

Data visualization in an open-source environment for land consolidation and water management

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Abstract

Land and water management are two areas that intersect with each other to improve people's environment. The project of land consolidation is one of the most significant projects whose primary focus is to solve the problem of fragmentation in a cadastral area, as well as to deal with owners and their interests. In this kind of a project, water management is an inevitable component. Poor quality of design and implementation of the water management system could be leading to a non-functional water system. This paper aims to discuss problems of area fragmentation and as well as ownership fragmentation in Slovakia, which led to land consolidation projects. Moreover, this paper will show a possible way of visualizing data in an open-source environment for land consolidation while using a programming language called R.

Keywords: land consolidation, data visualization, water management, R, Shiny

1 Introduction

Land consolidation is a project where the aim is to solve ownership fragmentation of particular parcels in the cadastral area, as well as the fragmentation parcels themselves. According to FAO (Food and Agriculture Organization of the United Nations, 2003), the process of land consolidation is an essential tool for making rural development. Furthermore, this process is of great importance for improving natural resources management and the use of rural space. Fragmentation can occur in a couple of ways (FAO, 2003):

1. as a fragmented farm - a farm that comprises several parcels located some distance from one another and
2. as fragmented ownership - the farmer is in the co-ownership with other farmers or with the absent owner (owner living in a distant city).

A process of land consolidation is a global issue with the goals to fulfill expectations not only from the institutional perspective but also from the perspective of farmers. For instance, authors from Slovenia (Lisec, A. et al., 2014) had discussed the connection of the owners' satisfaction with the process of land consolidation and land consolidation as the tool for better farming. In his paper, Mr. Hartvingsen from Denmark (Hartvingsen, 2014) discusses land reformation and land consolidation, where he is trying to solve the problem of fragmentation in parcels and ownership in 25 states of Central and Eastern Europe.

The problem of fragmentation is present in Slovakia as well when it all started around 1836 (Geisse, 2018). In the time of the Austro-Hungarian monarchy, where Slovakia belonged as well, the model of inheritance was based proportionally on every descendant of a married couple. That was usually a consequence of not leaving a will after someone's death, which, therefore, meant that every child who is left behind was entitled to inherit a proportionate share of agricultural land. As a result of such behavior, agricultural parcels were inevitably smaller and narrower. With such a problem, it was becoming difficult to grow agricultural goods, and therefore economical profit was lacking.

In later years, after World War II, there were several attempts to regulate the land (Geisse, 2018). Between 1949 and 1958, the aim of regulating the agricultural territory was under political influence through the process called „Nationalization". In this period, every parcel of the cadastral area was

merged into bigger ones, within existing field road network and water management facilities, with the primary motivation to use mechanical equipment fully and to establish joint maintenance of agricultural parcels. Small owners left without the possibility of taking care of their parcels and were forced to join farm cooperatives. This process is called „Collectivization“. After 1989, primarily was important a determination of the actual situation on the parcels as well as restoration of parcel records in cadaster. Not only was the aim to reorganize ownership records, but also to identify, ideally, all owners of specific parcels. Therefore, every parcel will belong to a known property list, but at the same time, there will be precise information about parcels without known owners.

In addition to improving the quality of agricultural production and preserving ecological elements, the issue of ownership and fragmentation of parcels is one of the main motivations for continuing land consolidation projects in Slovakia.

This paper aims on introducing the term of water management and anti-erosion measures in the process of land consolidation. Finally, at the end of this paper, a case study from Serbia will be presented as an example of a complete land consolidation project which was implemented in web application using R programming language and Shiny package.

2 The concept of water management and anti-erosion measures in the process of land consolidation

The project of land consolidation could be a helpful tool for contribution to landscape and water management. According to Mrs. Muchová (Muchová Z., 2016), the most common problems of the landscape in Slovakia are a sudden local flood, high water erosion, high wind erosion, pollution. Besides these, there is an alluviation of watercourses sediment in dams and ponds, and so forth. By rational planning of a land structure in a cadastral area such as consolidation of property rights, planning size, shape, and the right location of the parcels, hazards, which are made by a free movement of water, could be effectively avoided. In such an organizational process, it is an essential requirement to consult the landowners. On agreement with them, depends on in which direction will move this project of structuralizing parcels.

The benefits of a structured water management system in the cadastral area come along with possibilities of improving irrigation and drainage system, to solve ecological stability, to improve rural life quality, and so forth. For such reasons, land consolidation represents not only measures of adjusting the structure of parcels, but this kind of project shapes the future infrastructure of the whole cadastral area. Without considering water management measures into a land consolidation project, it could cause poorly usage of such a cadastral area. Adverse effects of not involving water and anti-erosion measures into land consolidation could be (Muchová et al., 2013): the emergence of floods on existing waterways, penetration of surface runoff and eroded material from the agriculture area to the urban area by new waterways, physical and chemical soil degradation by erosion processes, etc. Along with building a new water system or making anti-erosion measures, it is of great importance to maintain new facilities. From a hydrological point of view, the recommended procedure on how to execute the regulation of land territory is (Muchová et al., 2013):

1. determination of the perimeter of the cadastral area where land consolidation planned for erosion control design and water treatment facilities and measures,
2. analysis of the rainfall-runoff process in the field of land consolidation,
3. intensity determination of water soil erosion,
4. assessment of the severity of erosion of soil by water erosion,
5. dimensioning of water management and erosion control, as well as equipment and measures, including their localization in the area of a land consolidation project.

Based on the methodology mentioned above, it is possible to implement anti-erosion, flood, and water retention measures to alleviate the increasingly frequent problems related to climate change (flooding and droughts). From the water management point of view, those measures would secure the landscape against the tides water and waterlogging and provide a source of water to cover the humid deficit (reservoirs, ponds, polders, revitalization of watercourses, dams, drainage, etc.).

3 An example of land consolidation data visualization using programming language R with Shiny package, case study: Baranda (Serbia)

In such a complex project as land consolidation, landowners are an essential part of it. They must be persistently informed about the ongoing process and the current state of the project. The primary motivation for this case study was to create an application for providing data and up-to-date visualization on the plots that enter the project. This application was created using a programming language R with the package Shiny. The strengths of this programming language are statistical calculations and prediction modeling. This way of representing data gained through land consolidation project, serve as an inventive, non-standard procedure for spatial visualization data. Some of the data were picked from the PostgreSQL database to publish only these data, which would be beneficial for landowners.

Further, these data had been imported to an integrated development environment for R, called RStudio. The Shiny package is commonly used for creating an application that could be used as geoportal afterward. Shiny allows the development of interactive web applications directly from R script. Besides the possibility of publishing, this application, made for visualizing data of land consolidation, also allows users to switch between layers, to use a tool for measuring the area of the parcel, and to see basic statistics of the project through interactive graphs.

With the evolution of technology, customer expectations of cartographic web applications evolve, as well. Usually, tools that are used to develop such applications are either too expensive or too complex for an ordinary user. Creating a simple application is one way of contribution where landowners will have the opportunity to search and look at the parcels they own transparently. The author of this paper has the intention to present an effective development procedure for this kind of application. The application was made at the hand of open source programming language R together with open-source relational database PostgreSQL/ PostGIS (PostgreSQL: The World's Most Advanced Open Source Relational Database, 2019). As mentioned above, programming language R is usually used for statistical computing and graph visualization. It represents an open-source project, which was developed in Bell Laboratories by Mr. J. Chambers (a statistician who developed at first a programming language S). Together with his colleagues, he first used R language in 1993 (The R Foundation, 2019). Source code for R software was written in various programming languages such as C, Fortran, and of course, R ("Wrathematics", 2011). R language is under the free license GNU GPL, and it can be used in various operating systems. Despite the statistical background, the R environment contains packages for vector and raster data manipulation. Tools that are made for this specific application should help users to search and manipulate spatial data in the particular cadastral area. For the study case, the author chose the cadastral area in Serbia, specifically a village called Baranda. Figure 1 represents the location of Baranda.

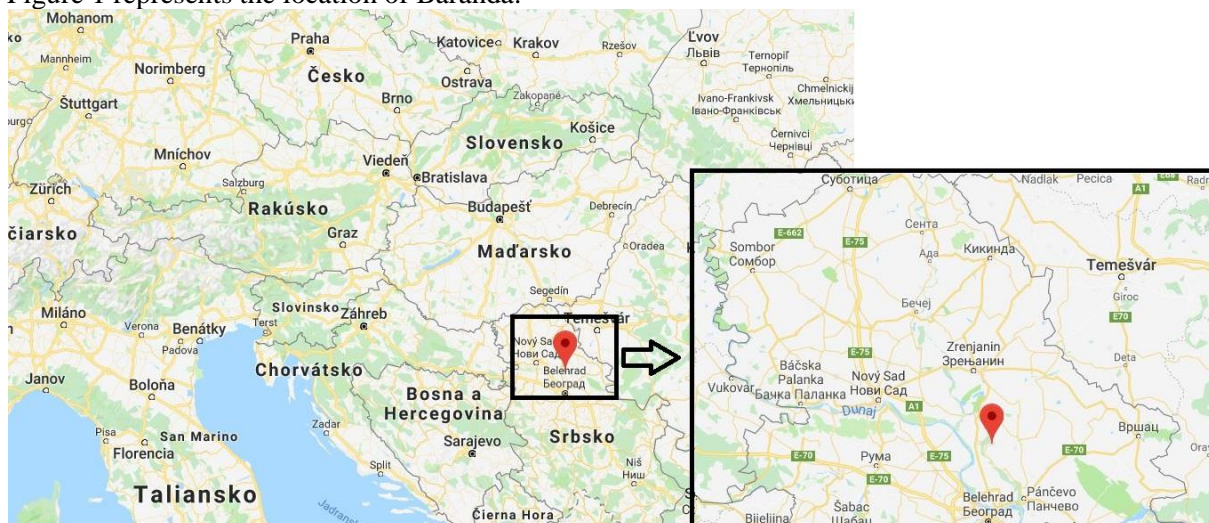


Figure 1: Geographical location of Baranda (source: maps.google.com)

The primary motivation for creating such an application was a necessity for the transparent representation of results made in a land consolidation project. The majority of the data were provided by the company „MapSoft“ from Belgrade, which was responsible for a land consolidation project. A raw database was delivered in a relational database system Microsoft SQL Server 2012 (Microsoft, 2019). In this database, there were 51 tables with a lot of redundant data such as names of officers working in cadaster, and so forth. After analyzing and cleaning all unnecessary data in the first database, the next step was the design of a new database in a relational database system called PostgreSQL. In a newly created database, there were nine tables with data about landowners and ownership interests, about land plots before and after the project of land consolidation, as well as information about the locations of wells within the cadastral area. Figure 2 shows a relational model of the newly created database.

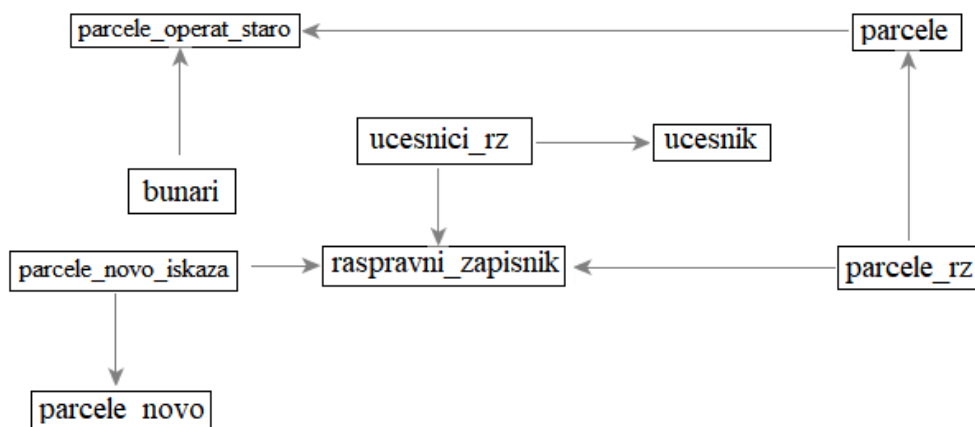


Figure 2: Relational model of new database (Aleksić, 2019)

The methodology of creating a database

In the PostgreSQL relational database, there were proposed a few queries which can be used as a verification of possible mistakes made by the MapSoft software used by MapSoft company. They usually use this software for determining the quality or area of land plots. For instance, one of the queries which were created is about controlling topology. As a general rule, every well should be placed within the boundaries of just one land plot. For gaining such information, the function which was used for checking mentioned topology rule named „st_within“ should be considering spatial objects, particularly land plots and position of wells. As a result, the author found out that every well (represented as a point feature) belongs to just one parcel (expressed as a polygon feature). Figure 3 shows an example of a user query altogether with a result.

Query Editor

```

1 SELECT parcele_operat_staro."broj_parcele", bunari."id"
2 FROM parcele_operat_staro, bunari, parcele
3 WHERE st_within(bunari."geom",parcele."geom") AND
4 parcele."broj_parcele"=parcele_operat_staro."broj_parcele" AND
5 parcele_operat_staro."broj_parcele"=bunari."broj_parcele";

```

Output pane

	broj_par text	id text
1	1340/4	BV-143
2	1084/6	SZ-100
3	936/20	SZ-10001
4	1308	SZ-10002
5	1540/4	SZ-10003
6	1083/17	SZ-101
7	1453/2	SZ-106
8	1446	SZ-107
9	1287/2	SZ-109
10	1252	SZ-114

Figure 3: Sample of a query

For the visualization of spatial data, which is essential for landowners, some data were imported from PostgreSQL to the RStudio environment. More specifically, the imported data represent polygons of land plots before land consolidation, land plots after land consolidation, and the location of wells inside a cadastral area. Before the spatial data were imported, there was the need for transformation between the coordinate systems Gaus-Krüger (the coordinate system in which data were gained) and WGS84 (the coordinate system which is usually used for representing spatial data when creating Shiny application). The transformation was performed in QGIS open-source software (QGIS, 2018) in order to correctly visualize spatial data.

R environment and used packages inside Rstudio

R is a language and environment for statistical computing and graphics (r-project, 2019). One of the few pros of using R is manipulating and storing a significant amount of data. In order for adequately manipulation and analysis of the data, the R environment offers a wide range of functions and packages. R is available as Free Software and could be downloaded from the official website of the project CRAN (The Comprehensive R Archive Network, 2019). The most common user interface for language R is RStudio, which also represents the integrated development environment. When the RStudio is opened, the user can find a console for writing and running the code (top left and bottom left), a global environment window which shows all defined variables (top right). Components like a browser for searching data directory with a plot window and a window used as help when manipulating with packages (bottom right) are shown in figure 4.

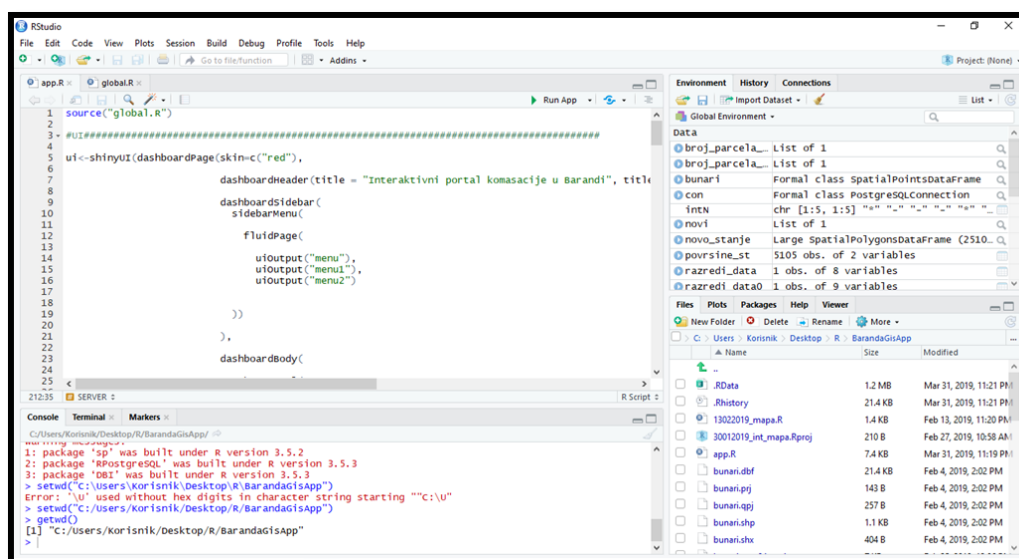
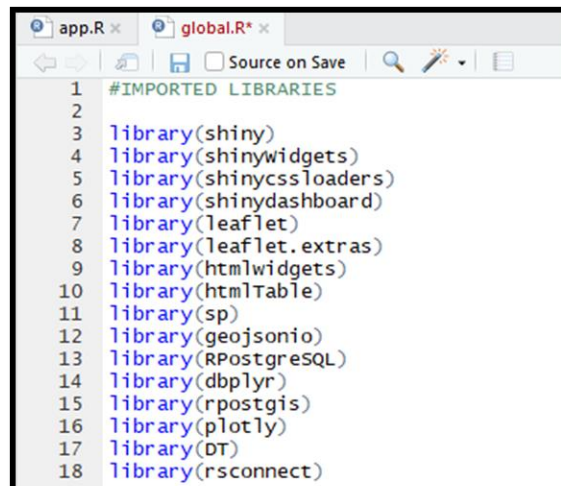


Figure 4: Appearance of RStudio environment (Aleksić, 2019)

During the creation of the application, which visualizes spatial data for land consolidation, there were used more than ten packages that contained tens to hundreds of features. The used packages are focused on data retrieval (function `read.csv`, package `RPostgreSQL`, `dbplyr`), data visualization (`htmlwidgets`, `leaflet`), spatial data (`sp`), a publication of results (`shiny`) and many others. Figure 5 shows a list of used packages during the creation of the application.

The image shows a screenshot of an RStudio editor window. The window title bar indicates two files are open: 'app.R' and 'global.R'. The 'app.R' file is active, and its content is displayed in a text editor. The code starts with a comment '#IMPORTED LIBRARIES' on line 1. Lines 3 through 18 list various R packages being loaded using the 'library()' function. The packages listed are: shiny, shinywidgets, shinycssloaders, shinydashboard, leaflet, leaflet.extras, htmlwidgets, htmlTable, sp, geojsonio, RPostgreSQL, dbplyr, rpostgis, plotly, DT, and rsconnect. The code is formatted with line numbers on the left and blue text for the package names.

```
1 #IMPORTED LIBRARIES
2
3 library(shiny)
4 library(shinywidgets)
5 library(shinycssloaders)
6 library(shinydashboard)
7 library(leaflet)
8 library(leaflet.extras)
9 library(htmlwidgets)
10 library(htmlTable)
11 library(sp)
12 library(geojsonio)
13 library(RPostgreSQL)
14 library(dbplyr)
15 library(rpostgis)
16 library(plotly)
17 library(DT)
18 library(rsconnect)
```

Figure 5: List of used packages in R (Aleksić, 2019)

Shiny and Leaflet packages

In general, the Shiny package is a product of an RStudio to make a web application created more simply. Communication of client and server, styling the appearance of the application, everything is solved through Shiny. The structure of a Shiny application consists of a user interface code (*ui.R*) and server code (*server.R*). These two parts belong to one file named “*app.R*”. In the first part of the application code, the creator of the application designs the user interface with the necessary buttons and tools, which the client will see upon the start of the application. The other part of the application belongs to the creation of the server code, which represents the back-end of the application (Das S. R., 2017). After completing the code, the application is being run, and the code is evaluated. The portion of the code is sent to the *ui.R* part for the output to be displayed to the end-user. The server function is always defined through two arguments: input and output.

In addition to Shiny, there is one more package that is popular when it comes to creating an application, that is Leaflet. This package includes many options that are designed to enhance the use of interactive applications. Among these options, Leaflet package consists of the selection of multiple base maps, interactive zooming in/out of map content, adding polygons in .shp and GeoJSON format, switching between multiple layers, and so forth.

The easiest way to add map tiles is through `addTiles()` function without any other defined arguments. This function, by default, will add OpenStreetMap as the base tilemap. As an alternative, third-party map tiles (free or paid) can also be used by adding additional map bases using plug-ins. Adding R objects to the base map in terms of polygons and points is possible through the function of package “*sp*” or other sources, too.

Furthermore, the polygons can be customized to meet specific data requirements. These polygons can be represented as separate lines or with content colored according to specific criteria. The integration of the Leaflet package is similar to the implementation of the Shiny package elements. First of all, the user interface code section defines “*leafletOutput()*”, which represents the location of the map within the user interface. “*renderLeaflet()*” function is then defined within the code that belongs to the server to provide a map with all its widgets added. The map object will be returned after using the “*renderLeaflet()*” command. Figure 6 shows the part of the code for the user interface and server where the Leaflet function enters.

```

tabPanel("Mapa",
  FluidRow(
    column(12, box(height = "auto" width = "auto", solidHeader = FALSE, status = "info",
      leafletOutput("m")>% withSpinner()),

server <- function(input, output, session) {

  output$m <- renderLeaflet({
    leaflet(options = leafletOptions(zoomControl = FALSE)) %>%
      htmlwidgets::onRender("function(el, x){L.control.zoom({ position: 'bottomright' }).addTo(this)}") %>%
      addTiles(group = "OSM (default)") %>%
      setView(lng = 20.495850, lat=45.086297, zoom=12)%>%
      addPolygons(data = staro_stanje,
        weight=0.8,
        color= "#ff4d4d",
        group = "Staro stanje",
        label=broj_parce,
        popup=povrsina_p)%>%
      addPolygons(data = novo_stanje,
        weight=0.8,
        color= "#1a0000",
        group = "Novo stanje",
        label=broj_parce)%>%

```

Figure 6: The implementation of Leaflet package (Aleksić, 2019)

The structure of the application for land consolidation in Baranda and output presentation

Within the first run of the application, the user gets to see the main panel, which represents base map zoomed to the cadastral area of Baranda. Additional mentioned features in the Leaflet package are included in the map, where users are allowed to switch between multiple layers or to determine the area of the parcel through the use of a dedicated tool. Polygons of the parcels represent the group of layers before land consolidation, the parcels after the land consolidation, and the points indicating the location of wells within the cadastral area of Baranda. The map window also includes a parcel location search tool, where the search criteria are the parcel number. At the bottom of the map panel is a table added using the "DT" package. In the table, users are provided with information about the area size in the state before land consolidation, which corresponds to the cadastral data. In this way, the user can determine the size of their old parcels and simultaneously view the location of the parcels on the map. In the sidebar, users can switch to the Republic Geodetic Authority official website in Belgrade, which provides more information on the prices of parcels in particular cadastral area. There is a short statistic of how many parcels and participants were in total before the land consolidation project. Also, there is a short statistics about the number of parcels and participants after the land consolidation, as well. This statistic is used as one of the criteria for assessing the success of a project. Figure 7 shows the appearance of the "Map" panel after the application is run.

Next to the „Map“ panel, another panel called "Statistics" was created. This panel is intended to inform participants of further statistical results in the land consolidation project. For the actual visualization is used package "plotly", which allows the interactive representation of data in the form of a pie chart. In the first pie chart, the information presented to the users is the number of parcels before the project started based on the quality of the soil. The second pie chart shows the number of landowners who owns only one parcel in this cadastral area. The overall structure of the code of the featured application can be found on the GitHub page via the link: <https://github.com/mimacharapp/app>. Figure 8 represents the appearance of the section in the "Statistics" panel.

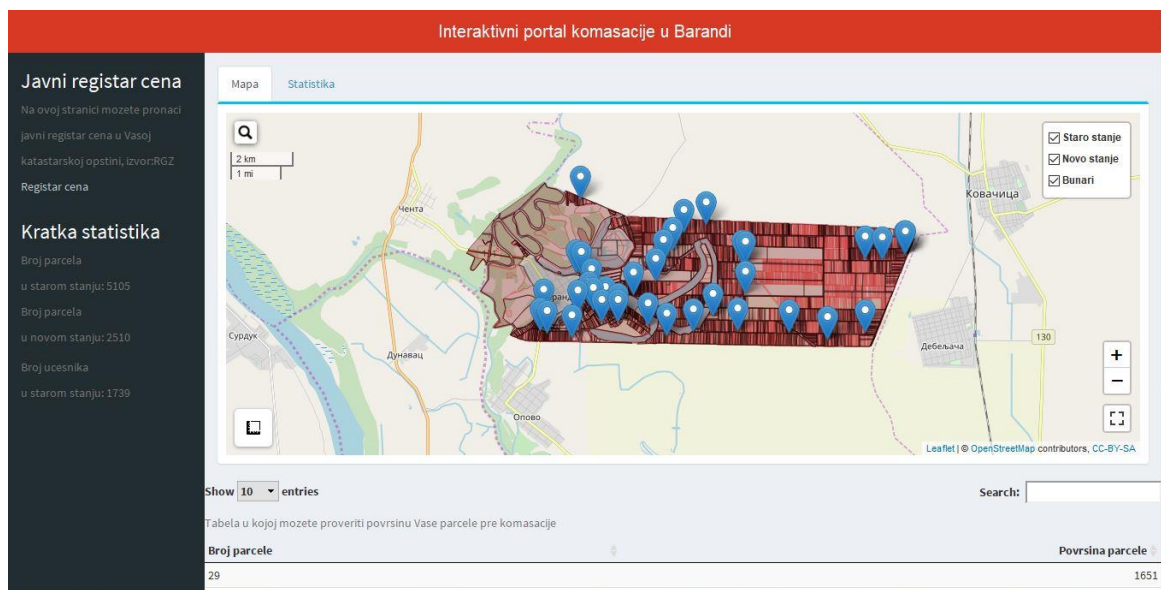


Figure 7: Appearance of the „Map“ panel

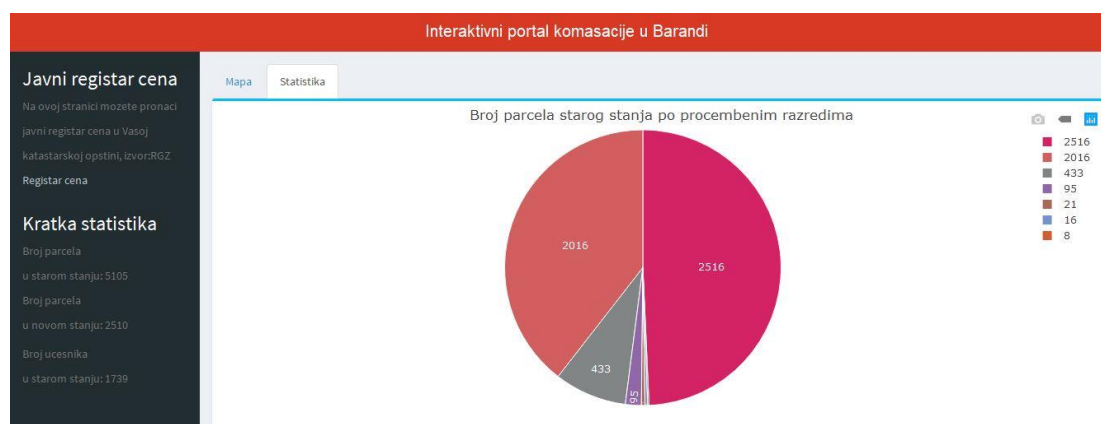


Figure 8: Appearance of the „Statistics“ panel

Evaluation of achieved results

The presented paper gives a reader an overview of the possibilities of the R language for creating an application presenting spatial data with the extension of statistical analysis tools. The use of the R programming language (mainly intended for statistical calculations) to visualize parcels and create an interactive application is an innovative approach with the advantage of quickly building an application using the Shiny package. Knowledge of other programming languages is not necessarily required when creating the application, as most of the functions and commands are available in R. Last but not least, the use of the R language is an indisputable advantage of its statistical background with a wide range of powerful analytical tools, which means that within the application, it is possible to attach the results of statistical calculations in the form of graphs and histograms. The developed application for the visualization of spatial data in the framework of land consolidation consists of useful tools as well as tools for performing simple queries. The created application is of great importance to landowners because it provides simple but essential information about the process of land consolidation. The owner is allowed to search through the parcels before the project started, use the measurement polygons tool, or find out the price of specific parcels. The results obtained in this way can be applied in water resource management, as well as where direct visualization and analysis of particular data are required.

4 Conclusion

Land consolidation is a complex project which could be beneficial for Slovakia. Importantly, land consolidation solves not only ownership interests and plot location, but it could be favorable for a water resource management of the countryside as well. The cadastral area has a spatial and functional layout of the territory, which is presented by the change of landscape structure. When it comes to a visualization of the data, the use of the R language and the RStudio environment has proven favorable. To a great extent, the appearance and functionality of the shown application were solved entirely only by using the R programming language. Possibilities for using other stylesheets (e.g., CSS) are possible but not necessary. The proposed application was tested in terms of user requirements on a sample group of selected users, and their comments were incorporated into the final design. From the owner's point of view, the components which are included in the application should be enough for briefly informing the landowners about the state of the land consolidation project. In this way, owners are provided with up-to-date information.

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