



Cloudiness and water from cloud seeding in connection with plants distribution in the Republic of Moldova

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Abstract

Clouds play an important role in maintaining the balance in the environment. Cloudiness can influence numerous important ecological drivers, including growth, survival and distribution of plants. The cloud cover dynamics and distribution may provide key information for delineating various types of plant and species distribution. During a year, different types of clouds on a territory can influence the distribution of plants and potential of cloud seeding. New properties of cloudiness may be important for new ecological patterns and new adapted values of ecological drivers. In the territory of the Republic of Moldova, 30 years of cloudiness were taken to show new distribution of clouds properties and their influence on sunflower (*Helianthus annuus L.*) and grapes (*Vitis vinifera*). The main result of this research is the first established map with the location of water derived from cloud seeding. In the last decade (2010–2020), the cloudiness increased by more than 15%. Another important focus of this research is the possibility of cloud seeding in line with recent deficit of precipitation, especially in dry areas. The territory of Moldova has 37% of semiarid and 6% of arid zones. The distribution and the potential of cloud seeding has been analyzed by means of Remote Sensing and GIS techniques and methodology, along with the Moderate Resolution Imaging Spectroradiometer. Satellite data in the resolution of 1 km² were downloaded for the period between 1990 and 2020. The exact distribution of clouds helped to determine the belts for the potential irrigation of crops. Extremely low cloudiness and a long period of drought may jeopardize the agricultural sector in the Republic of Moldova, and therefore, the irrigation from alternative water sources is of utmost importance.

Keywords Cloudiness · Remote sensing · GIS · Republic of Moldova · Alternative water · Cloud seeding · Grapes · Sunflower

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Introduction

The Republic of Moldova comprises the territory of 33,843 km². This mostly agrarian country relies on the production of wine and crops. The biggest problem is the increase in dry periods in the past 30 years. Due to the increase in temperature in Europe by more than 1.0 °C, the number of drought periods has increased dramatically. Only 3% of the territory is being watered, which is hardly enough. The resource of watering being used is groundwater. The problem with this resource lies in the decrease in quantity, as well as in the arguable quality of water. Great pollution of underground resources has been detected not only in urban, but also in suburban zones. The Republic of Moldova has moderate continental climate type Dfa according to the Köppen Climate classification (Köppen 1923). This climate type covers about 94% of the territory (Rubel et al. 2020). In recent decades, there has been a shift in the climate

of Moldova, manifested in the change of precipitation and extreme temperatures (Corobov 2002). The summers are hot, with average air temperatures of 20.4 °C within the last 30 years. The winters are mild and dry, and average air temperature in January is −4.1 °C. The average air temperature in July is 27.2 °C (Munteanu and Munteanu 2007). Cumulus clouds in the layer of troposphere play an important role in the hydrologic cycle on the Earth. This type of clouds, particularly over land, and how they interact with the carbon cycle are poorly understood. This type of cloud may be a response to climate change. The new results of the soil–water–atmosphere–plant model are supported by comprehensive observational evidence, from which we identify the dominant atmospheric responses to plant physiological processes (Bishop et al. 2014). When the concentration of CO₂ is higher than 800 ppm, the cloudiness is higher and it also influences the distribution, quality and the vegetation period of plants (de Arellano et al. 2012). Ten years of investigation of cloudiness and connection with the land have brought about the conclusion that ultraviolet radiation may be amortized for 20% by higher cloudiness. This effect is particularly expressed in the tropical belts and for plants in the tropical areas (Ilyas 1967). Clouds cover affects many important ecological processes, such as reproduction, growth, survival, and behavior. Cloud cover dynamic provides key information for distribution and adaptation of the plant to the land.

Weekly and monthly analysis of cloudiness with the help of satellite data, as well as their processing, may provide key information on the relation cloudiness-plants distribution. (Bui et al. 2019). Local, regional and global distribution of cloudiness may serve in finding the sustainable locations for cloud seeding (Wilson and Jetz 2016). It must be borne in mind that the use of water from clouds is possible only if it does not harm the balance of atmospheric precipitation. The biggest amount of precipitation in the last 30 years was detected in the south of Moldova, and it was 380 mm, whereas in the north was higher, being 570 mm. Statistical data on meteorological events show that southern parts of Moldova lie in semiarid zones. Within these zones, drought is also frequent, which requires new water resources (Didovets et al. 2020). According to the data from Meteorological Service of Moldova (1990–2020), the biggest amount of precipitation is in October.

Precipitation is mostly connected with the Atlantic cyclone system. The longest and the biggest river in Moldova is Nistru (Dniester) 1352 km long, followed by the river (Prut), 967 km long (Corobov 2013). Apart from climate change shifts on the territory of Moldova, another big problem for water use in agriculture is the pollution of the main rivers. The water resources in Moldova are quite limited due to pollution and degradation influenced by climate change.

It also strengthens the relationship between climate change and water resources, especially in the central regions and southeast regions as well (Ivanov 2012). The cities which would be the most vulnerable to drought and extremely high temperatures are Bălți, Rîbnița, Chișinău, Tiraspol (International Federation of Red Cross 2012). The change of local weather conditions includes the increase in temperature in almost 80% of the Republic of Moldova. The amount of precipitation and their distribution is misbalanced. In the southeast regions, there is a permanent possibility for a big flood (Dumitru 2018). After big drought in 2012, more than 20% of the Moldavian territory was affected. The capital Chișinău, which presents the most populated area with 669,624 inhabitants according to the census from 2012, is under the biggest threat of flooding (Muth 2012). After 1990, the majority of population left from the rural areas and inhabited the urban ones. These areas are vulnerable because of the deficit of water and in the suburban areas the agricultural potential is very low, without watering (Rowland 2009). The great climatic variability in the last decades in the Republic of Moldova is accompanied by great crops damage and deficit of water. Between 2000 and 2018, there was a significant increase in temperature. In 2012, the absolute maximum in the Republic of Moldova was 42.4 °C. These areas are in the central and northeast territories (Nedealcov et al. 2019). The main meteorological parameters (variables) like atmospheric pressure, humidity, air temperature, wind, water vapor, cloudiness and precipitation are significant for natural drivers and total budget of water (Hatfield 2016). The study, conducted in the USA, showed that the cumulative rainfall increases by 1.2% with the use of silver-iodide (Rosenfeld and Woodley 1989). When cloud seeding started in the USA, the measurements showed increased precipitation in mountains of the western USA (Dennis 1980). In Israel, one problem of using cloud seeding is pollution of glaciogenic cloud. Only clear and not contaminated droplets will be used in the process of cloud seeding (Givati and Rosenfeld 2005). The main goal of this manuscript was to determine the seasonal values of cloudiness on the territory of Moldova, within the period of 30 years (1990–2020), by means of advanced GIS methods and remote sensing. Numerical and geostatistical analyses with the help of GIS helped to determine the distribution of two most important crops in Moldova, sunflower and grapes, in relation to cloudiness as the factor which influences their growth in the vegetation period. GIS and remote sensing analyses determined the locations and the potential for obtaining the additional water from cloud seeding. After the capacity of this water resource, as well as its distribution, had been calculated, the potential for watering the crops in question was considered as well. The goal of this manuscript is to point to the danger for the sustainability of Moldavian agriculture in case of drought and water deficit. Other goals

were related to the determination of seasonal cloudiness on the whole territory of Moldova, its influence on the growth of crops and the potential utilization of water from clouds for agricultural purposes. The research aims to show that advanced GIS, remote sensing and numerical analysis may help in determining the locations for cloud seeding. Finally, the manuscript is supposed to highlight the connection between cloudiness and the growth of sunflower and grapes, especially when it is scarce. When the cloudiness is higher, i.e., sufficient, it may be used for watering in dry periods.

Materials and methods

The Republic of Moldova is a country situated in the eastern part of Europe. It borders with Romania in the west and southwest, and with Ukraine in the south, north, and east. The capital city is Chişinău. Larger cities used for the purpose of this research are Bălţi, Dubăsari, Tiraspol.

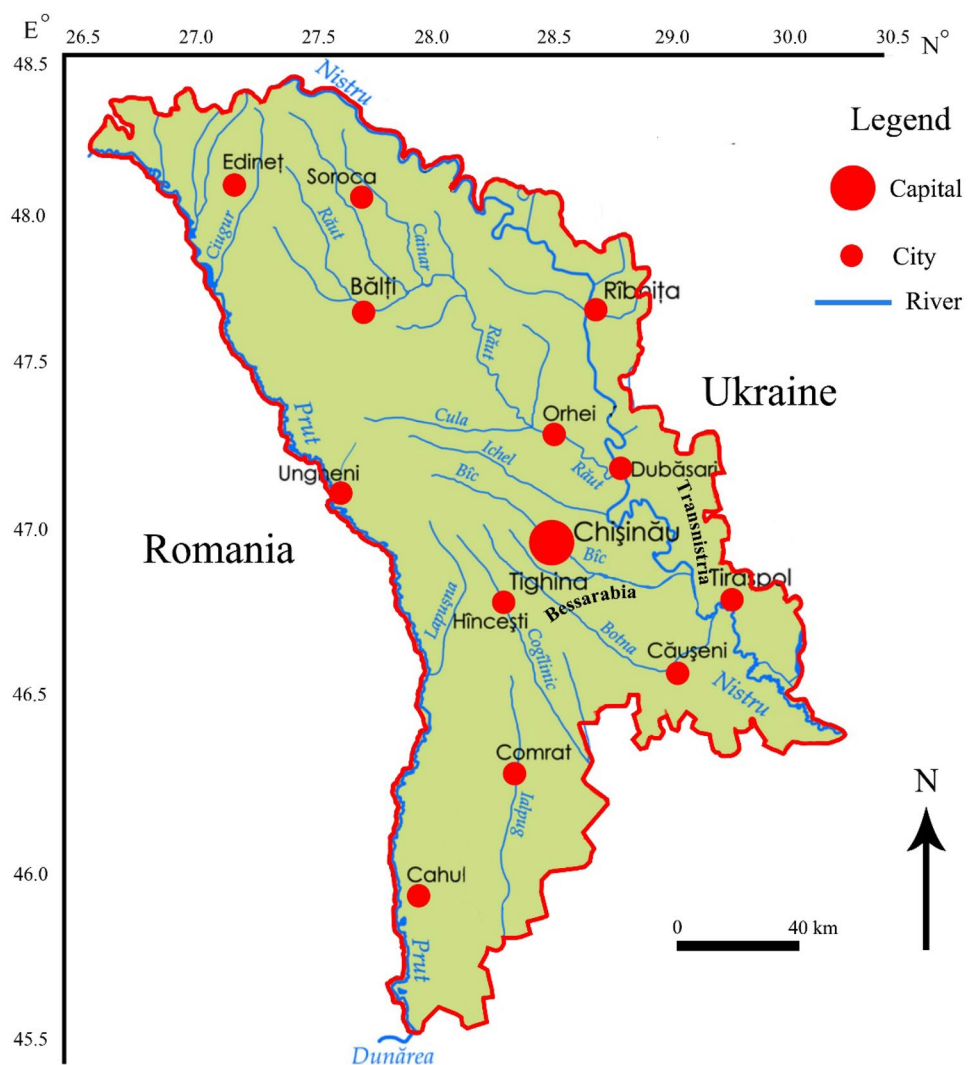
The highest percent of Moldova territory belongs to the Bessarabia region, between the area’s two main rivers, the Nistru and the Prut. The river Nistru divides Bessarabia and Transnistria into two parts (see Fig. 1).

According to the data from the last census, Moldova has 2,681,735 citizens. The relief of Moldova comprises hills and slightly undulating plains. The largest part of Moldova has the relief with mild slopes, not exceeding 1°. This part of central Moldova is known as *Moldavian Plateau*.

The northern part of Moldova is characterized by hills at altitudes ranging from 200 to 300 m.

This area is divided into the Northern Moldavian Plateau and the Nistru Plateau which partly borders with Ukraine. The eastern slopes of the Nistru Ridge have the elevation between 250 and 347 m. The south part of the Moldavian plateau is the Middle Prut Plain. This plateau has the average elevation of 200 m, with the maximum altitude of 260 m. This plateau presents an area without dense forest where the process of deforestation began in the nineteenth

Fig. 1 Geographical position and River network, including the main cities of the Republic of Moldova



and twentieth century. In this region, the vegetation varies between steppe and shrubs. The highest hills are situated in central *Ciulucuri* and the *Codru Plateau*, where the average altitude is between 350 and 400 m. In this region, there is a great number of valleys and sharp slopes. The highest point in the country is Bălănești Hill with the elevation of 429 m. The low area is situated in the lower Prut Valley. The region of Transnistria presents the left bank of the river Nistru. The Lower Nistru Plain can be regarded as the western end of the Eurasian steppe, and it has the average elevation of 100 m. Almost 75% of Moldova is covered by soil-type black earth (chernozem). The quality of soil is better in the north than in the south. This type of land is favorable for the cultivation of sunflower, wheat and grapes.

The hills have woodland soils; they are not fertile enough. The Prut River is a tributary of the Danube, which it joins at the far southwestern tip of the country. Over 95% of the water circulation in Moldova flows into two rivers—the Prut and the Nistru. Despite there is a great potential for the irrigation from these rivers, it is not being used. The most useful sources of drinking water are from groundwater wells and artificial lakes. The groundwater quality of two pilot areas in the Bălți and Cantemir showed the risk of water pollution. The water from shallow sources is used for drinking and irrigation, especially in the rural parts of the country. However, the quality of this water is arguable and the sources dry up frequently (Melian et al. 1999). Due to everything stated, there is an increasing need for new alternative water sources in order to provide the stability in future water supply in Moldova.

Numerical GIS and remote sensing analysis

For the purpose of this research, we have used open-source software Quantum Geographical Information System (QGIS) and System for Automated Geoscientific Analyses (SAGA). These two types of software were the main for all the calculations and spatial analyses of cloudiness, clouds distribution and locations suitable for cloud seeding. Apart from spatial, we have also conducted the analysis of the relief of territories under grapes and sunflower. Along with software for spatial and numerical analysis, we have also used specialized open-source code software DIVA-GIS. This software is very suitable for the analysis of crops. The software analyzes the parameters crucial for the growth and survival of the plant—the necessary amount of water and the temperature suitable for the growth, the maximum and the minimum temperature for the survival of the plant, and insolation. The satellite data, which were taken from the official site National Oceanic and Atmospheric Administration NOAA (<https://www.noaa.gov/>) and the series of satellite data taken from satellite missions Landsat (4, 5, 6, 7, 8, 9) from the server <https://earthexplorer.usgs.gov/> United States

Geological Survey (USGS), resolution of satellite data on clouds and DEM (Digital Elevation Model), varied from 30 m² to 1 km². By means of interpolation and the Clipper method, a grid of 1 km² was derived out of grids with different resolutions (Valjarević et al. 2018). After obtaining unified satellite data, with the same resolution, the analysis of cloudiness of Moldova was conducted, with the help of advanced algorithms within QGIS and SAGA. The algorithms used were zonal statistics, inverse distance weight algorithms (IDW), semi-automated classification (Ichii et al. 2002; Melgani et al. 2000; Boegh et al. 1999).

Satellite data were divided into three groups, in accordance with the years, for which they had been downloaded. The first group are gridded data from the period between 1990 and 2000, the second group belongs to the period between 2000 and 2010, and the third group to the period between 2010 and 2020. The data were also divided in line with the purity of satellite recordings which were being processed. The first group of satellite data were filtered, therefore, it contained haze, whereas the second group only contained data on cloudiness and clouds distribution. The total number of satellite recordings covering the territory of Moldova was 16 per year. Since there were 30 years of monitoring, the total number of satellite data was 460 (16 × 30). This number of data is a sequence long enough for the analysis of cloudiness and potential locations of cloud seeding (Heymsfield 1986; Abdollahi et al. 2021). The reflectance of satellite recordings varied between 1.38 mic = ρ26 to a maximum of 1.44 mic = ρ28. After being inputted in the QGIS software and after processing of shade and filtered algorithms, these recordings gave a better and pure picture of clouds' reflectance. With the processes of pixelization which include remote sensing technics, the possibility of detecting the clouds potential for seeding was high.

(Schneider et al. 2009; Sidi Almouctar 2021). With the help of QGIS software and remote sensing algorithms, semi-automatic classification plugin, supervised classification was conducted (Wang et al. 2012). For checking the average cloudiness, the database NASA's EOSDIS was used as well. From this database, it is very easy to download data at global scale for any place, including geographical coordinates (latitude and longitude). The following procedure was to eliminate shades and dead pixels from the recordings, within the same software QGIS in the process of semi-supervised classification. Low-level clouds have a mix of colors, and they vary between white and gray. High-level clouds have a mix of gray and blue colors (Kobler et al. 1995; Ramapriyan et al. 2010; Marley et al. 2003). Estimation and analysis of plants properties were performed by open-source software DIVA-GIS. The plants properties were analyzed in line with the amount of water and average air temperature per year.

The phenology of two investigated plants sunflower (*Helianthus*) and grapes (*V. vinifera*) was used from the

database of Eco-crop. In this database, there were 2568 plants, with all of their biological and ecological properties. The main characteristics of plants used in this research are growth period in days, killing temperature of the root, minimum temperature necessary for better growing of plant as well as maximum temperature. After georeferencing and vectorising the raster data, the process and analysis of the researched area started. The analysis included algorithms for determining relief properties, clouds properties and plants distribution and conditions. The semi- and global-ordinary kriging were employed through QGIS and SAGA (GIS) of spatial analyst. This method was used in order to obtain the locations suitable for the growth of sunflower and grapes. Although there are a few other methods for spatial analysis, the priority is given to semi-kriging and global kriging because it includes autocorrelation or the statistical relationship between the measured points. Another very important method used in this research was AHP (Analytic Hierarchy Process). This method in combination with multi-criteria decision-making algorithm gave satisfying results in determining the location for cloud seeding (Valjarević et al. 2021; Ying et al. 2007). Upon including all the necessary methods, maps were derived. These maps show the distribution and properties of clouds in the territory of Moldova in the last 30 years along with cloud seeding potential. Other maps

included in this research show plants distribution including three main meteorological parameters, them being average air temperatures, precipitation and cloudiness. The proximity tool is used for deriving raster matrix maps (Brewer et al. 2015; Li et al. 2008; Biswas et al. 2020; Valjarević et al. 2018). Zonal statistics was used to determine the belts suitable for the growth of sunflower and grapes as well as for the analysis of the cloudiness impact (Sonwalkar et al. 2010; Martin et al. 2012; O'Neill et al. 2016; Zelinka et al. 2020).

Results

After detailed GIS, numerical analysis of satellite recordings and available meteorological, and the analysis of the data on plants properties, the results obtained were divided into two categories. The first category referred to cloudiness, which was divided into six classes. Each class represented one belt of cloudiness of the territory of the Republic of Moldova (Figs. 2, 3, 4 and 5). In winter, in December, 92% of belts is with > 20 days with maximum cloudiness. Only the region near the capital Chişinău and the region of the city of Cahul in *Basarabeasca* have less cloudiness in December. After December, the month with high cloudiness in Moldova is February. January is the third month with high cloudiness

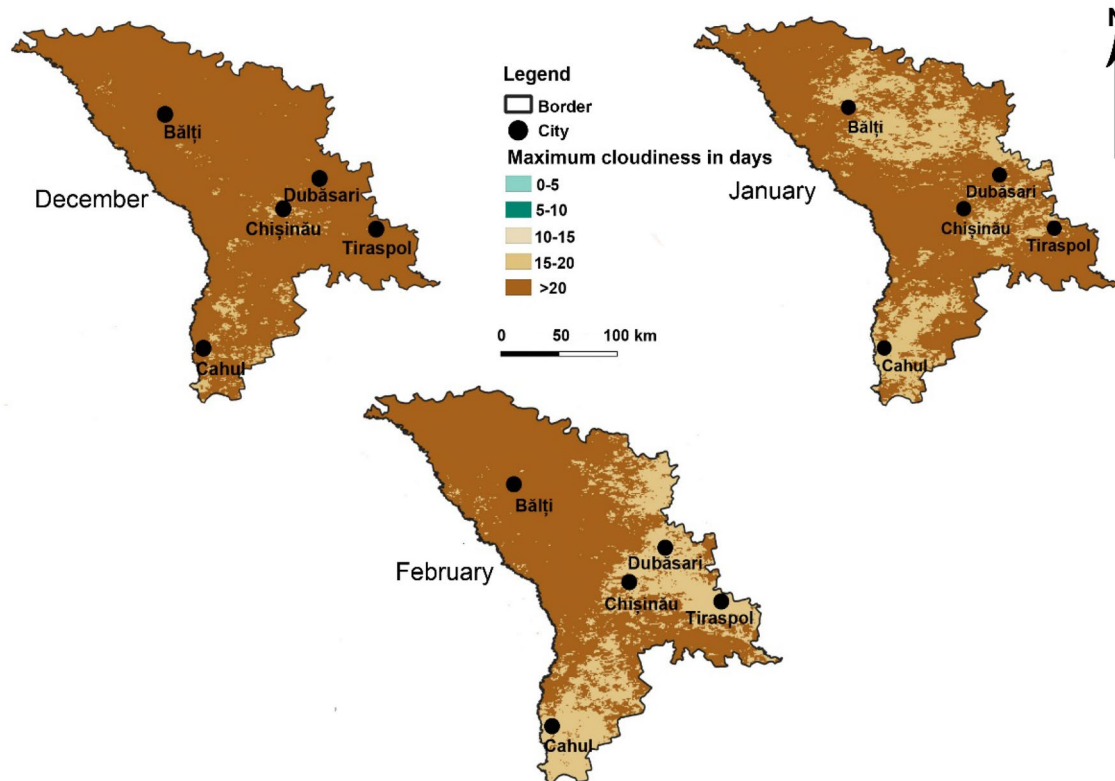


Fig. 2 The maximum cloudiness in Moldova in winter season from 1990 to 2020

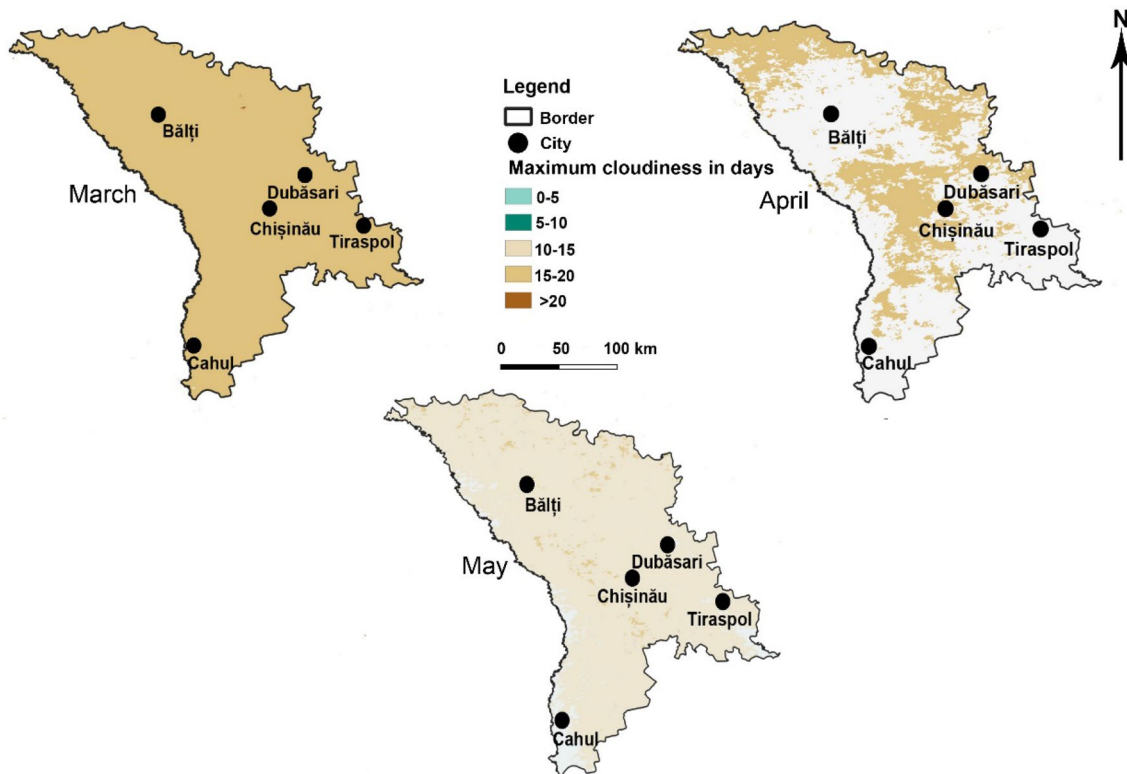


Fig. 3 The maximum cloudiness in spring season from 1990 to 2020

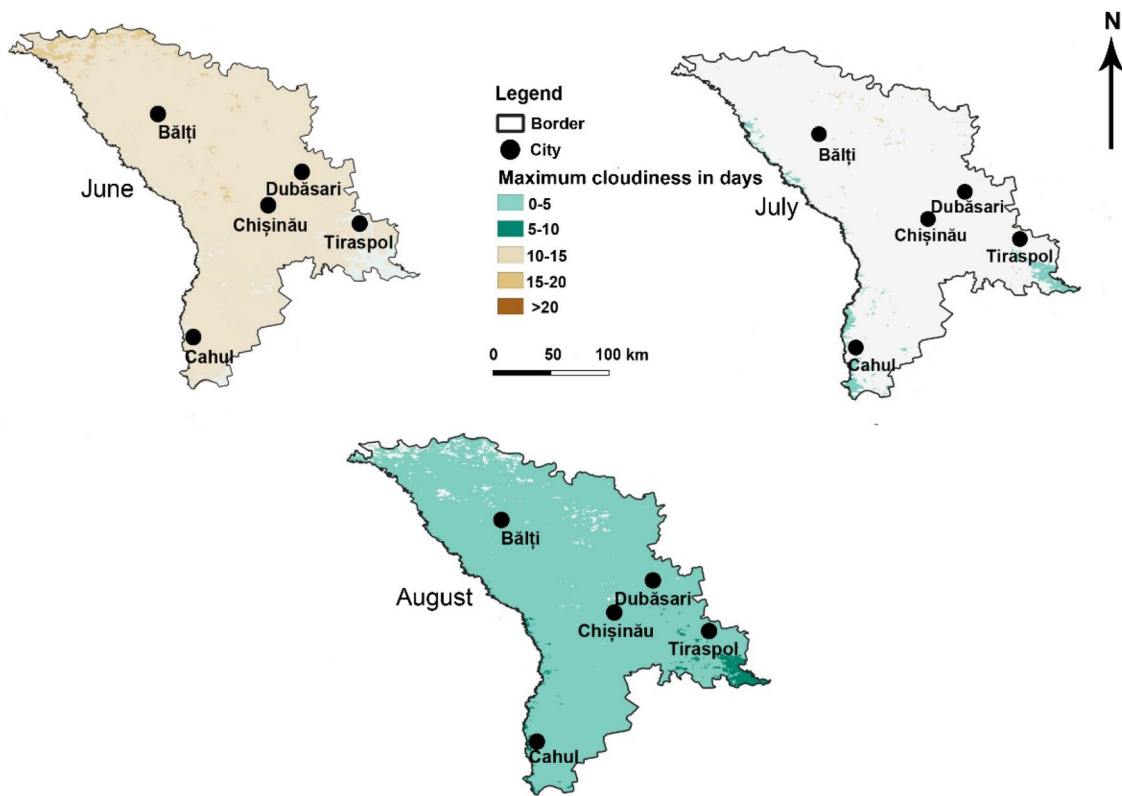


Fig. 4 The maximum cloudiness in summer season from 1990 to 2020

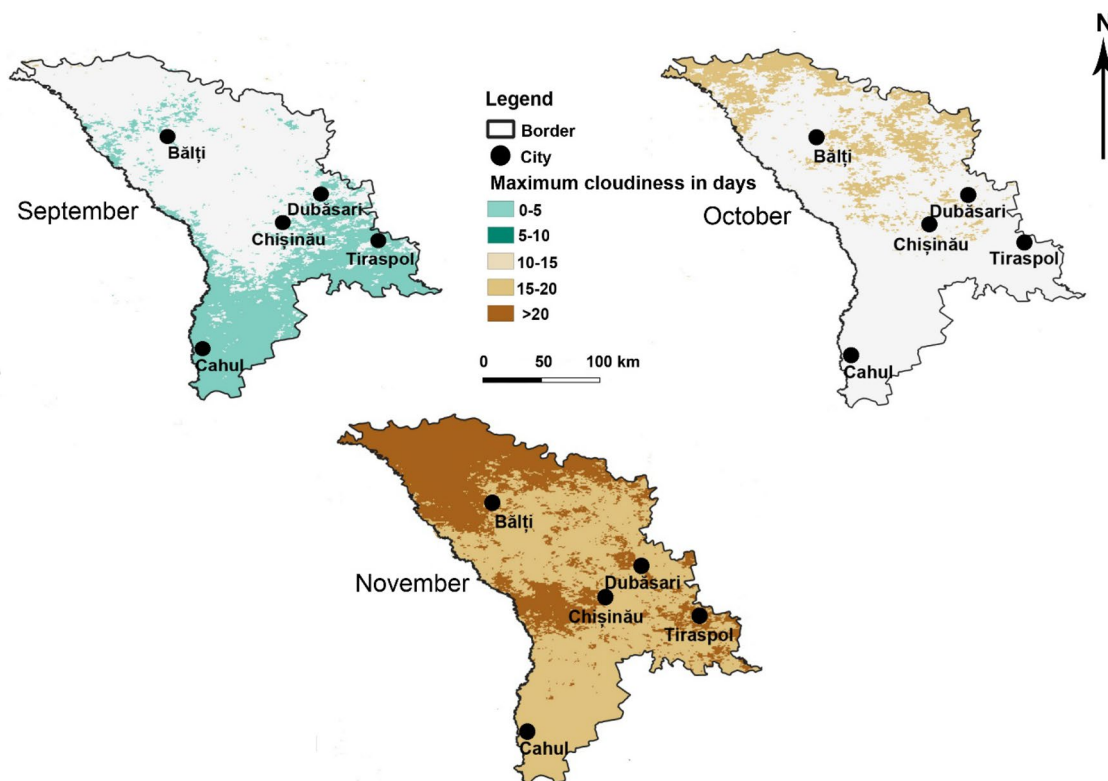


Fig. 5 The maximum cloudiness in autumn season from 1990 to 2020

(see Fig. 2). In total, winter season had 65% more cloudiness than the summer season within the period 1990–2020.

The city with the highest cloudiness in the winter period is Bălți and the region of (*Plateau Moldova*) in the north-west part of the country. In January, the territory with more than 20 days of cloudiness covers 82%, in February 88%. In January, the locations with less cloudiness accumulated in the south part of the country, and in February in the south and in the east between Dubăsari and Tiraspol (see Fig. 2). The cloudiness in December is the highest in the far east of the country, toward the border with Ukraine.

Spring season differs from the winter, and it has 23% overlapping with the autumn season, and 11% of overlapping with the summer. March is the month which has equal distribution of cloudiness in whole territory of Moldova.

This spring month is significant since March represents the month of the beginning of agricultural work. The values of maximum cloudiness are between 16 and 20 days. In April, the cloudiness between 16 and 20 days covers 42% of the territory, whereas 52% is covered with cloudiness lasting between 12 and 16 days. May has 94% of the territory with cloudiness lasting between 12 and 16 days, 1% of the territory with 16–20 days, 4% with 8–12 days and 1% with 0–4 days. The first decade of spring has cloudiness higher than in the autumn season in Moldova. Generally, spring

has more cloudiness in March than in May and in April in covered territories. The areas with low cloudiness in April are in the region of *Cimpia Nistrului Inferior* in the east near the cities Tiraspol and Dubăsari, in the region *Colinele Tigheci* near the city Cahul in the south and region *Cimpia Moldovei* near the city Bălți in the central part. In April, the region with the highest cloudiness is the urban region of Chișinău. During the spring season in Moldova, there are 31% less clouds than in winter season (see Fig. 3).

June is the month with 88% of cloudiness between 12 and 16 days and 9% with cloudiness between 16 and 20 days. Only 3% of the territory is covered by cloudiness lasting between 0 and 4 days. The minimum cloudiness is situated in the southeast territory in the area of the city Tiraspol (see Fig. 4). July has 17% less clouds than June. 95% of the territory is covered with cloudiness between 8 and 12 days and 5% of the territory with cloudiness between 0 and 4 days. The areas with minimum cloudiness are distributed in the southeast near the city Tiraspol and the southwest near the city Cahul. August is the month with the smallest average cloudiness in the last 30 years. 92% of the territory has cloudiness between 0 and 4 days. 5% of the areas have cloudiness between –8 and 12 days and 3% of territory between 4 and 8 days. Only areas near Tiraspol in the region *Cimpia Nistrului Inferior* close to the border with Ukraine have more

clouds in August. The summer has 34% less cloudiness than spring and 62% less than winter (see Fig. 4).

September has 75% areas with cloudiness of 8–12 days and 25% of cloudiness of 0–4 days. The areas with small distribution of clouds are in the region of *Cimpia Nistrului Inferior*, *Cimpia Moldovei Sud* and *Colinele Tigheci*. October is the month with 15% higher cloudiness than September. The cloudiness of 8–12 days occupies 43% of the territory, whereas cloudiness of 16–20 days occupies 57% of the territory. The areas with high cloudiness are distributed in the north and northeast parts of the country in the regions of *Platoul Moldovei* and *Podisul Nistrului*. November is the month with the highest cloudiness in autumn, and it has 12% more cloudiness than September. The cloudiness with more than 20 days is distributed in the northern regions and covers 38% of the territory. The cloudiness with 16–20 days covers 62% of the territory. Generally, the autumn season has cloudiness higher by 47% than summer and 24% higher than spring (see Fig. 5).

In the last 30 years in the territory of the Republic of Moldova, December is the month with the highest cloudiness. August is the month with a minimum of cloudiness. According to the crops prosperity, belts are divided into categories (Not situated, Very Marginal, Marginal, Suitable, Very Suitable, Excellent). The growing of grapes depends on water coefficient in growing season of plants. Grapes need water in vegetation period. Due to the frequency of drought periods in Moldova, the need for alternative water source increased. The belts (Not situated, Very Marginal, Marginal) present low possibility or no possibility for the growth of the plant.

The belts (Suitable, Very Suitable, Excellent) present a good or excellent possibility for growth of the plant, because there is a potential of cloud seeding or use of alternative water.

The areas excellent for vineyards cover large territory between cities Bălți, Dubăsari and Chişinău. This belt covers 72% of the territory. 2% of the territory is covered by the belt Suitable; the belt Marginal covers 24% of the territory and belt Not situated 2% of the territory. 26% or 7886 km² of the Moldavian territory does not have a possibility for vineyards. 74% of the territory or 22,448 km² has enough possibility for grapes growing and vineyard plantations, with cloud seeding included. The region with low possibility for plantation is on the southeastern and southern side of the Moldavian territory near Tiraspol and Cahul (see Fig. 5).

If cloudiness increases, thus followed by cloud seeding increase, excellent potential for grapes growth will cover 30% more territories. The territory of Very suitable land covers 5%, suitable 4%, marginal 14% and Not suitable 47% (see Fig. 6). The areas suitable for growth of grapes are located in the northeast parts of the country. The central city in this area is Bălți. The central part of the country presents the border between two zones (see Fig. 6). If cloudiness increases by 15%, the areas not suitable for grapes will decrease by 35% (Fig. 6). The analysis of sunflowers showed different results, because the budget of water is different than for grapes. The sunflower has better possibility for growth in the territory of Moldova if cloudiness stays at the same volume (1990–2000). 90% of the territory has excellent potential for sunflower growth, 0.5% suitable, 9% very marginal and 0.5% not situated. Only the areas near the city Cahul in

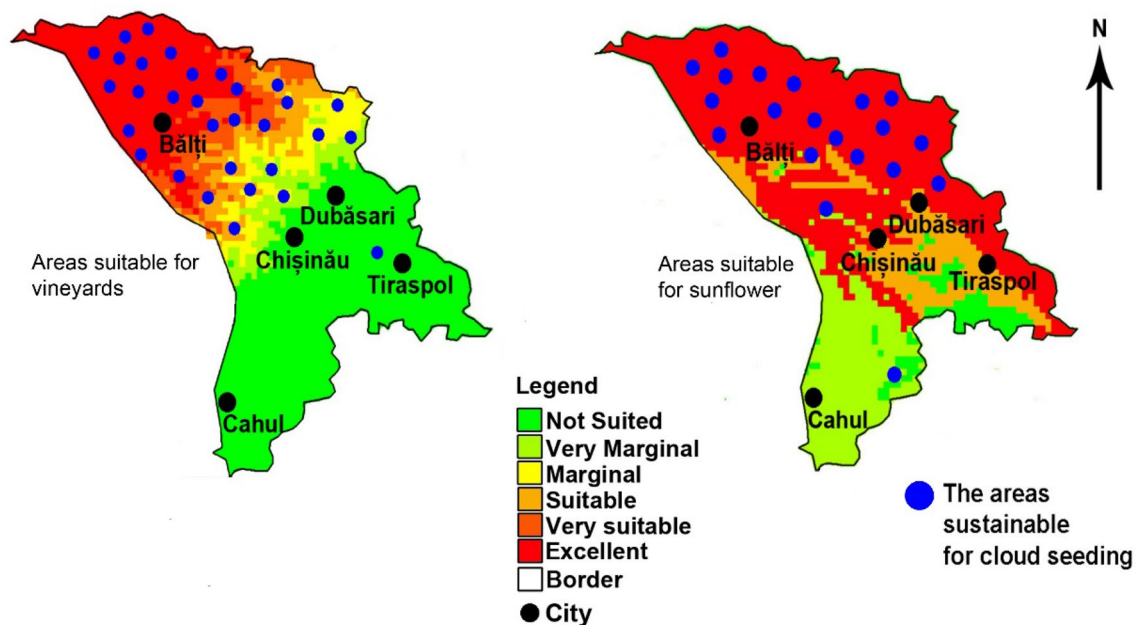


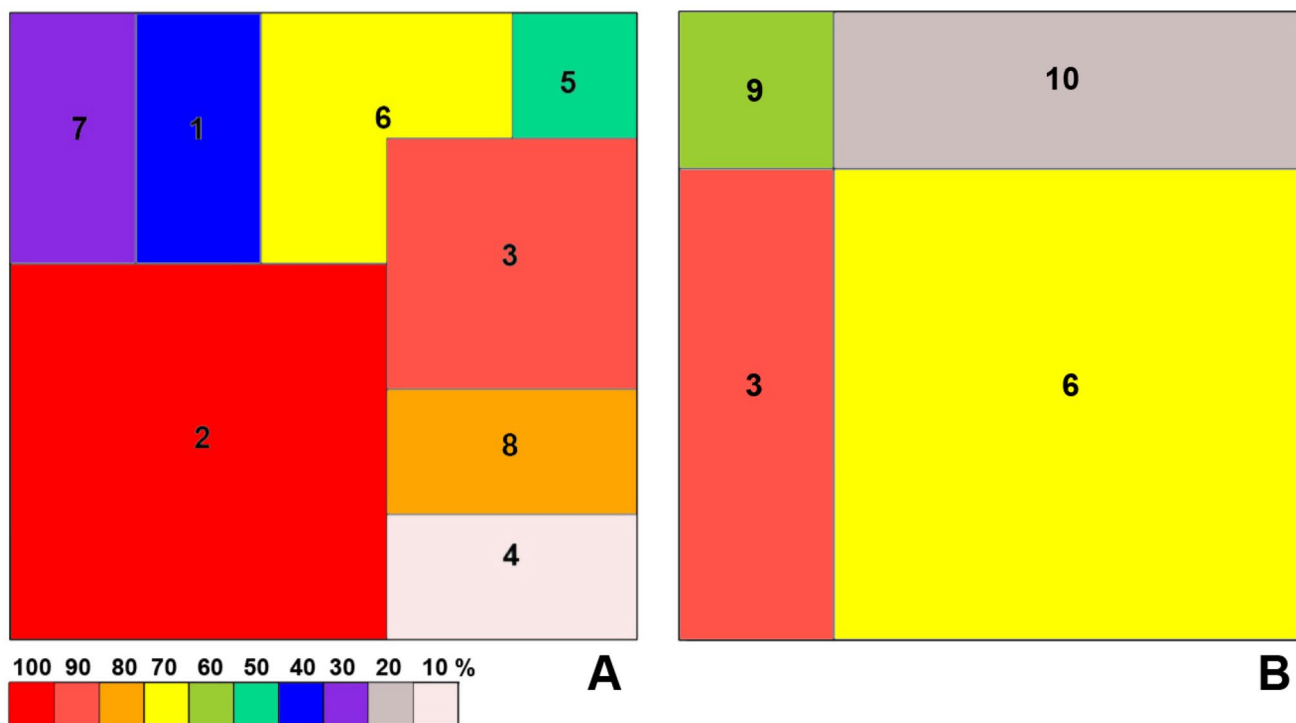
Fig. 6 Distribution of vineyards and sunflower areas in growing season with included increase in cloudiness by 15%

the southwest and areas in the southeast have a low potential for sunflowers plantation (Fig. 6). Increase in cloudiness by 15% is at the same time followed by the higher potential for cloud seeding. After detailed analysis, the areas suitable for sunflower are 22.5% or 7,615 km² of the Moldavian territory. The results obtained for sunflower were as follows: the excellent 52%, very suitable 5%, suitable 11%, marginal 2%, very marginal 24% and not situated 6%. With the increase in cloudiness by 15%, almost 32% of the Moldova territory will not be useful for sunflower growth and plantation. The excellent areas for sunflower growth are in the territory between Bălți and Dubăsari. The low possibility of growth of sunflower is on the territories in the southeast and southwest near the city Cahul (see Figs. 6 and 7).

Discussion

Apart from the visualization on the maps, for the purpose of the research, matrix mapping was used as one of the methods for the display of obtained results (Pengwei and Qingyun 2001). This spatial and statistical method may be useful in finding the connection among cloudiness, potential for cloud seeding and the change in territories covered

by grapes and sunflower. Figure 7A shows the changing of areas in different regions of Moldova. If cloudiness and water potential from cloud seeding increased by 15%, the region Cahul would be the most useful for water collection in summer and spring seasons. This region is followed by Dubăsari and Chişinău. These regions are in the southwest and central parts of the country. The increase in cloudiness in these regions is between 80 and 100%. The regions with a medium increase in cloudiness or 50% and 70% are Tiraspol and Bălți. These regions are located in the central-east and central sides of the country. The regions with less than 40% of the increase in cloudiness will be located in Ocnîța, Glodeni, and Ştefan Vodă. Ocnita is in the north and partly borders with Ukraine; Ştefan Vodă is in the south and borders with Ukraine. Glodeni is the city in the central part of Moldova and partly borders with Romania (see Fig. 7A and B). Due to the deficit of water, Dubăsari and Bălți, as more vulnerable regions, will lose more areas of vineyards and sunflower fields than the region of Soroca (see Fig. 7A, B). If there was not enough watering, the regions which border with Romania in the west, and with Ukraine in the north-east, could lose 80% of the territories under these crops. The central regions in the vicinity of the river Nistru should be exploited more in the future. Without permanent watering,



Changing of cloudiness and areas of plants in the regions

Fig. 7 A- The regions changing if cloudiness and cloud seeding increased by 15% (1- Ocnîța; 2-Cahul; 3- Dubăsari; 4- Ştefan Vodă; 5-Tiraspol; 6-Bălți; 7-Glodeni; 8- Chişinău), B-The regions with most

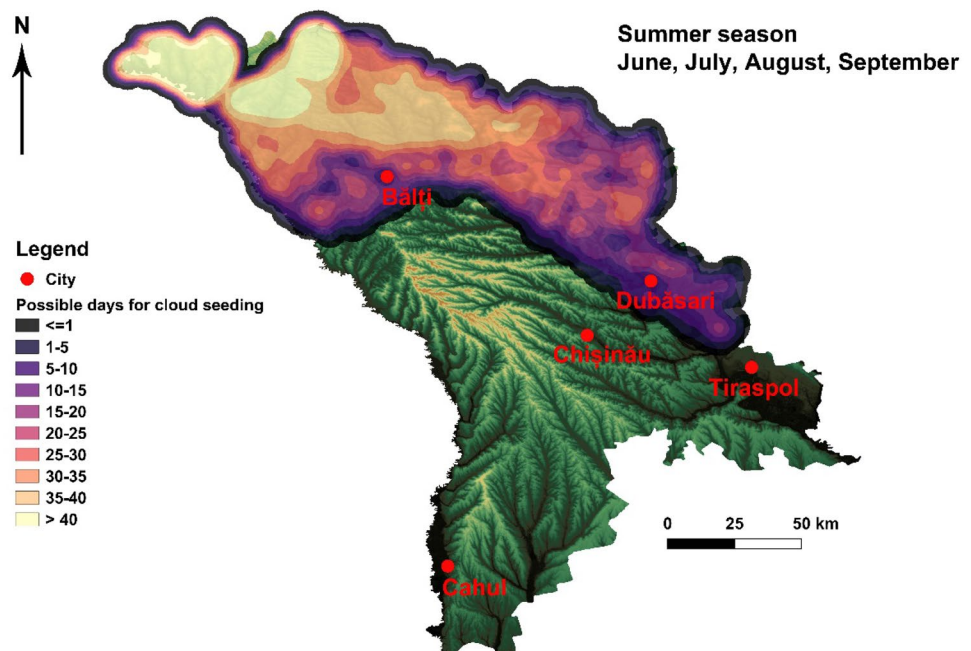
changes in plant areas if cloudiness increased by 15%; (3- Dubăsari; 6- Bălți; 9-Soroca; 10-Rezina). 1 cm² on the matrix graph is 10 km² in nature

the most endangered areas in the future would be situated in the belt of cities Ștefan Vodă, Purcari and Crocmaș. Upon systematic GIS and numerical analysis, it was concluded that cloud seeding is useful in dry seasons, during spring, at the beginning of May, and later in June, during the summer season. The conducted digitization of 480 satellite recordings showed that the overall potential for watering by means of cloud seeding in Moldova is 4%. The average altitude at which cloud seeding would be performed (the densest parts of clouds) would be between 1200 and 1600 m. The best results of cloud seeding would be in May on 22% and in June on 15% of the territory, whereas the worst would be in July, being 0.9%. The yearly amount of cloud seeding in the whole territory would be about 10×10^{14} L. Summer season has small areas of average cloudiness, but it would still be suitable for cloud seeding in the territory of 1.9% in June, 2.3% in July, and 2.7% in August. The cloud seeding may be successful in the southeast and south parts of the country. This kind of water can be important in the stabilization of plant growth (see Fig. 8). In comparison with 1990, there was an increase in cloudiness by 15% in 2020. Belts in which grapes and sunflower prosper are connected to the belts of cloudiness. In comparison with other countries in the region, a significant anomaly was detected in July and August (Valjarević et al. 2020; Henderson-Sellers 1992; Gorczynski 1943). Since spring has enough cloudiness, particularly in March and May, it is possible to compensate for the deficit of water in August, by means of cloud seeding.

In the summer season, 4% of the territory would have more than 40 days for cloud seeding. Two cities Bălți and Dubăsari are in the belt of 5–10 days for cloud seeding in

the summer season. The central and south parts of the country are generally not suitable for cloud seeding. The cloud seeding potential is in correlation with the aridity zones of Moldova (Daradur et al. 2019). Cloud seeding distribution is equal to the areas suitable for the growth of grapes and sunflower (see Figs. 6 and 8). The main indicators of plants growth are cloudiness, air temperature, precipitation. The plants which are the most important for the agriculture of Moldova are under pressure due to the changing of climate on regional scale. Within this research, we compared the distribution of clouds in the territory of Moldova, by means of the analysis of satellite recordings from the period between 1990 and 2020. All meteorological and topographic data were taken from the database of NOAA (National Oceanic and Atmospheric Administration) and High-Resolution Infrared Radiometer Sounder (HIRS); missions Landsat (4, 5, 6, 7, 8, 9) from the server United States Geological Survey. This research covered the territory of 33,843 km² and two important plants, grapes and sunflower in relation to the deficit of water in growing season. There have been a lot of similar research in the countries of Eastern Europe, but on different crops and with different methodology (Pyankov et al. 2010; Zajač 1978). The plants still depend on climate patterns and weather conditions (Drever 1994; Fürst-Jansen et al. 2020; Ielpi 2018). This paper included one big database with the phenology of plants and with the main meteorological parameters, solar radiation, precipitation, cloudiness, air temperature. Very similar investigations which are approved were conducted in closer European countries such as Bulgaria and Romania (Eikelboom et al. 1998; Thomaidi et al. 2017; Andreu and Vilà 2010). Regardless of the fact that

Fig. 8 The most efficient areas for potential cloud seeding in Moldova



the error of satellite recordings, especially those taken from the satellite mission Landsat 4, was up to 5%, this research may still serve as the base for a more comprehensive study on all the alternative water sources available in the Republic of Moldova. This research was established at regional scale, and it would be the first step for broader research in the future. The regional cloud dynamics may be observed through qualitative and quantitative analysis. These analyses, along with other ecological drivers, precipitation and temperature will provide better insight of changes of crops areas. Within the research, a connection was found between the distribution of clouds (cloudiness) and the growth of sunflower and grapes. Another important part of the research was watering these crops by means of cloud seeding. Regardless of the error during the processing and the analysis of satellite recordings, which was up to 5% (1990–2010) and 3% (2010–2020), the conclusion was that 4% of the territory of Moldova is suitable for cloud seeding. Finally, Moldova is absolutely an agricultural country, and each decrease or loss of crops would have huge consequences.

Conclusion

Remote sensing and GIS methods are very useful in estimation of cloudiness properties within a long period, in this case (1990–2020). These methods and procedures are successful at finding the patterns between cloudiness properties and water used from cloud seeding. Sunflower and grapes present 70% of all Moldavian agricultural potential. The changing of cloudiness and water deficit in the last 30 years (1990–2020) showed the changing of fields with sunflowers and grapes. In the last 10 years (2010–2020), the increase in cloudiness was pronounced in the central and southeast and partly in the north part of Moldova territory. These territories are connected with the decrease in areas with sunflowers and grapes. These territories include the areas with most frequent droughts. The ecological drivers were established in the territory of Moldova, and they are connected with the increase in average air temperature and increase in cloudiness by 15% within 30 years. In the last decade, areas with sunflower and grapes had to be watered by means of new alternative water, during the periods of drought. It is necessary to find resistant and adaptive species of grapes and sunflower, if cloud seeding turned out to be unsuccessful. These species must survive the increase in average air temperature, increase in cloudiness, decrease in precipitation and higher number of droughts per year. This research was conducted in the territory of Moldova based on a very long period of satellite monitoring (1990–2020). The changing of regional climate in the Republic of Moldova may be fatal for the production of main plants. The agricultural system of the country will be in danger, and only new strategies such as

new irrigation spatial plans or cloud seeding could be helpful in the future. If cloudiness was constantly increasing in the future, only north parts of the country would be favorable for grapes growing. The seasonal variability of cloud cover is typically more important for plants than day length and angle of the sun ecliptic. The mitigation of cloudiness effects on the crops must be in a new strategy on land adaptation and farming the new resistant sorts of grapes and sunflowers. These plants must be resistant to meteorological and ecological effects, especially to the changing of cloudiness, insolation through the year, deficit of water in growing season. This type of water is necessary and important and, therefore, must be used. The water from cloud seeding is the future of watering especially in semiarid and arid areas in Moldova.

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

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