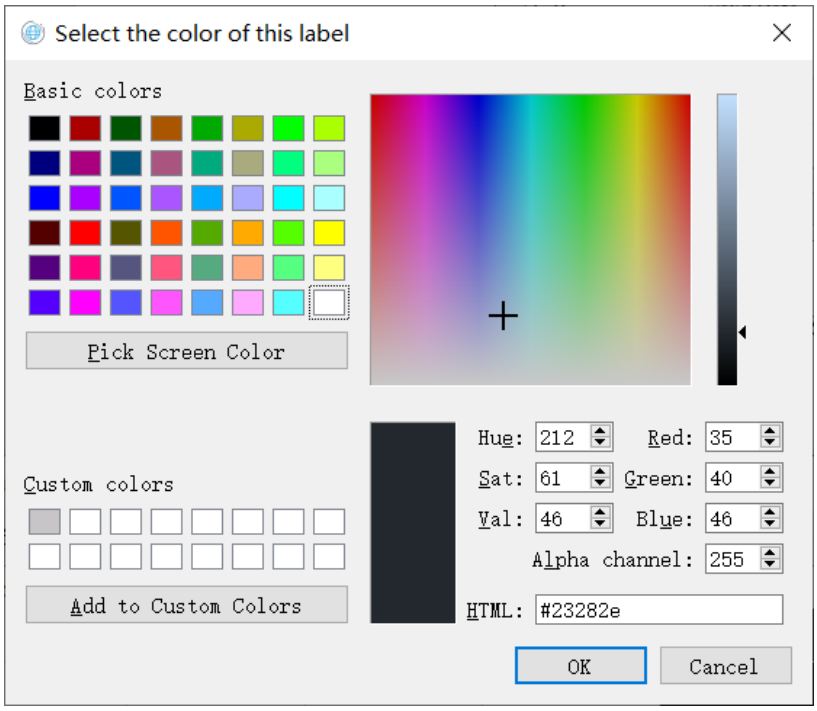


to switch to a custom symbolization scheme. Click the "Set Symbolic Scheme" button 

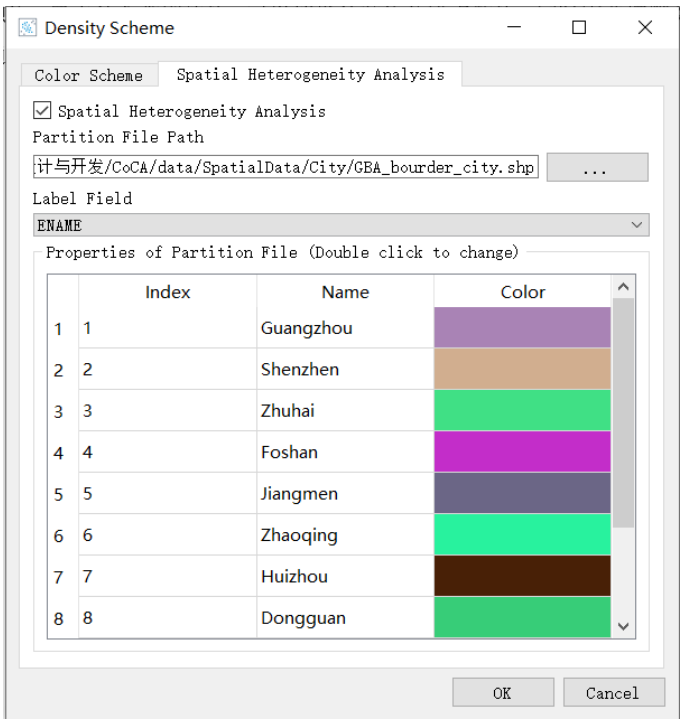
to open the following interface for setting the symbols and zoning display of land parcels：



Click on the colors of each category to jump to the interface shown below, where you can modify the color for that category based on user needs. Clicking on the values of each category can switch the color breakpoints. In addition, adding or deleting categories can be done through the category setting box at the bottom：



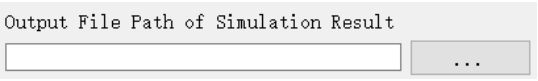
Another important point is that this model supports the display of zoning data, which can be achieved through the "Zoning Statistical Analysis" module. It includes selecting zoning polygonal data, zoning labeling fields, and color settings, similar to the above method.



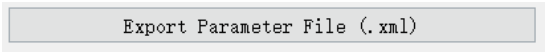
Click the "OK" button 

, to complete the custom symbolization settings.

To facilitate further research, click the button in the "Output File Path of Simulation Result" feature ... , and select the save path for the simulation results in the pop-up dialog box.



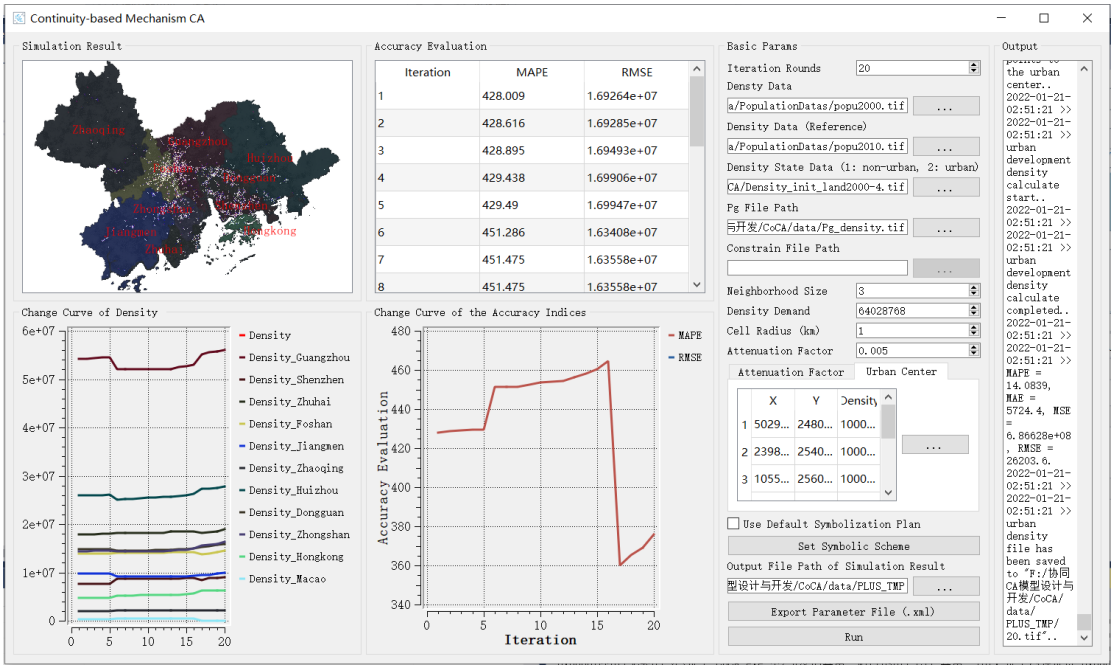
Click the "Export Parameter File" button



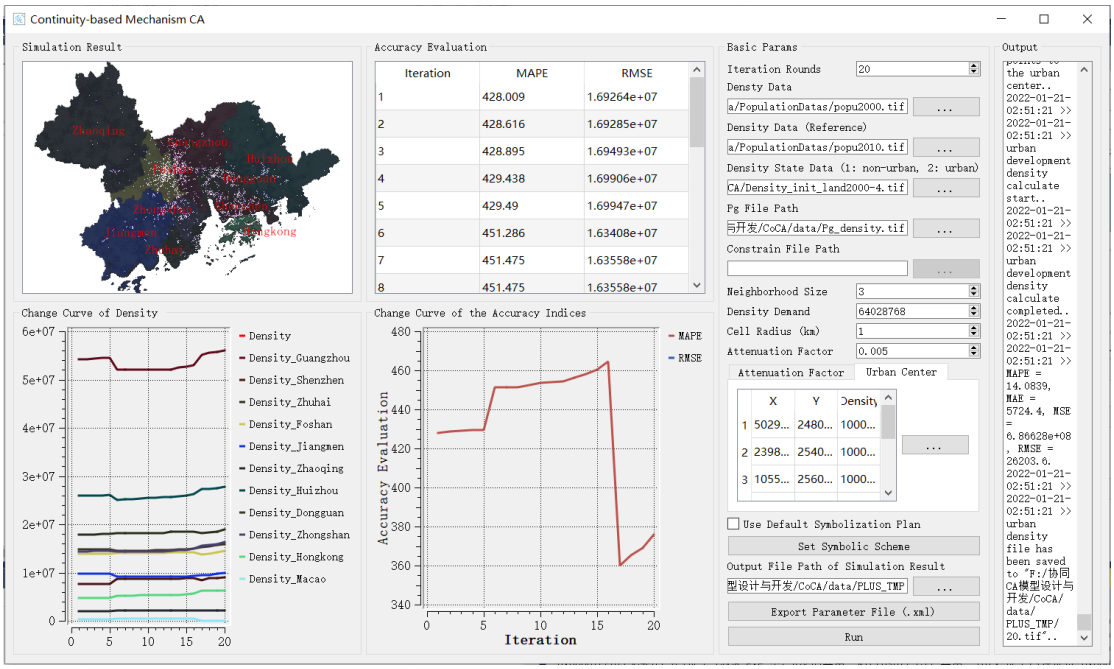
to save and export all current parameter settings in XML file format.

Finally, in the simulation interface, click the "Run" button

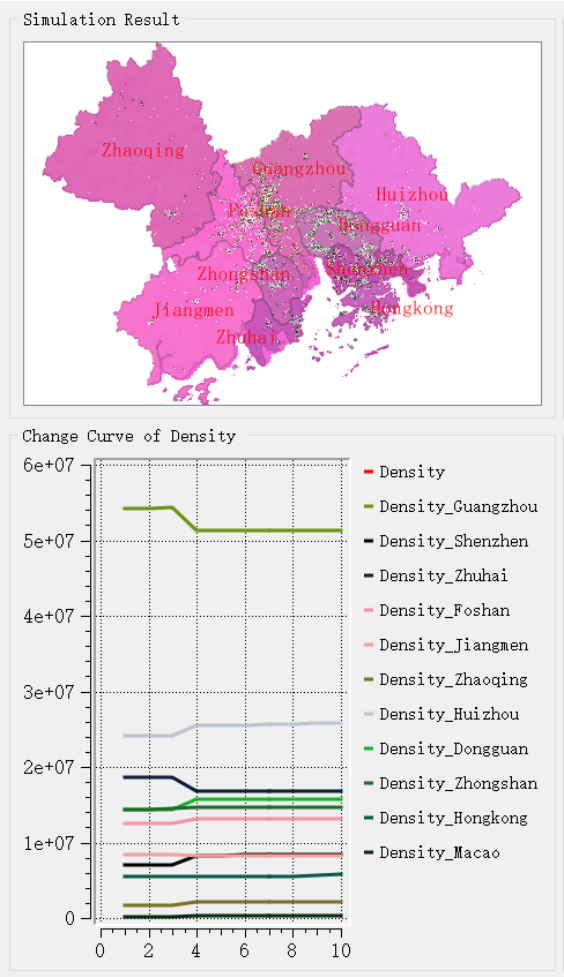
to automatically perform the simulation of urban feature continuity changes, as shown in the following figure：



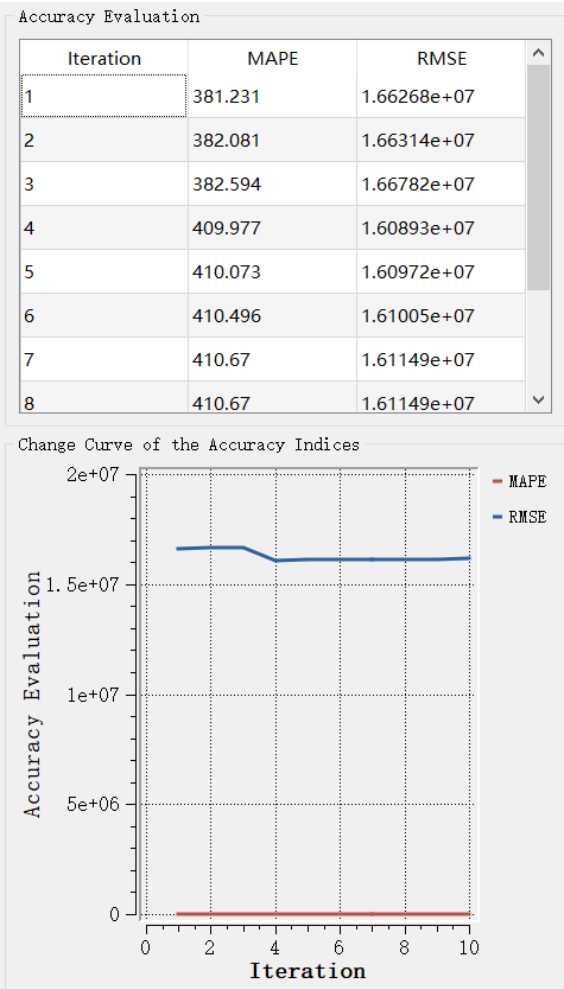
After the program finishes running, this system will display the final urban feature change map, accuracy evaluation indicators for each iteration, density change line graph, and line graphs showing changes in various accuracy evaluation indicators, as shown in the following figure:：



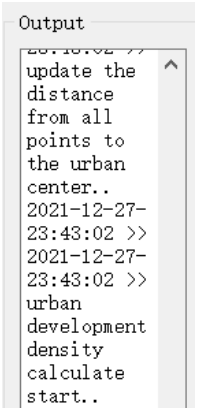
The module for urban feature change map in the top left corner allows you to traverse and display each area by zooming in. The density change line graph below corresponds to the changes in density during the simulation process.



The accuracy evaluation indicators module, located in the middle of this system, displays the changes in various accuracy indicators in this simulation. The accuracy evaluation indicators change line graph below corresponds to the changes in each accuracy indicator in this simulation (under the zoning statistical settings, the calculation units are polygonal zones rather than grids).



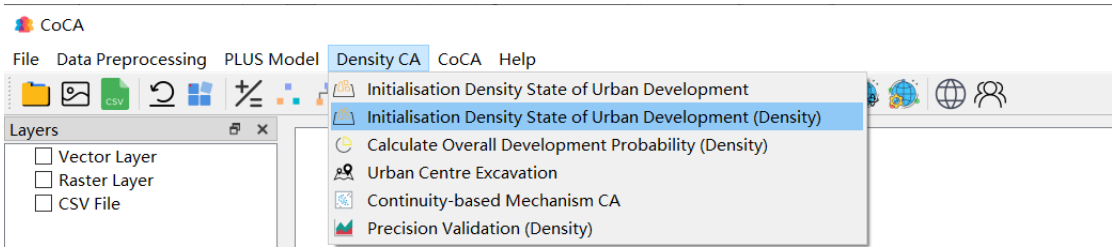
In addition, we provide a Log output interface for checking relevant outputs. The Log output interface for the urban feature density change simulation module is shown in the figure below：



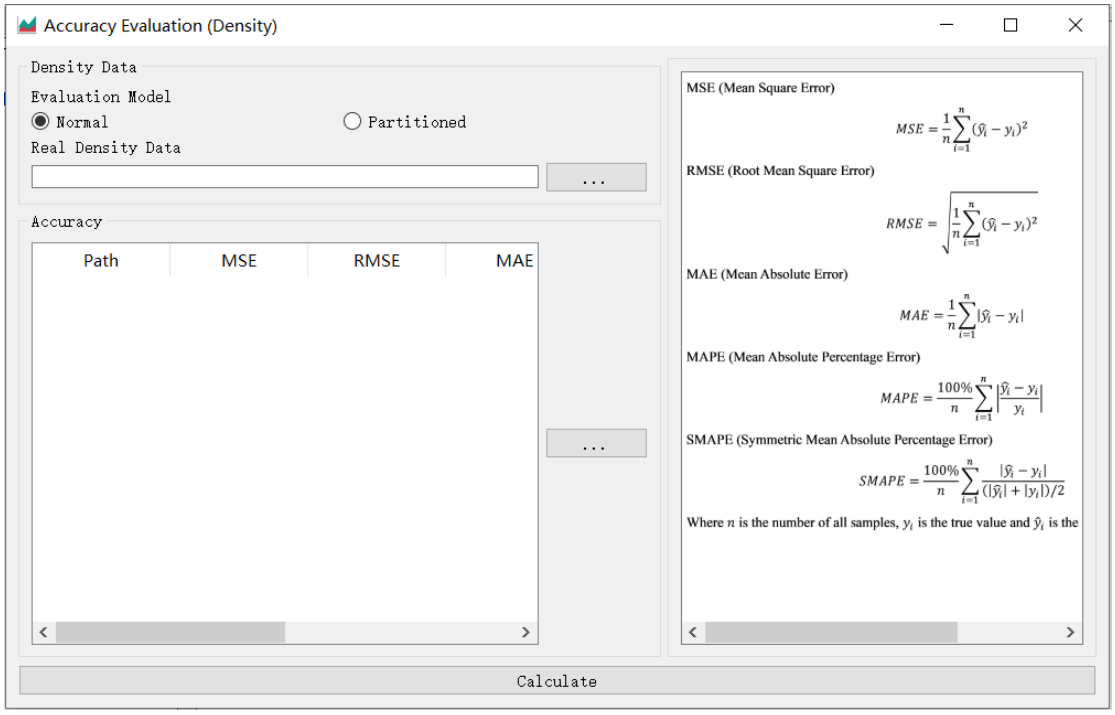
5.5. Accuracy evaluation

"Click on the 'Density CA' option in the menu bar and select 'Precision Validation

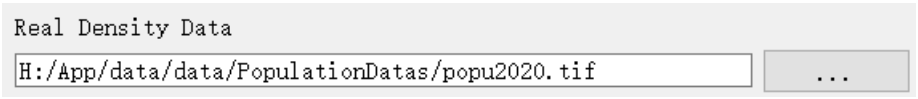
(Density)' from the pop-up menu.



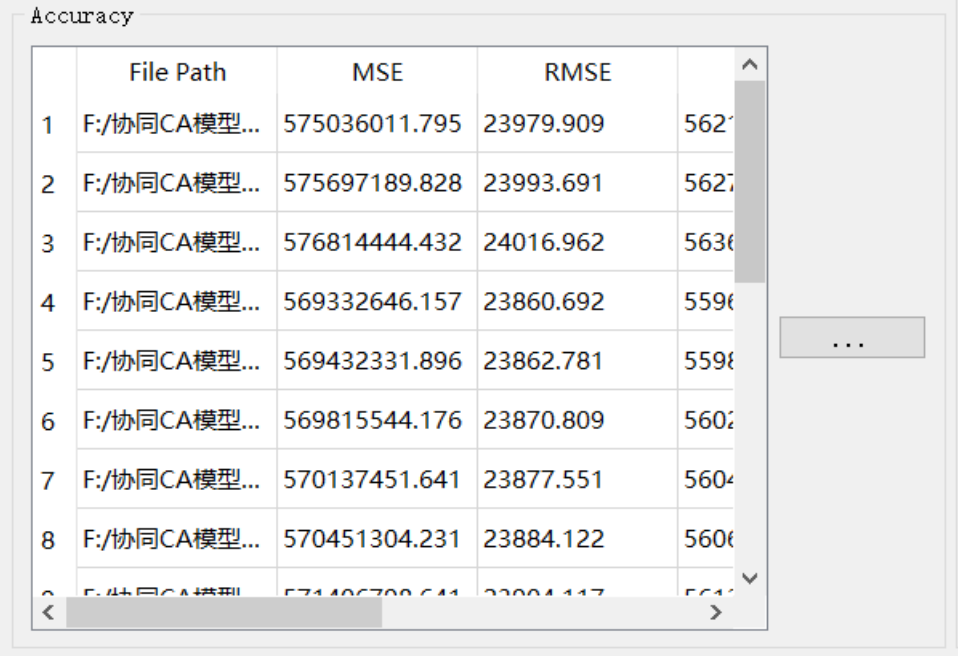
Alternatively, you can open the precision evaluation module by clicking on the 'Precision Validation (Density)' button in the toolbar, as shown in the figure below：



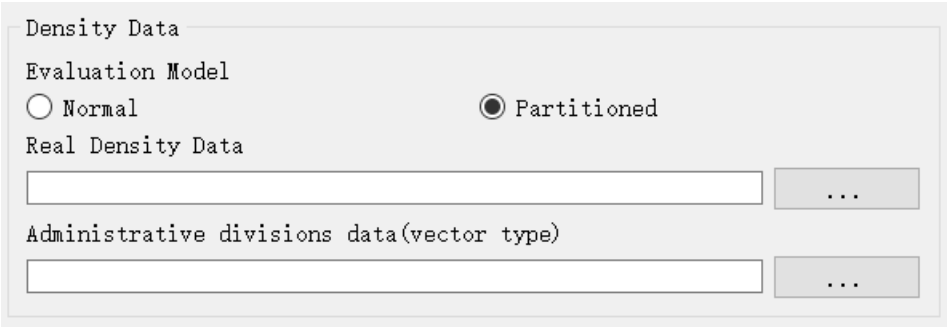
First, click on the button to the right of 'Real Density Data' ... , and select the path where the real data is stored in the pop-up folder selection dialog, as shown below：



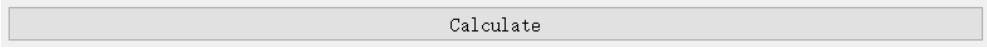
Next, click on the button to the right of 'Accuracy' ... , and import the land data for accuracy assessment in the pop-up dialog, as shown below：



If users need to perform zone-based statistics, please select the 'Zoning Statistics' mode and choose the zone data for calculation through the file selection dialog.



After completing these steps, click the 'Calculate' button

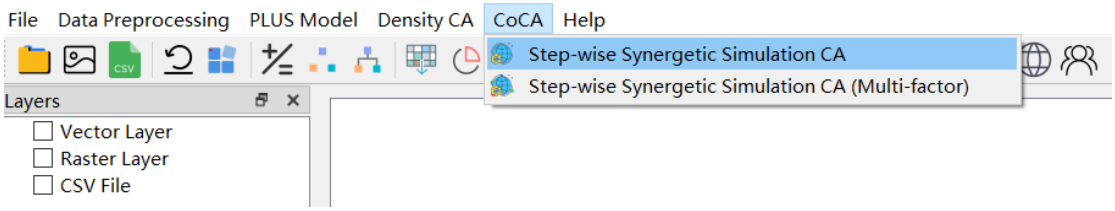


to start the execution of the precision evaluation function."

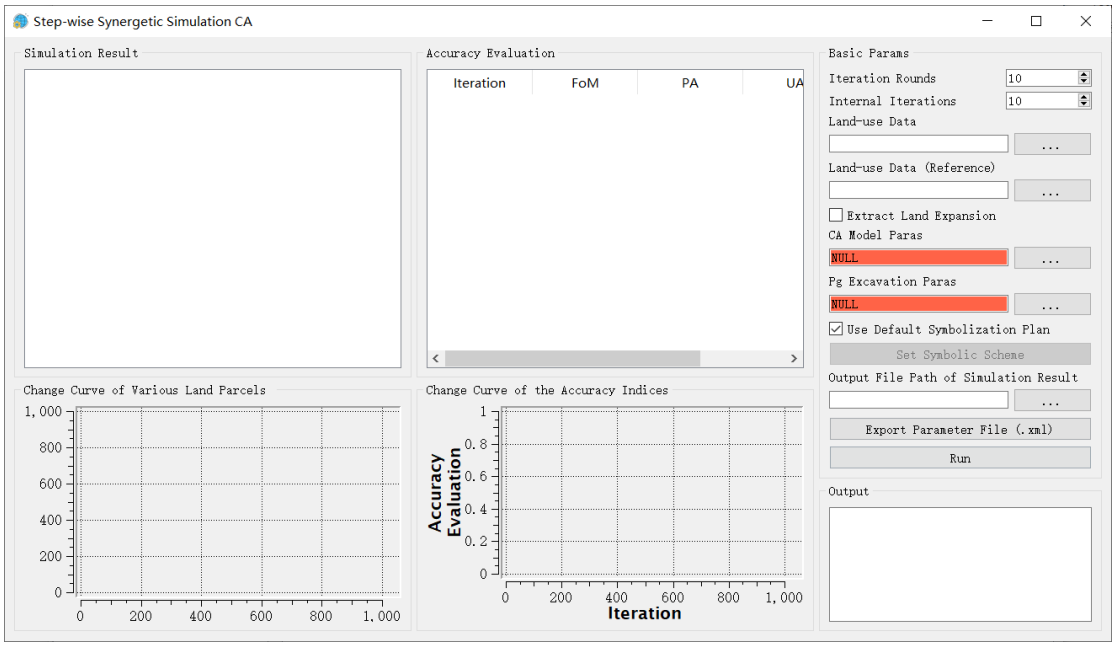
6. Simulating urban land-population-economy changes based on CoCA model

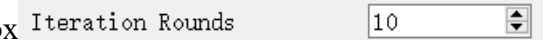
6.1. Simulating urban single-element changes

Click on the 'CoCA' option in the menu bar and select 'Step-wise Synergetic Simulation CA' from the pop-up menu.

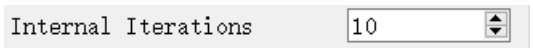


Alternatively, you can open the Simulation of City Land-Population-Economy Changes module by clicking on the 'Step-wise Synergetic Simulation CA' button in the toolbar, as shown in the figure below：



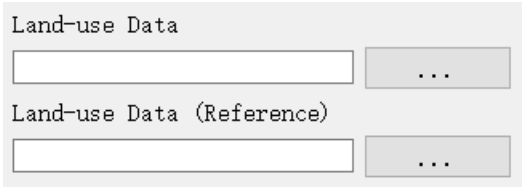
First, set the number of iterations for each collaboration by entering the value in the internal iteration count input box 

Set the collaboration count by entering the value in the external collaboration count input box



Next, click on the buttons to the right of 'Land-use Data' and 'Land-use Data

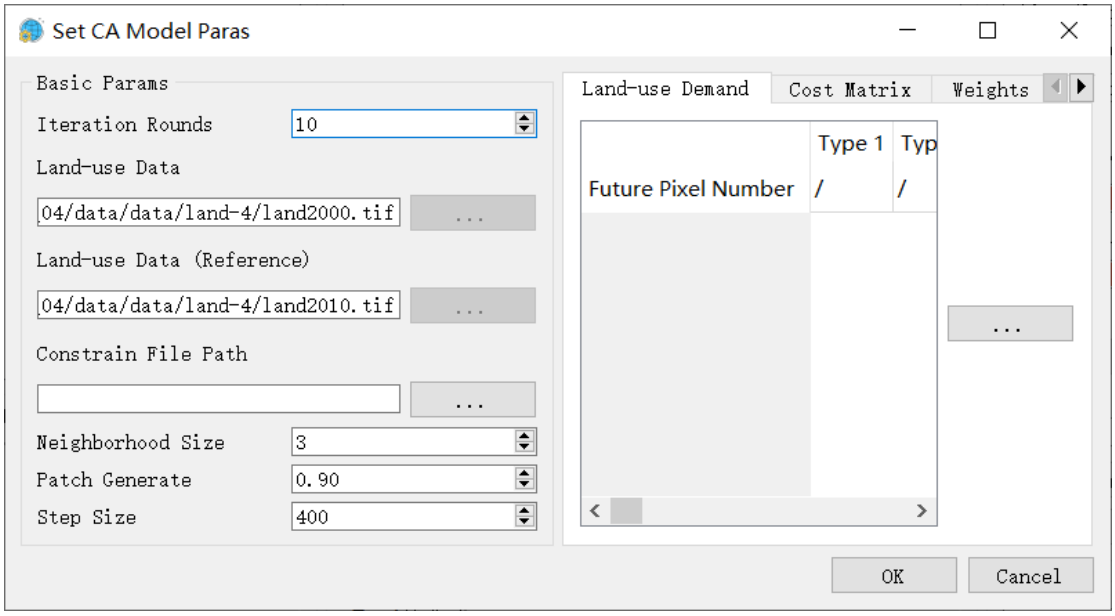
(Reference)' ...，and select the respective paths where the real land-use data is stored before and after the change in the pop-up folder selection dialog, as shown below：



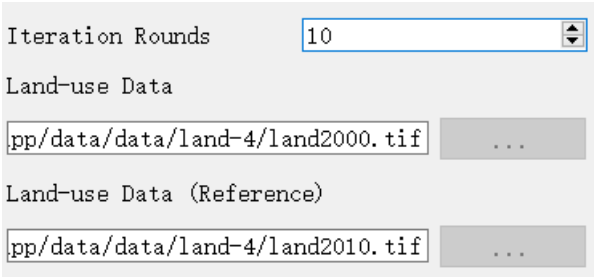
Also, select whether to extract the expansion area ☐ Extract Land Expansion。

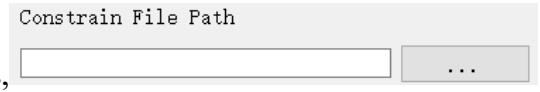
Next, we need to set the parameters for the Cellular Automata (CA) model. Click on the 'CA Model Paras' button

...，and the system will automatically display the CA parameter setting sub-interface, as shown below：



In the CA parameter setting sub-interface, the 'Iteration Rounds', 'Land-use Data', and 'Land-use Data (Reference)' will be automatically set based on the parameters from the previous interface and cannot be modified externally, as shown below：

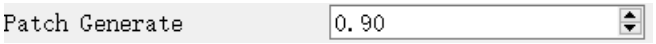


The 'Constrain File Path' is default empty. If you want to limit the development in specific areas, 

click on the button to the right 

, select the path where the restriction file is stored in the pop-up folder selection dialog. Please note that the data format must be: GByte raster data within the same projection range containing only 0 and 1. 0 indicates prohibited development land, and 1 indicates permissible development land.

After that, set the neighborhood size by entering the value in the input box to the right of "Neighborhood Size" 

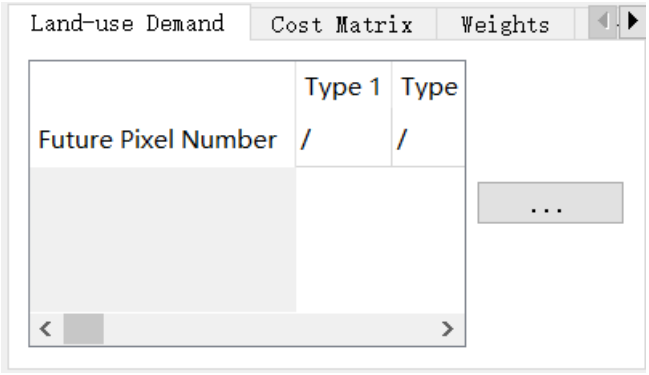
; Set the attenuation coefficient size by entering the value in the input box to the right of "Patch Generate" 

; Set the step size by entering the value in the input box to the right of "Step Size" 

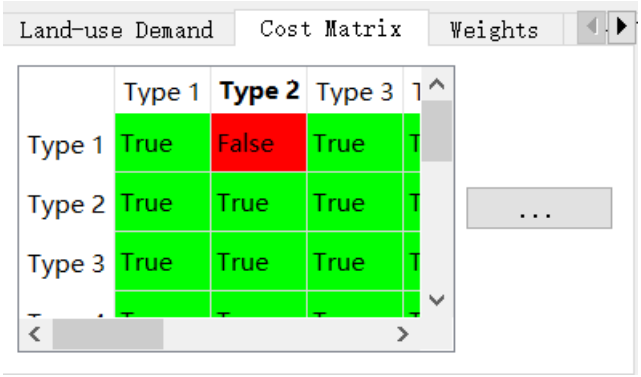
。

Click on the button under "Land-use Demand" 

, In the pop-up dialog, you can select a CSV file that customizes the development counts for each land-use type. The format of the CSV file is "Type_1,Type_2,Type_3...Type_n". If the user ignores this function, the system will automatically use the development counts for each land-use type based on historical data.

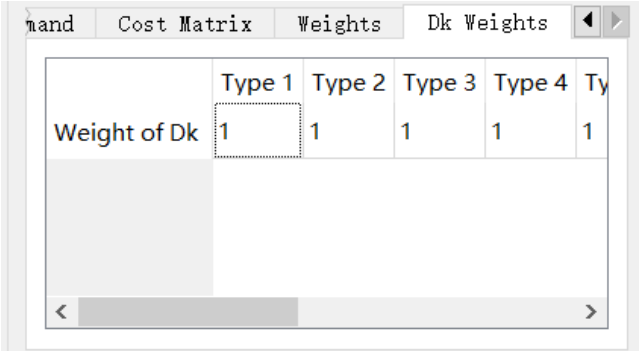


Double-click on the conversion matrix in "Cost Matrix" to customize the conversion restrictions for each land-use type, as shown below (indicating that Type 1 cannot be converted to Type 2):



Double-click on the neighborhood weights in "Weights" to customize the weights for each land-use type in the pop-up dialog. The default value is 1, as shown below：

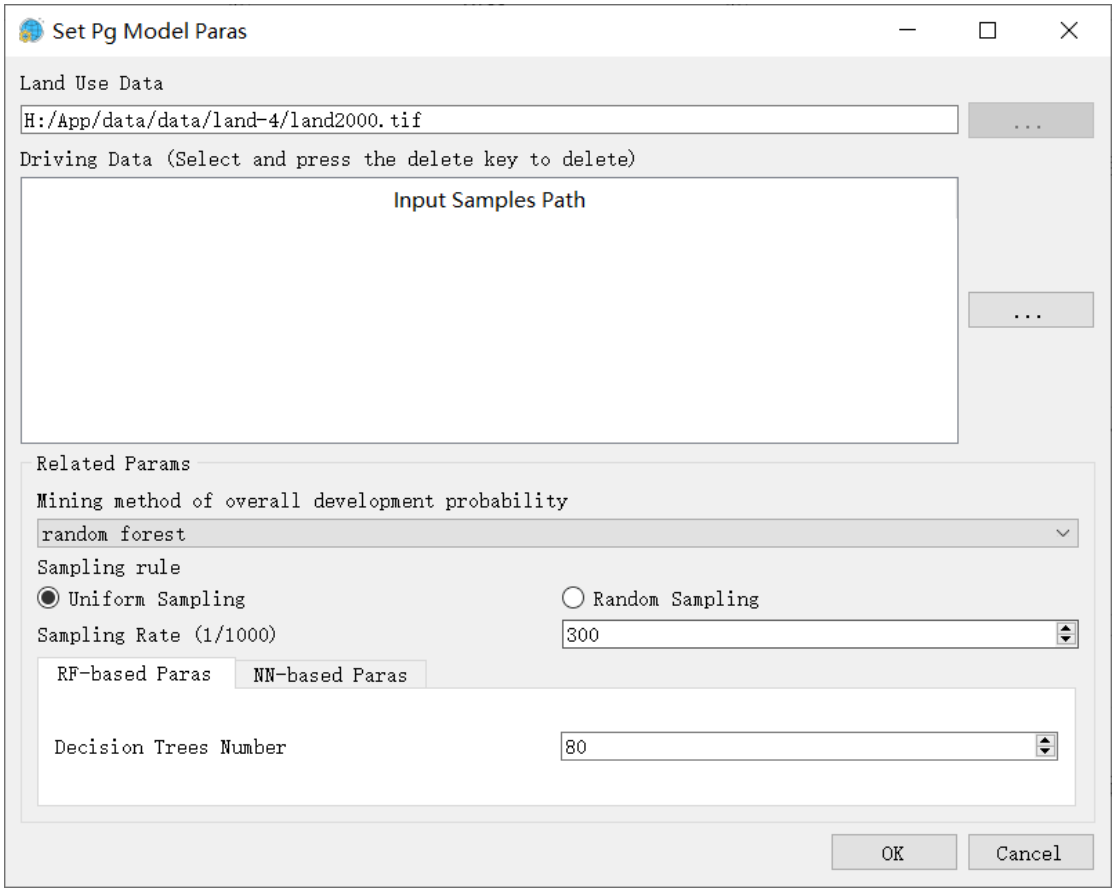
Double-click on the Dk weights in "Dk Weights" to customize the weights for each land-use type in the pop-up dialog. The default value is 1, as shown below:



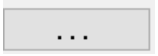
After setting the parameters mentioned above, click "OK" to complete the CA parameter settings. At the same time, the system will automatically save the current parameters as an XML project file.

Next, we need to excavate the overall development probability (Pg) of the CA model. Click on the button in "Pg Excavation Paras"

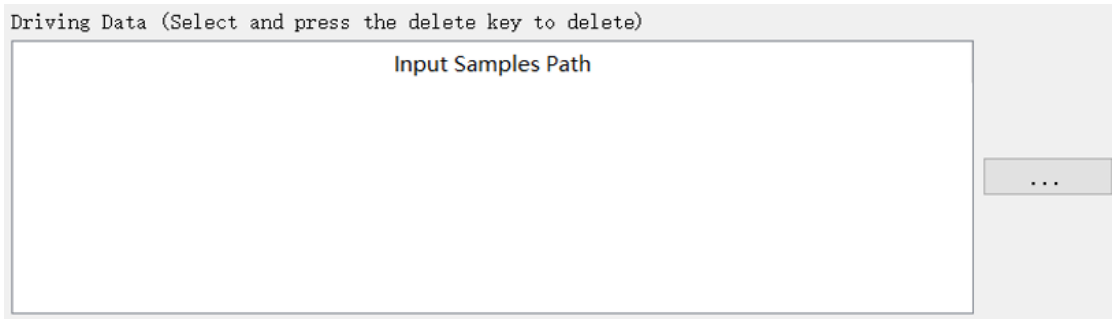
，and the system will automatically pop up a sub-interface for excavating the overall development probability (Pg), as shown below：



In the sub-interface for excavating the overall development probability (Pg), the "Land-use Data" will be automatically set based on the parameters from the previous level, and it cannot be modified externally, as shown below：

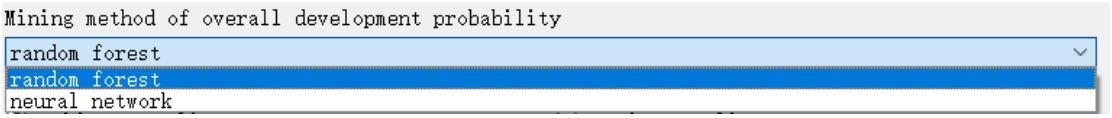
Next, click on the button in "Driving Data" 

, and the system will automatically pop up a dialog box where the user needs to select the driving factor dataset for training.

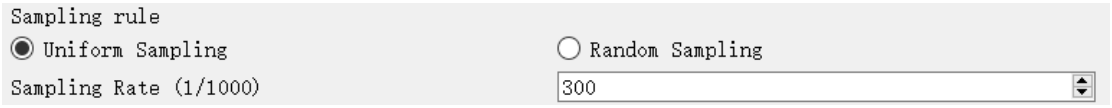


Once that is done, select the mining method of the overall development probability

from the drop-down box labeled "Mining method of overall development probability". The default method is the random forest model, as shown below：

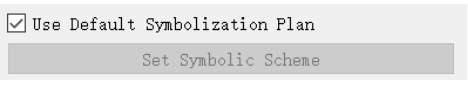


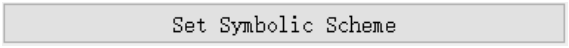
Then, choose between rule-based sampling or random sampling in the "Sampling rule". If random sampling is selected, you can set the sampling rate in the "Sampling Rate", as shown below：



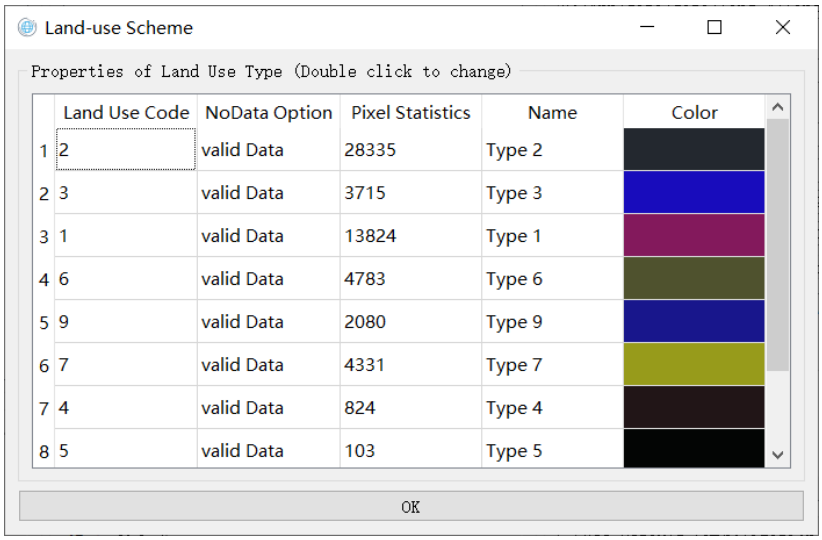
Finally, based on the selected method for excavating the overall development probability, set the model parameters in either "RF-based Paras" or "NN-based Paras", as shown below：

Click "OK" to complete the parameter settings for excavating the overall development probability (Pg). At the same time, the system will automatically save the current parameters as an XML project file.

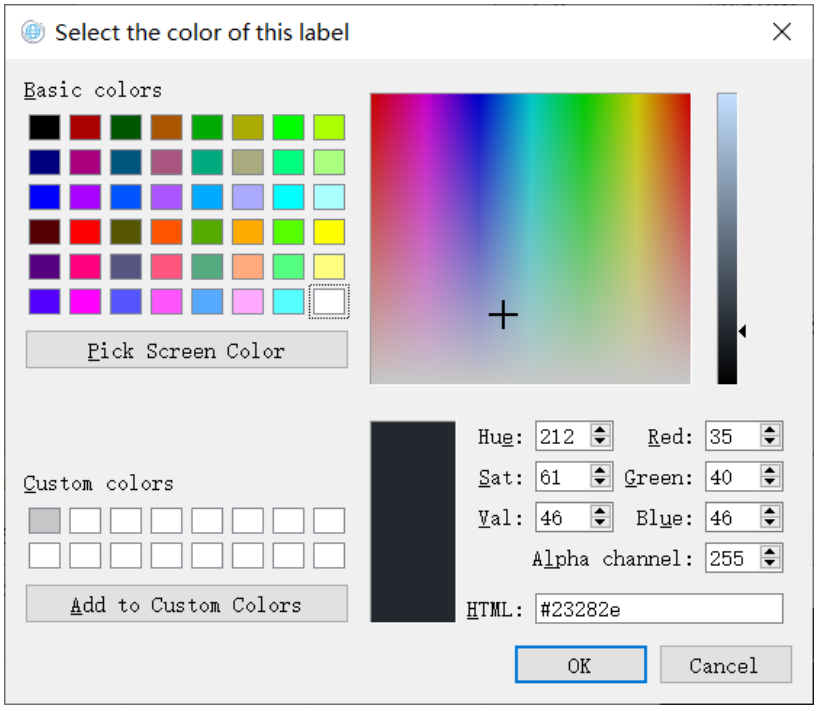
If you need to customize the display symbols for different land parcels, you can click on the checkbox "Use Default Symbolization Plan" to use a custom symbolization scheme 

。Click on the "Set Symbolic Scheme" button to set the vector land parcel symbols in the popped-up interface 

as shown below：



Click on the color of each category to jump to the interface shown in the following figure to modify the color of the category according to user needs：

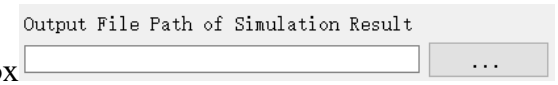


Click the "OK" button 

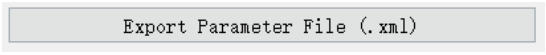
, to complete the customization of symbolization.

To facilitate further research, click the button in the "Output File Path of Simulation Result" feature 

, and select the path to save the simulation results

in the popped-up dialog box 

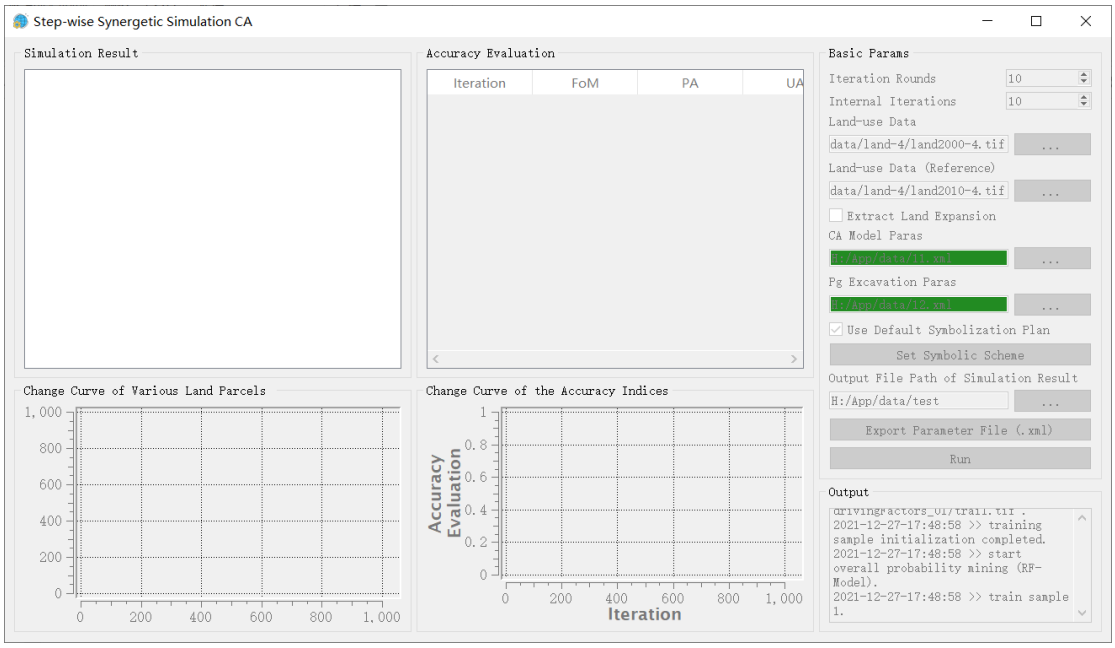
。

Click the "Export Parameter File" button 

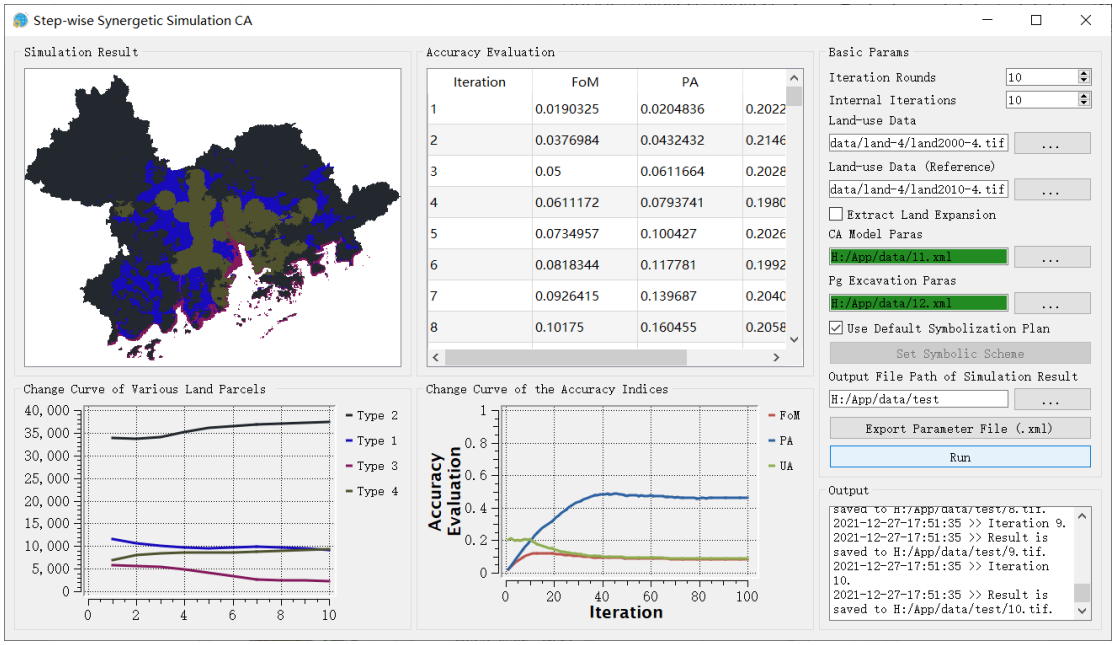
，to save and export all current parameter settings in XML file format.

Finally, click the "Run" button on the simulation interface 

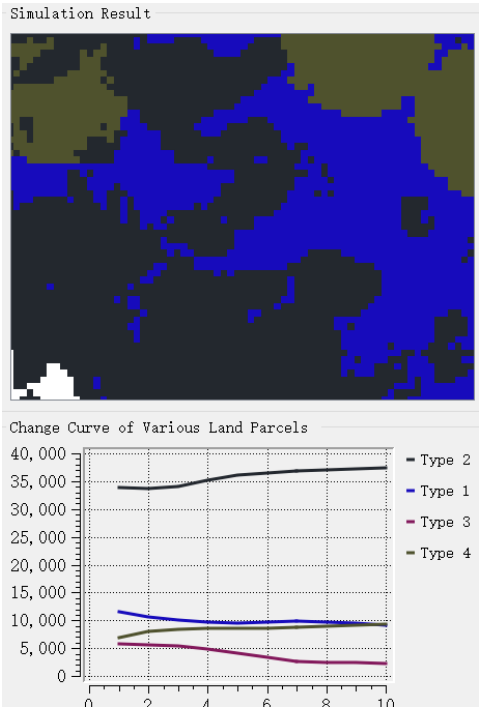
，to automatically perform the simulation of urban land-population-economic changes, as shown in the figure below：



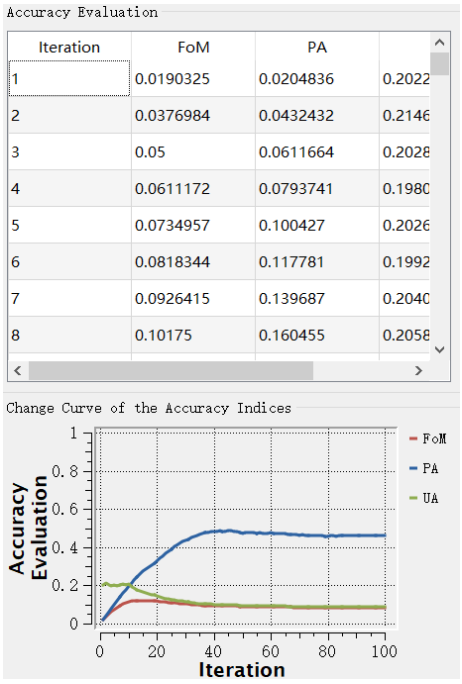
After the program finishes running, the system will display the final land use type map, accuracy evaluation indicators for each iteration, line graphs showing the changes in the number of land parcels for each type, and line graphs showing the changes in accuracy evaluation indicators, as shown in the figure below：



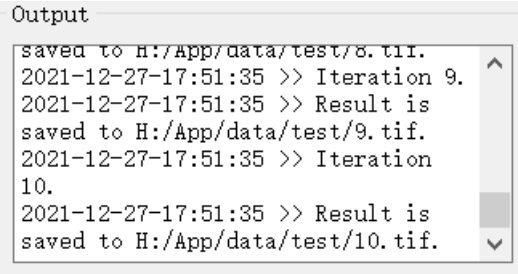
The land use type map module in the top left corner allows for zooming in and out to display each area. The line graph below shows the changes in the number of land parcels for each type of land during this simulation.



The accuracy evaluation indicators module in the middle of the system displays the changes in various accuracy indicators during this simulation. The line graph below shows the changes in each accuracy indicator during this simulation.

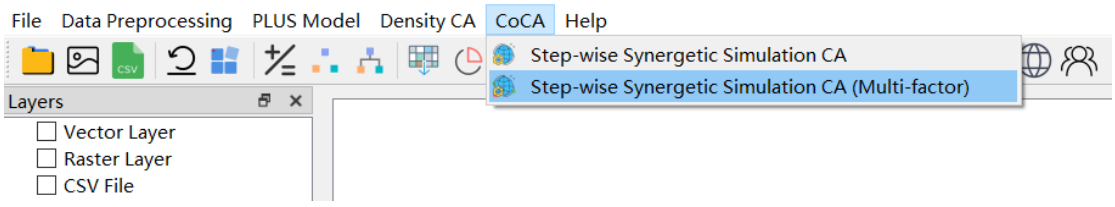


In addition, we provide a Log output interface for checking relevant outputs. The Log output interface for the urban land-population-economic change simulation module is shown in the following figure：

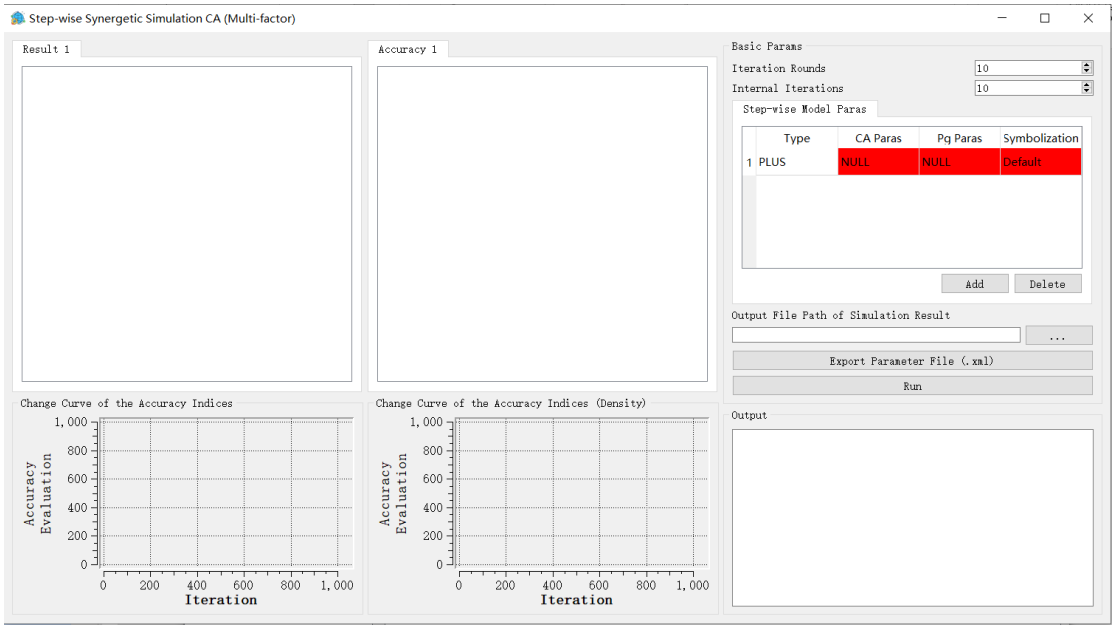


6.2. Simulating multi-factor coordinated changes in the city

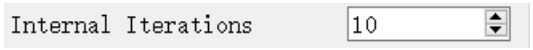
Click on the menu bar "CoCA" and select "Step-wise Synergetic Simulation CA (Multi-factor)" from the pop-up menu



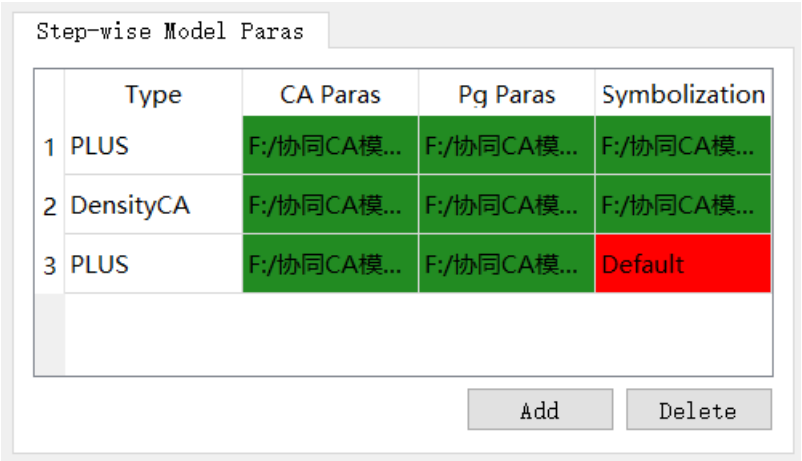
We can also open the module for simulating urban land-population-economic changes by clicking the "Step-wise Synergetic Simulation CA (Multi-factor)" button on the toolbar  as shown in the figure below：



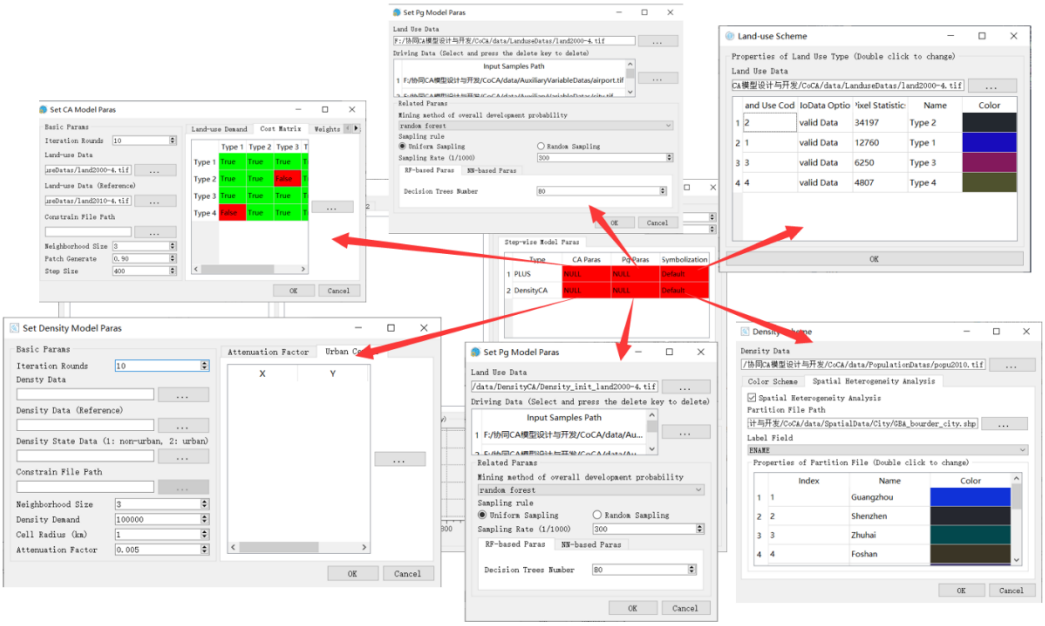
First, set the number of iterations for each collaboration in the internal iteration count input box 

; Set the collaboration count using the external collaboration count input box 

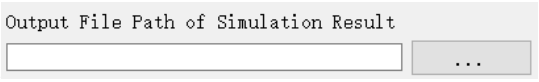
We can add or delete sub-CA models using the "Add" and "Delete" buttons. By double-clicking on the sub-CA model parameter table, you can switch models, set CA parameters, set Pg parameters, and visualize them, as shown in the figure below：

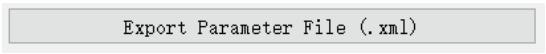


Next is the parameter setting for each sub-CA model, which is similar to the previous content, as shown below：

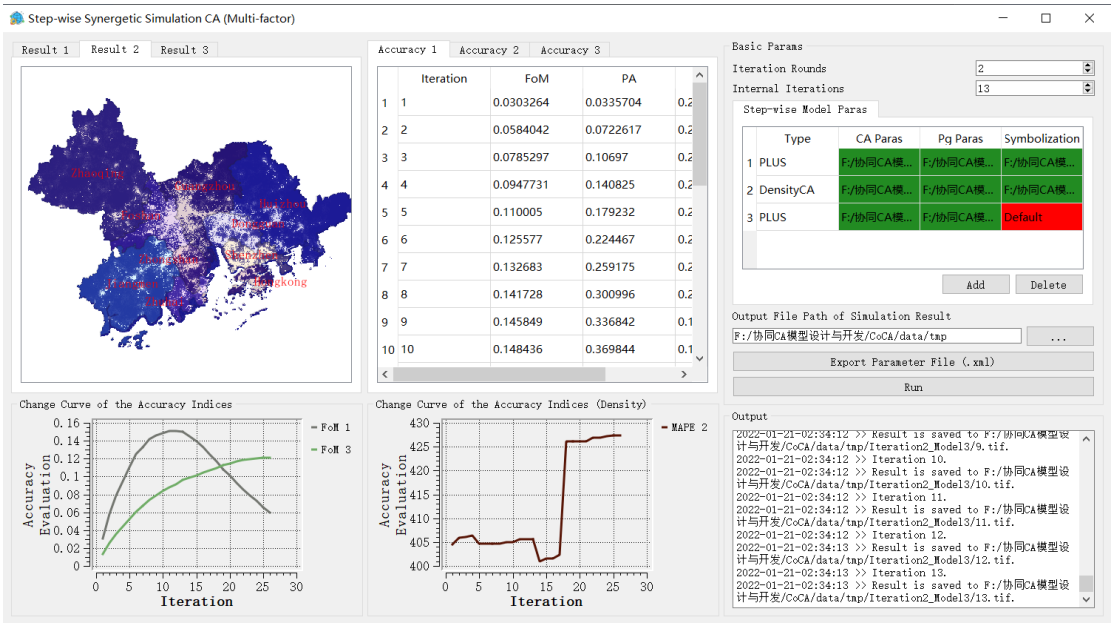


For the CA parameter and Pg parameter settings interface of the PLUS model, refer to section 6.1, and for symbolization, refer to section 4.3. For the DensityCA model, refer to section 5.4 for the CA parameter setting interface, section 6.1 for the Pg parameter setting interface, and section 5.4 for symbolization.

To facilitate future research, click the button in the "Output File Path of Simulation Result" feature  , in the dialog box that appears, select the path to save the simulation results. 

Click the "Export Parameter File" button  , to save and export all the current parameter settings in XML file format.

Finally, in the simulation interface, click the "Run" button  to automatically simulate urban land-population-economic changes, as shown in the figure below.：

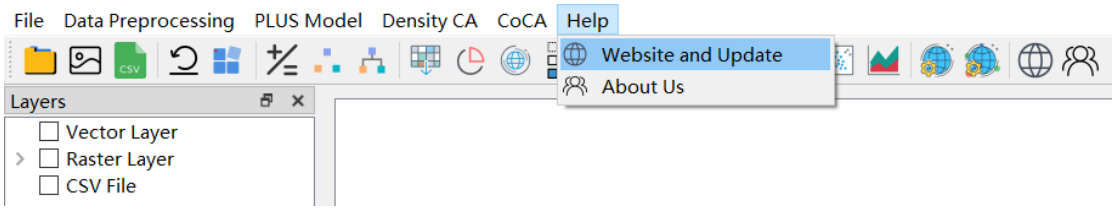


To ensure efficient model execution, this version of the software supports a maximum of 5 collaborative simulations of cellular automata. The accuracy display section only shows FoM and MAPE, while the rest of the sections are similar to the above modules.

7. Help

7.1. Website and Update

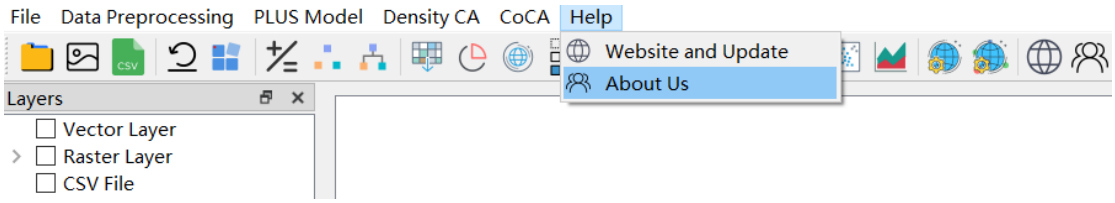
Click on the menu bar "Help" and select "Website and Update" from the pop-up menu.。



We can also open the official website of the development team by clicking the "Website and Update" button on the toolbar  providing convenience for obtaining timely software updates and other related information in the future.

7.2. About us

To access information about the development team, click on the menu bar "Help" and select "About Us" from the pop-up menu.



We can also view information about the development team by clicking the "About Us" button on the toolbar  ， as shown below：

8. Copyright Statement and Contact Information

CoCA：Cooperation Development Mechanism CA

Version 1.1.0

CoCA was developed by the following laboratories：

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