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DEVELOPMENT OF GEO-DA BASED ANDROID APPLICATION FOR SPATIAL AND STATISTICAL ANALYSIS OF SERBIAN LONG-TERM PRECIPITATION DATA

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Miljan Jeremić[1], Miljana Milić[2], Jelena Milojković[2], Milan Gocić[3]

[1]Knjaževac gymnasium, Knjaževac, Republic of Serbia
[2]University of Niš, Faculty of Electronic Engineering, Niš, Republic of Serbia
[3]University of Niš, Faculty of Civil Engineering, Niš, Republic of Serbia

Abstract. *Precipitation is one of the most important parameters to consider while analyzing risks from natural weather threats like floods and droughts. To prevent significant infrastructural and financial damage and loss, a good analysis of data and its visual presentation must be enabled. This also requires a reliable source of precipitation data for the region of interest. It is important to interpret and visualize the data obtained from meteorological stations to make an assessment, a forecast, or issue a warning. This paper describes the development of an Android application that enables visualization and analysis of average annual precipitation data for the period from 1946 to 2019, in the territory of the Republic of Serbia. Necessary precipitation data were acquired on the request from the official weather monitoring service for the Republic of Serbia (RHMSS).*

Key words: *Precipitation, Android application, Geo-Da environment, Visualization*

1. INTRODUCTION

The evolution of mankind in all areas of life produced some undesirable effects. They are the weather and climate changes. Climate change is characterized by an increase in temperatures, but also by changes in the precipitation pattern, its annual distribution as well as the intensity distribution, but also by the increased frequency of extreme weather events and periods with extreme climatic conditions [1]. Such changes strongly impact the environment, the economy, and people's health and safety [2], [3], [4], [5], [6], [7]. To assess the climate

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Corresponding author: Miljana Milić
University of Niš, Faculty of Electronic Engineering, Aleksandra Medvedeva 14, 18000 Niš, Republic of Serbia
E-mail: miljana.milic@elfak.ni.ac.rs

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changes for some territories and make future climate projections, it is necessary to use available and reliable long-term climatic and meteorological data sets [8].

The climate change can only be detected as a long-term process [9], [10]. It requires the processing of large meteorological data sets that are acquired over a long period of time. These data sets are measured and assigned to a particular territory. Measured meteorological data consists of many different meteorological indices, which makes the amount of information quite large [11]. Meteorological data could be obtained manually or automatically from sensors at meteorological stations, satellite observations, radar data, and smart mobile devices [12]. In general, national meteorological centers or similar dedicated organizations are usually responsible for the systematic observation of weather conditions across a specific area [13].

To deal with a massive amount of information, for long-time periods, it is necessary to develop computing methods for easier, faster and more reliable processing and visualization. In the field of meteorological data, one of the most appropriate is the spatio-temporal analysis [14]. The spatio-temporal data analysis is a useful tool in the field of application development. It is a relatively new computational technique that enables the analysis of large spatio-temporal databases. Spatio-temporal patterns arise when data is collected over time and space and has at least one spatial and one temporal attribute. An event in a spatial data set describes a spatial and temporal phenomenon that exists at a given time and location [15]. It contains information about the value of the observed variable, and its time and coordinates of sampling. To assess such data structures a combination of time series and spatial-statistical analysis is required [16].

This paper describes a development of a specific Geo-Da based Android application that performs the spatio-temporal analysis of precipitation data for the territory of the Republic of Serbia for the 74 years long period. The application should identify statistical and geospatial relations over the acquired data and use the Geo-Da software tool to obtain certain meteorological and climatic conclusions, assumptions and forecasts that could be used for decision-making actions in the fields of science, economy, politics, agriculture, education etc.

2. STUDY AREA

In the year 2014 the territory of the Republic of Serbia experienced one of the worst natural disasters i.e., an extreme flood [17]. The flood prevention system either failed to prevent damage or was never implemented. The riverbeds were rarely cleaned and maintained for decades, and the embankments were not renovated. The pumping stations were also neglected and their functionality was rarely checked. The authorities of the Republic of Serbia have conducted a post-disaster damage assessment after the floods. In general, the serious unpreparedness disturbed the lives of many people and did severe damage to urban systems, agriculture, and the local economy [18], [19]. These are the main reasons that confirm the necessity of developing, one easy-to-use, highly available and affordable, mobile phone-based application for following the precipitation trends for different areas in the Republic of Serbia.

The necessary data for development of such an application can be acquired from 28 national meteorological stations that are shown on the map in Figure 1 [20].

The meteorological data that are gathered for the analysis cover the area between 46°11′ N (Hajdukovo) to 41°51′ N (Dragaš, Kosovo) latitude and 23°01′ E (Senokos, Dimitrovgrad) to 18°51′ E (Bezdan, Vojvodina) longitude. This covers an area of approximately, 88,499km^2, and is bounded by a 2,114km borderline. Serbia's climate is a mix of continental in the north, with cold dry winters and warm, humid summers with well-distributed rainfall patterns, and the Mediterranean in the south, with hot, dry summers and autumns and average comparatively cool and rainy winters with substantial mountain snowfall [21]. Climate variances are caused by differences in height, closeness to the Adriatic and Aegean Seas, vast river basins, and exposure to the winds [22].

Northern Serbia has a continental climate, shaped by air masses from northern and western Europe. Strong Mediterranean influences can be noticed in mild winters and hot summers in Serbia's south and south-east [21]. The Dinaric Alps and other mountain ranges, on the other hand, help to cool a large portion of the warm air masses. Because of the mountains that encircle the plateau, the winters in Raška (region) are particularly harsh [23] [24]. For the period 1981 to 2017, the average annual air temperature for the area with a height of up to 300 m was 11.6°C. The average yearly temperature in areas between 300 and 500 meters in height is around 11.0°C, while over 1,000 m altitude is around 7.5°C [25]. According to the Republic Hydrometeorological Service of Serbia, the record of the coldest weather in Serbia measured the temperature of −39.5°C (January 26, 2006, Karajukića Bunari in Pešter), while the highest daily temperature was 45.2°C (July 24, 2007, Leskovac) [25].

Fig. 1 Map of national meteorological stations in the Republic of Serbia

Precipitation is one of the most essential climatic elements [21], [26]. Considering the atmospheric processes and the characteristics of the relief, the precipitation on the territory of Serbia is irregularly distributed in time and space. The typical annual amount of precipitation for the entire territory of Serbia is 896 mm. Annual average precipitation values increases with altitude. Dryer areas, with precipitation below 600 mm, are located in the north-east of the country, in the South Morava Valley and part of Kosovo [27]. The area of the Danube Region, the valley of the Great Morava and its continuation towards Vranje and Dimitrovgrad, has up to 650 mm of precipitation during the year [27]. Going east, in the area of the Homolje Mountains, the annual amount of precipitation reaches values up to 800 mm. Similar conclusions stand for the mountainous areas in south-eastern Serbia. The larger areas at the west and south-west are the rainiest areas of Serbia. According to the Pešterska plateau and Kopaonik, the values reach 1,000 mm per year, while some mountain peaks in south-western Serbia have even larger annual precipitation indices [27].

Figure 2 depicts the average annual precipitation in Serbia for the period 1946-2019. In the lowest parts of Serbia, annual precipitation values range from 540 to 820 mm. In locations over 1,000 m, the average precipitation is from 700 to 1,000 mm, and up to 1,200 mm on some mountain peaks in south-western areas.

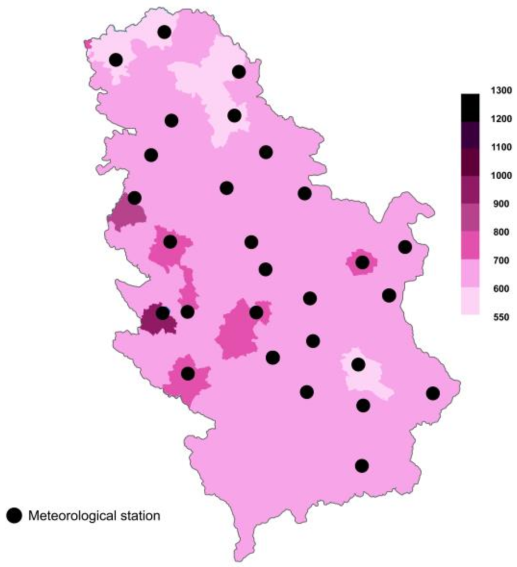


Fig. 2 Mean annual precipitation with a spatial distributionfor the period 1946-2019 in Serbia

Figure 3 provides the spatial distribution of the coefficient of annual precipitation variation for the precipitation data for the selected meteorological stations. Zlatibor and Loznica have a coefficient of variation of about 17%, while Kopaonik has the largest variation of over 32%. The coefficient of precipitation variance in Serbia is mostly less than 20%.

The majority of Serbia experiences the continental precipitation, with higher amounts of rainfall in the warmer months. The rainiest months are June and May. The month of June receives 12 to 13% of the total yearly rainfall. The months of February and October receive the least precipitation, accounting for 5 to 6% of the total yearly precipitation. The territory in southern Serbia has a Mediterranean precipitation regime, with a maximum in November, December, and January, and a minimum in August, due to relief, slopes of high mountain massifs, and the impact of the Mediterranean climate [28].

The snowfall and snow cover formation are characteristic for the period from November to March, and sometimes in April and October. For the mountain regions above 1,000 m these can appear during other months. The highest number of days with snow cover (30 to 40% of the total annual number of days with snow) is in January [29]

The extreme values of ever measured precipitation so far are:

- The driest year was 2000, when only 223.1 mm was measured in Kikinda.
- The rainiest year was 1937, when as much as 1,324.5 mm was measured in Loznica.
- The highest monthly amount of precipitation was registered in June 1954 in Sremska Mitrovica, 308.9 mm.
- The highest daily amount of precipitation was registered on October 10, 1955 in Negotin, 211.1 mm.

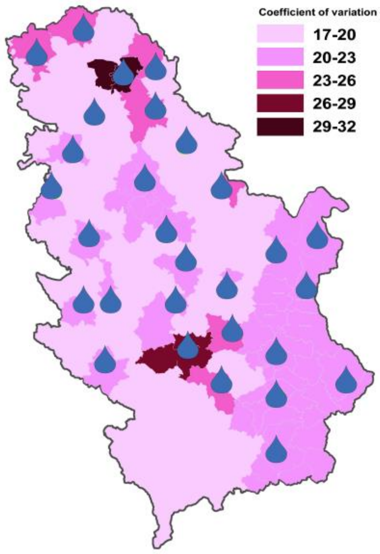


Fig. 3 Annual variations of precipitation data in Serbia

3. Development of Geo-Da Based Application using MIT App Inventor Environment

Figure 4 depicts the methodology for developing an Android application using the available data. It starts with the data gathering and finishes with an appropriate visualization of precipitation geo-data. In particular, the waterfall methodology was used in this study for the application development. The waterfall technique is a systematic and sequential paradigm for developing information systems [30]. The steps of the Waterfall approach are: 1 Definition and analysis of the system requirements, 2 Design of the software system, 3, Unit implementation and testing, 4 System integration, and 5 System operation and maintenance. This traditional project management flow, provides a project with a well-defined and simple structure. Waterfall is a linear and sequential method, that enables the team to divide the project into manageable, explainable phases with distinct outputs. Only once the previous phase has been finished and approved does the team move on to the following step.

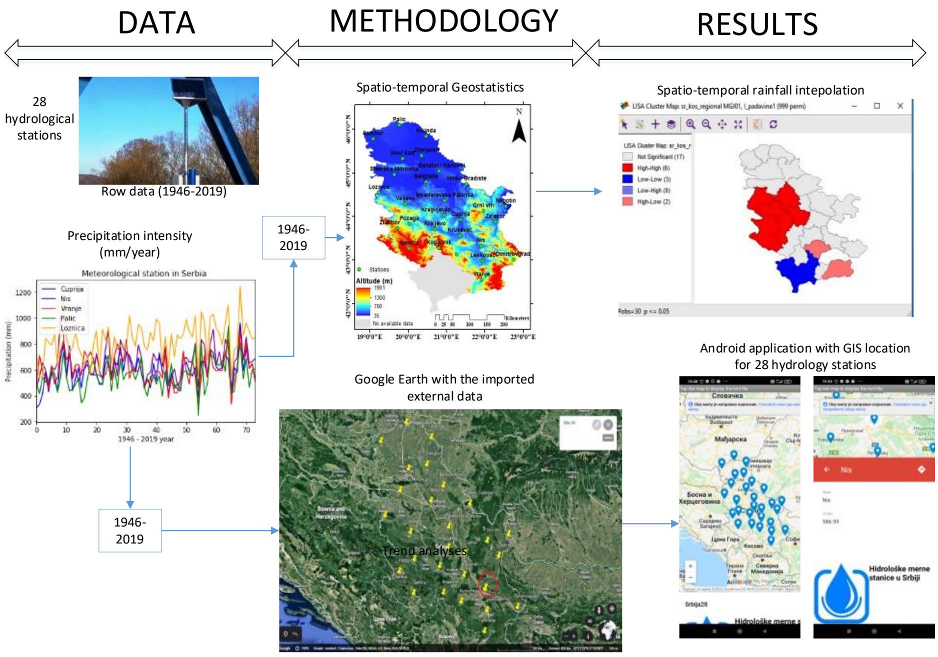


Fig. 4 Methodology for Android application development

The amount of raw meteorological data is quite large for a direct processing. This necessitates some feature extraction to reduce the amount of data to some meaningful and manageable size [31]. In particular, the necessary precipitation data was acquired on the request from the official weather monitoring service for the Republic of Serbia [Data source: Republic Hydrometeorological Service of Serbia; available online at www.hidmet.gov.rs, accessed on the 5th of December 2022]. Some parts of the data set are also available online at the web platform of this service [32]. Each data sample consists of information about the year, month, geographic location of the place, and the precipitation value for each month of the year. Using the analytical queries with the ORACLE database and its services, classification by months for 74 years was obtained over the data set. In this way the feature extraction process resulted in the parametric numerical and visual data systematization by the time period and location of the input signals. The extracted features are stored in the feature database and are used for further processing. Resulting data structures contain the average values of precipitation for all 28 locations that could later be linked to the KML database in order to enable their visualization. It should be emphasized that the main purpose of the application for precipitation visualization did not require any data adjustment. These data should be used and visualised in its “raw“ version, since the aim of the application is to visualize these values for the specified place and time and display it in the appropriate way.

Table 1 Geographic position of the meteorological measuring stations by their longitude and latitude

City	Longitude	Latitude
Kininda	20.47	45.85
Novi Sad	19.85	45.33
S. Mitrovica	19.63	44.97
Beograd	20.47	44.80
Loznica	19.23	44.55
Valjevo	19.92	44.28
Crni Vrh	21.97	44.13
Kragujevac	20.93	44.03
Zajecar	22.28	43.88
Kraljevo	20.70	43.72
Krusevac	21.35	43.57
Nis	21.90	43.33
Kopaonik	20.80	43.28
Vranje	21.92	42.55
Palic	19.77	46.10
Sombor	19.08	45.78
Zrenjanin	20.35	45.40
Dimitrovgrad	22.75	43.02
B. Karlovci	20.80	45.05
S. Palanka	20.95	44.37
V. Gradiste	21.52	44.75
Negotin	22.55	44.23
Zlatibor	19.72	43.73
Sjenica	20.02	43.27
Pozega	20.03	43.83
Kursumlija	21.27	43.13
Loznica	21.37	43.93
Valjevo	21.95	43.98

Two forms of acquired data are illustrated in Table 1, representing geographic positions of the meteorological measuring stations, and Table 2, representing the form of „raw“ precipitation data that needs to be visualized [32]. Table 2 gives the exact values of measured precipitation values at 28 meteorological stations at the territory of the Republic of Serbia from April to September 2022.

The process and programs that enable described data synergy are shown in Figure 5.

Geo-Da software is a free, user-friendly platform, that enables different spatio-related data analysis. It is developed at the University of Illinois and Chicago, and was funded by federal agencies like the National Science Foundation (USA), and the National institute of Health (USA) [33], [34]. It is an open-source platform which can run under different operating systems. Its main areas of implementation are spatial data analysis, geovisualization, spatial modeling and autocorrelation.

A graphical, intuitively designed interface to methods of exploratory spatial data analysis is accomplished by incorporating spatial statistical tests into simple map representation, linking data views of spatial and non-spatial distributions, and enabling real-time exploration of spatial and statistical patterns. It can import, convert and export data in different formats, [35], [36]. Then, it can transfer variables and create new ones. The software allows one to get new insights from spatial data by interactively exploring the data.

Table 2 Measured precipitation values in mm from April to September 2022, from 28 meteorological stations in the Republic of Serbia

Measuring station/ Month 2022	April	May	Jun	July	August	September
Palic	33.5	35.3	68.6	14.2	73.5	126.3
Sombor	35.6	56.4	36.1	19.6	39.0	112.1
Novi Sad	54.5	17.9	43.6	13.8	103.9	159.0
Zrenjanin	45.1	25.0	19.9	1.5	87.4	132.9
Kikinda	37.7	53.2	61.5	10.0	80.7	60.2
B. Karlovac	68.1	18.1	17.4	24.3	78.4	157.5
Loznica	57.6	31.2	171.5	68.2	122.9	167.0
S. Mitrovica	65.5	11.8	42.8	12.4	129.0	134.4
Valjevo	42.7	32.8	94.2	24.6	42.6	64.2
Beograd	80.1	32.2	43.3	63.9	89.7	98.0
Kragujevac	35.6	77.6	103.3	66.3	66.2	56.9
S. Palanka	75.4	62.4	120.9	79.3	99.3	108.6
V. Gradiste	81.7	42.1	38.9	42.2	54.4	160.7
Crni Vrh	48.9	58.7	55.9	69.4	75.5	84.4
Negotin	70.0	33.7	47.2	44.1	61.5	40.2
Zlatibor	66.9	61.0	126.7	26.3	44.7	94.3
Sjenica	55.7	75.9	76.4	63.4	52.1	96.3
Pozega	38.2	45.9	92.9	8.5	30.6	59.8
Kraljevo	41.7	32.1	127.5	38.1	124.9	99.3
Kopaonik	105.4	78.6	133.0	106.6	118.3	156.5
Kursumlija	52.5	22.1	84.3	30.1	85.8	107.6
Krusevac	40.1	28.9	93.3	53.3	102.2	119.8
Cuprija	37.8	50.6	83.3	18.7	101.6	99.5
Nis	58.1	23.0	43.5	58.6	119.2	67.9
Leskovac	67.9	47.1	82.2	35.9	83.0	122.3
Zajecar	38.3	36.2	124.7	44.1	24.2	54.3
Dimitrovgrad	73.0	52.7	111.1	81.7	111.8	96.3
Vranje	55.0	35.6	81.5	43.5	38.9	100.1

One can detect patterns and correlations, find trends with different maps and statistical views, and detect outliers. At the end, after exploring the spatial data in multiple views, the software can produce global and local spatial autocorrelation statistics as well as spatial regression models.

MIT App Inventor is a suitable and worthy environment for creating Android applications [37], [38]. Its application is shown in Figure 6. This web-based environment is designed to operate with command blocks; similar to the Arduino [38], Mbot [40], [41] and Scratch [42], [43] environments where commands are dragged into the workspace and parameter values are then set in commands. The Java Script programming language is used in the background.

This data processing aims to visualize the average precipitation in millimeters for 74 years, for the selected hydrological measuring station with the developed application. Data is aggregated by year and month starting from 1946 until 2019 [20].

KML (Keyhole Markup Language) is a file format that displays geographic data in an Earth browser such as Google Earth. KML uses a tag-based structure with nested elements and attributes and is based on the XML standard [44], [45].

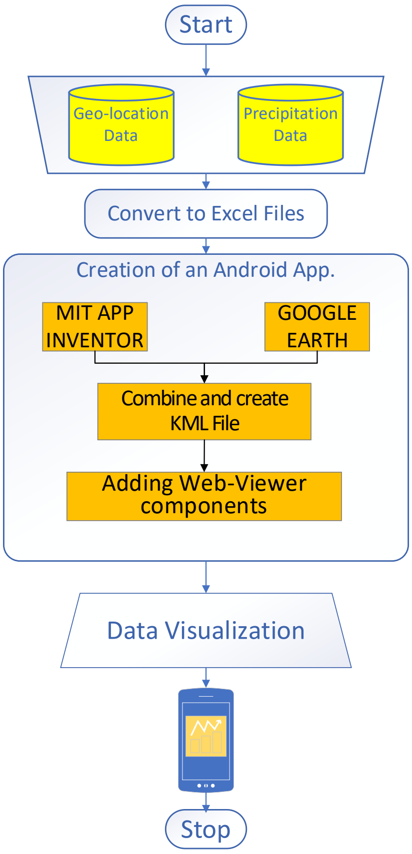


Fig. 5 Android application algorithm development

Using the Google Earth application at earth.google.com, we import a newly created KML file with geo-data on the locations of the hydrological measuring stations [46], [47], [48], [49]. Their average precipitations for 74 years are displayed on the map after importing the file (Figure 6). All stations are shown on the map of Serbia and are denoted with blue markings. By clicking on a particular hydrological measuring station, in the upper left corner, one can obtain the exact average amount of precipitation for 74 years. After all the imported files are located in the Google Earth web environment, one should now save the newly created project and download that link from the project for use in the MIT App Inventor Android environment.

The WebViewer component is used to display geospatial and numerical data from the Google Earth environment, which recognizes that a KML file with all the necessary data has been generated from the user. This component is certainly the most important in the created application because it regulates the selection and display of the measuring station, and the overall display of all measuring stations in the Republic of Serbia.

After selecting of the hydrological measuring station from the map, the application shows the name of the measuring station and the data related to the average amount of precipitation for the selected measuring station.

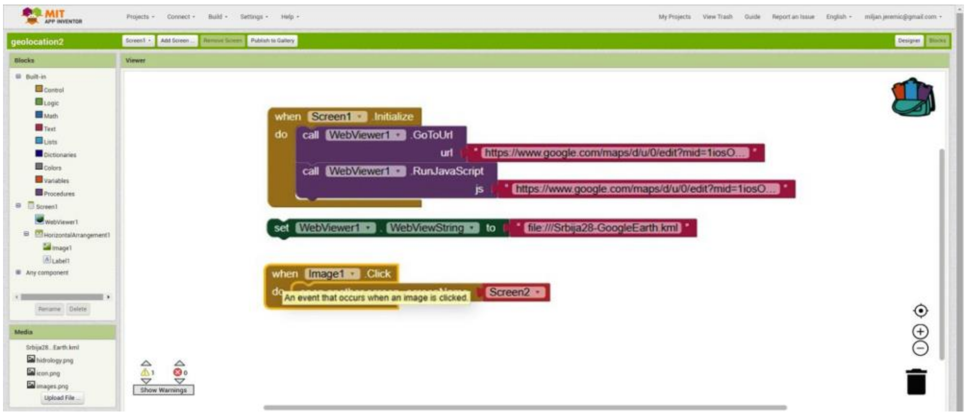


Fig. 6 MIT App Inventor

4. VISUALIZATION OF PRECIPITATION DATA

Precipitation data can be loaded and viewed using the developed Android application, as illustrated in Figure 7. As mentioned before, there are 28 measuring stations displayed on the map of Serbia. The map for the selected station can provide information about a specific location, i.e., its yearly precipitation value.

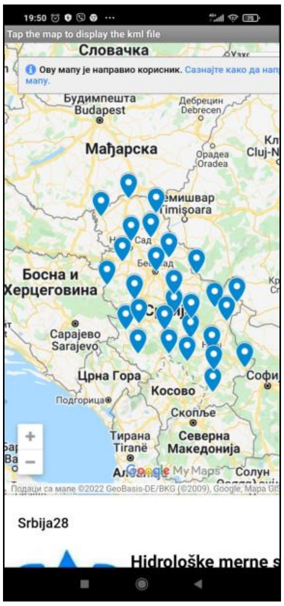


Fig. 7 Map of Serbian meteorological stations

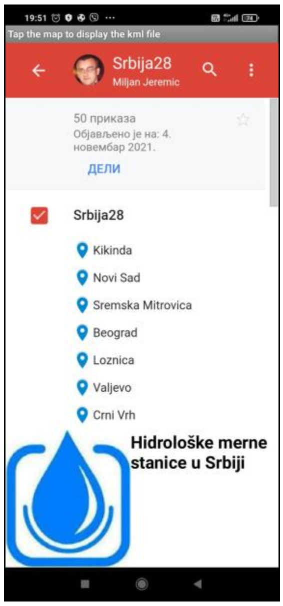


Fig. 8 List of meteorological stations

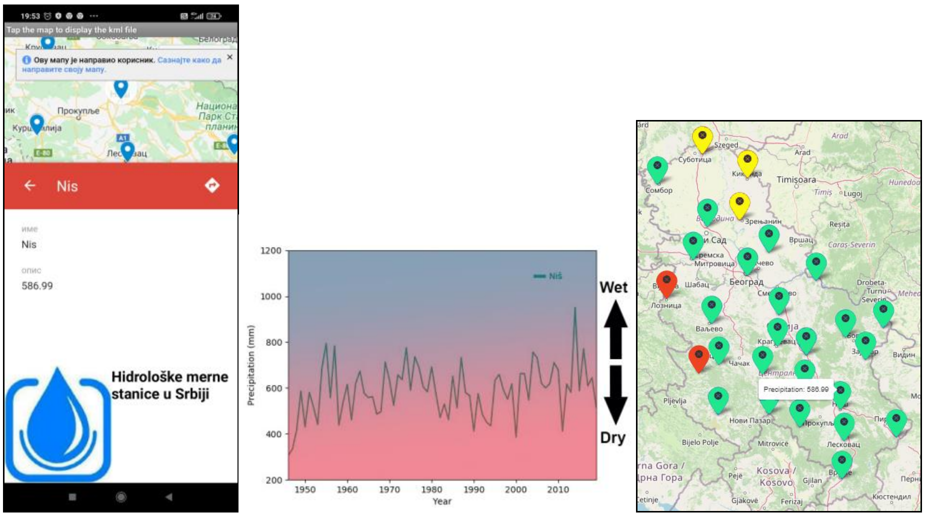
The annual amount of precipitation is depicted on the Serbian map in various colours, with yellow representing precipitation below 580 mm, green representing precipitation between 580 and 800 mm, and red representing precipitation exceeding 800 mm.

Figure 8 shows the list of the meteorological stations monitored by the application, as it appears in the Android application.

The time series of annual precipitation of the selected three meteorological stations in Serbia (Niš, Palić, and Loznica) are presented in Figures 9, 10 and 11, respectively. Each figure displays the selected meteorological location on the map of Serbia, with the corresponding average annual precipitation for the period 1946-2019 (Figures 9 a), 10 a) and 11 a)). For the given period, the average annual precipitation at selected locations ranged from 557 mm (Palić) to 830 mm (Loznica).

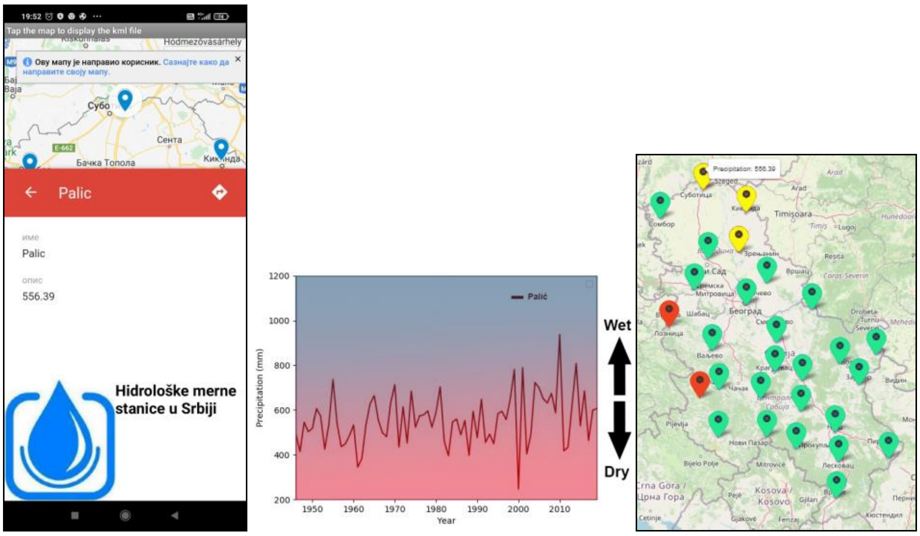
The time series of annual precipitation of the selected three meteorological stations in Serbia (Niš, Palić, and Loznica) are presented in Figures 9b), 10b) and 11b), respectively.

Precipitation data for cities of Niš, Palić, and Loznica on the map of the Serbian metheorological stations are shown in Figures 9c), 10c) and 11c), respectively.



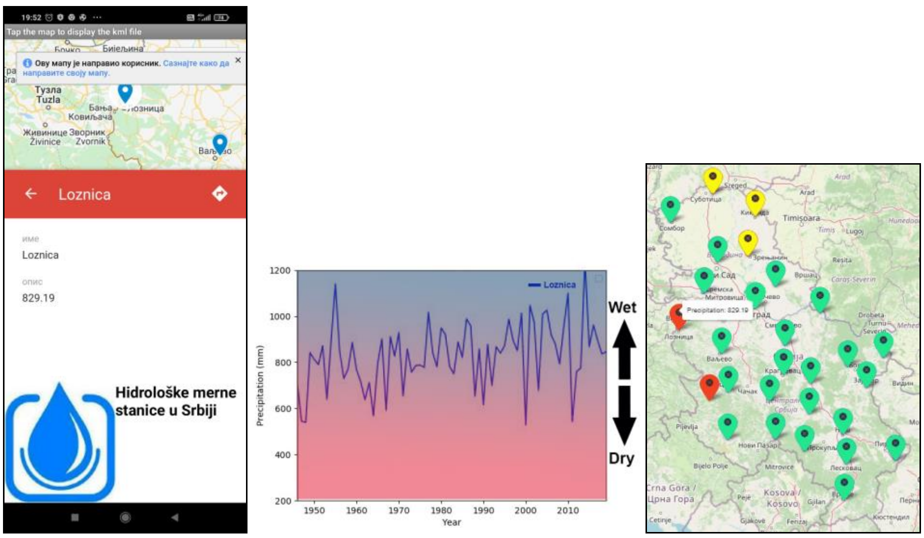
a) b) c)

Fig. 9 Precipitation data for the city of Niš obtained from the Android application: a) anual precipitation value for the selected city, b) time series of long-term annual precipitation for the selected city, and c) precipitation data for the city of Niš on the map of Serbian metheorological stations



a) b) c)

Fig. 10 Precipitation data for the city of Palić, obtained from the Android application: a) anual precipitation value for the selected city, b) time series of long-term annual precipitation for the selected city, and c) precipitation data for the city of Palić on the map of the Serbian metheorological stations



a) b) c)

Fig. 11 Precipitation data for the city of Loznica, obtained from the Android application: a) anual precipitation value for the selected city, b) time series of long-term annual precipitation for the selected city, and c) precipitation data for the city of Loznica on the map of the Serbian metheorological stations

5. CONCLUSION

The methodology and the Android Geo-Da based application for visualizing average annual precipitation data for 28 meteorological stations in Serbia from 1946 to 2019 is described in this paper. The application could be valuable in water resources as well as agricultural planning and management.

With the collection of new precipitation data, for the period after 2019, the application would have to be updated. Changes of the data sources should not influence the functionality of the application if their structure remains the same. On the other hand, the KML file would also have to be updated in order to keep the application functional.

The focus on further research in this field should be put on the development of advanced application options that enable monitoring of natural hazards such as drought and flood that also rely on precipitation data. Further, in our future research a newer version of the described application should be developed with the implementation of some mathematical and soft-computing approaches that predict extreme weather conditions, and enable early alarming and timely reacting.

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