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RESEARCH ARTICLE

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GIS and remote sensing techniques for the estimation of dew volume in the Republic of Serbia

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Abstract

With the help of satellite data and numerical geographical information system (GIS) methods, the total capacity of dew volume on the entire territory of the Republic of Serbia was estimated. Multicriteria GIS analysis and satellite detections with the support of methods such as kriging and semi-kriging gave satisfactory results in the present research. After the download of satellite data, they were compared with meteorological data for precipitation, evaporation and air temperature. A very precise grid in $1 \times 1^{\circ}$ of longitude and latitude was created. The average estimated dew potential for the territory of Serbia is 20–40 mm·year^{-1} for the south of the country, 15 mm·year^{-1} for the north, 30–50 mm·year^{-1} for the central region and 20–30 mm·year^{-1} for the east. In most drought regions, it is $< 10\ \text{mm·year}^{-1}\text{·m}^{-2}$. Counties with the largest dew capacity (between 15,200 and 20,000 L) include Borski, Nišavski and Jablanički in the eastern part of the country, as well as Zlatiborski, Raški and Peć in the western and southern parts, respectively. On the other hand, counties with the lowest dew capacity (2,000–3,000 L) encompass northern parts of Serbia (Sremski, Severno-Banatski, Srednje-Banatski, Južno-Banatski, Severno-Bački and Zapadno-Bački). The possibility for dew use is particularly strong during the spring. The estimated total capacity of the dew potential for Serbia is 1.5×10^7 L. By comparing the obtained data for Serbia, it is concluded that the amount of this type of water resource is not large, but enough for use in agricultural and other economic sectors.

KEYWORDS

dew volume, geographical information system (GIS) analysis, maps, satellite detection, Serbia, utilization

1 | INTRODUCTION

The Republic of Serbia has a relatively small area of 88,361 km^2, with intensive production of various industrial grains. Plants such as corn, soybean, wheat and sunflower are the most important agricultural products of the country. Although Serbia has large river and canal networks, there is still not enough water for irrigation purposes. The spatial distribution of main climate parameters is caused by specific geographical location, orography and local influence as a result of the combination of relief, the distribution of air pressure on a major scale, aspects of terrain, the presence of river systems, vegetation cover, urbanization and so on.

The northern part of the country, the Vojvodina region, is entirely located within the Pannonian Plain, covering the southeastern parts of the Carpathian (Pannonian) Basin. Several mountain systems are present in the country, including the Dinaric Alps (stretching through the west and southwestern parts) and the Carpathian, Balkan and Rhodope Mountains that occupy the eastern and southeastern regions of the country. The mean altitude of the Republic of Serbia is 473 masl and varies (when regarding hypsometric properties) between 29 masl in the eastern parts of the country (on the borders with Bulgaria and Romania) and 2,656 masl in the Prokletije Mountains in the south (Bajat *et al.*, 2015). The country is generally characterized by three main climate types: continental, moderate continental and modified Mediterranean. A typical continental climate dominates northern parts of the country (Unkašević and Radinović, 2000; Hrnjak *et al.*, 2014), while the southern and southwestern regions are more subjected to Mediterranean influences (Bajat *et al.*, 2015; Bačević *et al.*, 2017; Radaković *et al.*, 2018).

The Adriatic Sea represents a significant source of heat and moisture, and it has a certain influence on the inland climate. However, this influence is modified by coastal relief properties (i.e., the Dinaric Alps) and is suppressed to a certain point (Perčec Tadić, 2010). The mean annual surface air temperature for Serbia for the last 50 years is 10.4°C. The amount of rainfall over Serbia is relatively unevenly distributed, reaching an average of 739 mm (Bajat *et al.*, 2012, 2015). As pointed out by Tošić *et al.* (2014) and Hrnjak *et al.* (2014), the climate of northern Serbia is moderate continental, characterized by cold winters and hot, humid summers. The maximum precipitation occurs in June, while the minimum occurs in February. According to Radaković *et al.* (2018), the climate of central Serbia is determined both as a cold climate without a dry season and with hot summers, and as a temperate climate without a dry season and with hot summers. The southernmost part of Serbia (Kosovo and Metohija region) is characterized by a moderate continental climate with cold winters and warm, humid summers. A huge range of extreme temperatures and a varying distribution of precipitation over the months is one of the main features of this region (Bačević *et al.*, 2017). Therefore, as pointed out by Mihajlović et al. (2015), the climate zones of the country encompass Cfwax", Cfwbx", Dfwbx" and ET with Cfwbx", indicating certain complexity and zonal diversification. The interplay between air temperatures and precipitation dictates the intensity of these changes (e.g., Gavrilov *et al.*, 2003; Tošič and Unkašević, 2005; Pavlović *et al.*, 2012; Hrnjak *et al.*, 2014; Republic Hydrometeorological Service of Serbia, 2014; Gavrilov *et al.*, 2016). The results of the climate change models and various case studies indicate great impacts on multiple sectors and the ecosystem services in Southeastern Europe (including the Republic of Serbia), implying that this part of the continent will be among the hotspot regions, with the highest number of severely affected agricultural and economic sectors (e.g., Lung and Hilden, 2017; Lukić *et al.*, 2019; Milanović *et al.*, 2019).

It has been observed that humidity greatly impacts anthropogenic systems and biodiversity in general. Humidity affects the ability of plants and animals to achieve optimal thermal conditions through process of evaporation. It also affects the precipitation formation. One of the most widely used parameters in climatological research is relative humidity (RH; %). According to contemporary research, secondary parameter known as dew point (DP) represents a better indicator of humidity because it is not percentage dependent on air temperature and does not display high variability during the day (e.g., Park *et al.*, 2017; Matthews, 2018; Romano *et al.*, 2018). Despite respective water potential, there is not enough water for irrigation and agricultural production in the Republic of Serbia. One example of this is the Danube–Tisa–Danube Canal, built in the 18th century and covering the northern province of Vojvodina. The capacity of this canal is 300 million m^3, with a length of 980 km. This would only be enough for the irrigation of 3.5% of the territory of Vojvodina and 0.5% of the territory of Serbia. Many areas in the world have dew potential, but dew collectors are usually installed near the coastal belts of the Mediterranean region or in semi-arid areas (Bachelet *et al.*, 2016; Ayal and Filho, 2017). Lekouch *et al.* (2012) performed systematic measurements in the arid region of Morocco at Mirleft (43 masl, 200 m from the coast) for a year (May 1, 2007–April 30, 2008) and Id Ouasskssou (240 masl, 8 km from the coast) for three summer months (July 1–September 30, 2007). Their data show that 15 sites in Morocco can collect water from dew or fog. The other relevant issues concerning dew use could be identified in its use and measurement (Xi-zhong *et al.*, 1998; Zhang *et al.*, 2012; Ritter *et al.*, 2019). Lysimeters were used to determine dew and hoar frost formation for a low mountain range and alpine grassland sites for the hydrological years 2013–2015. The present research showed that dew can amount to 16.1% of total precipitation. The dew in winter will be transformed into frost in 38% of the Alpine region (Groh *et al.*, 2018). The experimental study of Jacobs *et al.* (2012)

pointed out that in the central Netherlands a pyramid collector design was able to collect about 20% more dew than the inclined planar collector, but the use of roof rainwater collection has shown better performance as a supplemental water source in this part of Europe. Pioneering dew research in the late 1950s and early 1960s was established and introduced by Monteith (1963). Contemporary studies on dew have outlined that it may support the water budget of plants, since the ratio of potential condensation to potential evaporation is roughly 1:7 in humid climates and 1:14 in arid climates. A similar piece of research supported by outdoor measurements of dewfall in the Negev Desert in Israel showed that the maximum total dewfall is ≤ 0.2 mm·day^{-1} in any case, whereas the actual evaporation of about 5–6 mm·day^{-1} is not uncommon. Other reports counted 100–200 dew nights, which amounted to 50–100 mm·year^{-1} (Zangvil, 1996; Goldreich, 2003). The theoretical background for dew occurrence was identified and experimentally shown for the 11 independent cities (Beysens *et al*., 2005; 2016; Meunier and Beysens, 2016). All the above-mentioned studies pointed out the difficulties of dew use. Following these studies, an observation can be posed that in future, under the influence of climate change, dew will stand as one of the alternative water resources in 20% of countries, especially in the Mediterranean and Continental belts. Many agricultural plants may not overcome these circumstances without irrigation, implying that dew may present an additional source of water used in the agricultural sector. Hence, the agrometeorological and hydrological aspect of dew is very important. In the Middle East, in desert areas, the phenomenon of dew was recorded in ancient times. There is no documentary evidence that the ancients were aware of the agricultural significance and potential of dew, although the peoples of the deserts and semi-arid regions of the Middle East, Asia and Yucatan probably noted that dew exerted some influence on their crops, as pointed out by Wallin (1967). The early work on dew potential and its possible use started in the mid-1940s and 1950s (Masson, 1954; Hoffmann, 1955; Ventskevich, 1958; Lloyd, 1961; Wang and Barger, 1962). Atmospheric moisture from any source such as precipitation, frost, drizzle, mist or dew influences plant growth, moisture-requiring plant-disease agents and insect pests, and, ultimately, animal life. Dew is one of the atmospheric moisture phenomena that is not easily observed, recorded, measured or assessed with respects to its agricultural influence. The largest dew collectors, established in India in semi-arid areas, gave good results for dew collection. The dew water accumulated over 192 days was 12.6 mm with a maximum of 0.556 mm·night^{-1} (Sharan *et al*., 2011).

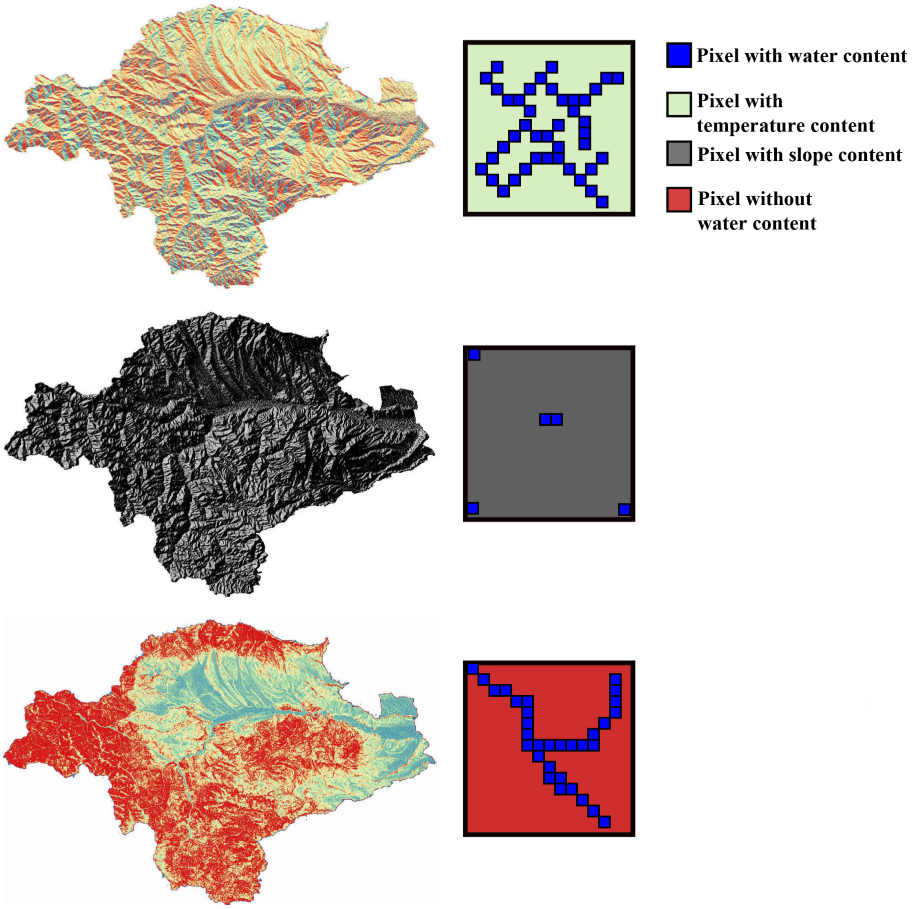

FIGURE 1 Three sub-numerical methods for dew volume calculations

The purpose of the new method presented in the present paper is to provide the first theoretical calculation of dew potential in the Republic of Serbia, as well as its detailed geospatial analysis for agriculture purposes in times of pronounced climate change.

2 | METHODS

An approximation for calculating the DP formula was used. The reason for this lies in the necessity to find grid dispersion and present it on the map of the Republic of Serbia. The map has a resolution of 1 × 1° in latitude and longitude (Figures 3 and 4). The authors obtained the highest satellite image resolution available from LANDSAT 8 (10 m) and combined it with JAXA and ASTER DEM (30 m) because it matches well with it and is symmetrical with a 360° arc. Geographical information system (GIS) and data modelling are very powerful tools for calculating and describing some data of meteorological properties (Lew, 1987; Blake *et al.*, 2007; Tomazos and Butler, 2009). The geospatial analysis of meteorological properties gives a complete insight into the dew potential of Serbia. For that purpose, GIS software QGIS, Grass GIS and SAGA were used, combined with tools for three-dimensional and grid calculations. The satellite recordings data were downloaded from the official webpage of the United States Geological Survey (USGS).

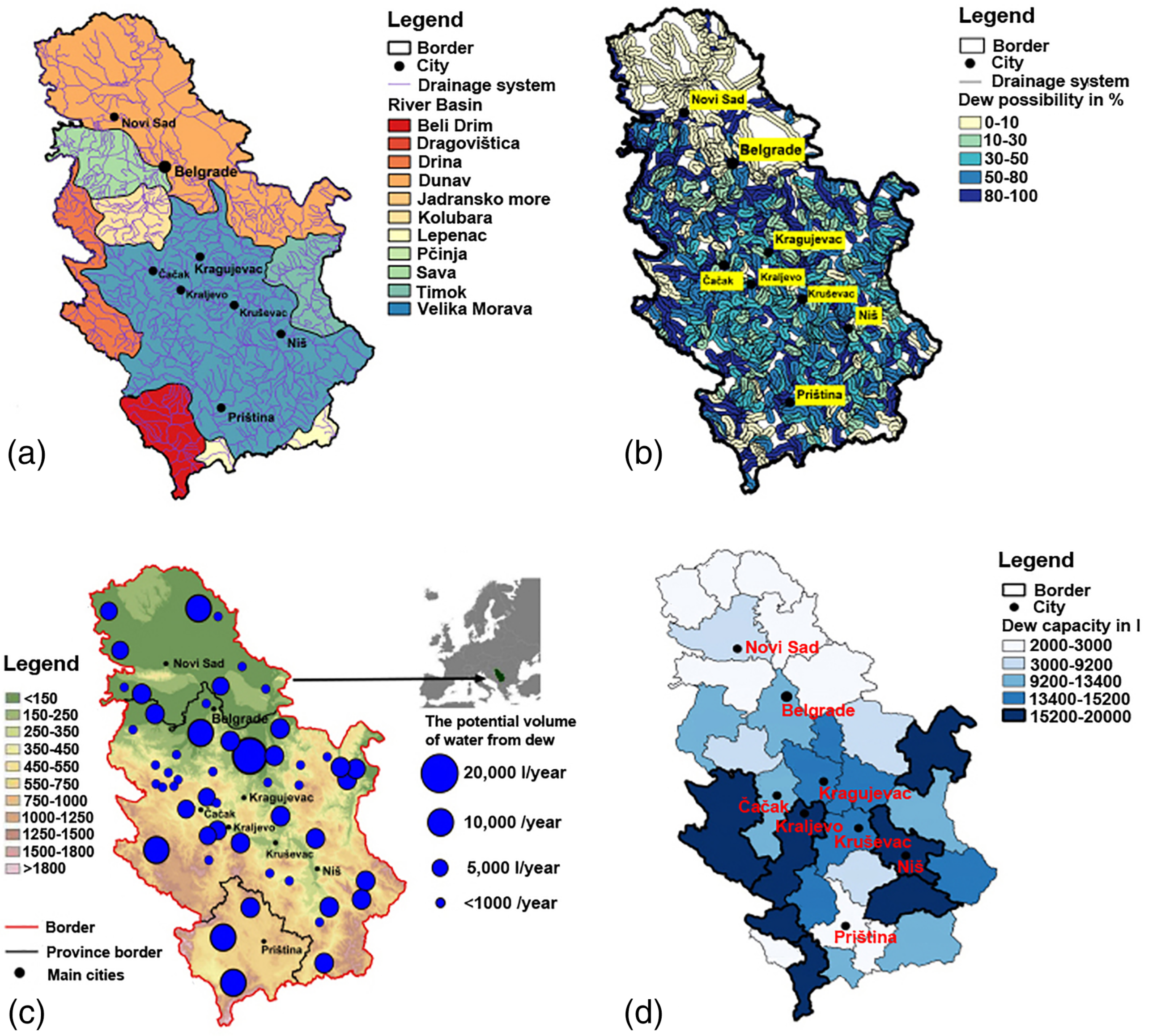

FIGURE 2 (a) The main river basins with their drainage networks; (b) buffer zones with the calculated dew possibility utilization throughout the year (%); (c) the main areas in the Republic of Serbia identified for potential dew utilization; and (d) theoretical dispersion of dew (L) in counties of the Republic of Serbia

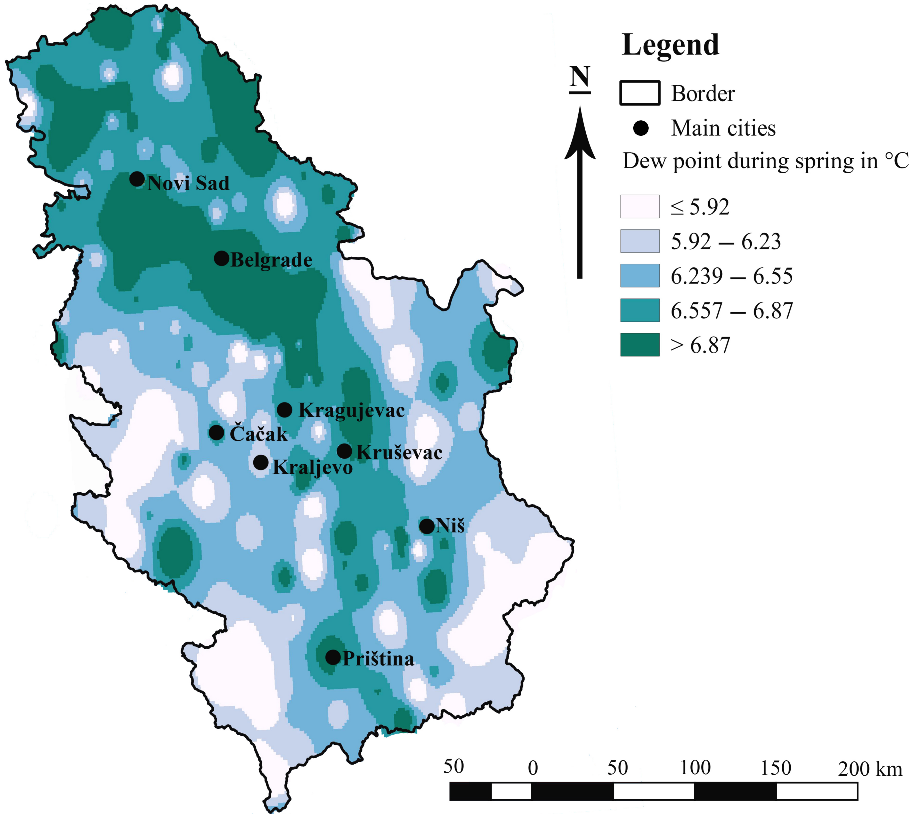

FIGURE 3 Dew point (DP) distribution in spring

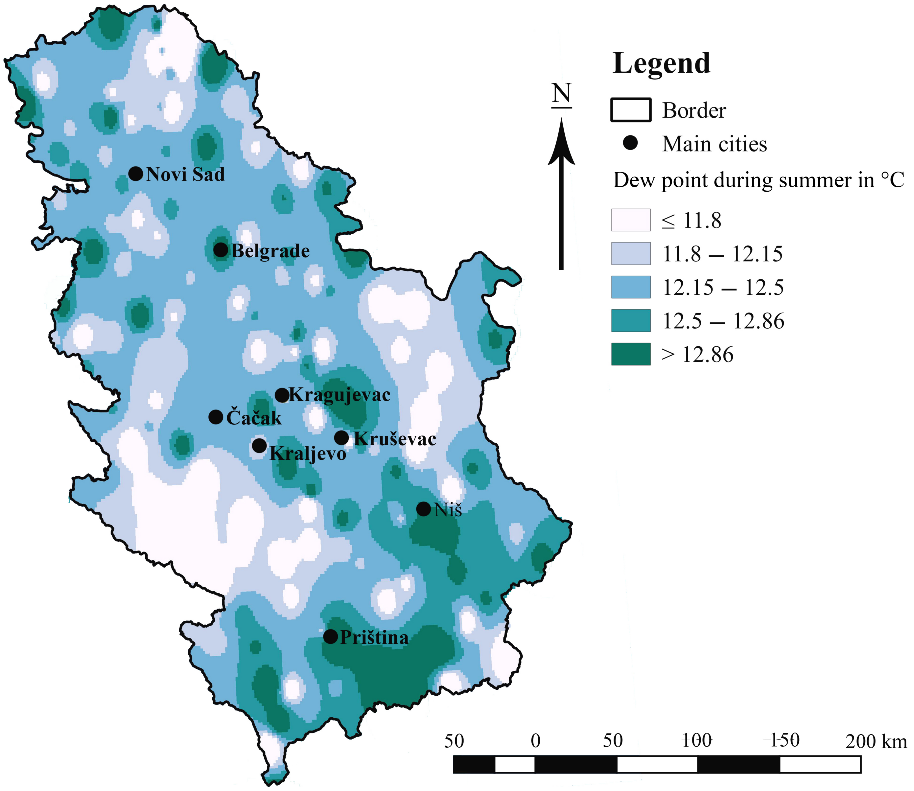

FIGURE 4 Dew point (DP) distribution in summer

Aster Global Dem Normalized Difference Vegetation Index Data (NDVI) were downloaded from the official webpage Earth Explorer—LANDSAT (http://earthexplorer.usgs.gov/); GRID with 10 m resolution from the Japan Aerospace Exploration Agency (JAXA); and ASTER DEM v.2 with 30 m resolution from Earth-data the National Aeronautics and Space Administration (NASA). After download, the data were inserted into the GIS software. In GIS, the territory of Serbia was cropped together with the elevation file and grid file of data for the DPs across the territory. The raster data were then georeferenced and vectorized in QGIS. An ordinary kriging method was employed through QGIS and SAGA (GIS) of Spatial Analyst. Although there are a few other methods, the priority is given to ordinary kriging and global kriging because it includes autocorrelation or the statistical relationship between the measured points. Upon including all the necessary methods, maps were derived. These maps show the possibility and dispersion of dew use in the territory of Serbia (Valjarević *et al*., 2018). One cell corresponds to 100 km^2 with a resolution of 30 m. Dew data, containing properties of areas covered with potential dews, were inputted into the cells. This grid also includes data for elevation, aspect, area of dew and potential volume.

To determine dew yield, it is necessary to solve a thermal equilibrium equation between sensitive and latent heat fluxes:

$$\frac{\mathrm{dTc}}{\mathrm{dt}}\left(\mathrm{Mc_c}+\mathrm{MC_W}\right)=\mathrm{R_i}+\mathrm{R_{he}}+\mathrm{R_{cond}} \tag{1}$$

where $\mathrm{T_c}$ is the surface temperature of dew collector; M and m (kg) represent the masses of dew collectors and condensate, respectively; $\mathrm{c_c}$ and $\mathrm{C_W}(\mathrm{J}\times\mathrm{kg}^{-1}\times\mathrm{K}^{-1})$ represent the specific heats of dew collectors; t(s) is time; $\mathrm{R_i}$(W) is the cooling energy and it must be $< 100\mathrm{Wm}^{-2}$; $\mathrm{R_{he}}$(W) is heat exchange with ambient air; and $\mathrm{R_{cond}}$ is the energy gain due to the latent heat of condensation *per* unit of mass $\mathrm{L_c}(\mathrm{J}\times\mathrm{kg}^{-1})$. The condensation and heat exchange can be expressed as:

$$\mathrm{R_{cond}}=\mathrm{L_c}\frac{\mathrm{dm}}{\mathrm{dt}} \tag{2}$$

$$\mathrm{R_{he}}=a\mathrm{S_c}\left(\mathrm{T_a}\text{-}\mathrm{T_c}\right) \tag{3}$$

where $a(\mathrm{W}\times\mathrm{K}^{-1}\times\mathrm{m}^{-1})$ represents co-efficient of convective heat transfer; T_a(K) is the temperature of the ambient air; and $\mathrm{S_c}(\mathrm{m}^2)$ is the surface. The parameter a is correlated with the thickness of the thermal boundary layer and depends on the air speed $\mathrm{V}(\mathrm{m}\times\mathrm{s}^{-1})$, usually higher than that of natural convection ($\approx 0.6\ \mathrm{m{\cdot}s^{-1}}$, according to Beysens *et al.*, 2005). According to Pedro and Gillepsie (1982), the laminar flow regime is expressed as:

$$a=\mathrm{kf}\sqrt{\frac{\mathrm{V}}{\mathrm{L}}} \tag{4}$$

The factor $\mathrm{f}\left(\mathrm{W}\times\mathrm{k}^{-1}\times\mathrm{m}^{-2}\times\mathrm{s}^{\frac{1}{2}}\right)$ is empirical and varied. The equation representing the condensed mass is described by the rate of condensation:

$$\frac{\mathrm{dm}}{\mathrm{dt}}=\left\{\frac{\mathrm{wS_c}\left(\mathrm{p}_a\left(\mathrm{T_a}\right)\text{-}\mathrm{p_{sat}}\left(\mathrm{T_c}\right)\right)\rightarrow\mathrm{if}\rightarrow\mathrm{possitive}}{0\rightarrow\mathrm{if}\rightarrow\mathrm{negative}}\right\} \tag{5}$$

where $\mathrm{p_{sat}}(\mathrm{T_c})\times(\mathrm{p}_a)$ is the saturation water vapour pressure at dew collector temperature; and $\mathrm{T_c}$(K) and $p_a(T_a)\times(P_a)$ are the water pressure in the humid air above the dew collectors. According to Pedro and Gillepsie (1982), this volume is approximately:

$$\mathrm{w}=0.65a/\left(\mathrm{p_0}\mathrm{c}_a\right) \tag{6}$$

where $\mathrm{p_0}$ is the atmospheric pressure; and $\mathrm{c}_a = (1.01\times10^3\mathrm{j}\times\mathrm{kg}^{-1}\times\mathrm{k}^{-1})$ is the specific heat of the air.

According to experimental measurement of these equations (Pedro and Gillepsie, 1982; Nikolayev *et al.*, 1996; Muselli *et al.*, 2002, 2009; Beysens *et al.*, 2005; Lekouch *et al.*, 2012; Beysens, 2016), T_a - $\mathrm{T_d}$ rarely exceeds 1 K. Finally, Equation (3), after all calculations, is:

$$\mathrm{R_{he}}=a\mathrm{S_c}\left(\mathrm{T}_a\text{-}\mathrm{T_d}\right) \tag{7}$$

Generalized average monthly temperatures and RH were used, as shown in the following formulas:

$$\mathrm{T_{dp}}=\mathrm{T}_a\text{-}\frac{100\text{-}\mathrm{RH}}{5} \tag{8}$$

where $\mathrm{T_{dp}}$ is the temperature of the DP; T_a is the average air temperature; and RH is the relative humidity (%):

$$\mathrm{RH}\approx100\text{-}5\left(\mathrm{T}\text{-}\mathrm{T_{dp}}\right) \tag{9}$$

A generalized formula for the calculation of all fields for potential dew use is described using:

$$\mathrm{d_{pot}}=\frac{\mathrm{Log_2}\left(\mathrm{kf}\sqrt{\frac{\mathrm{V}}{\mathrm{L}}}\right)}{\left(\mathrm{P}^2\times\left(\mathrm{T_a}\text{-}\mathrm{T_d}\right)\sqrt{\text{-}\frac{\mathrm{dT}}{\mathrm{dz}}}\right.} \tag{10}$$

where P^2 is the area of total dew collectors or surface; $\text{-}\frac{\mathrm{dT}}{\mathrm{dz}}$ is the lapse rate; T is temperature; and z is altitude.

After the equation had been established and checked, the process of coding and creating the GRID and digitization began. The code was prepared in Geo-Python programming language and PostGIS. These codes are robust

TABLE 1 Meteorological stations used with average dew height

Number	Meteorological station	φ (°N)	λ (°E)	*H* (masl)	Average dew height (mm·m^{-2})
1	Babušnica	43.07	22.43	495	20
2	Beograd	44.80	20.47	132	30
3	Bujanovac	42.45	21.78	400	10
4	Ćuprija	44.13	20.82	365	30
5	Crni Vrh	44.12	21.95	1,037	70
6	Čumić	44.13	20.82	365	30
7	Dimitrovgrad	43.02	22.75	450	20
8	Jošanička Banja	43.38	20.75	555	60
9	Knjaževac	43.57	22.27	281	50
10	Kragujevac	44.03	20.93	185	30
11	Kraljevo	43.72	20.70	215	40
12	Kruševac	43.57	21.35	166	40
13	Kuršumlija	43.13	21.27	382	40
14	Leskovac	42.98	21.95	230	20
15	Loznica	44.55	19.23	121	30
16	Negotin	44.23	22.55	42	40
17	Niš	43.33	21.90	202	40
18	Pirot	43.15	22.60	370	30
19	Sjenica	43.17	20.00	1,038	40
20	Smederevska Palanka	44.37	20.95	121	20
21	Sokobanja	43.65	21.85	300	50
22	Valjevo	44.28	19.92	176	50
23	Veliko Gradište	44.75	21.52	82	20
24	Vranje	42.48	21.90	432	20
25	Zaječar	43.88	22.28	144	50
26	Zlatibor	43.73	19.72	1,028	60

and flexible since it is possible to use and implement them into QGIS software. This application is part of open-source GIS software. Some codes in QGIS software were coded with the support of the Geo-Python code because QGIS software uses 80% of Python's core. Subsequently, separate dew volume data for the entire territory were created for each grid.

The approach of Vuollekoski *et al.* (2015) was used, where two seasons for the calculation of DP at the regional and national scales (spring and summer) were performed, respectively. Dew potential calculation did not include the winter, because the process of sublimation occurs over the entire territory during this period. With the help of statistical data for the period 1958–2018, the final calculation was derived for the DP use. These data present monthly average temperatures from 26 meteorological stations. Data from these stations cover 60 years and are characterized by continuous measurement. For the main meteorological stations used in the study, see Table 1. For the calculation in present time, scientists have used numerous methods and algorithms. Two artificial neural networks and gene-expression programming are useful for the estimation and calculation of daily DP temperatures. Therefore, a similar approach was used here (Friedlein *et al.*, 2006; Shiri *et al.*, 2013; Shiri, 2018).

According to the 26 meteorological stations, new and refreshed data for climate properties were used. These data cover the period between 1958 and 2018. A total of 60 years of data sets is enough for the calculation of meteorological parameters, and this period covers 23 year cycles, which is in accordance with the World Meteorological Organization (WMO) standards. The average volume of dew height in this period was 36.2 mm·m^{-2}. According to estimated data from the meteorological stations, the eastern and western parts of the country, close to the big valleys, have the maximum potential for dew use. The mountainous area in the south has great potential as well.

3 | NUMERICAL DEW DISTRIBUTION ANALYSIS

The behaviour of the seed canopy is strongly connected with plant reflectance. Different plants have different reflectance ratios. The satellite recordings varied between 0.7 and 1.15 μm. For the purpose of the present research, satellite recordings from LANDSAT 8 were used, while CORINE 2012 (Coordination of Information on the Environment) recordings were used as a secondary source (Pinter, 1986). Dew use is of ecological importance in arid and semi-arid areas. In the Eastern Mediterranean, the necessity for dew is growing every year. Scientists in Turkey tested potential plant diseases in the case of late annual precipitation. Early calculations for the effects of dew were shown in the process of evapotranspiration of the plants. This ratio is 2:1 of water-use efficiency *per* year (Ben-Asher *et al.*, 2010). With a specially created algorithm inputted into the GIS, the potential dew use was calculated in litres (L). By using the two main methods, pixelization and relief analysis of the land cover, it is possible to determine how many litres may be derived from dew in two seasons (Jacobs and Nieveen, 1995).

The procedure contained the following algorithms: the first step was inputting the formula for DP calculations into the GIS software. This formula was coded in Geo-Python. After that, remote sensing data were inputted into QGIS. Once the data had been inputted, a standard GIS procedure followed. The next step was sorting out pixels with and without potential water. Primarily, raster calculations were performed in the GIS software, after which the first marked points with slope calculations were obtained. After slope analysis, the slope map was derived. These slope maps marked all the points with a potential dew volume. The aspect algorithm possesses a module to calculate the direction of relief in GeoTiff. These algorithms gave satisfactory results in the fine calculations of relief properties. A Hillshade algorithm gave important results for shade and dew volume. In this algorithm and procedure there are two important parameters: the azimuth–horizontal angle and the slope–vertical angle. The final results were obtained by calculations of all four algorithms. The relief algorithm, before all the other algorithms, is supposed to conduct an analysis of the area in order to show the position of a possible gridcell with potential dew water (Figure 1). Five types of data were inputted into this algorithm: precipitation data grid, average temperature data grid, evaporation data grid, DP data grid and land cover data grid.

4 | GIS MULTICRITERIA ANALYSIS

GIS methods and spatial variability function can be used in mapping the soil properties (e.g., Lieb, 2015; Stankov *et al.*, 2019). In the present research a semi-spatial generalized model was used (Wang *et al.*, 2018). Most of the models used in spatial research are based on a Gaussian distribution. QGIS has a wide range of spatial models, which can be successfully applied. The GIS multicriteria analysis gives better results since it includes many standard methods. The new method established in the research is pixel analysis. When combined with other methods it gives satisfactory results, especially because it follows the scale and resolutions of the remotely sensed data. Shade and relief methods with the support of aspect and slope analysis may help to estimate the possibility and volume *per* 1 m^2. When remote sensing data were downloaded from the official webpage of the USGS, satellite recordings of various resolutions were manipulated to obtain more accurate data. The data from the USGS have a resolution of approximately 30 m. By using relief analysis algorithms such as clipper and buffer belts methods in QGIS, the finest resolution of 10 m was successfully obtained. This resolution made it possible to determine how many litres of water may be derived from dew collectors. The potential dew collectors or separators, according to the analysis, were established with the estimation of the slope. The slope presents one of the important parameters for dew use. Another very important parameter is altitude. Dew altitude was estimated with the help of zonal statistics and relief analysis. The final analysis was performed in order to show the precise distribution of dew occurrences across the entire territory of the country. In the present research, the standard global kriging method employed through the QGIS and SAGA spatial algorithms button was replaced with the semi-kriging method. The semi-kriging method and nugget values between -0.7 and 1.1 on the z-axis and between 0.4 and -0.7 on x-axis were used. In addition, modified Gaussian regression and Kolmogorov prediction were used as well. Furthermore, the average nearest neighbour Euclidean distance was used. Lag size was 0.5°. Although there are many other methods, semi-kriging was chosen because it includes the statistical relationship between the measured points. Another reason why this method is a good option is the fact that it includes standard variance, the median and other statistical calculations. Estimation error is very low at $< 2\%$.

Many numerical GIS methods describe a climatology parameter through time, but only a few are found to be successful in this approach (Kienast *et al.*, 1996; Spalević *et al.*, 2012; Streletskiy *et al.*, 2012; Frankl *et al.*, 2016; Tomaszkiewicz *et al.*, 2016). In the present research, several GIS algorithms were used to calculate and find patterns for dew dispersion and use. In the process of cross-validation, downloaded satellite images from the LANDSAT 8 were used as test data. For the iteration tool, average data of the cell obtained after semi-kriging algorithms were used. For the iteration, three data calculated from the DP equation were used. Thereafter, test data and training data were merged into the main data. The first analysis of dew possibility included standard GIS algorithms such as kriging, semi-kriging and interpolation. Combined with advanced GIS methods such as segmental mapping, numerical buffer analysis, belts predisposition and analytical hierarchy process (AHP), satisfactory and opaque results of dew volume for the entire territory of Serbia were obtained. The mapping method includes belts with a radius of 10 km^2. The buffer segmental method includes three types of radii: the first radius is 10 km, the second, 20 km, and the third, 50 km. All the buffers follow river directions and valley slopes. A calculation of dew capacity follows the AHP procedures and numerical estimations. These methods are experimental, and the procedure is theoretical. With the application of these methods it is possible to obtain reliable data, which were measured and expanded with the new research.

5 | RESULTS AND DISCUSSION

The relief analysis gave the following results. In the first step, basic relief properties from GeoTiff were calculated. The downloaded tiff had a 10 m resolution. This resolution gives many possibilities for advanced calculations. After slope calculation, it was found that the average slope of Serbia with a good possibility for dew use is between 8.9 and 9.1°. Aspect calculations showed that the maximum aspect for potential dew use is 43.5° and the minimum is 0.7°, especially in lowland areas in the province of Vojvodina in the north of the country. The azimuth of the area with good possibilities for dew use shows a radiant between 0 and 195.1° in northwest expositions. The main study of the relief showed that the southern territories in the province of Kosovo, the northern part of the province of Vojvodina and valleys of large rivers have huge possibilities for dew use (Figure 2a–c). The average altitude of favourable terrains for dew exploitation varies between 70 and 120 masl in the province of Vojvodina in the north of the country. In the province of Kosovo and Metohija it varies between 350 and 550 masl; in central Serbia it varies between 250 and 400 masl; in southern Serbia it varies between 300 and 400 masl; in western Serbia it varies between 600 and 700 masl; and in eastern Serbia it varies between 500 and 600 masl.

Upon calculating the possibilities for dew use, covering the entire territory of Serbia for the first time, the potential volume of dew water was estimated by using the GIS multifunctional algorithms and methods. These methods have estimation errors in the range of 1–3%. Factors affecting the estimate are the slope, number of clear nights, average air temperatures and DPs by day. The GIS analysis is presented by using a fine grid resolution (Kidd and Huffman, 2011). This resolution varied between 1 and 3 m. In a 1 m^2 cell, it was very precisely calculated how many litres could be obtained from the existing dew. The reason for the better estimation lies in the long period of meteorological data collection (60 years) from 26 meteorological stations. These meteorological stations have a continuous sequence of analysed data. The DP data were calculated with the use of average parameters *per* month for the observed period. With the GIS decision analysis and multifunctional adapting methods, dew potential was calculated for the first time for the entire territory. The adaptive method analysis in the pixel creates special algorithms with scale parameters. In that way, downloaded remote sensing data will be very accurate and have a minimum of errors. Shadow effects may show the volume of dew in one pixel. After applying this method, semi-kriging methods presented the dew cells' distribution in the area. After numerical and geostatistical GIS analyses it was found that there is some potential for dew use in the territory of Serbia. This potential presents a small amount of water *per* year, but it could be useful and helpful during dry periods. These climate conditions are present in the main area, in the central, eastern and partly in the western areas of Serbia. On the other hand, in the river valley areas, there is great potential for dew use and agricultural farming (Figures 2b, c, 3 and 4). The total amount of water used from dew is approximately 10×10^7 L. This volume is not enough, but it would be a first step in the use of dew in Serbia. The area that might be useful after the GIS estimation is about 1,000 km^2. More than 30% of dew use potential lies within the basin of Great Morava (Figure 2a, b). This region may give 70% of dew potential during the spring and 30% during the summer (Figures 2b, 3 and 4). According to the Köppen climate classification, the higher part of the valley belongs to the Dfa type, while the middle and lower parts belong to the Dfb. Inside the central region of the valley, according to meteorological data, there are many colder nights with the presence of temperature inversion. The middle zone of the valley has prevailing local winds which enhance temperature inversion. These winds contain a high volume of water vapour as well. This part of Serbia is very important because it connects the capital Belgrade with Kragujevac, which is the fourth most populous city. More than 2.8 million citizens live in this area, which makes up almost 25% of the total country's population. Western tributaries of the Great Morava also possess great potential for dew use, at about 25% (Figure 2b). These rivers encompass the West Morava and South Morava. Other rivers are the Rasina near Kruševac, the Crnica near Paraćin, the Lepenica near Kragujevac, the Jasenica near Smederevska Palanka, the Nišava near Niš, and the Toplica near Prokuplje and Kuršumlija. The province of Kosovo with a 20% of dew use potential is in third place (Figure 2a, c). The greatest potential for dew use is near Prizren and in the valleys of the White Drim, the Lepenac and the Binačka Morava near Gnjilane. Other rivers are the Lab near Podujevo and the Erenik near Djakovica. Western Serbia has 5% of the potential for dew use (Figure 2a, b). This part of Serbia has short rivers with a huge hydropotential: the Djetinja near Užice, the Lim near Prijepolje and the Vapa near Sjenica. The greatest potential for dew use in this part of Serbia is in the basin of Drina. This potential was estimated at 10% (Figure 2a, b). Great potential lies in the valleys of the rivers which are Danube tributaries: the Visošica near Pirot, the Beli Timok, the Crni Timok and the Timok near Zaječar (Figure 2a, b). It is interesting that this belt has enough potential in the gorges in the Stara Planina mountain. This belt has an elevation between 800 and 1,000 masl. The southern part of the province of Vojvodina has the potential for 10% (Figure 2a, b). As can be observed in Figures 3 and 4, the dew potential is higher during the spring than during the summer. As can be observed in Figure 3, during the spring the DP distribution is more pronounced in the valleys of the large rivers, such as the Tisa, Danube, Sava, Drina and Begej, as well as West Morava, South Morava and Beli Drim. On the other hand, during the summer (Figure 4), where high aspects of relief are present, the DP has a low potential.

The reason for this observation lies in the fact that the province of Vojvodina has a combination of Steppe and Continental climates. The potential is distributed near the Danube in the vicinity of Novi Sad, the Begej River near Zrenjanin, and upper parts of the Tisa near Subotica. Potential dew collectors inside this belt would be placed at an elevation of 200 masl. The results show that 75% of the dew potential could be used during the summer and 25% during the spring. The average potential volume of dew in the south is 20–40 mm·year^{-1}, in the north is 15 mm·year^{-1}, in the central region is 30–50 mm·year^{-1} and in the east is 20–30 mm·year^{-1}. In the

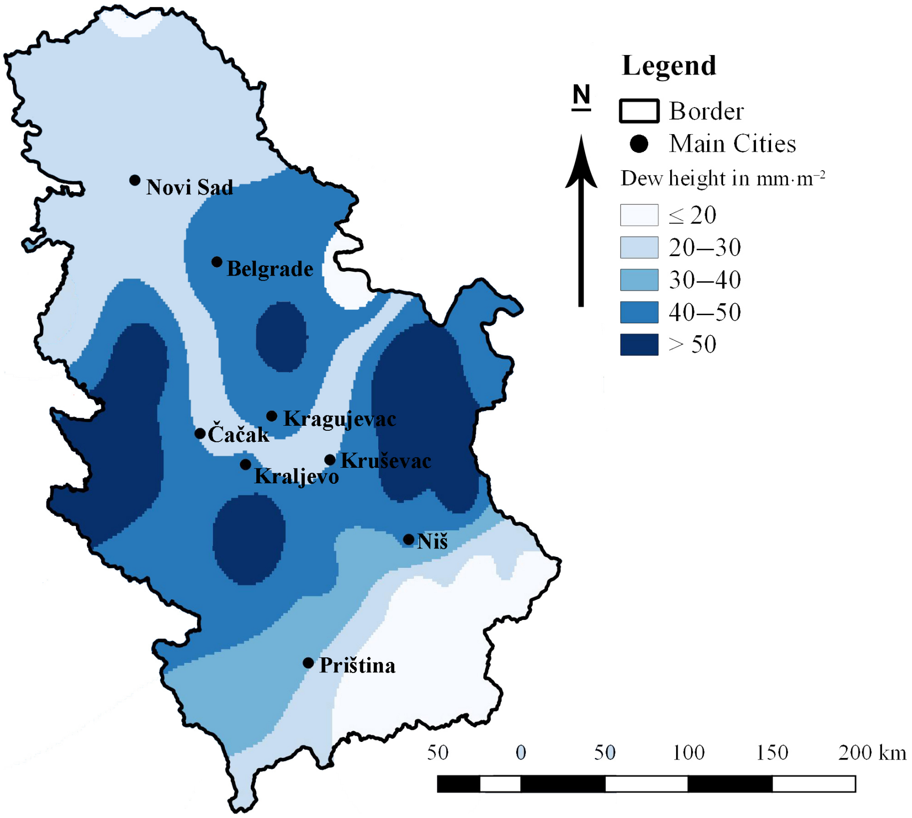

FIGURE 5 Grid-based dew dispersion map of the Republic of Serbia

most drought region it is < 10 mm·year^{-1}·m^{-2}. Figure 2d shows the theoretical dispersion of dew (L) in the counties of the Republic of Serbia. As can be observed, counties with the largest dew capacity include Borski, Nišavski, Jablanički in the eastern part, as well as Zlatiborski, Raški, Peć and Prizren in the western and southern parts, respectively. Dew capacity in this part of Serbia varies between 15,200 and 20,000 L. On the other hand, counties with the lowest dew capacity encompass northern parts of Serbia (Sremski, Severno-Banatski, Srednje-Banatski, Južno-Banatski, Severno-Bački and Zapadno-Bački), with values ranging between 2,000 and 3,000 L (Figure 2d). Figure 5 shows a final grid-based dew dispersion map. Dew height has the highest potential in the western, central and eastern parts of the Republic of Serbia (ranging between 20 and > 50 mm·m^{-2}), while northern and southeastern parts of the country experience the lowest dew potential (≤ 20 mm·m^{-2}).

The grid-based map shows that areas close to the South, the West and the Great Morava as well as Drina have a high potential for dew use. Between the cities of Belgrade and Kragujevac, in an area close to the settlement of Velika Plana, one spot with a high potential for dew use was identified. The area close to the Kopaonik Mountain also has great potential. Areas in the north part of the country, in the province of Vojvodina, and in the south, in the Preševo valley, have a low potential for dew use, ≤ 20 mm·m^{-2}. The grid map also showed zonality of the Republic of Serbia on three parts: the province of Vojvodina has a low potential for dew use, central Serbia has a high potential and the province of Kosovo has a medium capacity for dew use (Figure 5).

As shown by Mihajlović *et al.* (2015), the Köppen climate zones of Serbia will probably experience a shift toward warmer and drier climate zones in future (according to different climate scenarios). The authors pointed out that crop yields of winter wheat, corn and soybean will increase on average under the A1B and A2 scenarios over the 2001–2030 and 2071–2100 periods, as well as present climate period. This fact highlights the necessity for intense investigations oriented toward the use of dew in the Republic of Serbia and in surrounding regions in Southeastern Europe.

6 | CONCLUSIONS

The obtained grid in this study could be very useful in future for many calculations and estimations for the potential use of dew. Dew belongs to low precipitations, but its potential has not been thoroughly investigated or used in the Republic of Serbia. With the presence of extreme weather events in future and the unequal dispersion of precipitation, dew may represent an alternative water resource. In Serbia, dew is usually generated near a large river basin and during clear summer and spring nights. Serbia has relatively small territory, but the potential for dew use may be significant in some areas of the country. These areas lie in the valleys of the main river basins. The greatest potential for dew use lies in the middle zone, in the valley of Great Morava. Furthermore, the tributaries of the Great Morava, the West and the South Morava have a strong potential as well. This belt occupies the zone between 400 and 600 masl, with a very slight inclination. The possibility for dew use is particularly strong throughout the winter, as well as during the spring. The potential of this belt reaches 50%. The maximum dew usage would reach 150 million L·year^{-1}. Although there is great potential in Serbia for the use of dew, the government still does not support any project focused on dew potential. Despite the fact that Serbia has large river systems and thousands of lakes, this is still not enough to irrigate the whole territory. The territory of potential dew usage, according to estimations obtained in the present study, would cover approximately 1,000 km^2. This presents only 1.4% of the territory and it is not sufficient for the irrigation of all-season plants. After installation of potential dew collectors, it could be known in more detail whether there is enough potential for the irrigation of some plants, and could this be sufficient for the enhancement of domestic agricultural production. Finally, over the past decade, meteorological data in Serbia have shown a decrease in precipitation and an increase of air temperature, especially in the central part of the country. All the aforementioned facts implicate that the Serbian government should include the potential of dew resources when creating special action plans. Dew potential can be used as an alternative water source in some semi-arid and mountainous areas. The paper presents a new approach to potential dew use estimation. With methods such as advanced geographical information system (GIS) algorithms and numerical meteorological analysis, it is possible to perform very precise calculations for dew volume. This relatively new method, with the help of satellite-detection analysis, can give satisfactory results. The limitation of these methods lies in the difficulty of measuring the volume of dew in autumn or in seasons with a huge precipitation volume. In future, with the help of special sensors, it could be possible to check the theoretically obtained volume of dew in the Republic of Serbia. Mankind must find a way for the better use of alternative water sources, especially in semiarid and arid areas. As a consequence of climate change, a change in the climate belts around the world can be expected. In a Continental humid climate with warm and hot summers, where the possibility of a deficit in precipitation is high, the identification of alternative water resources would be very important. In the present research these methods were used theoretically. Another difficulty in this type of research is the estimation of dew volume in the collectors since dew data are always mixed with precipitation, fog and drizzle. This problem could be addressed in future work.

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