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Baltica

BALTICA Volume 32 Number 2 December 2019: 202–209
https://doi.org/10.5200/baltica.2019.2.7

Application of aerial photogrammetric technology for determination and parametrization of areas affected by extraction of raw materials

Audrius Armanavičius, Jonas Satkūnas

Armanavičius, A., Satkūnas, J. Application of aerial photogrammetric technology for determination and parametrization of areas affected by extraction of raw materials. *Baltica, 32 (2), 202–209*. Vilnius. ISSN 0067-3064.
Manuscript submitted 19 July 2019 / Accepted 27 November 2019 / Published online 12 December 2019

Abstract. Extraction of mineral raw materials is increasing due to economic development and must be a normal process under due control and environmental supervision. However, there are a number of sites where the exploitation was stopped and mining sites were abandoned without proper restoration. Also, there are sites where mineral resources were or are extracted illegally thus making significant damage to the environment and economy. In order to collect information on land impacted by mining and extraction activities, for the first time a special project was carried out for the entire territory of Lithuania. The project consisted of gathering of information on damaged areas from various sources, field surveys and systematization of collected data. In order to obtain volumetric data, a special technology of aerial photogrammetry was developed and successfully applied. It was detected that the number of damaged sites > 0.3 ha reached up to 3,300. It is estimated that a total amount of illegally extracted minerals in last 15–20 years could be up to 15 million m^3. The aerial photogrammetry was proved as a relevant technology and this could be applied for the control of the restoration of damaged land as well as for the monitoring of hazardous geological processes, e.g. coastal erosion, karst.

Keywords: *UAV measurements; proved mineral deposits; indicated mineral resources; sand and gravel; quarries; illegal excavation*

✉ *Audrius Armanavičius (audrius.armanavicius@gmail.com), Jonas Satkūnas (jonas.satkunas@gamtc.lt), Nature Research Centre, Institute of Geology and Geography, Akademijos Str. 2, LT-08412 Vilnius, Lithuania*

INTRODUCTION

In terms of value, rates of extraction and consumption, the world's most important mineral resources are aggregates such as gravel, sand, dolomite, crushed stone that are extracted in open mines, quarries and pits. Peat is harvested in open fields as well. All mining places interrupt natural landscape and change land use for a certain period of time (Buddhi *et al*. 2018).

It is noteworthy that demand for mineral raw materials is constantly increasing, and over the last century there were extracted more mineral resources than during the entire previous existence of mankind (Motūza *et al.* 2018).

During the recent years, nine types of minerals have been extracted in Lithuania: fresh and mineral groundwater, dolomite, limestone, gravel, clay, peat, sand, oil and sapropel (Januška *et al.* 2018). Due to the growth of construction industry during the last 6 years there was observed an increase of extraction rates of limestone, dolomite, sand and gravel. Some exhausted quarries were replaced by new ones.

The mineral resources are extracted according to the specially elaborated mining and restoration plans which comprise e.g. the description of the way and means of exploitation, depth of the quarry, estimated time of extraction, way of restoration of the site after exploitation (making of a water body or planting of a forest, etc.). In this way, the extraction process is planned and managed by a mining company and supervised by state institutions, like Lithuanian Geological Survey, Environmental Protection Department under the Ministry of Environment and The Environmental Protection Agency. The proper implementation of the mining and restoration plans allows to save the surrounding environmental values in the best way (Čyžienė 2015). In addition, the mining companies must comply with the requirements of the listed-above state institutions. These consist of: providing quarterly reports on mining, paying the fees for the extracted minerals, properly closing the quarries after the completed mining and restoration of the used land and the surrounding environment according to the plan.

The Lithuanian Geological Survey under the Ministry of Environment possesses information on areas undertaken by industrial quarries that are exploited with permissions and follow the above-mentioned mining plans. However, so far there are no available systematic records regarding the damaged land caused by other types of mining (i.e. pits, small quarries with the area not exceeding 0.5 ha and depth not more than 2 m) as well as their environmental state. The lack of such information causes serious problems like these: public authorities cannot take decisions concerning the management of the territories that were damaged by the mining activities; public authorities cannot effectively stop illegal mining and demand a proper restoration. This results in the losses of the state budget due to free use of resources avoiding payment of taxes.

In 2015 the Lithuanian Geological Survey started the implementation of the State Management Plan for the Damaged Land 2014–2020 approved by the Minister of Environment of the Republic of Lithuania (by Order No. D1-578). This action comprised an audit of all mining damaged areas > 0.3 ha, and the project was titled “Collection and systematization of information on damaged lands” (Juozapavičius *et al.* 2015).

The purpose of this investigation was to accumulate information on the extent of illegal or abandoned mining areas and to identify the condition of the land damaged by any mining operation. Other goals were addressed to: i) calculate excavated mineral resources, ii) accumulate and locate information on damaged lands in Lithuania into the State Geological Information System and initiate the recultivation works.

METHODOLOGY

In the course of implementation of the project “Collection and systematization of information on damaged lands” the inquiries to the state institutions, environmental protection departments as well as to municipal administrations were distributed asking information on the damaged territories. This was followed by a detailed analysis of the aerial images of the period 2012–2014 of the whole territory of Lithuania in order to identify mining activities. In total, about 2,800 map sheets at a scale of 1:10,000 were reviewed. This allowed to identify territories with a size > 0.3 ha revealing traces of mining activities located outside the boundaries of legal mining areas (quarries). The identification of the ownership rights of all the lands damaged by the mining works was performed according to the data of the Real Property Cadastre and Register. The detected damaged areas were divided into small quarries which were established by land owners for their local needs and other mining/excavation damaged areas >0.3 ha (regardless of the land ownership form). All areas were grouped into the following (Fig. 1):

1) located on the lands of the State land;
2) located on land of complex property;
3) located on leased state-owned land;
4) located on private land;
5) land affected by mining operations in peatlands;
6) small legal quarries or pits.

The investigation revealed 3,300 territories damaged by the mining operations (Fig. 1). 1,796 of these land sites are private property. There were identified 614 small quarries. The number of peatlands is 106; however, they occupy 12,166 ha or 77.9% of the total area affected by mining activities. Therefore, it is assumed that major environmental damage was caused by exploitation and abandonment of peatlands. In a vast majority of such peatlands, the drainage systems are destroyed (Figs 2, 3).

In the following stage, a number of damaged areas were selected for detailed mapping.

1,172 sites were selected in total:

1) land of complex ownership – 72 sites,
2) state land – 449 sites,
3) small quarries – 614 sites,
4) peatlands – 37 sites.

All mapped territories were divided into two groups: (1) open areas without coverage of trees or bushes and (2) vegetated areas. Surface mapping of vegetated areas was performed using Spectra Precision Promark 700, GPS, Trimble R6 and Stonex S10N devices. In addition to GPS systems, direct geodetic measurements were also performed. The following robotic tachometers were employed: Trimble 5603 DR Standard, Trimble S6 DR 300+ and Leica TCR 705. The mapping in open areas was carried out using the remote sensing method – aerial photogrammetry with unmanned aerial vehicles (UAV). Airborne photogrammetry is being increasingly applied for digital terrain models (Müller *et al.* 2014), monitoring of slope instability (Chandler, Moore 2014), structural geology (Vasuki *et al*. 2014) and elsewhere; however, in Lithuania the UAV-based photogrammetry was firstly introduced and applied by joint stock company GJ Magma for measurements of quarries. In the same way, the UAV photogrammetry was tested for measuring damaged lands. Two UAV

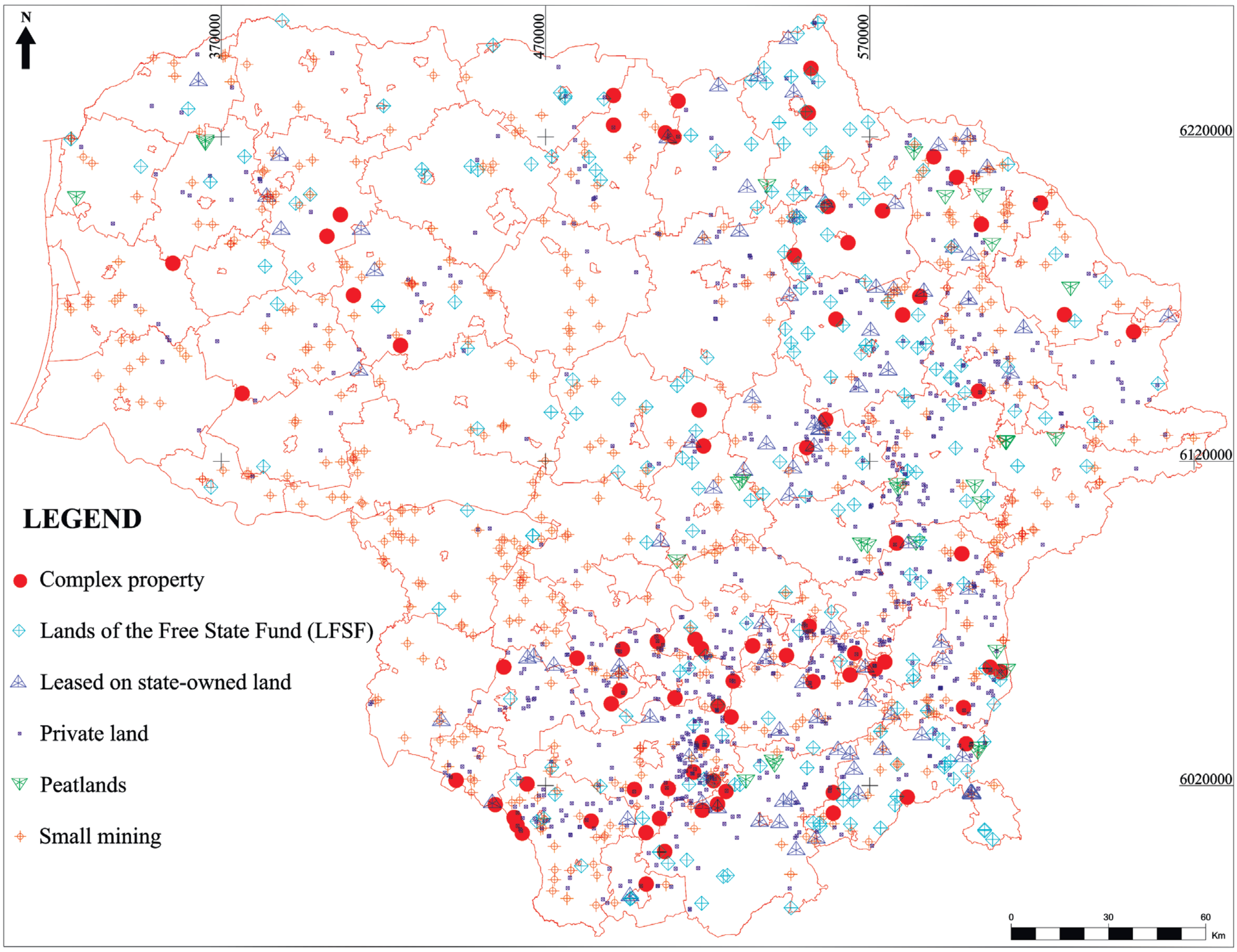


Fig. 1 Location of damaged land plots in Lithuania

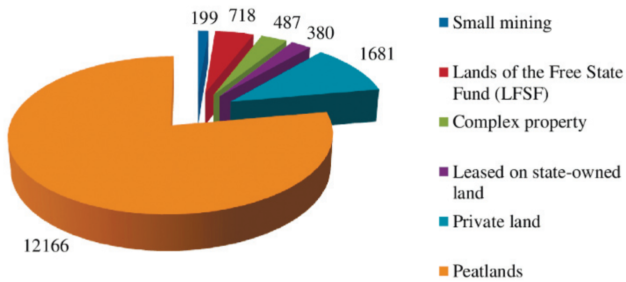


Fig. 2 Damaged land area distribution (ha)

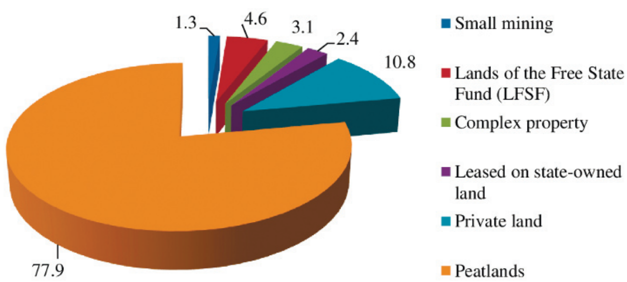


Fig. 3 Damaged land area distribution (%)

probing systems were employed: Sensefly eBee (eBee 2014) and Trimble UX5 (UX5 2016). The base of both systems is a lightweight airplane with a built-in photographic component (Fig. 4).

Using these aerial probing systems, a flight for an UAV is planned with planning software: software eMotion for UAV SenseFly eBee and Aerial Imaging for UAV Trimble UX5. In order to start mapping of a damaged area, ground control points (GCPs) must be set for the determination of the total of points of the aerial photographs that are overlapping (red flags in Fig. 5). This helps to determine accurately coordinates and altitudes of the above-mentioned GPNS mobile receivers. The flights designed for probing of the area provided a great number of photos (green area in Fig. 5) and produced a large set of aerial mapping data, resulting in a cloud of dots (Bemis *et al.* 2015).

Using software Postflight Terra 3D-EB or Trimble Business Centre 3D, spatial images (models) of the damaged site were created (Fig. 6).

The photo resolution of the used aerial photogrammetry systems ranges from 2.4 to 30 cm/px. The resolution used for the mapping of the damaged areas was up to 5 cm/px. A different resolution of up to 10 cm/px was used for the peatland mapping. The manufacturer's unmanned vehicle characteristics show a tolerance of about 1px, with a total measurement error < 10 cm when estimating errors (Bemis *et al.* 2015).

During the field works, all damage properties that were unique to each mining site were identified. It was important to identify the typology of the mineral material extracted from the specific mining site (gravel, sand, clay, peat or loam). The properties of the mineral material (its colour and grain size), altitude of the water level (if the groundwater surface is reached) and the depth of the pond were also determined (Fig. 7). Water level altitude was determined by GPNS according to the methodology described above. Water depth was measured manually.

Fig. 4 Drone Trimble UX5 and Sensefly eBee collecting data

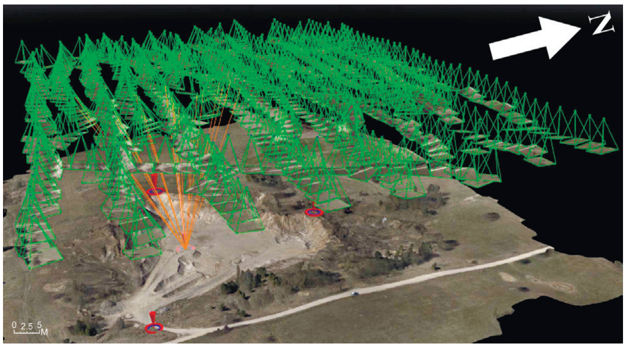
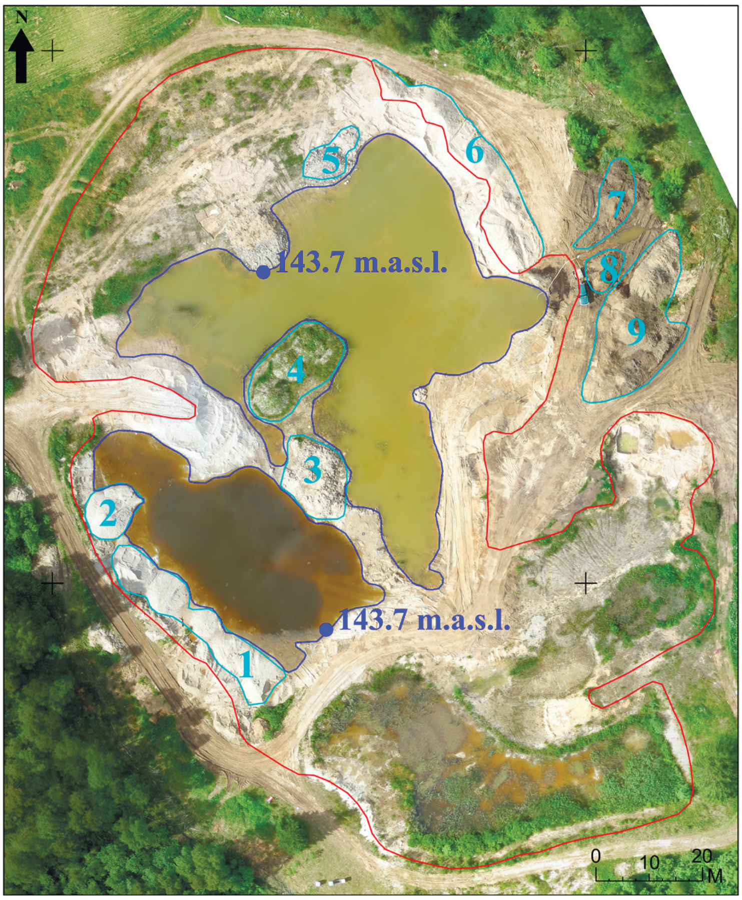


Fig. 5 UAV data collection view of Pavištytis quarry (Janauka village, Vištytis eldership, Vilkaviškis district, Lithuania, 54°25'05.0"N 22°48'58.9"E (WGS))

In the successive stage, 3D models of excavation spaces were created and the volumes of excavated or piled material were calculated. In order to reconstruct the former top surface of relief of the site, it was very important to obtain topographical maps of the site at scale 1:10,000 that were made before the excavation of the site. In the absence of topographical maps, a plane surface was taken from the top of slopes of the excavated pit. The AutoCAD Civil 3D 2010 or GeoMap 3D 2015 software complex method were used to calculate the volume of the identified material excavated or piled between the bottom surface and the top surface. 3D models of mining-affected plots were created for peatland areas, but the quantity of harvested peat was not calculated due to the specific technology of peat extraction and lack of reliable data. Peat extraction was carried out more than half a century ago, and there were no reliable cartographic data of that time. Therefore, it was not possible to reconstruct the surface of the natural peatlands before extraction had commenced. In addition, the drainage systems in the peatlands are no longer working and the former fields of peat harvesting are flooded, thus complicating the mapping of these areas.

Fig. 6 3D model view of a small mining site No. 3144 (Minkeliai village, Sužionys eldership, Vilnius district, Lithuania, 54°57'06.9"N 25°28'58.1"E (WGS))



Data of damaged area, identification No. 10294			
Row No.	Area, m²	Average thickness, m	Volume, m³
EXCAVATED			
1(gravel)	12302	1.7	21034
Total	**12302**	**1.7**	**21034**
COVERED			
1(gravel)	245	0.3	75
2(gravel)	81	0.8	65
3(gravel)	147	0.8	112
4(gravel)	201	0.9	183
5(gravel)	60	0.6	33
6(gravel)	299	0.6	175
7(soil)	90	0.4	38
8(soil)	43	0.7	28
9(clay/sand loam)	368	1.1	420
Total	**1534**	**0.7**	**1129**
TOTAL DAMAGED	**13836**		

LEGEND
- Excavated area
- Covered area
- Water line

Fig. 7 Data of damaged area identification No. 10294 (Kulskiai village, Paukštakiai eldership, Plungė district, Lithuania, 55°59'23.8"N 21°59'40.1"E (WGS))

RESULTS AND DISCUSSION

The study "Collection and systematization of information on damaged lands" resulted in the identification of 3,300 sites damaged by the mining operations. Among them, 614 small quarries were identified of which 483 were in use and other small quarries were already depleted. A total of 3,025,870 m³ of mineral resources were extracted from these quarries. The total surface area of these quarries is equal to 212.18 ha (Table 1).

The surface of areas of land damaged by excavations in areas of the State land and complex property has been estimated at 618 hectares. The volume of illegally extracted mineral raw materials is more than 14.8 million m³ (Table 2).

By comparing the situation of these affected mining areas with the boundaries of protected areas, it was found that almost every fifth of the total number of damaged areas is located in a national or regional park, reserve or Natura 2000 area. The total damaged area is nearly 96 ha and the excavated resources amount to 1,262,710 m³ (Table 3).

By comparing the situation of the operating small quarries with the boundaries of mineral deposits, it was found that 49 of such deposits were damaged. The total area of damaged deposits is 162.58 ha and 3,448,030 m³ of those minerals are excavated in areas of measured or indicated mineral resources.

Thus, 2,253,150 m³ of gravel and sand deposits were mined illegally. According to the data of the Lithuanian Geological Survey, such amount is mined in all legally operated Lithuanian deposits in one quarter of a year (Table 4).

37 abandoned and unused peatlands were checked by employing the mapping technology. All these peatlands have been used in the past; the drainage

Table 1 Excavation of mineral resources in small-scale mining

Condition	Number of quarries	Mineral resources	Area (ha)	Volume (m³)
Operating	464	Gravel	84.88	1,586,690
		Sand	114.92	1,281,040
		Sand and gravel	9.14	129,570
		Peat	3.22	28,470
		Clay	0.02	100
Not open	80			
Closed	70			
TOTAL	**614**		**212.18**	**3,025,870**

Table 2 Excavated mineral resources in damaged areas of State land and complex property

Mineral resources	Area (ha)	Volume (m^3)
Gravel	192.80	3,663,000
Sand	360.90	9,848,000
Sand and gravel	3.80	129,000
Peat	59.20	1,197,000
Clay	1.30	6,400
TOTAL	**618.00**	**14,843,400**

Table 3 Damaged lands of State land and complex property in protected areas

No.	Protected areas	Area (ha)	Volume (m^3)
1	Anykščiai Regional Park	1.09	13,700
2	Daugyvėne Landscape Reserve	1.53	5,300
3	Dubysa Regional Park	3.87	82,600
4	Dzūkija National Park	1.27	11,930
5	Gedžiūnai Forest BDS	3.99	51,700
6	Grąžutė Regional Park	0.65	10,300
7	Gubernia Forest BDS	0.10	1,000
8	Juostos Hydrographic Reserve	0.43	2,100
9	Karšuva Forest HDS	0.53	0
10	Krekenava Regional Park	10.49	179,800
11	Lančiūnava Forest BDS	4.07	36,400
12	Lapių Geomorphological Reserve	4.69	0
13	Meteliai Regional Park	0.39	2,600
14	Nemunas Loop Regional Park	1.05	20,200
15	Nemunas Valley Meadows BDS	0.70	11,500
16	Neris Regional Park	3.20	174,500
17	Pagramantis Regional Park	1.44	24,400
18	Panemuniai Regional Park	11.01	133,550
19	Rambynas Regional Park	0.37	0
20	Rūdininkai Forest BDS	0.24	2,800
21	Salantai Regional Park	2.95	48,600
22	Sanžilė Landscape Reserve	1.05	7,300
23	Šventabrastis Landscape Reserve	1.61	16,400
24	Tytuvėnai Regional Park	1.32	25,500
25	Trakai Historical National Park	0.41	7,100
26	Varniai Regional Park	11.56	240,600
27	Veisiejai Regional Park	0.53	400
28	Vilkaičiai Geomorphological Reserve	0.69	33,100
29	Vištytis Urban Reserve	0.83	10,700
30	Žagare Regional Park	0.66	2,100
31	Žemaitija National Park	23.25	106,530
TOTAL GRAVEL AND SAND		**95.97**	**1,262,710**

*BDS – Birds Directive Sites, HDS – Habitats Directive Sites

systems that have survived in most of them and the former draining trenches in the uncovered areas are clearly visible. All these mapped areas are located in the database of the Lithuanian Geological Survey and assigned to measured or indicated deposits. Out of the 37 mapped peatlands, 21 are classified as measured, 14 are indicated, and 2 have been measured in the already exploited peatland Baltoji Vokė. The total area covered by the measurements was 6,278.04 ha; of this amount, 3,653.55 ha are measured and 604.71 ha are indicated deposits (Juozapavičius *et al*. 2015).

More than half of the abandoned peatlands are now in protected areas (Table 5). The total area of peatlands measured in protected areas is 5,615.62 ha which makes up 89% of the land of this category. The most protected areas include the previously indicated used peatlands. Only 3 peatlands are not protected.

Table 4 Excavated mineral resources of State land and complex property in deposits proved and indicated explored

Mineral resources	Area (ha)	Volume (m^3)
Proved mineral deposits		
Gravel	66.64	1,707,990
Sand	20.77	301,200
Clay	58.22	1,194,880
Total	**145.63**	**3,204,070**
Indicated mineral resources		
Gravel	15.51	207,080
Sand	0.62	4,000
Sand and gravel	0.82	32,880
Total	**16.95**	**243,960**
TOTAL	**162.58**	**3,448,030**

Table 5 Damaged peatlands in protected areas

Protected areas	Area (ha)
Proved mineral deposits	
Taujėnai-Užulėnis BDS	255.20
Sartai Regional Park	212.45
Gelžė Botanical-Zoological Reserve	411.23
Tyruliai Botanical-Zoological Reserve	2,226.27
Tytuvėnai Regional Park	13.95
Total	**3,119.10**
Preliminary deposits	
Geidukonys swamps HDS	14.68
Kazimierava swamps HDS	21.27
Aukštaitija National Park	7.16
Adutiškis Guntauninkai Forests BDS	20.20
Gervelė swamps HDS	28.00
Grąžutė Regional Park	83.00
Salantai Regional Park	26.73
Rėkyva Botanical-Zoological Reserve	275.70
Total	**476.74**
Exploited deposits	
Baltoji Vokė BDS	2,019.78
TOTAL	**5,615.62**

*BDS – Birds Directive Sites, HDS – Habitats Directive Sites

Table 6 Damaged areas of private property or leased on state-owned land in deposits proved and indicated explored

Property	Number of quarries	Area (ha)
Proved mineral deposits		
Leased on state-owned	15	53.05
Private	20	32.60
Total	**35**	**85.65**
Preliminary deposits		
Leased on state-owned	9	6.83
Private	15	11.63
Total	**24**	**18.46**
TOTAL	**59**	**104.11**

The other 11 are considered valuable areas for biodiversity protection. Meanwhile, 2/3 of the abandoned measured fields have no protection status. It is expedient to complete extraction of remaining resources of peat and afterwards restore them into wetlands. The surface area of such peatlands is 534.45 ha. It is not possible to determine the accurate amount of peat resources without direct exploration works. Exploration has been recently carried out only in Purvai-Butniūnai, Juodžiukas, Rimšiškės, Tamošaičiai, Plynoji peatlands, and amounts of resources were measured. Other deposits require proper geological exploration.

After evaluating the actual condition of the peatlands during field work, it was detected that some of the fields were already completely excavated.

All detected damaged areas in private ownership, leased or transferred by the state, where the State land does not constitute 0.3 ha, remained uncharted in the list. Data on areas affected by mining in these locations are only indicative, as determined by orthophoto maps of the Republic of Lithuania. 59 cases of State and private land plots coincide with proved mineral reserves or indicated mineral resources. The total area of the damaged proved mineral reserves is 85.65 ha (Table 6).

CONCLUSIONS

The study has clearly shown that the actual situation in Lithuania regarding the scale of damaged mines in non-industrial quarries was not known and not systematized. A pioneering investigation carried out for the whole territory of Lithuania has revealed (or detected) 3,300 territories damaged by the excavations outside legal industrial mining areas. The scale of environmental influence is huge. An innovative methodology to measure the damaged land and all small quarries was implemented. As a result of the study, the Lithuanian Geological Survey received detailed information on excavated mineral resources, types of excavated deposits, water levels of water basins, land use and proposals for the management of damaged areas in small quarries and quarries located in State land and complex ownership lands. For the first time, a numerical 3D database of quantities of damage was created in Lithuania. A methodology for identifying and calculating damaged areas has been developed. A successful performance of large-scale mapping and excavated areas volume calculation was only possible with the most advanced UAV-based aerial mapping and photogrammetric technology.

ACKNOWLEDGEMENTS

The collection of the data and measurements using UAVs were performed by company GJ Magma. We would like to thank the reviewers – prof. S. Wolkowicz and an anonymous reviewer for their accurate comments and efforts towards improving our article.

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