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QUANTIFICATION OF ECONOMIC AND SOCIAL RISKS OF DEBRIS FLOWS FOR THE BLACK SEA COASTAL REGION OF THE NORTH CAUCASUS

ABSTRACT. Debris flows are the most frequent and disastrous natural hazards among other exogenic processes at the Black Sea coastal region of the North Caucasus. Numerous debris flow releases are reported every year between Novorossiysk and Krasnaya Polyana. The debris flows bring economic losses, and sometimes loss of human lives. Quantification of the economic, individual and collective debris flows risk is based on their spatial distribution, repeatability, debris flows' regime, as well as economical and social characteristics of the territory accounted for. Estimation of the individual debris flow risk shows that the level of such risk corresponds to "allowable" and "acceptable" degrees [Vorob'ev, 2005] – less than $3{,}3 \times 10^{-6}$. The maximal values of the economic debris flow risk are estimated in the Adler region – more than 1 mln. rub. per year.

KEY WORDS: Black Sea, the Caucasus, coastal zone, debris flows, risk

INTRODUCTION

Despite considerable efforts directed to decreasing unfavorable consequences of natural hazards in many regions of the World by various mitigation measures, the reported economic costs (as a result of "emergency situations" in Russian literature) are gradually increasing. This increase is explained by "high population growth and density, migration and unplanned urbanization, environmental degradation and possibly global climate change" [UNEP, 2002]. The "global increase" is excluded from the more recent report of UNEP [2012], which is more focused on the regional specific assessment and combination of natural and technological disasters. On the other hand, the draft of the WG II IPCC 5th Assessment report [IPCC, 2014] now includes the climate change adaptation policies, various aspects of vulnerability and the related economic issues. The converging of the climatic and the economic factors in consideration of the natural hazards is naturally related to the "risk-taking propensity" [Kates, 1971] or the concept of risk [Kates & Kasperson, 1983; Myagkov, 1992].

The risk estimation in Russia started in the 1970s and 1980s, first in relation to seismic risks [Kantorovich et al., 1973; Keilis-Borok et al., 1984]. A general probabilistic concept of the seismic risk was developed, the problem of prognosis of great earthquakes was formulated and the corresponding mathematical methods were developed. At that time the risk was understood as the probability of a seismic event of a certain magnitude. The theoretical and practical aspects of the natural hazards risk estimation came into focus in 1990s [Myagkov, 1995; Ragozin, 1997]. The methods of the risk estimation of snow avalanches [Andreev & Bozhinskii, 1994; Kazakov, 2000; Seliverstov et al., 2008], coastal erosion [Belov, 2000; Buriva, 2000], underflooding [Dzetsker, 1995], dangerous cryological processes [Kuznetsova et al., 1995], and karst [Tolmachev, 2000; Elkin, 2004] were developed. Thus, the qualitative understanding of the risk of separate natural hazards, up to different types of risk and temporary dynamics to be accounted for [Fuchs et al., 2013; Shnyparkov et al., 2012], became an established paradigm expressed as "the probability of undesirable consequences (events)" [Heinimann, 1998; Kienholz et. al., 2004; Myagkov & Shnyparkov, 2004]. The natural hazards on the territory of the Russian Federation are well documented [e.g. Osipov & Shoigu, 2000–2003] and endangered regions are determined [e.g. Atlas, 2005–2011]. However, the quantitative assessment of various natural hazards risk in specific regions of Russia is still an ongoing activity. The quantitative data are also required for the multi-risk assessment [Kappes et al, 2012]. The latter combines the effect of all possible types of natural hazards on a territory of interest, complicated by the so-called "domino effects" [Marzocchi et al., 2009] and difficulties in the homogenization of existing indexes for assessment of risk of individual types of natural hazards [Marzocchi et al., 2012; Selva, 2013].

One of the fast developing areas in the Russian Federation in present times is the Black Sea coastal region of the North Caucasus (Fig. 1). The territory is exposed to various natural hazards with debris flows being the most extensive one. The debris flows risk assessment is conceptually similar

Fig. 1. Debris flow hazard zones in the Black sea coastal zone (yellow lines). Territory of the presented debris flow risk assessment is shown by red line.

to the risk assessment of other natural hazards [Kurbatova et al., 1997; Myagkov & Shnyparkov, 2004]. Risk depends on exposure, vulnerability and protection of an object exposed to a natural hazard. Various mathematical concepts allowing quantitative comparison of debris flows risk at different areas inside an analyzed region can be proposed [e.g. Liu & Lei, 2003], based on estimation of hazard, characterized by the magnitude and the corresponding frequency of the debris flows, and estimation of the vulnerability [Totschnig & Fuchs, 2013], characterized by potential losses due to a potential damaging phenomenon for an area per certain time period. In general, the values of interest are the possible quantity of victims and injured and the value of possible losses [Myagkov, 2000; Romanget. al., 2003; Fuchs et al., 2007; Staffler et al., 2008].

Up to now, very few attempts were made in relation to the quantitative risk assessment of debris flows for the territory of Russia. For the first time, the debris flows risk was presented at small scale by Shnyparkov et al. [2009]. Barinov [2009] made an attempt to estimate the debris flow risk for the territory from Anapa to Tuapse (the Black Sea coast). The selected characteristic was the degree of risk determined by the width of a debris flow channel and the height of a corresponding debris flow. Finally, the social risk in terms of individual risk was estimated for the Black Sea Coast of the North Caucasus [Shyparkov et al., 2013]. Such estimation was based on the geophysical characteristics of the individual debris flow basins (distribution, repeatability, duration of the debris flow-danger time periods, the degree of exposure of a territory to debris flow hazard), social characteristics of the territories (population, population density, population distribution, duration of the population presence in the corresponding territories during a day) and a coefficient of lethality [Bründl et al., 2009; Shyparkov et al., 2013]. The methods of the debris flow risk assessment are developed for regional [Chen et al., 2010; Shyparkov et al., 2013] and local [Delmonaco et.al., 2003] scales. The following parameters are used for the social risk estimation [Shnyparkov et al., 2012]: the individual risk, as the probability of human death due to debris flows during a year; and the collective risk, which is the probable quantity of deaths due to debris flows in a year.

The economic debris flow risk assessment, in addition to the geophysical characteristics, involves the monetary values of specific objects and the physical vulnerability of the elements at risk [Chen et al., 2010] or the gross domestic product values [Liu & Lei, 2003]. The specific of the economic characteristics used in the risk estimation is the use of the regional gross products and its analogues for the municipalities. The parameter describing the economic debris flow risk is the probability of economic loss per year. Thus the method is applicable both for the large and for the small spatial scales.

THE DEBRIS FLOW ACTIVITY AT THE BLACK SEA COASTAL REGION OF THE NORTH CAUCASUS

The history of the debris flow event observations at the Black Sea coastal region of the North Caucasus (Fig. 1) already exceeds 100 years [Shyparkov et al., 2013]. At the corresponding published map [Atlas, 2007] the Black sea coastal region of the North Caucasus is characterized by the low degree of the debris flow danger, with only the high mountains zones having a medium degree of the debris flow danger (Fig. 2).

Contrary to that, Table 1 presents an example of the registered debris flow events in 2013 in the same region. The previous most catastrophic debris flows events are listed in Shyparkov et al. [2013]. In the entire database, the most frequent debris flows occur in the region of Novorossiysk, Tuapse, Lazarevskoe and in the Mzymta river basin. The releasing debris flows endanger the federal road M-4, roads of the Republican and local statuses, the railroad from the upper reach of the Tuapse river to Adler and higher along the Mzymta river, and several settlements.

Fig. 2. Fragment of map of the debris flows danger [Atlas, 2007]. The colors correspond to low and medium degree of danger, the hatching corresponds to the showers-related debris flows.

Table 1. The debris flow events at the Black Sea coastal region of the North Caucasus in 2013

Site of a reported debris flow	Date	Weather conditions and reported consequences
Krasnaya Polyana region, Krasnaya Polyana, Rzhanoi ruchei river	24.01.2013	Intensive showers. 2 debris flows up to 20 000 m^3
Tuapse region, the road Dzhugba–Sochi	20.02.2013	Intensive showers. Landslide-flow release on a road. The damaged section about 50 m
Adler region, federal road A-149 Adler–Krasnaya Polyana, 27 km close to Moldovka settlement	23.02.2013	Intensive showers. The road was closed
Krasnaya Polyana region, left tributary of Mzymta river above Rzhanoi river	13.03.2013	Intensive showers. Technical road was closed
Sochi region, Lazarevskoe	26.05.2013	Intensive showers. Waterspout enters to the land. The ground floors of many apartment houses were completely flooded
Tuapse region, railroad Tuapse–Shepsi	02.07.2013	Debris flow release on the railroad. 6^{th} and 7^{th} cars of the train Adler–Vladikavkaz were exposed to the debris flow. About 10 trains were delayed. The delay was 7 hours.
Krasnaya Polyana region, federal road A-149 Adler–Krasnaya Polyananear the Trout Farm	07.09.2013	Intensive showers. 2 debris flows release. No injuries. Several cars are damaged; all the traffic was directed around.

CONDITIONS OF DEBRIS FLOWS FORMATION

Climatic conditions of debris flows formation are characterized by relatively high mean annual air temperatures of 3,7°C at Achishkho and 13,8°C in Lazarevskoe. The highest temperatures are reported in July–August and the lowest – in January. The leading role in the debris flows formation plays liquid precipitation. The annual precipitation increases in the Black Sea coastal region of the North Caucasus from Novorossiysk (724 mm) to Adler (1377 mm), with the maximal values reported for the upper reach of Mzymta river (3200 mm at Achishkho). The maximum of precipitation is in the winter season from November until March, when 60–70% of the annual norm falls in some areas. Heavy showers occur all year round, with a reported intensity up to 30 mm per day at the coast and up to 100 mm per day in the mountains. The extreme intensity of precipitation per minute is normally reported in June–August, and is often caused by waterspouts enters to the land.

The long time period with positive temperatures favors a long duration of the debris flows hazardous season – from 6–7 months in high mountains, 7–9 months in the medium altitudinal range and 10–11 months in the lowlands. The duration of the principal debris flows hazardous season (90% of all the reported debris flows) is 4, 5 and 9 months respectively. The waterspouts play an important role in the debris flows formation [Barinov, 2009; Shishkina, 1967]. The frequent thaws in winter seasons coupled with high temperatures and high probability of liquid precipitation favor formation of slush flows or snow debris flows.

The orographic conditions of the Black Sea coastal region of the north Caucasus are also favorable for debris flows formation. The mountain ridges along the coast are 600–700 m a.s.l. in the northen part of the region and 2000–2500 m a.s.l. in the southern part. Numerous water streams cross the ridges, with the basin areas from several hundreds m^2 to tens of km^2. The inclination of the torrents, especially in the upper parts, reaches 40–50°, flattening out in the medium and low parts.

Lithologically, the Back Sea coastal region of the North Caucasus can be divided on two parts [Chernyavskii & Efremov, 2010]. The north-western part from Anapa to Tuapse is constructed by flysch and subflysch carbonate and terrigenous-carbonate deposits of Cretaceousperiod and Palaeogene. The deposits are intensively dislocated, rumpled into complex small, often isocline, folds, complicated by breaks and small thrusts. The south-eastern part from Tuapse to Adler is constructed by subplatform deposits of Cretaceous period, Palaeogene and Neogene. Stratified deposits of limestone and sandy-argillaceous grounds usually form gentle folds. The grounds' resistance to denudation and erosion is also different. The largest areas of the grounds with high erosion potential are situated from Anapa to Novorossiysk, from Krinitsy to Ashe and from Golovinka to the Russian–Abkhazian border.

High seismic activity (up to 9–10 at the Richter scale) also favors the formation of debris flows. The most seismically active areas are from Anapa to Novorossiysk and from Sochi to the Russian–Abkhazian border, including the Mzymta basin.

Geobotanical conditions are limiting the activity of the debris flows formation. More than 80% of slopes are forest-covered. The most abundant are oak forests with hornbeam, ash, apple-tree, pear and other trees. Relatively small areas are the hornbeam, beech, pine, fir and chestnut forests. The natural forests are replaced by large areas of scrubs and mountain steppe vegetation between Anapa and Arkhipo-Osipovka. Considerable part of the river basins is covered by orchards.

The anthropogenic actions play a very important role in the formation of the debris flows, intensifying the debris flows activity [Sokratov et al., 2013]. It is especially pronounced in the territories near Novorossiysk and in the upper reaches of Mzymta river (the site of the Olympic Winter Games 2014). Quite often the piles from the borrow cuts and construction sites were positioned at the stream canals. The increase in the debris flow activity in the areas of Tuapse and Sochi is caused by entire deforestation, usually not accompanied by the required recultivation.

The factors listed above result in the formation of three types of debris flows in the Black Sea coastal region of the North Caucasus:

"Classical" debris flows (Fig. 3) normally form in the high mountain areas of the region.

Fig. 3. The debris flow bed in the upper reach of the Ashe river near Lygatkh settlement.

The causes are the intensive short showers, long heavy showers and intensive snow melt accompanied by liquid precipitation. They usually form in the time period from June to October. Snow debris flows are rare and form in March–April. The recurrence of smaller debris flows (below 1000 m^3) is once per 3–5 years. The larger ones (up to 10 000 m^3) take place once per 15–20 years. The largest debris flows (more than 10 000 m^3) happen once per 50–100 years.

Debris floods usually form in middle and low altitudinal zones (Fig. 4). The causes of formation are intensive showers and the waterspouts entering the land. Most often they take place in summer-autumn seasons. The recurrence is once per 10 years.

Fig. 4. The bed of the Khotsetai river, which the debris floods are passing through.

Fig. 5. Small debris flow at Krasnaya Polyana.

In addition to these major debris flow types the small debris flows are wide spread on a local level. Such small debris flows (Fig. 5) form in the territories exposed to anthropogenic activities (roads, rail road, new construction sites), and repeat annually. Their volumes are normally the first dozens of m^3.

ESTIMATION OF SOCIAL RISK

The social risk of debris flows was estimated at the spatial scale of 1:200 000. Based on the authors' 2012 field survey 118 potentially debris flows-endangered streams basins were identified. The morphometric characteristics of each basin were calculated (area, inclination, the degree of exposure of a territory to debris flow hazard).The reoccurrence of debris flows was extracted from previous publications describing such characteristics of debris flow activity at the regional level. The duration of the debris flow season was taken from Belaya [2004]. The population numbers were taken from the 2002 population census and the population allocation inside the basins was assessed during the field trip. All data were gathered in a unified database.

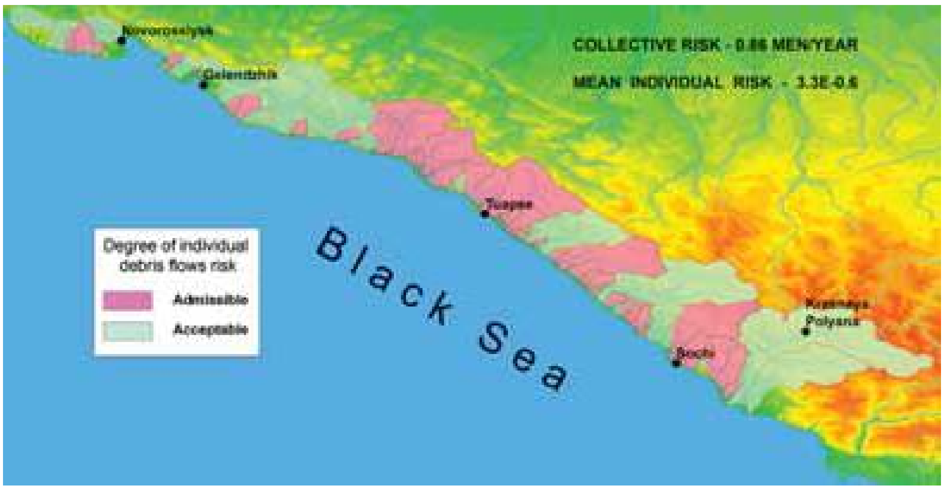

Fig. 6. Social risk in the Black Sea Coastal region of the Northern Caucasus.

The social risk estimation was made by the method suggested by Elkin [2004], adjusted for individual and collective snow avalanche risk estimation at small scale [Seliverstov et al., 2008]. For the medium scale, as required for the social debris flows risk estimation at the Black Sea coastal region of the North Caucasus, the population allocation was incorporated into the risk equations [Fuchs et al., 2013; Shnyparkov et al., 2012; 2013].

The estimation and mapping of the social (individual and collective) risk was made for each of the 118 basins in ArcGIS. Than the areas with equal values of the individual debris flows risk were extracted for two grades (Fig. 6): $1 \times 10^{-5} - 1 \times 10^{-6}$and less than 1×10^{-6}, which corresponds to "admissible" and "acceptable" individual risk [Vorob'ev, 2005].

ESTIMATION OF ECONOMIC RISK

The local municipal governments are the level representing the average statistical spatial/temporal cycle of the life activity of the population both due to their authorities and due to the territory of responsibility. This allows accepting a municipal region as a calculation unit for determination of a standard of the social-economic development and its relation to the natural hazards risks. It can be postulated that the effect of local natural hazards such as the debris flows on the territorial nature/economy system at the municipal level has an areal (mesolevel) character. A single territorial system reacts as a unity regardless of the specific elements of the system affected by harmful or dangerous natural processes. That is why the social-economic potential should be estimated (calculated) for the system as a whole, not for the local objects. In other words, a road closure or destruction of a bridge, power line, etc. by a debris flow (flood) affects the functionality of the whole territorial nature/economy system.

Such way the debris flows risk estimation corresponds to the medium spatial scale. The nominal municipal gross product at the level of the municipality should be taken as a base for the economic characterization. The data on the area of a territory, population, commercial and non-profit basic assets, the volume of the industrial and agricultural production, are available for modeling at this level. This is not enough for calculation of such a basic aggregate characteristic of the territorial nature/economy systems of municipalities as a gross regional product. Also, the Federal State Statistics Service of the Russian Federation does not develop this parameter for the municipal level, so that is why the values of the gross municipal products do not exist in the Russian statistical organizations.

Due to that, a specific method was used for the calculations, allowing not to directly maintain records of potentially vulnerable industrial and social objects, but to estimate the consequences of the debris flows for the systems. This permits to limit ourselves by a set of aggregated social-economic characteristics for the corresponding administrative-territorial units. It has to be noted that the quantity of available information decreases proportionally to the increase in the division of the administrative levels. The method incorporates an estimation of a superposed directly calculable standards characteristic of the economic activity of municipalities identical to the gross domestic product for the entities of the Russian Federation. The method contains an iterative procedure of obtaining the summarized values of the economic activities in the municipalities (or nominal municipal gross product) in its monetary value. To do that:

- The industrial and agricultural production volumes in their monetary values are summarized with the production and distribution of electricity, gas and water, which allows to calculate directly the production volume for the real sector of economy (production of commodities);
- Per capita standard in an entity of the Russian Federation is calculated for the

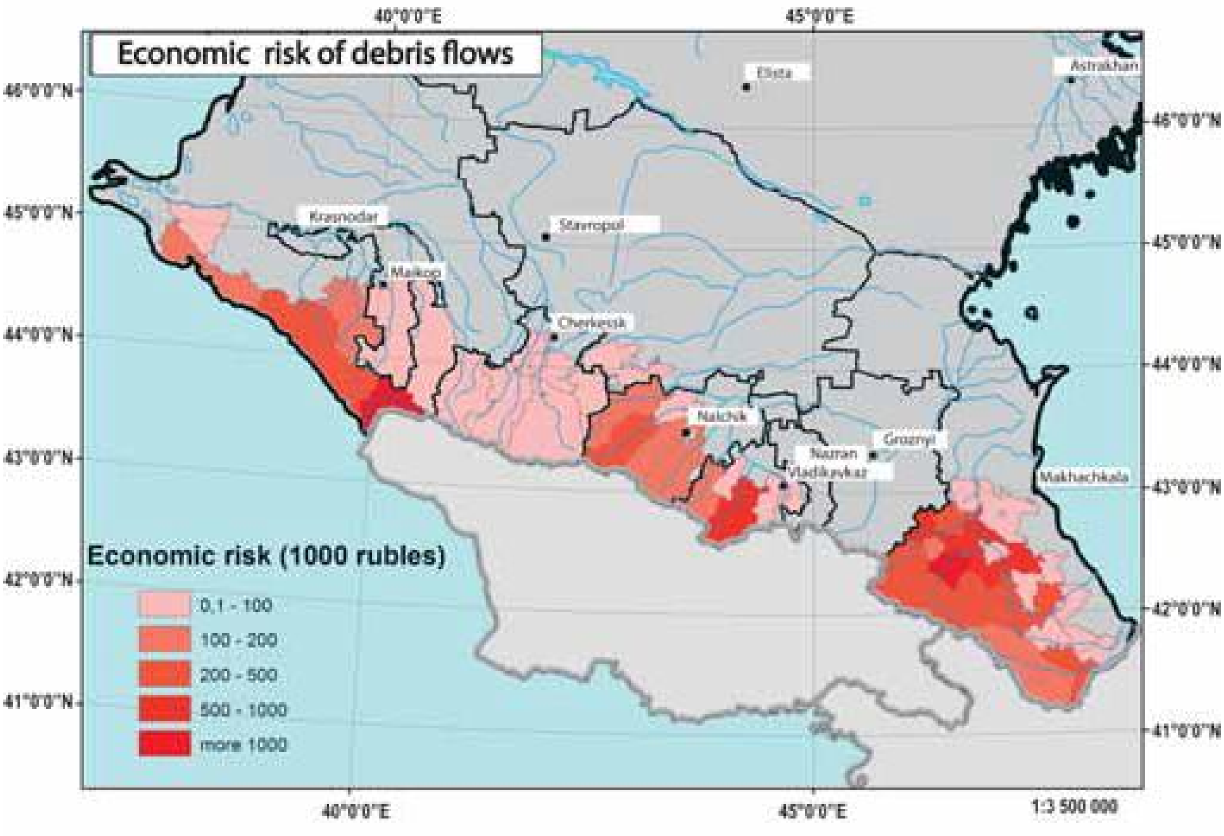

Fig. 7. The economic risk of debris flows in the Northern Caucasus.

service sector (the volume of services in their monetary value per the entity divided by population in the entity), with the obtained value multiplied by the population in the municipality, which provides the value of normative volume of services in monetary value;

- The production value (directly calculated) and the services value (normative approach) in their monetary values are summarized, providing the value of the nominal municipal gross product.

Below is an example of such calculation for one of the municipal regions (Tlyaratinskii region, Republic of Dagestan):

1. The degree of the debris flow affection of the territory (ratio of debris flows affected territory to the total area) – 78,5%, or spatial vulnerability – 0,785.

2. The duration of the debris flow season – 180 days, or the temporal vulnerability: per year – 0,5, per day – 1.

3. Repeatability of the debris flows – once per 11 years, or 0,09.

4. The basic assets of the region – 176 200,0 th. rub.

5. The coefficient of vulnerability of the constructions (buildings, roads, etc.) to debris flows – 0,05.

The losses due to debris flows in the region – 204,8 th. rub.

The results of such calculations in terms of the economical debris flows risk are presented in Figure 7.

CONCLUSIONS

The estimation of the social risk of debris flows in the Back Sea coastal region of the North Caucasus showed that the collective debris flow risk is equal to 0,86 victim per year, i.e. less than 1 person is killed by debris flow in the region. The level of the individual debris flow risk does not exceed the category of "admissible" and in average is equal to $3{,}3 \times 10^{-6}$. None of the 118 debris flows basins corresponds to an "unacceptable" risk of debris flows. About 65% of the basins correspond to the "admissible" level, the remaining to the "acceptable" level of the debris flows risk.

The economic risk in the Black Sea coastal region of the North Caucasus is relatively high. The maximal values were found for the Adler region, including the Mzymta river basin. The quantity of potential loss in monetary value in this municipality exceeds 1 mln. rub. per year (corresponding to €20,600 as of September 2014). This is comparable with some regions of the Kabardino-Balkar Republic, Republic of North Ossetia–Alania and the Republic of Dagestan. The economic debris flows risk decreases in the direction to the north, reaching the minimal value for the region of 100 000–250 000 rub. per year (approx. 2,000–5,000 €).

The approaches used in the present work allow comparison of different areas and municipalities in relation to various types of debris flow risk. Explicitly social and economic are determined and used for the classification. Such comparison can be used by governmental organizations in prioritizing funds allocation for the debris flows protection and mitigation measures and for economic and land-use planning.

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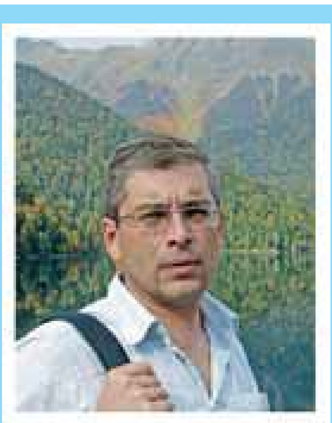

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