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Digital inventory of agricultural land plots in the Kemerovo Region

Artem O. Rada*, Aleksandr D. Kuznetsov

Kemerovo State University, Kemerovo, Russia

* e-mail: rada.ao@kemsu.ru

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Abstract:
Cadastral and geodetic land works are expensive, which makes aerial photography extremely valuable for land traceability and inventory. The present research objective was to develop a new digital survey technology for registration of agricultural lands. We assessed the accuracy of the new method and evaluated its decision support options. The study featured the case of the Kemerovo Region – Kuzbass, Russia.
The aerial survey took place in 2021 and involved 17 municipalities of the Kemerovo Region. The software and hardware complex included an unmanned aerial vehicle (UAV) and a module for aerial photography. Photogrammetric, cartometric, and satellite methods were used to define the coordinates of feature points. We developed new software (Sovhoz.avi) to perform the land inventory.
The photogrammetric and cartographic methods proved efficient in determining the feature points and boundaries of land plots. They also appeared accurate enough for land inventory and decision support. The study updated the available land inventory data. About 30% of all land plots were recorded incorrectly; some plots marked as agricultural appeared to belong to the local forest reserves or urban territories. Incorrect data (1.64%) were excluded from the official inventory. The survey covered a total area of 41 000 ha and revealed 1700 illegally used land plots. The updated inventory of unused lands included 3825 new plots (163 400 ha), which can attract prospective investors.
The results can be used by the local authorities to make land management decisions and identify illegal land use.

Keywords: Agricultural land, food, land inventory, unmanned aerial vehicle (UAV), aerial survey, illegal land use

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INTRODUCTION

The present research featured a new aerial survey software and hardware complex, which included a camera-equipped unmanned aerial vehicle (UAV) and digital twin software tailored for agricultural inventory. The new technology provided a digital account of agricultural lands in the Kemerovo Region aka Kuzbass (West Siberia, Russia). The article introduces an assessment of its accuracy and decision support options.

Food security remains one of the main global issues [1–3]. In fact, famine relief is one of the seventeen Sustainable Development Goals set up by the United Nations [4]. Stable food production and availability presupposes efficiency, land availability being the most important production factor in agriculture [5, 6]. Agricultural land depletion, shortage, and irrational use make it difficult to provide the growing world population with food [7–10]. Therefore, land-use efficiency is an important task of resource-intensive digital precision farming [11–13].

Agricultural land resources are limited. Therefore, their inventory and management require high-quality accurate information about the terrain, its configuration, location, etc. These data help plan agricultural work, calculate potential yields, make decisions on the allocation of machine time, seeds, fertilizers, etc. [14].

Accurate land survey is also vital for crop selection, rotation, and logistics [15]. If an agricultural land plot has a complex terrain and the current crop market conditions are unstable, a high-quality land survey can provide the maximal economic effect [16]. Obviously, agricultural organizations are interested in complete and detailed information about their land.

The poor quality of land data is a relevant agricultural issue in Russia and some other countries [17, 18]. As evidenced in practice, traditional paper maps are mostly inaccurate. They are out of date and fail to chart all the lands in actual agricultural use. For instance, a shrub-overgrown area can still be registered as fit for farming, with crops, seeds, fertilizers, and equipment operation time allocated for its cultivation. Land-use efficiency presupposes official registration, state inventory, and open access, which can prevent mining development of agricultural lands [19, 20]. Land-use efficiency ensures fair taxation, protects the interests of stakeholders, determines the required amount of state support, and assesses the main agricultural indicators. In addition, it enables small farmers and agribusinesses to use land as collateral for a bank loan.

Official state inventories often contain faulty or no data at all, which causes irrational use of agricultural plots and land law violations. Most of these problems result from the high cost of traditional geodetic and cadastral work. Traditional land surveys require a lot of man labor and high transportation costs. As a result, they can be too expensive for most agricultural enterprises [21, 22]. Many agricultural land users are not interested in geodetic investigations of their lands: they prefer to refrain from even one-time cadastral surveys, not to mention regular ones. Digital twins of agricultural areas can solve this problem. Visual data are gathered by UAVs and processed by specialized software.

Aerial surveys and drone-mounted infrared cameras are able to solve a wide range of tasks, e.g. maintaining linear infrastructure facilities, tracking forest fires, monitoring construction and mining operations, counting game population, looking for missing people, developing smart city projects, etc. [23–28]. UAV-based aerial surveys are cheap and require no physical presence on location, thus preventing subjective and objective human errors [29]. Therefore, the new complex increases the accuracy and reduces the cost of agricultural land surveys.

UAVs have become focus of numerous scientific publications on cadastral work and real estate inventory. For instance, Puniach *et al.* wrote about a UAV-based update of cadastral data on territories with frequent landslides [30]. The study covered an area of about 50 ha and involved a DJI S1000 octocopter, which hovered at 145 meters above the ground. A Sony ILCE A7R camera provided an 80% direct overlap and a 60% side overlap. It took 500 images and fixed 33 control points. The data were processed using Agisoft PhotoScan Professional, which determined a landslide with an accuracy of up to 0.5 meters. The research made it possible to update the cadastral database and support the farms affected by landslides. The study demonstrated acceptable accuracy in surveying small agricultural plots. In fact, some studies limit the cadastral capabilities of UAVs to small hard-to-reach areas [31].

Šafář *et al.* studied liDAR laser scanning as a means of updating cadastral records in the Czech Republic [32]. Their research involved a DJI Matrice 600 Pro hexacopter, a LiDAR RIEGL miniVUX-1, and PosPac software. The survey results met the local accuracy requirements. Even a partial use of UAVs in construction monitoring reduced their costs by 18–20%. However, the study, like most publications on this issue, focused on the cadastral registration of capital construction objects, not land plots [33, 34].

Brookman-Amissah *et al.* proved that UAV-based aerial survey determined boundaries of land plots with an accuracy stated by the legislation of Ghana, i.e. up to 3 ft, or 91.5 cm [35]. However, the research involved a lightweight UAV (430 g), which could perform only in the most ideal weather. The research provided no data on heavier commercial-grade UAVs. Thus, the problem of using aerial digital surveys for land inventory is at its initial development stage. It requires new methods for surveys and data processing on larger areas, as well as field tests in real weather conditions.

STUDY OBJECTS AND METHODS

The research featured agricultural land plots located in 17 municipal districts of the Kemerovo Region (West Siberia, Russia). The complex included two unmanned aerial vehicles (UAV): a cantilever high-wing aircraft with a Lun 20 gasoline engine (Spetsialmiy Tekhnologicheskiy Tsentr LLC, St. Petersburg, Russia) and an all-wing drone with a Geoscan 201 electric engine (Geoscan, Saint-Petersburg, Russia). Their maximal takeoff weight was 18.6 and 8.5 kg, respectively. This research employed commercial aircraft-type UAVs, unlike previous studies that featured light helicopter-type drones. In good weather and with no vertical drops, a Lun 20 drone is able to survey an area of 20–55 km^2 per flight, a Geoscan 201 drone – about 9 km^2.

The Lun 20 carried a module for cartographic aerial photography, which included: a turntable to compensate for the wind drift, a Phase iXM-50 aerial camera (Phase One, Denmark), a Javad TRE-3N OEM board for tracking geographic coordinates (Javad GNSS Inc, USA), and a cloud assessment camera. The Geoscan 201 carried a Sony RX1R II digital camera (SONY, Japan) and a Topcon GNSS receiver (Topcon Corporation, Japan). High-precision dual-frequency GNSS receivers Javad Triumph-2 (Javad GNSS Inc, USA) and Trimble R10-2 (Trimble Inc, USA) provided on-ground horizontal and vertical control of geographic coordinates.

The software part of the complex was represented by the Sovhoz.avi, a platform for digital inventory and management of agricultural land. The software was developed at the Digital Institute of the Kemerovo State University (Kemerovo, Russia). It stores aerial photography data and those obtained from external sources, e.g. official data on the agricultural land plots obtained from federal, regional, and municipal sources. The platform has been accumulating available data on officially registered agricultural land plots since August 2020. The list of sources included:

– Federal Service for State Registration, Cadaster, and Cartography (*Rosreestr*) – digital data on 35 000 sites (2019);
– Ministry of Agriculture and Processing Industry of the Kemerovo Region – digital data from the Unified Federal Information System of Agricultural Lands (2020);
– Committee for State Property Management of the Kemerovo Region – paper documents on 26 000 land plots (2020);
– Municipal Property Management Committees – digital data on 13 000 plots from 17 municipalities of the Kemerovo Region; and
– Municipal Authorities – digital data on 22 000 share lands, federal lands, and plots under registration (2020).

The UAV aerial survey took place in 2021. It aimed at clarifying the available data, forming a unified database of agricultural land management, and identifying illegal land use. The study had several stages. The first stage included an on-ground horizontal and vertical control of geodetic coordinates using GNSS receivers in the RTK mode. After that, the results of aerial photography were linked to geographic coordinates (MSK-42 Zone 1, BSL 1977).

The second stage lasted from May 10 to September 16, 2021. Two teams used the Lun 20 and the Geoscan 201 to perform an aerial survey of agricultural lands. The equipment was checked and programmed a day before the survey, which was carried out on sunny and dry days with a lot of sunlight and moderate or no wind. The obtained nadir images with a pre-set forward and side lap made it possible to construct an orthophotomap and a digital terrain model.

The third stage included data processing for subsequent managerial decisions by the authorities and land users. This stage made it possible to justify the use of photogrammetric and cartometric methods as means of determining the geographical coordinates of land plots.

The present research used standard methods of computer science, probability theory, and mathematical statistics to compare the coordinates obtained by satellite geodetic (GNSS), photogrammetric, and cartometric (orthomosaic) measurements. The procedure followed the requirements of the Order of the Federal Service for State Registration, Cadaster, and Cartography (*Rosreestr*) dated October 23, 2020, No P/0393 "Accuracy and method requirements for determining the feature point coordinates of land plot boundaries and buildings contours".

When it goes about agricultural land plots, the root mean square error (MSE) for determining feature point coordinates cannot exceed 2.5 m, and the pixel projection for aerial photographs should be 35 cm. However, this rule is not applied to private household plots, gardens, garages, and houses. To simulate unfavorable working conditions, the calculations were carried out for points with limited visibility and signal interference. The Agisoft Metashape software (Zhivoy Soft OOO, St. Petersburg, Russia) was used to compare the results of the photogrammetric and cartometric methods. This software in its professional edition determines the geographical coordinates using the photogrammetric method or an orthophotomap.

The MSE for the feature points were calculated by the following formula to compare the survey results obtained by different methods:

$$m = (10 + 1\times10^{-6})\times D \tag{1}$$

where D is the vector length between the feature point and base station point, mm.

The MSE for the location of the feature point of the contour σ, determined by photogrammetric method, was calculated as follows:

$$\sigma = \sqrt{\sigma_o^2 + \sigma_n^2 + \sigma_c^2} \tag{2}$$

where σ_o is the MSE of the orthophotomap; σ_n it the MSE of the base station point; σ_c is the MSE of the control point.

The MSE of the feature point according to the cartometric method was calculated as follows:

$$m = 0.0005\times M \tag{3}$$

The coordinates determined by various methods were tested for accuracy, and the data of the digital land survey were compared. After that, the results were studied for errors, inconsistencies, and violations.

RESULTS AND DISCUSSION

The new software and hardware complex conducted an aerial survey of agricultural land in the Kemerovo Region. The results were used to compare different methods of measuring feature points. In case of the photogrammetric method, the mean square error (MSE) was $\sigma = \sqrt{0.05^{22}+0.18 \ +0.007^2} = 0.053$ m. This MSE did not exceed the regulatory requirements specified above. Tables 1–3 compare three methods as in the case of the Topki municipality. The difference between the feature point coordinates obtained by different methods (Δ) was calculated based on the geodetic inverse.

Table 1 shows that the difference between the results of satellite and photogrammetric methods stayed within 10 cm, as specified in the regulatory requirements. Table 2 compares the data obtained by satellite imagery and cartometrics.

Table 1 Satellite method vs. photogrammetric method

Point	Satellite method		Photogrammetric method		Difference		
	X, m	Y, m	X, m	Y, m	ΔX, m	ΔY, m	Δ, m
topki1	1310048.280	617173.700	1310048.295	617173.7108	–0.015	–0.011	0.018
topki2	1310055.216	617162.459	1310055.214	617162.4656	0.002	–0.007	0.007
topki3	1310018.896	617140.355	1310018.896	617140.3557	0.000	–0.001	0.001
topki4	1310011.957	617151.709	1310011.957	617151.705	0.000	0.004	0.004
topki5	1309996.704	617202.782	1309996.709	617202.8057	–0.005	–0.024	0.024
topki6	1309962.871	617182.499	1309962.925	617182.4253	–0.054	0.074	0.092
topki7	1309817.231	617335.634	1309817.226	617335.6422	0.005	–0.008	0.009
topki8	1309857.820	617399.271	1309857.815	617399.2792	0.005	–0.008	0.010
topki9	1309817.909	617376.728	1309817.925	617376.7499	–0.016	–0.022	0.027
topki10	1309819.796	617373.463	1309819.809	617373.4673	–0.013	–0.004	0.014
topki11	1309799.636	617361.148	1309799.637	617361.1525	–0.001	–0.004	0.005
topki12	1309974.076	616743.343	1309974.075	616743.3386	0.001	0.004	0.005
topki13	1309949.763	616775.568	1309949.775	616775.5402	–0.012	0.028	0.030
topki14	1309939.604	616767.828	1309939.621	616767.8154	–0.017	0.013	0.021
topki15	1309963.933	616735.588	1309963.931	616735.5874	0.002	0.001	0.002
topki16	1310339.023	615177.752	1310338.993	615177.7349	0.030	0.017	0.034
topki17	1310344.018	615183.604	1310343.971	615183.5602	0.047	0.044	0.064
topki18	1310349.038	615179.145	1310349.032	615179.1342	0.006	0.011	0.012
topki19	1310344.136	615173.292	1310344.125	615173.2815	0.011	0.010	0.016
topki20	1310320.547	615146.909	1310320.531	615146.8989	0.016	0.010	0.019
topki21	1310288.354	615110.297	1310288.307	615110.3011	0.047	–0.004	0.048
topki22	1310280.513	615117.21	1310280.507	615117.194	0.006	0.016	0.017

Table 2 Satellite method vs. cartometric method

Point	Satellite method		Cartometric method		Difference		
	X, m	Y, m	X, m	Y, m	ΔX, m	ΔY, m	Δ, m
topki1	1310048.280	617173.700	1310048.342	617173.7878	–0.062	–0.088	0.107
topki2	1310055.216	617162.459	1310055.244	617162.4891	–0.028	–0.030	0.041
topki3	1310018.896	617140.355	1310018.928	617140.4121	–0.032	–0.057	0.066
topki4	1310011.957	617151.709	1310012.099	617151.6668	–0.142	0.042	0.148
topki5	1309996.704	617202.782	1309996.892	617202.8369	–0.188	–0.055	0.196
topki6	1309962.871	617182.499	1309962.92	617182.4028	–0.049	0.096	0.108
topki7	1309817.231	617335.634	1309817.256	617335.6739	–0.025	–0.040	0.047
topki8	1309857.820	617399.271	1309857.829	617399.3105	–0.009	–0.039	0.040
topki9	1309817.909	617376.728	1309818.126	617376.8517	–0.217	–0.124	0.250
topki10	1309819.796	617373.463	1309819.948	617373.4828	–0.152	–0.020	0.154
topki11	1309799.636	617361.148	1309799.735	617361.2129	–0.099	–0.065	0.118
topki12	1309974.076	616743.343	1309974.117	616743.2482	–0.041	0.095	0.103
topki13	1309949.763	616775.568	1309949.777	616775.6203	–0.014	–0.052	0.054
topki14	1309939.604	616767.828	1309939.546	616767.689	0.058	0.139	0.151
topki15	1309963.933	616735.588	1309964.053	616735.6928	–0.120	–0.105	0.160
topki16	1310339.023	615177.752	1310338.921	615177.6718	0.102	0.080	0.130
topki17	1310344.018	615183.604	1310344.108	615183.3738	–0.090	0.230	0.247
topki18	1310349.038	615179.145	1310348.931	615179.0497	0.107	0.095	0.143
topki19	1310344.136	615173.292	1310344.112	615173.221	0.024	0.071	0.075
topki20	1310320.547	615146.909	1310320.464	615146.8618	0.083	0.047	0.096
topki21	1310288.354	615110.297	1310288.337	615110.2457	0.017	0.051	0.054
topki22	1310280.513	615117.21	1310280.535	615117.2026	–0.022	0.007	0.023

Table 2 demonstrates that the difference between the data obtained by satellite mapping and cartometrics was bigger than in the previous case and reached 25 cm. However, this MSE also stayed within the maximal allowable values. Therefore, the cartometric method proved sufficiently accurate, if compared to the satellite imagery, which served as control. Table 3 compares the data obtained by photogrammetric mapping and cartometrics.

Table 3 Photogrammetric method vs. cartometric method

Point	Photogrammetric method		Cartometric method		Difference		
	X, m	*Y*, m	*X*, m	*Y*, m	Δ*X*, m	Δ*Y*, m	Δ, m
topki1	1310048.29	617173.71	1310048.34	617173.788	–0.047	–0.077	0.090
topki2	1310055.21	617162.47	1310055.24	617162.489	–0.031	–0.023	0.039
topki3	1310018.9	617140.36	1310018.93	617140.412	–0.032	–0.056	0.065
topki4	1310011.96	617151.7	1310012.1	617151.667	–0.142	0.038	0.147
topki5	1309996.71	617202.81	1309996.89	617202.837	–0.183	–0.031	0.186
topki6	1309962.93	617182.43	1309962.92	617182.403	0.005	0.022	0.023
topki7	1309817.23	617335.64	1309817.26	617335.674	–0.029	–0.032	0.043
topki8	1309857.82	617399.28	1309857.83	617399.31	–0.014	–0.031	0.034
topki9	1309817.93	617376.75	1309818.13	617376.852	–0.201	–0.102	0.225
topki10	1309819.81	617373.47	1309819.95	617373.483	–0.139	–0.016	0.140
topki11	1309799.64	617361.15	1309799.73	617361.213	–0.098	–0.060	0.115
topki12	1309974.08	616743.34	1309974.12	616743.248	–0.042	0.090	0.100
topki13	1309949.78	616775.54	1309949.78	616775.62	–0.001	–0.080	0.080
topki14	1309939.62	616767.82	1309939.55	616767.689	0.075	0.126	0.147
topki15	1309963.93	616735.59	1309964.05	616735.693	–0.122	–0.105	0.161
topki16	1310338.99	615177.73	1310338.92	615177.672	0.072	0.063	0.096
topki17	1310343.97	615183.56	1310344.11	615183.374	–0.137	0.186	0.231
topki18	1310349.03	615179.13	1310348.93	615179.05	0.101	0.084	0.132
topki19	1310344.12	615173.28	1310344.11	615173.221	0.012	0.061	0.062
topki20	1310320.53	615146.9	1310320.46	615146.862	0.067	0.037	0.077
topki21	1310288.31	615110.3	1310288.34	615110.246	–0.031	0.055	0.063
topki22	1310280.51	615117.19	1310280.53	615117.203	–0.028	–0.009	0.029

According to Table 3, the results obtained by cartometrics and photogrammetric mapping were very similar, and the MSE stayed within 25 cm. Therefore, a much cheaper aerial survey can replace traditional cadastral and geodetic works, as well as satellite imagery.

The next stage featured the Sovhoz.avi platform, which identified inconsistencies in the available data on agricultural land plots. The analysis involved software and visual control of data using the feature point coordinates of the land plots. The analysis of the data provided by the Federal Service for State Registration, Cadaster, and Cartography showed that the Kemerovo Region has a lot of agricultural land plots with unidentified boundaries. Their area is shrinking, but very slowly.

In 2017, there were 2.44 million ha of land with undetermined boundaries. In 2020, their area decreased by 22%, shrinking to 1.90 million ha. However, the total area of agricultural lands in the Kemerovo Region is about 2.9 million ha. Consequently, 65.5% of all agricultural land has unclear plot boundaries. This situation makes land-use efficiency and business turnover impossible. Moreover, it causes conflicts as it violates the legitimate interests of land users and renders faulty taxation.

The cadastral measuring of all agricultural land boundaries in the region costs 2.7 billion rubles, or 35 million US dollars (January 2022). Land users simply cannot afford it: in 2020, the total value of commercial products produced by agricultural organizations and farms of the Kemerovo Region was about 34.9 billion rubles. Thus, land users would have to spend about 7–10% of their annual revenue on cadastral work. Obviously, they would appreciate much cheaper digital methods.

The Sovhoz.avi software also found some discrepancies in the data obtained from the Committee

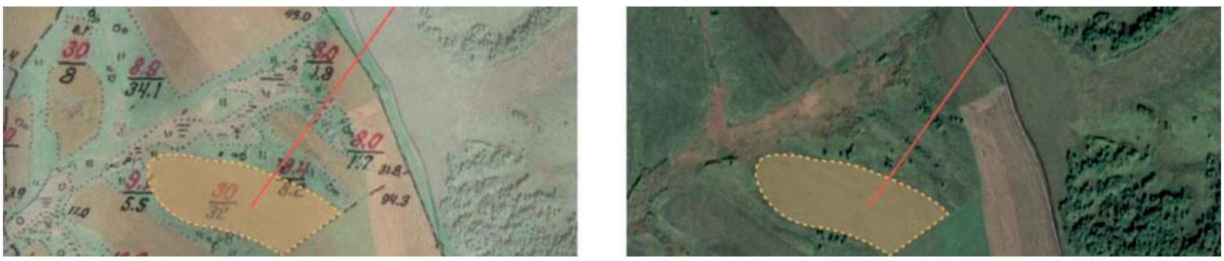

Figure 1 Faulty boundaries revealed by comparing a digitized paper map with the aerial photography data

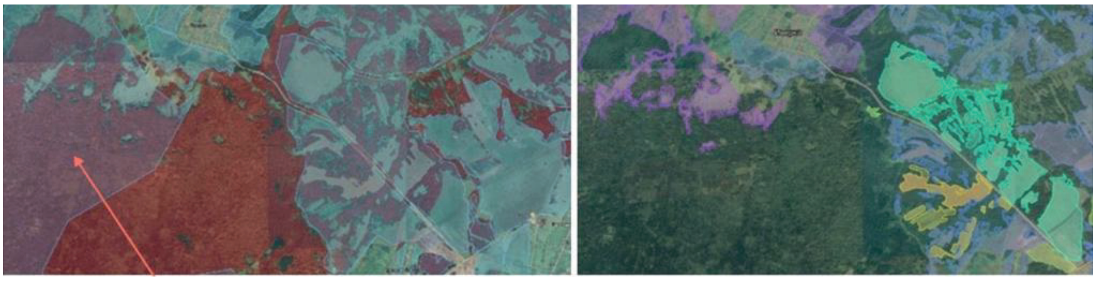

Figure 2 A land plot with a land-use error

Figure 3 An urban land plot misclassified as agricultural

for State Property Management and the Ministry of Agriculture and Processing Industry of the Kemerovo Region. After 1200 paper maps were digitized, 30% of them appeared to be faulty to some extent. Figure 1 illustrates an example of such an error detected after comparing a digitized paper map with the aerial survey data.

According to the paper map provided by the State Property Management Committee, the area of the land plot was about 32 ha. According to the coordinates obtained by the photogrammetric mapping, it was about 16.3 ha. This means that the land owner has to pay almost twice as much land tax while allocating extra resources to cultivate the acres that are not there. The error triggers incorrect agricultural work planning because most indicators, e.g. yield, are initially incorrect. The error occurred as the field partially overgrew with trees and shrubs. A prompt correction will allow the farmer to plan their costs, calculate their yields, and reduce their taxes.

The data on all previously recorded agricultural land plots were subjected to continuous automated control. This measure corrected numerous errors found in the data provided by the authorities. In the Izhmorka municipality, the survey revealed several agricultural plots (5189 ha) on the forest fund lands. The Ministry of Agriculture and Processing Industry of the Kemerovo Region misclassified them as agricultural. Figure 2 is a Sovhoz.avi screenshot which visualizes such an error that affected an area of 2352 ha.

The red arrow on the left slide highlights the area that was classified as agricultural by the Ministry of Agriculture and Manufacturing Industry of the Kemerovo Region. However, the aerial survey on the right slide shows that this area is covered with forest. The data provided by the municipal authorities of the city of Novokuznetsk were subjected to similar control. The Sovhoz.avi platform identified several areas located in the city center and along the main highways that were mistakenly recorded as agricultural (Fig. 3, red circle). As a result, 670 land plots with a total area of 9144.96 ha were removed from the system.

The Sovhoz.avi platform currently contains data on 96 600 agricultural land plots with a total area of 2.4 million ha. After verification, about 0.04 million ha, which is about 1.64% of the total area, were excluded because the data were found unreliable. Since April 30, 2021, the platform has been used by the authorities and local governments of the Kemerovo Region. The users are mostly interested in such options as “view the plots”, “check and change boundaries”, and “check and change attributes”.

In May 2021, Sovhoz.avi was used to monitor the agricultural land use rights. Illegal use of agricultural

Table 4 Number and area of illegally used land plots in the Kemerovo Region

Municipality	May 2021		January 2022		Difference	
	Plots	Area, ha	Plots, number	Area, ha	Plots, number	Area, ha
Belovo	0	0	5	973.11	5	973.11
Guryevsk	4	60.43	8	261.77	4	201.34
Izhmorka	10	345.22	10	345.22	0	0
Kemerovo	6	158.53	5	89.03	–1	–69.50
Krapivino	7	355.29	0	0	–7	–355.29
Leninsk-Kuznetskiy	79	1031.00	27	708.37	–52	–322.63
Mariinsk	8	287.77	29	1112.95	21	825.18
Novokuznetsk	6	161.45	114	2018.35	108	1856.90
Prokopyevsk	13	972.13	95	3871.29	82	2899.16
Promyshlennoe	3	151.95	2	68.82	–1	–83.13
Tisul’	6	51.84	7	1108.50	1	1056.66
Topki	20	345.26	169	3874.49	149	3529.23
Tyazhin	150	11176.53	1037	22136.58	887	10960.05
Chebula	0	0	3	608.88	3	608.88
Yurga	8	418.35	128	2729.34	120	2310.99
Yaya	55	553.75	31	295.88	–24	–257.87
Yashkino	24	907.29	24	907.29	0	0
Total	399	16976.79	1694	41109.87	1295	24133.08

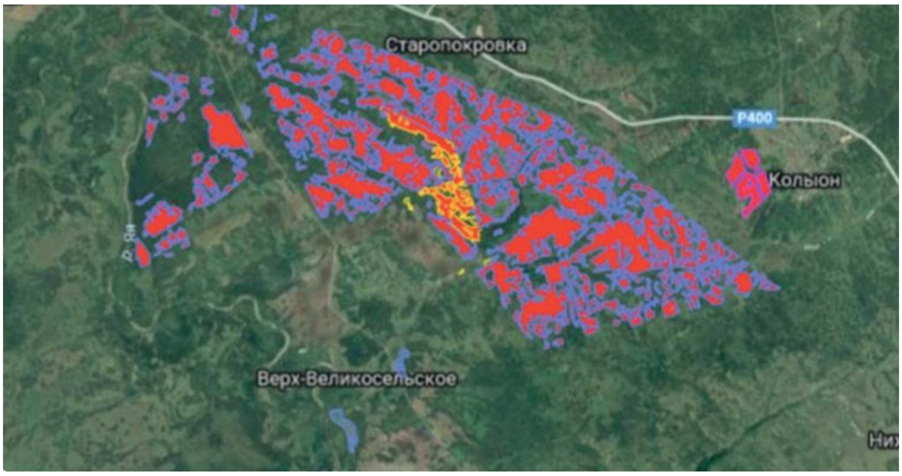

Figure 4 A case of unused land plots with good transport accessibility

land has become a relevant issue in the region as a result of incomplete and conflicting information, as well as a long period of no official control. Agricultural enterprises and individual farmers did not bother to obtain official permission when they decided to develop new plots, thus violating the fiscal interests of the state. In the end, farmers had neither accurate data on the size and configuration of their own lands nor any legal right to use them in transactions. The first stage of the monitoring revealed 688 plots (24 300 ha) with no official registration. While the agricultural profile of these plots was obvious from the aerial survey, the system lacked information about their state registration and permits.

Of the initially identified 688 plots, 488 plots (65.1%, 15 300 ha) proved to be charted correctly. However, 34 plots (7.6%, 1100 ha) had to be inspected by specialists. The inspections revealed that all the plots were used for farming, e.g. animal sheds, barns, etc. The farmers were sent official recommendations to register their land plots. Table 4 illustrates the changes in the number and total area of illegally used land plots in 2021–2022.

Table 4 shows that the scale of illegal agricultural land use differs from municipality to municipality. The Tyazhin municipality is responsible for about 45.4% of the total area and 68.5% of the total number of illegal agricultural land plots. Its disadvantageous location and poor transport accessibility make any control a very complicated task. In some areas, e.g. in the Krapivino municipality, almost all illegal land plots were officially registered in 2021, while in other municipalities they were identified later.

Figure 5 A case of an easy-to-introduce land plot without trees

The Sovhoz.avi software can also identify unused agricultural land plots. Agricultural land-use efficiency is vital for food security and agricultural development. Unused land plots can be offered to businesses that are interested in investing in the local agriculture.

Unused land plots are very different. The Sovhoz.avi platform divided them into those that are easy or hard to introduce into agricultural use. The classification was based on two criteria deduced from the digital inventory data. The first criterion was the location of the plot in relation to settlements and roads. High transportation costs make hard-to-reach areas economically unviable. Therefore, easy-to-introduce areas are located near highways and settlements (Fig. 4), where farmers can hire workers, build warehouses and garages, etc.

The second criterion is vegetation. Unused land plots get overgrown with shrubs and trees. Their uprooting is not cost effective. A field with trees and shrubs is difficult and inefficient to cultivate. Sovhoz.avi can identify trees and shrubs. Figure 5 illustrates another case of an easy-to-introduce land plot in the Novokuznetsk municipality.

Areas with grass and trees are easy to spot (right slide) and measure (left slide, red area). The trees did not prevent Sovhoz.avi from identifying a country road that goes through the overgrown area. The monitoring revealed 3825 unused easy-to-introduce land plots with a total area of 163 400 ha and verified 1682 plots (44%) with a total area of 36 500 ha. These areas can be recorded in a separate inventory to be offered to potential investors.

Hard-to-introduce plots are far from highways and settlements. They are hard to cultivate because of trees and shrubs. Figure 6 gives an example of a hard-to-introduce land plot.

The left slide shows field boundaries (highlighted) charted according to feature point coordinates. The dark green spots are trees and shrubs. The aerial survey (right slide) confirmed that the plot indeed belongs to those hard to introduce into agricultural use. It contains two birch groves, while its southern part is overgrown with shrubs. This plot would be very difficult to return to economic circulation.

The Sovhoz.avi platform revealed 29 140 hard-to-introduce plots with a total area of 447 100 ha. Apparently, hard-to-introduce plots are much more numerous because all convenient plots are already in agribusiness. The platform verified 13 111 plots (44.9%) with a total area of 171 100 ha. These plots may return to economic circulation if the situation in agriculture and food market changes, e.g. prices and food demand continue to rise in 2022.

CONCLUSION

The new aerial survey software and hardware complex, which included a camera-equipped unmanned aerial vehicle and the Sovhoz.avi digital twin software, proved to be an efficient and cheap means of agricultural land inventory. The digital inventory of agricultural land in the Kemerovo Region revealed numerous errors in the available official records. The most common errors included: unidentified boundaries (about 65% of all agricultural plots in the region), distortions of the

Figure 6 A case of a hard-to-introduce land plot with trees

geometric boundaries, and incorrect area calculation. Some plots located in urban areas or forest reserves were misidentified by the authorities as agricultural.

The aerial survey data and the Sovhoz.avi platform can provide local authorities with effective decision-making support. In January 2022, the Kemerovo Region had 1700 illegally used land plots with a total area of about 41 000 ha. The land users were recommended to register their land plots officially. The research also provided a new, updated inventory of unused agricultural land plots, which were divided into those easy or hard to introduce into agricultural use. Easy-to-introduce land plots have a good transport accessibility and no trees or shrubs (3825 plots with a total area of 163 400 ha). They form a promising reserve for the local agricultural development and can be offered to potential investors.

CONTRIBUTION

A.O. Rada supervised the research, set goals and objectives, edited the manuscript, and formulated the conclusions. A.D. Kuznetsov formulated the hypothesis, conducted the research, and wrote the manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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ORCID IDs
Artem O. Rada https://orcid.org/0000-0001-7678-8402
Aleksandr D. Kuznetsov https://orcid.org/0000-0002-1986-3039