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THE POND OF GOD: THE LARGEST LANDSLIDE-DAMMED LAKE IN ROMANIA

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Abstract

On the Romania territory, the East Flysch Carpathians represent a typical European landslide region. Usually, the natural dam lakes formed here by landslide processes have a small size and a short lifespan. The main natural dam lakes formed on the Eastern Carpathians territory which did not fail ar Cuejdel and Red lakes. The Red Lake (surface – 12.1 $10^4 m^2$; volume – 721,404 m^3; max. depth – 10.5 m) formed in 1837 is the oldest landslide-dammed lake in Carpathians Mts. and Cuejdel Lake (surface – 13.95 $10^4 m^2$; volume – 925,347 m^3; max. depth – 16.5 m) is the youngest with two formation stage: stage 1. year 1978, when a small lake appeared; stage 2. year 1991, when a big landslide occurred and the landslide body totally blocked the Cuejdel valley. However, the recent investigations carried out in the NE of Romania, indicate that the largest landslide-dammed lake is the Pond of God from Moldavian Plain (surface – 38.86 $10^4 m^2$; volume – 1,476,300 m^3; max. depth – 3.8 m). The lake was formed in 1971 by a large landslide-dam in the upper part of the Puturosu catchment basin (left tributary of Jijia River). The genesis of this lake has been difficult to establish so far because the landslide and the natural dam area were hydro-technically consolidated. The main objective of this study is to mention and describe for the first time in the national and international limnological literature the genesis, evolution and the morpho-bathymetric parameters of the lacustrine basin and landslide-dam area.
Kaywords: landslide, natural dam, lacustrine basin, morpho-bathymetric parameters, Moldavian Plain

1. INTRODUCTION

The damming of watercourses by landslides or other slope processes is an important geological hazard in the present times (Delaney and Evans, 2015; Evans et al., 2011; Fan et al., 2012a,b). The lakes formed by natural dams persist in the landscape for up to a few minutes to thousands of years, depending on the density and material of the dam, hydrological particularities of catchment basin and pattern of landforms flooded (Evans, 2006; Evans et al., 2011; Mihu-Pintilie et al., 2016; Romanescu, 2009; Romanescu et al., 2012, 2013; Romanescu and Stoleriu, 2014; Stoleriu et al., 2014). In 1991, J.E. Costa and R.L. Schuster (US Geological Society) completed an ample work on the typologies and main characteristics of natural dams which lead to the emergence of lacustrine basin formations naturally (Costa and Schuster, 1991; Evans, 2006). Following the analysis of more than 180 natural dams, they showed that 84% are formed by rocks and materials produced by landslides and slope processes, 7% have a volcanic origin, being formed through seismic eruptions and lava discharge, and 9% display complex composition and causality (Costa and Schuster, 1988; Mihu-Pintilie et al., 2016). The most common encountered dams obstructing rivers and determining water accumulation are the effect of landslides processes like: slides/slumps, mud/debris/earth flows, rock and debris avalanches, liquefaction of sensitive clays, peat slides or scree (Dai et al., 2005; Delaney and Evans, 2015; Peng and Zhang, 2012; Schneider et al., 2013). Also, they can be formed by the sediments transported by rivers during floods, due to gravitational collapses and caving in, as a result of volcanic activity, wind processes, or can be constructed by animals, like beavers (Costa and Schuster, 1988, 1991; Mihu-Pintilie et al., 2016; Mihu-Pintilie, 2018; Schuster and Evans, 2011).

Most of the landslide-dammed lakes is formed in mountain areas, with narrow valleys and steep slopes, where the accumulation of water needs a relatively low volume of obstructive materials. The temporal interdependence of the lakes is in direct ratio to the geomorphological relationship between the natural dams and the shape of the flooded valleys (Costa and Schuster, 1988, 1991). In some cases, landslide-dammed lakes are dangerous for human society causing floods through the accumulation of a large quantity of water and then through the releasing the water over the dam, as flood waves, or through literally breaking the dam (Cui et al., 2013; Dong et al., 2009; Huss et al., 2007; Korup, 2012; Korup and Wang, 2014; Li et al., 1986; Safran et al., 2015; Schuster and Evans, 2011; Wang et al., 2016). Evans et al. (2011) estimated that roughly 20% of major rockslide dams fail within 75 days of formation. However, not all landslide dams are unstable or have failure potential. Some lakes become permanent features of the landscape and a number of rockslide dam sites have been utilised as foundations of dams constructed for water supply, hydroelectric power generation, fish farming or just for conservation the biodiversity (Borowiak, 2014; Bretcan, 2007; Cudowski et al., 2013; Delaney and Evans, 2015; Evans, 2006; Evans et al., 2011; Gadzinowska, 2013; Gastescu, 1971; Marszelewski et al., 2017; Mihu-Pintilie et al., 2014a,b,c, 2016; Mihu-Pintilie, 2018; Pasztaleniec et al., 2013; Romanescu et al., 2018; Türk et al., 2016).

In Romania, the East Flysch Carpathians represent a typical European landslide region (Alexandrowicz and Alexandrowicz, 1999; Baroň et al., 2004; Hradecký and Pánek, 2008; Mihu-Pintilie et al., 2016; Mihu-Pintilie, 2018; Pánek et al., 2010;). Some natural lakes are formed here by landslide processes, with the highest frequency in the Eastern Carpathians, Curvature and Moldavian Subcarpathians (Mihu-Pintilie, 2018; Romanescu et al., 2012, 2013). Usually, landslide-dammed lakes have a small size and a short lifespan. This is the reason why in the romanian dedicated literature are mentions only a few examples: Betiş L. (Maramureş Mts.), Black L. (Buzău Mts.), Balătău L. (Ciuc Mts.), Bolătău and Iezer (Obcina Feredeului Mts.), Bolătău L. (Curvature Mts.), Green L. (Curvature Subcarpathians), Devil's L. (Nera Mts.), Izvorul Măgurii and Tăul Zânelor (Bârgău Mts.), Cuejdel L. (Stânişoarei Mts.), Red L. (Hăşmaş Mts.) and Pond of God (Moldavian Plain) (Romanescu et al., 2013; Mihu-Pintilie, 2018) (Figure 1). In reality, the number of landslide-dammed lakes it is much higher but due to their relative isolation in uninhabited areas, without causing damage for human society, their inventory is incomplete (Mihu-Pintilie, 2018; Mihu-Pintilie et al., 2014a,b,c, 2016).

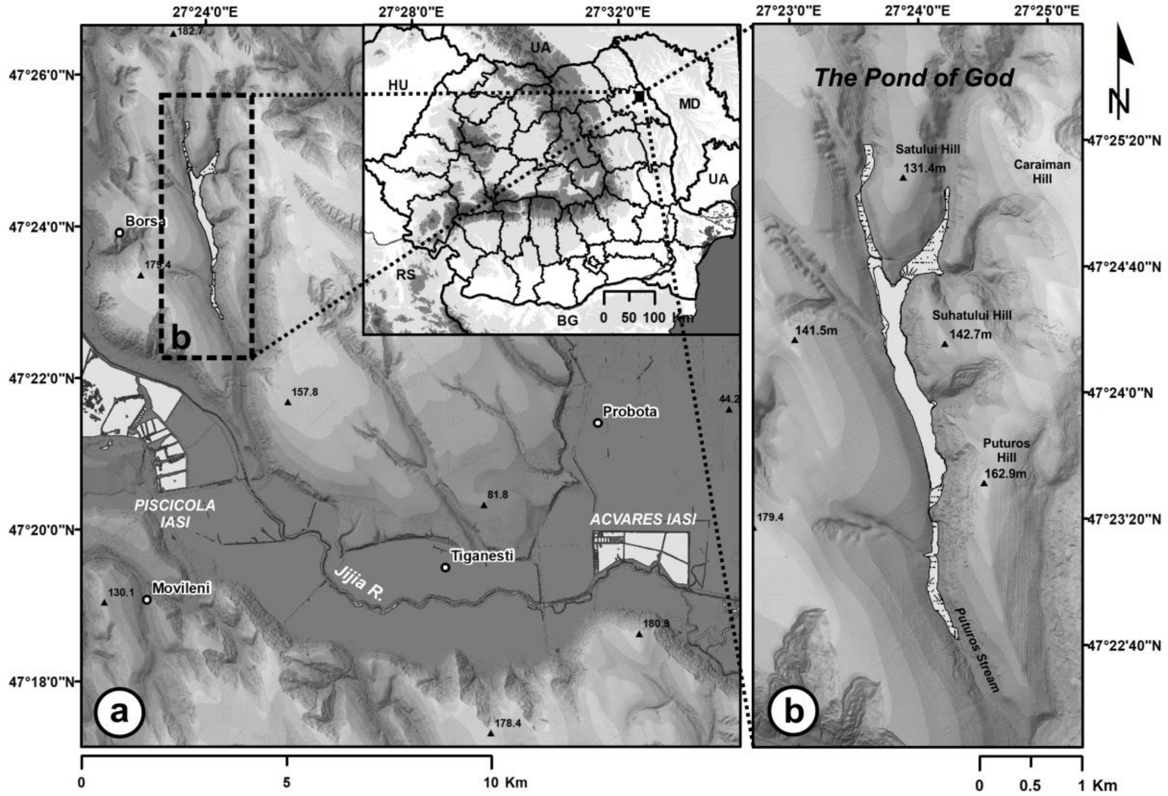

Figure 1. a. Geographic location of the Pond of God on the territory of Romania; b. DEM around the landslide-dammed lake in 2015

The landslide-dammed lakes in Romania have been studied mainly by geologists, geomorphologists and geophysicists, and less by researchers in other fields (Mihu-Pintilie, 2018; Romanescu et al., 2013). In these study, until 2012 shown that the Red Lake is the largest natural dam lake which did not failed (Romanescu et al., 2013). After this year, our new topographic and bathymetric measurements indicate that in presents time, the Cuejdel Lake is the biggest lacustrine basin formed by an landslide in Carpathians Mts. (Mihu-Pintilie, 2018; Mihu-Pintilie et al., 2014a,b, 2016). The Red Lake seems to be the oldest, as it was formed in 1837, and Cuejdel Lake is the youngest with two formation stage: in 1978, when a small lake appeared and in 1991, when a big landslide occurred and the landslide body totally blocked the valley (Mihu-

Pintilie et al., 2016; Romanescu et al., 2013). However, the recent investigations carried out at the level of the limnographic landscape in the NE Romania indicate that the largest landslide-dammed lake is the Pond of God from Moldavian Plain (Puturosu hydrographic basin). The genesis of this lake has been difficult to establish so far because the landslide and the natural dam area were hydro-technically consolidated in the ‘90. The main objective of this study is to mention and describe for the first time in the national and international limnological literature the genesis and evolution of the largest landslide-dammed lake on the territory of Romania which did not failed.

2. REGIONAL SETTING

Puturosu stream is a left tributary of Jijia River, which drains the central part of Moldavian Plain (Jijia Plain) from the northeast of Moldavian Plateau. The total area of the catchment is 27.04 km^2, maximum altitude is 220.5 m, lowest altitude is 41.5 m and the length of water course is 11.41 km. The Pond of God was formed in 1971 by a large landslide-dam in the upper part of the catchment basin (47º24’02” N / 27º23’45” E). On the left, its tributaries are the creeks of Puturosu, Siliştea, Caraiman and Suha, while on the right Valea Satului and Pătraşcu. The distance from the Pond of God landslide-dam to the confluence of Puturosu creek with Jijia River is 5.8 km. In the upstream sector of the lake (northeast part), there is the Vâlcele and Borşa settlememnts, while the downstream sector includes the locality of Mihail Kogălniceanu (Iaşi County). The name of the lake was attributed by the locals, meaning the pond created by God, thus attesting the formation through a natural process of the lacustrine basin (Figure 1).

3. METHODS AND TECHNIQUES

Two sets of data were used to mapping the lake surface and landslide-dam area. The first set of data consisted in the digitization of the aquatic surface using old topographic maps: the basic map, called „Plan Director de Tragere” – Ed. 1957 (Figure 2a) and Topographic map (1:25,000) – Ed. 1975 (Figure 2b). In this way the initial landscape of the Puturosu valley and the moment of formation of the Pond of God in 1971 were identified. The second set of data consisted in generating the digital elevation model (DEM – Ed. 2015) corresponding to the current water surface and to the landslide-dam which occurred the Puturosu valley. This was done by spatial processing in GIS software (ArcGIS 10.2) of LiDAR files with the *.tiff* extension, achieved within the national project SMIS-CSNR No.17945: *Lucrări pentru reducerea riscului la inundaţii în bazinul hidrografic Prut-Bârlad de către ANAR – Administraţia Bazinală de Apă Prut-Bârlad*. To join the LiDAR files a geodatabase and a raster dataset was created. A DEM with a resolution of 0.5 m / pixel resulted, which was filtered using flow direction, sink and fill tools to reduce the errors generated by uniting the *.tiff* files (Figure 2c). The resulting maps indicate the key stages of the landscape dynamics in the middle section of the Puturosu basin, during the last 58 years, as well as genesis and evolution of landslide-dammed lake, currently known as Pond of God.

4. RESULTS AND DISCUSSION

4.1. Morphometric parmeters of landslide-dam area

According to the field investigation and following talks with the locals, the landslide that blocked the Puturosu valley occurred on the western slope of Puturos Hill (162.9 m) in the summer of 1971. The main triggering factor of gravitational processes was cumulative precipitation from June to August (Figure 3a). The landslide scarp occurred in the altitude range (H2) 145 m – (H1)157.5 m (area of source rock mass 6.90 $10^4 m^2$) and affected an total area of 56.88 $10^4 m^2$ on a length of (L) 503.5 m. The difference between elevation of distal limit of debris (H3 – 67.5 m) and elevation of top of source rock mass (H1) is 90 m. The *Fahrböschung* ($\tan^{-1}$ H/L) parameter is 10.09º, a value specific to medium-sized landslides in the Moldavian Plateau (Table 1; Figure 3b).

In the present time, the natural dam is made up of compact clays and terrigenous sediment, covered with plantations of shrubs and forest vegetation to stabilize the slopes. The depth of the diluvium does not exceed 8 m but the considerable length of the dam (L – 925 m) has led to the accumulation of water and maintenance of the lake in time. In the 90's, a small artificial barrage was built in the output area to manage the water resource. Currently, the construction is partially clogged and the mechanism is inoperative. For this reason, water flow on the surface of the natural dam through a lateral breach. The folood-plain downstream of the lake is entirely covered by hydrographic vegetation, the wetland having continuity up to the confluence with the Jijia River (Table 1; Figure 3b).

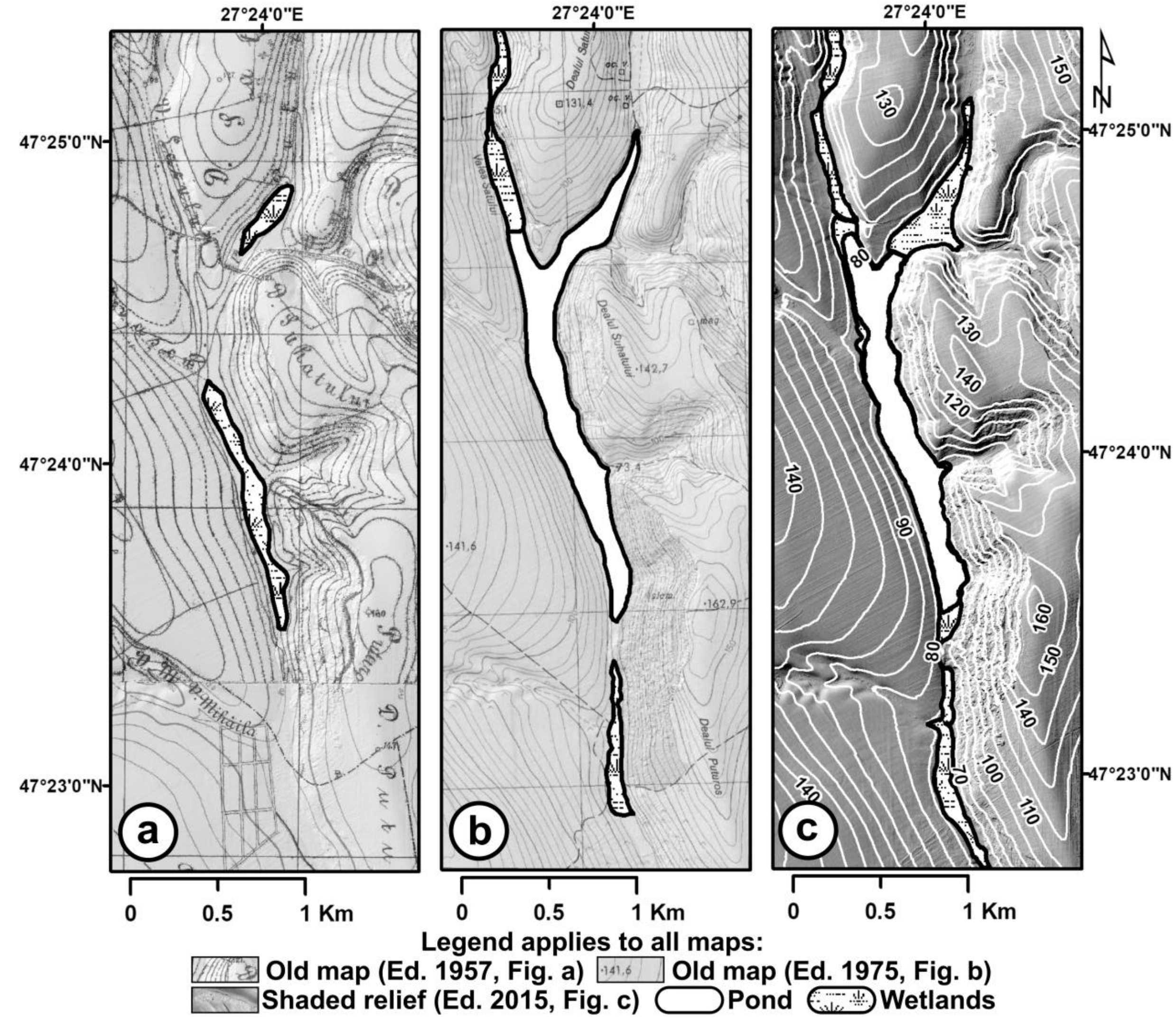

Figure 2. The genesis of the Pond of God: a. The wetland area in the upper basin of Puturosu stream in 1957 (Planurile Directoare de Tragere – Sheets 48761 and 48771); b. The lake extended in 1975, four years after formation (Topographic map, 1:25,000 – Sheets L-35-019-D-b and L-35-019-D-d); c. The lake extend in the present time (2015)

4.2. Morpho-bathymetric parameters of lacustrine basin

According to the measurements made within the national project SMIS-CSNR No.17945 (LiDAR data) in 2015 the elevation of the lake mirror is at 77.5 m and the area of water (A) is 38.86 $10^4 m^2$. From this point of view, the Pond of God is the largest landslide-dammed lake in Romania, much larger than Cuejdel Lake (A – 13.85 $10^4 m^2$) from Stanisoarei Mts. or Red Lake (12.1 $10^4 m^2$) from Hasmas Mts. The lacustrine basin surface (A/cosα) is 39.62 $10^4 m^2$ and corresponds to the surface of the initial valley, characterized by a low longitudinal slope and steep banks. The lenght of lake (L) is more than 2.2 km, the average width (W_{avg}) is 170.7 m and the maximum width (W_{max}) is of 280 m. Form coefficient (Ax_{min}/Ax_{max}) it's just 0.14 indicating an elongated shape of the water surface. The perimeter of pond (P) is of 5.2 km and develop one sinuosity coefficient ($P/\sqrt{\pi A}$) of 4.8. In general, morphometric parameters of the Pond of God are specific to the natural dam lakes, with an asymmetrical longitudinal profile, the elongated shape along the flooded valleys and a subunit shape coefficient. The only known bathymetric parameters were: max. depth (H_{max}) – 3.8, water volume - 147.63 $10^4 m^3$, avg. depth ($H_{avg}=V/A$) – 2.5 m and volume coefficient ($3H_{avg}/H_{max}$) – 1.97 (Table 2; Figure 4).

Table 1. Summary parameters for landslide-dam that formed the Pond of God (year 2015)

Parameters of landslide-dam	Landslide-dammed lake
	Pond of God
Date of occurrencce	1971
Geographic coordinate (lat. / long.)	47°23´51´´N / 27°23´53´´E
Location in Romania	Moldavian Plain (Jijia Plain)
River basin	Puturosu R.
Trigger	Rainfall (?)
Landslide type	Slide
Elevation of top of source rock mass (H1)	157.5 m
Elevation of base of source rock mass (H2)	145 m
Area of source rock mass	6.90 $10^4 m^2$
Elevation of distal limit of debris (H3)	67.5 m
Area of debris	56.88 $10^4 m^2$
Horizontal distance between H1and H3 (L)	503.5 m
Vertical height of path (H =H1-H3)	90 m
H/L	0.178
Fahrböschung ($\tan^{-1}$ H/L)	10.09º
Dam type*	Avalanches slides
Dam materials	Clay
Dam height (H_{dam})	8 m
Dam lenght (L_{dam})	925 m
Dam width (W_{dam})	122 m
Dam volume (V_{dam})	-
References	Mihu-Pintilie (2018)

Table 2. Morpho-bathymetric parameters of Pond of God lacustrine basins (year 2015)

Morpho-bathymetric parameters	Lacustrine basin
	Pond of God
Elevation of lake mirror	77.5 m
Area of lake mirror (A)	38.86 $10^4 m^2$
Lacustrine basin surface (A/cos*a*)	39.62 $10^4 m^2$
Lenght ($L=A/W_{avg}$)	2,276 m
Avg. width ($W_{avg}=A/L$)	170.7 m
Max. width (W_{max})	280.9 m
Major axis (Ax_{max})	2,244 m
Small axis (Ax_{min})	328 m
Form coefficient (Ax_{min}/Ax_{max})	0.14
Perimeter length (P)	5,278 m
Sinuosity coefficient ($P/\sqrt{\pi A}$)	4.78
Volume (V)	147.63 $10^4 m^3$
Avg. depth ($H_{avg}=V/A$)	2.5 m
Max. depth (H_{max})	3.8
Volume coefficient ($3H_{avg}/H_{max}$)	1.97
References	Mihu-Pintilie (2018)

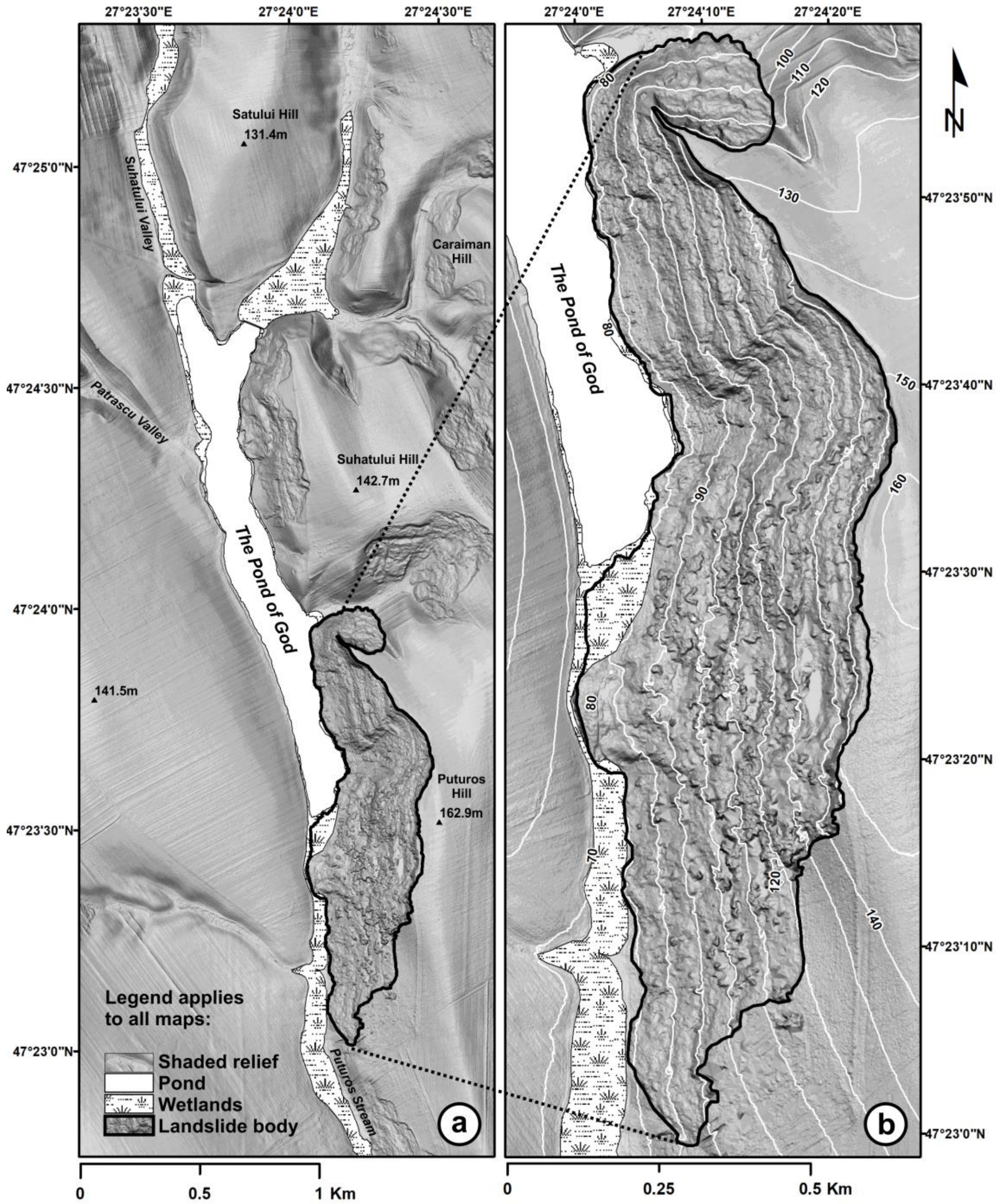

Figure 3. The Pond of God in 2015: a. Shaded relief around the landslide-dammed lake (DEM made using LiDAR technology); b. Detail on landslide-dam area.

4. CONCLUSIONS

Most of the landslide-dammed lakes is formed in mountain areas. On the Romania territory, the East Flysch Carpathians represent a typical European landslide region. Some natural lakes are formed here by landslide processes, with the highest frequency in the Eastern Carpathians, Curvature and Moldavian Subcarpathians. The main natural dam lakes which did not fail ar Cuejdel and Red lakes. However, the recent investigations carried out at the level of the limnographic landscape in the Moldavian Plain indicate that the largest landslide-dammed lake on the Romania territory is the Pond of God: surface – 38.86 $10^4 m^2$; volume – 1,476,300 m^3; max. depth – 3.8 m. Because the genesis of this lake has been difficult to establish so far, in this study is mentioned and describe for the first time in the national and international limnological literature the genesis, evolution and the morpho-bathymetric parameters of the lacustrine basin and landslide-dam area. (Table 3).

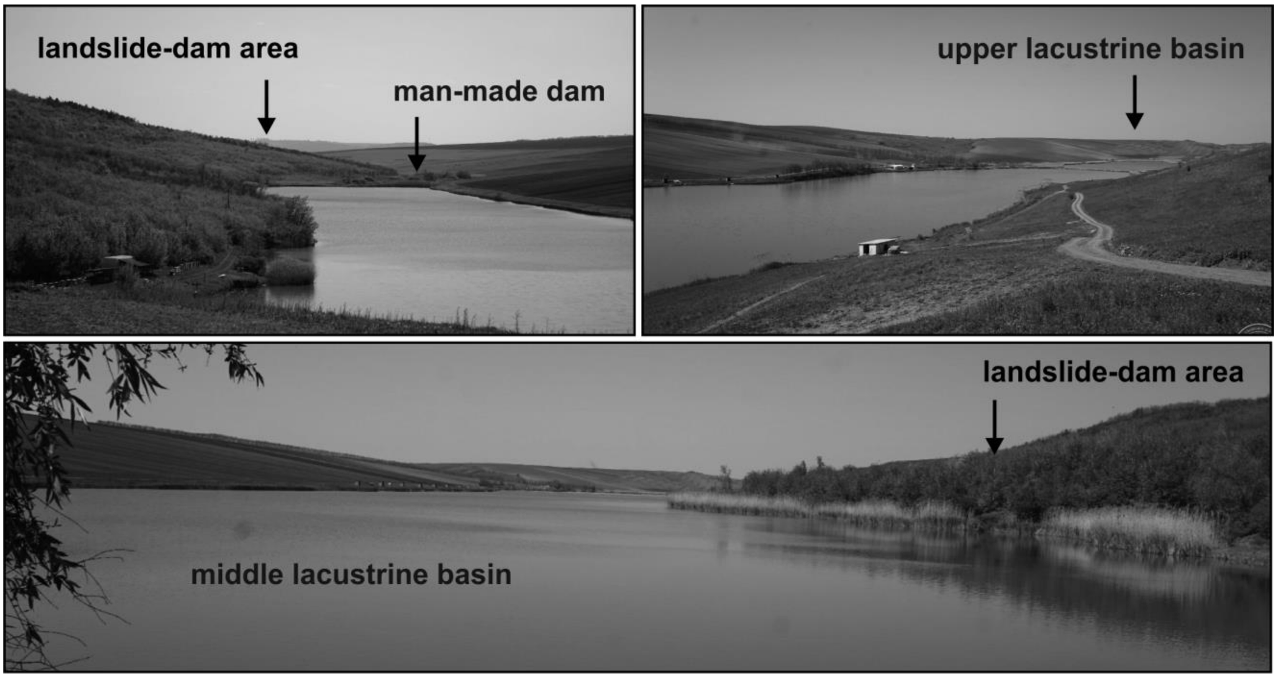

Figure 4. Different views on the middle, upper and landslide-dam area of lacustrine basin in the summer of 2017

Table 3. Well-documented historical landslide dams and morphological parameters of the main natural dam lakes formed on the Romanian territory (Mihu-Pintilie, 2018)

Lake name	River	Relief unit	Lake		
			Surface [$10^4 m^2$]	Volume [m^3]	H max. [m]
Balătău	Trotuş	Ciuc Mts.	4.50	-	3.0
Bălătău-Ponoare	Cuejdel	Stânișoarei Mts.	0.25	5,900	7.9
Betiş	Ampoi	Maramureş Mts.	2.00	-	9.0
Black L.	Buzău	Buzău Mts.	1.6	-	5
Blue L.	Cuejdel	Stânișoarei Mts.	0.1	-	4
Bolătău	Sadova	Obcina Feredeului	0.25	-	5.2
Bolătău	Zăbala	Curvature Carp.	-	-	-
Bolătău	Zăbala	Curvature Carp.	7.00	-	3.5
Cuejdel	Cuejdel	Stânișoarei Mts.	13.95	925,347	16.5
Constellation L.	Cuejdel	Stânișoarei Mts.	0.34	6,541	4.3
Devil's L.	Nera	Nera Mts.	-	-	9.3
Green L.	Şuşiţa	Curvature Subcarp.	0.5	-	4
Iezer	Sadova	Obcina Feredeului	0.75	31,414	4.3
Izvorul Măgurii	Ilva	Bârgău Mts.	0.2	-	2.0
Mocearu	Buzău	Buzău Mts.	7.00	-	8.0
Red L.	Bicaz	Hăşmaş Mts.	12.1	721,404	10.5
The Pond of God	**Puturosu**	**Moldavian Plain**	**38.86**	**1,476,300**	**3.8**
Tăul Zânelor	Colibiţa	Bârgău Mts.	0.3	-	4.0
Veselaru	Bistriţa tributary	Moldavian Subcarp.	0.5	-	5

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