Disaster Risk in Central Asia: Socio-Economic Vulnerability Context and Pilot-Study of Multi-Risk Assessment in A Remote Mountain Area of the Kyrgyz Republic

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Abstract—The Kyrgyz Republic, as well as other countries of Central Asia, is highly exposed to natural-environmental hazards, which continues undermining efforts to achieve sustainable development. National disaster risk assessment procedures in Central Asian countries are mainly based on the evaluation of hazards without a detailed analysis of vulnerability and resilience. Additionally, the available practices of hazard assessments are mostly based on a zone-by-zone approach, which would make it difficult to develop a comparative assessment of facilities located in the same hazard zone. This situation hampers the efforts of the local governments to effectively plan and implement disaster risk reduction (DRR) actions when they cannot differentiate the individual facilities according to the risk level in order to focus the existing capacity (which is usually very limited) on increasing the resilience and reducing the vulnerability of the facilities with the highest risk. For improvement of DRR practices, the quantitative comprehensive approach of risk analysis applied in this study is used for risk assessment of educational institutions in one of the most seismically active and most disaster-prone mountain regions of Central Asia - the Alay valley, a wide intermontane valley situated in between the two biggest mountain systems in Asia: Tian Shan and Pamir. The developed multidisciplinary study suggests that the quantitative multi-risk assessment approach - can play a crucial role in understanding risks and can significantly improve the quality of disaster risk reduction planning.

Index Terms —Central Asia, Kyrgyz Republic, Multi-Risk Assessment, Quantitative Approach, Hazard, Vulnerability.

I. INTRODUCTION

Central Asia[1] (CA) is highly exposed to a variety of natural hazards, particularly, to earthquakes and weather-related events. Along with the four other nations of CA, the Kyrgyz Republic (KR, or Kyrgyzstan) also shows significant vulnerability to hazard because of the relatively low level of socio-economic development. Due to the interaction of multiple types of hazards and vulnerabilities (physical, social, economic) the KR and, similarly, the other nations of the CA region are very exposed to disasters risk[2].

In CA countries, as in many other countries in the world (Great Britain - 1948, Canada - 1948, USA - 1950, France - 1950, Algeria - 1964, etc.), the Civil Defense service has given way to a modern disaster management service. But in the case of CA, this transformation has taken place relatively recently, only in 1991, after the collapse of the Soviet Union. Along with the creation of new (or updated) governmental agencies, the main strategic platform of new agencies was changed from the focus on civil defense and preparedness for wartime to disaster preparedness, recovery and response. It is important to note that the development of the new DRR paradigm of these agencies is actively being promoted by the UN and other international agencies. International assistance to promote the new disaster risk management (DRM) standards in CA has resulted in a gradual transition from the activities connected exclusively with the response to investments into decreasing the risk of their occurrence [2]. Thus, the new principles and approaches of DRM in CA (as a new concept and terms) are just beginning to be used in research, management and educational practices. The activities of the Ministry of Emergency Situations of the Kyrgyz Republic (MES KR) are still mostly based on assessments of hazards, while the assessment of vulnerability, resilience and risk are not fully integrated into the national standards of DRM.

Central Asia has a high level of seismic hazard due to the tectonic activity arising from the on-going Indian sub-continent/Eurasia continent collision [3]. In addition, the complexity of different geographical and climatic conditions makes this area highly susceptible to natural hazards [4]. Many hazard studies have been conducted in Kyrgyzstan, mostly studies of seismic [5,6] and landslides [7,8,9,10,11] hazards, however these studies were carried out to assess the seismic hazards on the national or regional level, at the scale of large geographic regions, so the results of these studies

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[1] In the present work, the concept of Central Asia is being considered under the geopolitical definition: as the region occupied by five post-Soviet states: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan.

[2] For the purposes of this research, the term "disaster" is defined as a "serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources" and "risk" is defined conceptually as "the combination of the probability of an event and its negative consequences" [1].

are difficult to use for the assessment at the local level (in the context of small regions, districts and villages). For such a local analysis, more detailed studies are needed, with micro specifications of different risk components for objects located within the same microregions and administrative units.

For that reason, we aimed our research on the development of a quantitative multi-risk assessment of educational institutions (see Table I) situated in the same - geographic area, -hazard zones, -ecosystem, -biome and - administrative district in the South of KR. Our analysis created an effective background for the development of tailored DRR actions, when specialists become capable of selecting objects (facilities/institutions) and activities based on the analysis of diverse and extensive data representing natural and social factors of risk. This is an important contribution to the consideration of DRR as an integral part of social and economic development. Around this time UNICEF also conducted the assessment of the safety of education institutions in the Kyrgyz Republic [12], but this study also was developed on the national level (covering all national schools) and was based on the rapid visual assessment method (visual inspection, visual overview and interviews) without applying any instruments and devices.

Now, by using calculated multi-risk values, DRR actions for this group of institutions could be planned and conducted according to a phased approach, from institutions with higher to lower multi-risk values. Such an opportunity would be very important in developing mountain regions, where unstable economies, lack of financial resources, or high levels of hazard exposure combined with a high level of vulnerability. Therefore, results of our assessment had been transmitted to the local government of the target district (who are responsible for planning and conducting DRR activities on the local level) and to a wide group of interdisciplinary agencies involved in DRM at the national level.

TABLE I: QUANTITY AND TYPES OF EVALUATED INSTITUTIONS

Institution types	#	People		
		Teachers	Pupils	Total people
Schools	17	702	6108	6810
Kindergartens	11	48	654	702
School based kindergartens	13	20	333	353
Home based kindergartens	7	7	70	77
TOTAL	48	777	7165	7942

This paper has four principal purposes: (1) to review the disaster risk situation in KR in the context of economic statistics of the CA region, (2) to describe the development of a quantitative multi-risk assessment methodology for individual objects, (3) to demonstrate the application and final results of the multi-risk assessment to a set of educational institutions in a specific geographic area located in a remote mountain region in the South of KR, and (4) to share and analyse the larger conceptual and programmatic "lessons learned" from that application. The term "multi-risk assessment" is defined as comprehensive risk resulting from the interaction between possible multi-dimensional hazards and vulnerabilities.

II. BACKGROUND AND RATIONALE

A. Socio-economic setting

When the Soviet Union dissolved in 1991, five countries emerged in CA: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, stretching from the Caspian Sea in the west to China in the east and from Afghanistan in the south to the Russian Federation in the north (see Fig. 1). Now, these independent countries are classified as "landlocked developing countries with economies in transition" [13].

Fig. 1. Map of Central Asia. The black rectangle outlines the case study area

CA is a large region marked by a range of different geographic environments, including high passes of the Tian Shan and Pamir mountains, vast deserts, and treeless and grassy steppes. The region is prone to many natural disasters such as earthquakes, floods, landslides, mudflows, snowfalls, avalanches, droughts and extreme temperatures.

In the Kyrgyz Republic, there are no rich nature hydrocarbon resources, but thanks to its geographic-geological and climatic context, the country is rich in water, related hydroelectric potential and mineral resources [4].

The Kyrgyz Republic is almost entirely mountainous, with 90% of its territory above 1,500 m (MASL) and 75% covered by permanent snow and glaciers. The Kyrgyz Republic is the second smallest country (after Tajikistan[3]) by surface area - 199 950 square km. and second smallest country (after Turkmenistan[4]) by population - 6 315 800 people in CA. At present, KR shows the second lowest rate of nominal GDP (after Tajikistan[56]) - 8,1 billion US$, GDP per capita – 3,87 int.$ and human development index rank – 122 (rank out of 189) in CA.

The service sector dominates the national economy of the KR (49,8 % of GDP), but the GDP heavily depends on gold exports, remittances and direct financial assistance provided by the Russian Federation [14,15]. The low level of economic development in the KR made the country highly vulnerable to any types of external (political and economic) and internal (social tensions, inter-ethnical conflicts, land

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and natural resources conflicts, etc.) shocks. Furthermore, the impacts of natural hazards adversely affect its socio-economic stability and sustained economic growth.

B. Vulnerability and exposure to natural hazards

In addition to the general socio-economic indicators of CA countries, Fig. 2 provides characteristics of the countries' vulnerabilities and exposures to natural hazards. The indexes of exposure (considered as the amount of elements which are exposed to one or more natural hazards) and vulnerability (considered as susceptibility, lack of coping and adaptive capacities which make people or systems vulnerable to the impacts of natural hazards) are indicated in percentage according to the World Risk Report [16], where these indicators were evaluated in great detail, based on 28 specific indicators [17].
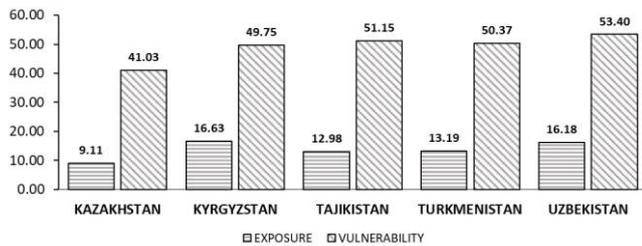

Fig. 2. Vulnerability and exposure indexes (%) of Central Asian countries. The highest index corresponding to the highest level of vulnerability and exposure [16]

As shown in Fig. 2, Kyrgyzstan shows the highest index of exposure to natural disaster among countries in the region, followed by Uzbekistan, Turkmenistan, Tajikistan and Kazakhstan (lowest exposure index in CA). For vulnerability, Uzbekistan shows highest index in CA, followed by Tajikistan, Turkmenistan, Kyrgyzstan and Kazakhstan (lowest vulnerability index in CA). Moreover, it is interesting to note that, for the years 2016-2017 the level of vulnerability in all CA countries other than Tajikistan has been increased (see Fig. 3), with unchanged levels of exposure.
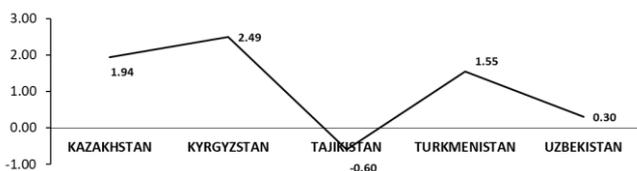

Fig. 3. The changes over 2016-2017 years for the Vulnerability indexes (%) of Central Asian countries. [18], [16]

Population growth is contributing to the vulnerability of societies to disasters [19] in all CA countries (Fig. 4). In the longer term, over the last 26 years after independence (1991-2017), Tajikistan demonstrates the relatively highest regional rate of population growth in CA (65,2%), followed by Uzbekistan (54,6%), Turkmenistan (51,9%), Kyrgyzstan (38,9%) and Kazakhstan (9,6%).
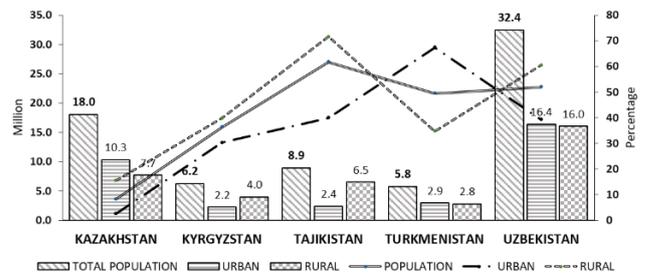

Fig. 4. Population of Central Asian countries
The numbers above columns indicate the pop-n size in 2017 (in million people).
The columns represent the level of total, urban and rural population in 2017 (in million people)
The lines represent the population growth trends in the period 1991-2017(in percentage)
Source: calculated from World Bank Open Data.

On one hand, population growth resulting in a corresponding growth of density and urbanization is another sign of the increasing vulnerability of countries to disasters. According to the World Bank, Kazakhstan is the most urbanized country in CA (57,3%), followed by Turkmenistan (51,1%), Uzbekistan (50,5%), Kyrgyzstan (36,1%) and Tajikistan, which is the least urbanized country in CA (26,9%).

On the other hand, it cannot be said that the rural population of CA (which low dominated in the regional context with 51,8% or 37 million people) has a relatively lower level of vulnerability from disasters regarding the urban population. Actually, a large portion of the population of CA living in remote, mountainous areas. These regions are marked by weak communication systems, the absence of good roads and adequate levels of healthcare infrastructure. That creates difficulties during and after disasters and can be a critical issue during catastrophic events when the rapid evacuation of a high number of people and effective emergency response measures would be needed but become impossible due to the missing infrastructure.

As every country in CA has a different economic structure, the population growth affects their socio-economic development differently. However, in all CA countries, these processes amplify pressure on the natural environment and urban infrastructures, which is generally not compensated by the current rate of socio-economic development. This missing balance results in exposing CA economic systems to increased disaster risk.

C. Hazards and disaster risk

In CA, earthquakes cause the largest impacts on the national economy and population [4]. Considering the proportion of surface area and population exposed to the hazards, Kazakhstan and Turkmenistan are mostly affected by problems related to droughts, Kyrgyzstan by earthquakes and landslides, Tajikistan by earthquakes, landslides and floods and, to a lesser extent, Uzbekistan also by earthquakes, landslides and floods [5,20].

In KR, mudflows and flash floods represent the most common types of natural hazards (in terms of number of events) followed by snow avalanches, landslides and earthquakes, but landslides represent the most dangerous type of hazard (in terms of victims) followed by earthquakes, snow avalanches, mudflows and flash floods (see Table II and Fig.5).

TABLE II: DISTRIBUTION OF MAIN TYPES OF NATURAL HAZARDS IN KR
SOURCE: CALCULATED FROM HAVENITH ET AL. [4]

Hazards	Events		Victims	
	Number	%	Number	%
Earthquakes*	547	14	130	21
Landslides	752	20	279	44
Snow avalanches	851	22	125	20
Mudflows and flash floods	1658	43	73	12
Rock falls	32	1	22	3
TOTAL	3840	100	629	100

Note*: Earthquakes generating intensities of I>7balls (Russian Intensity scale MSK) similar to I>7 on Modified Mercalli scale
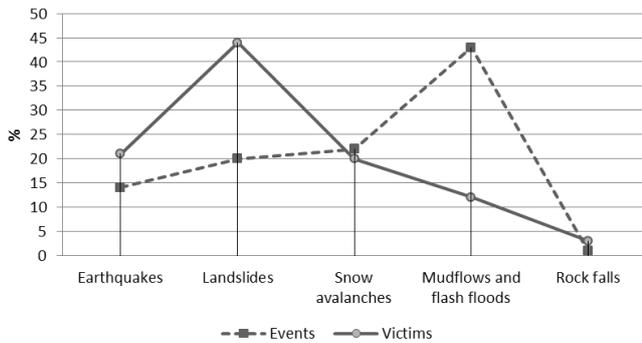

Fig. 5. The ratio between the numbers of events and victims of the main types of natural disasters in KR (%). [4]

Landslides in KR often occur as consequence of earthquakes and extreme weather events (intense downpours, snowfalls, rapidly changing temperatures and snow melting during spring or winter seasons) and they are often more damaging and deadlier than the triggering event itself [4,21].

As noted above, CA countries are prone to a different type of disasters. The figure below provides a summary comparison between indexes of natural hazard-related risk according to the World Risk Report [16], where risk is defined as the interaction of physical hazards and the vulnerability of exposed elements.
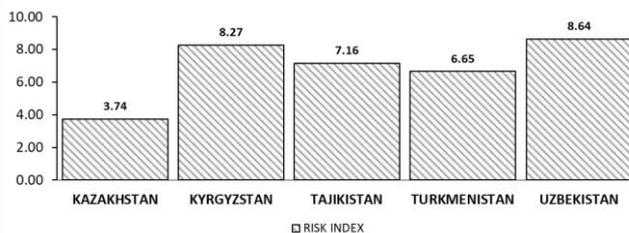

Fig. 6. Risk index (%) of Central Asian countries. The highest index corresponding to the highest level of risk [16]

Uzbekistan shows the relatively highest risk index in CA, followed by Kyrgyzstan, Tajikistan, Turkmenistan and Kazakhstan. Different levels of socio-economic development and environment conditions justify the different levels of disasters impacts in each country. Analysis of risk index dynamics for 2016-2017 shows that the risk index has been increased in all CA countries, with highest indices in Tajikistan and Kyrgyzstan (see Fig. 7).
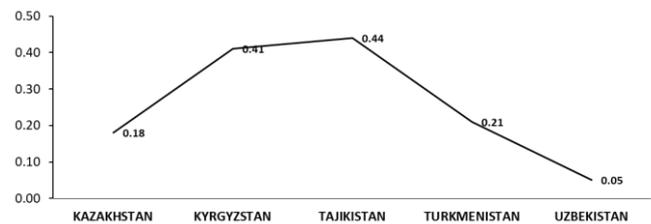

Fig. 7. The changes over 2016-2017 years for the Risk index of Central Asian countries [18], [16]

D. Rationale

It is also recognized that many areas of CA can be affected by major catastrophic disasters [22]. Given such circumstances, the most vulnerable would be the more urbanized countries with the smallest economies. According to the World Bank, Tajikistan is most exposed to the impacts of 100-years and 250-years earthquakes (52 % and 70% of GDP) and Kazakhstan is most exposed to 100-years floods (11% of GDP). Kyrgyzstan is also mostly exposed to the effects of 100-years and 250-years earthquakes (34 % and 61% of GDP), and less to 100-years floods (7% of GDP) [23]. Negative impacts from catastrophic disasters could hamper the development of CA countries for many years after the events.

In the KR the low regional level of socio-economic development is combined with a high level of vulnerability and exposure generating a high level of disaster risk. Therefore, for all CA countries, and especially for Kyrgyzstan, it is very important to improve DRR mechanisms and increase investments in order to reduce existing risk, to minimize (reduce) the creation of future risk, and to respond more efficiently to disasters.

Unfortunately, the current disaster risk assessment procedures developed for the KR still do not systematically consider the social impacts [4]. This deficiency, or "gap" between past and current disaster risk paradigms, was the main reason for the development of a multi-risk pilot assessment in a remote mountain area in the South of KR, the Chong-Alay district, located along the Tajik border and near the border with China (please refer back to Fig. 1 – location map and Fig. 8 – target area map in the next chapter). This area was selected as it is located in one of the most seismically active regions of Central Asia and can also be considered as an earthquake hotspot on a worldwide scale. The last most devastating earthquake in Kyrgyzstan and the CA region, occurred in the immediate vicinity of the target area of our research on October 5, 2008: a M=6.6 earthquake hit this 3-border region and killed 75 people in Nura village (Kyrgyz Republic), which was entirely destroyed besides the most recently built school and the rural medical post [24]. As the earthquake hit in the evening all people were at home; therefore, the stability of the school did not really help protect people. However, under other circumstances, especially when earthquakes hit a region during daytime (and during working days), the safety of a school site is of prime importance. Earlier, on 1 January 2008, an M = 5.6 earthquake had already struck Southern Kyrgyzstan (Kara-Suu, Nookat and Alai districts of Osh province). There were no fatalities, but about 5,300 people were in need of humanitarian assistance. In addition to numerous damaged or destroyed houses and infrastructure,

one rural medical post was severely damaged, one secondary school was destroyed, seven schools were considered unsafe and 15 secondary schools, one primary school and three kindergartens required minor repair [25]. During the same year, on May 12, 2008, an M=7.9 Wenchuan earthquake had struck the Longmenshan Mountains in Sichuan Province, China, during a working day. During this event, approximately 100 schools were destroyed and far more than 10,000 children had been killed in the collapsed school buildings [26]. More recently, in spring 2017 (April 23 – May 11), a school and a kindergarten had been buried under a massive landslide (4.3-km-long landslide with volume over 2 million cubic meters) in Southeast KR (Kurbu-Tash village, Uzgen district, Osh province). Fortunately, a farmer had alarmed the people in the valley that his fields in the upper reaches of the hills started to slide down the slope and were transformed into a large landslide and then in an earthflow. All people were immediately evacuated, and the school and kindergarten were closed – before all buildings disappeared below this 10 m thick earthflow [4,27]. These examples show how important it is to assess risk for such strategic sites as educational institutions. Therefore, we essentially focused our risk studies on school and kindergarten sites located in the villages of the Central and Western Alay Valley.

III. Structure of Research

A. Target area and object of research

The geographical target, the Allay valley, is a remote and intramountainous region of the KR. The target area represented by Chong-Alay district with 21 villages with a population of 26,893 people, distributed over an area of approximately 1,500 km², at altitudes between 2,290 to 3,030 m. (MASL) - Fig. 8.
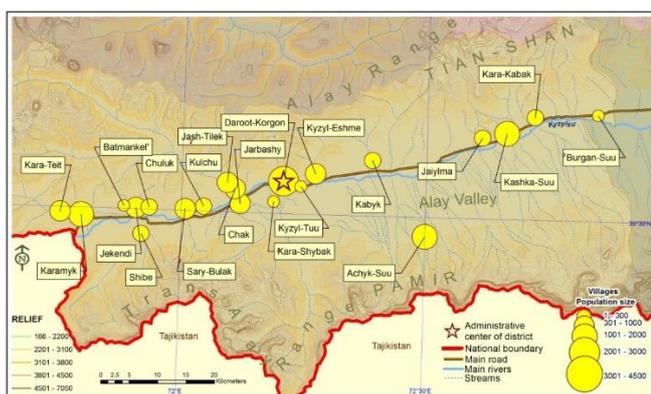

Fig. 8. Chong-Alay district (Osh Province, Kyrgyz Republic)

The Chong-Alay district occupies the western part of Alay valley (running east-west) which hosts the Kyzyl-Suu River (and becomes Vakhsh River in Tajikistan, which flows to the southwest into the Amu Darya River). The northern part of the valley is bordered by the Alay Range (Tian Shan mountain system) and the southern part by the Trans-Alay Range (northernmost range of the Pamir mountain system) along the Tajik border, with Lenin Peak (7,134 MASL). This region is marked by intense tectonic deformation and a high seismicity [28,29].

The social targets of this study are all education facilities

(48 schools and kindergartens) located in Chong-Alay district and distributed in 21 villages. These institutions play a pivotal role in the daily life of remote mountain communities, while also serving as community development centres, public meeting places, social events venues and emergency shelters during disasters. Children spend much of their daytime in these facilities and children are more vulnerable than adults to environmental risks [4,30]. It is thus critical to ensure that education facilities are as safe and as functional as possible during and after a disaster. So, our pilot multi-risk assessment covered all 48 education facilities of Chong-Alay district with 7,942 people in total (teachers and pupils) – see Table I.

B. Assessment data and methods

1) Assessment data

The research was based on field surveys, which were focused on the investigation of the environmental and technical conditions of target institutions. Table III summarizes the dataset and types of information collected, assessed and used by the assessment.

TABLE III: Dataset of Assessment

Risk components	p	#	Indicators (primary data)
1	2	3	4
H [Hazard]:			
Geotechnical	x1	1.	Minimal level of underground waters
		2.	Soil bearing capacity
Other natural	x2	3.	Floods threats
		4.	High winds threats
		5.	Intense snowfalls threats
		6.	Raising of ground water level threats
		7.	Landslides threats
		8.	Snow avalanches threats
		9.	Riverbank erosion threats
Seismic	x3	10.	Shear wave velocity
V [Vulnerability]:			
Fire safety	x1	11.	Access to fire water supply
		12.	Existence of fire barriers in design
		13.	Access to fire alarm system
		14.	Fire safety of electric wiring
		15.	Existence of fire-extinguishing means
		16.	Fire Retardant Treatment
		17.	Access to reserve emergency exit
Disaster education	x2	18.	Trained children and teachers
Retrofitting	x3	19.	Type and quality of retrofitting activities
Structural	x4	20.	Type and stability of bearing wall materials
		21.	Type and stability of foundation materials
		22.	Depth level of foundation in the ground
		23.	Total height of foundation
Ex [Exposure]:			
People	-	24.	Teachers and pupils

Note: *p* - the priority coefficient has been integrated for consideration of the relevant contribution of each type of hazard and vulnerability to multi-hazard and multi-vulnerability values.

Each of the 48 education institutions (facilities) was evaluated according to the assessment of 24 main indicators which characterized: 3 types of hazard, 4 types of vulnerability and 1 type of exposure. All indicators were represented in quantitative characteristics.

2) Assessment methods

The process of multi-risk assessment was conducted

according to four main consecutive stages of assessment: I - field survey and primary data collection; II - converting of assessment results to quantitative characteristics; III - normalization of quantitative characteristics in a single system; and IV - calculation of resulting values of risk for each target institutions:

1) Field survey and primary data collection (stage I): the assessments of risk components were conducted in collaboration and under the supervision of the relevant national agency of the KR. Assessments of all selected indicators for each of the 48 target institutions were conducted by an interdisciplinary team of researchers, according to national standards.

2) Converting of assessment results to quantitative characteristics (stage II): as shown in the dataset table (Table IV), during the field surveys, most primary data (17 of the 24 indicators), had initially been assessed in qualitative form (descriptive analysis - according to national standards). These indicators, with qualitative information, have been converted into a quantitative format. The converting process was based on a relative quantitative system of characterisation applied to each specific indicator. For example: within the assessment of the threat of natural hazards (see Table IV, "Other natural" type of hazard), was applied relative quantitative approach (points system) which was used to characterize the threat levels from each type of natural hazard (7 types of natural hazards). In this case, the score points were the following: the minimum points "0" - when no threat could be identified for this type of disaster, "1" - when a moderate threat could be identified for this type of disaster and the maximum "2" - when a strong threat could be proved for this type of disaster. During the final stage, all points for each institution were summarised with indication of a total score (not normalized) which characterizes the total threat of each institution from 7 assessed types of natural disasters.

3) Normalization of quantitative characteristics in a single system (stage III): for developing the final calculation of all individual indicators within single multi-risk framework, final quantitative values were normalized according to the unified system (five ranks system along with a unified colour code) – see Table IV. The normalization ranks specify how dangerous the conditions of each risk indicator - according to their contribution to the related risk component (see Table III) and to the resulting values of multi-risk.

TABLE IV: DATASET OF ASSESSMENT

Ranks of danger		Normalized value
Maximum:	5	0,81-1,00 (1.00)
High:	4	0,61-0,80 (0.80)
Medium:	3	0,41-0,60 (0.60)
Low:	2	0,21-0,40 (0.40)
Minimum:	1	0,00-0,20 (0.20)

4) Calculation of resulting values of multi-risk (stage IV, final stage): this exercise was based on conceptual disaster risk equations developed by Blaikie et al. [31], Alexander [32], Dilley et al. [33],

Van Westen [34] and risk assessment principles of European Commission and United Nations [35,36]. The applied disaster risk conceptual equation had been considered as a function of a hazard (H), vulnerability (V) and exposure (Ex):

$$Risk = Hazard\ (H)\ x\ Vulnerability\ (V)\ x\ Exposure\ (Ex)\ (1)$$

Where: hazard (H) – the dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage; vulnerability (V) - the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard and exposure (Ex) - are the people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses [1].

The adapted equation of multi-risk had been presented as a function of multi-dimensional values of hazard and vulnerability (multi-hazard and multi-vulnerability) and exposure (Ex).

$$Multi-risk = \sum(H_{n1p1} + H_{n2p2})\ x\ \sum(V_{n1p1} + V_{n2p2})\ x\ Ex\ (2)$$

Where: n – the number of hazards and vulnerabilities types; p – the priority coefficient.

The priority coefficient: for all hazards it was established according to economic impact from each type of hazard in the target area [37] and for the vulnerability - according to the differentiation of quasi-probabilistic impact from each type of vulnerability. In summary, the priority coefficient determines the level of contribution of each type of hazard and vulnerability to resulting values of multi-hazard and multi-vulnerability. The application of the priority coefficient has resulted in the improved accuracy and adequate calculation of final multi-risk values.

The adopted multi-risk assessment approach was based on heuristic models [38] and the holistic principle, where the assessment was viewed as a function of the whole and not so much as a collection of parts [39,40]. The following sections provide a detailed clarification of the assessment. Each type of hazards, vulnerabilities and exposure had been evaluated in accordance with their specific indicators (see Table IV) and relevant national standards.

3) *Hazard* assessment

- *Seismic hazard assessment (micro-zonation survey).*

According to outcomes of a few regional hazard assessment studies [5,10,20,28,37,41] in the target area, earthquakes considered as the most dangerous and destructive type of natural hazard. Target area is a highly seismically prone area, with 89% with a seismic intensity of 9 and higher and 11% with a seismic intensity of 8 on the MSK scale[7] (highest grades of seismic hazard) [28, 44]. However, the available macro-seismic data are insufficient for this study as they do not provide data to estimate seismic hazard for each single-target institution and have been used as a basis for our more detailed seismic micro-zonation

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[7] Medvedev–Sponheuer–Karnik scale

survey.

For this multi-risk assessment, we applied the Multichannel Analysis of Surface Waves (MASW) method for measurements of shear-wave velocity (Vs) in location of each evaluated facilities. The field study (MASW tests) has been developed under the leadership of the University of Porto (Portugal) and in collaboration with the Institute of Seismology, National Academy of Science of the KR. This parameter strongly constrains seismic shaking intensity at local scale – Vs-distribution over depth is the most important component also called - site effects, which indicate the local amplification potential for seismic waves and mark the local seismic hazard [see also [42,43,44]].

The seismic motion at the bedrock is generally different from the seismic motion at the free surface, depending on the intensity and the frequency content of the seismic energy. In general terms the classification is defined by means of the equivalent vertical shear wave velocity averaged over the first 30 m, designated as Vs30 (the shear-velocity down to 30 m).

Within assessment of twenty-six (26) measurements for characterizing the seismic amplification potential for the 48 target institutions/facilities of target area were conducted. Since the obtained range of Vs30 velocities did not cover the full range of any of the Vs30 classification systems (Eurocode 8 [45], NEHRP [46]) we established our own scale to classify the Vs30 values obtained for the 26 MASW measurements. According to applied normalisation system (see Table V) measured Vs30 values were normalised in five classes that extend from the smallest measured Vs30 velocities (254 m/s) to the highest measured values (776 m/s). The relative rating (valid only for our sites) reflects the expected seismic amplification potential starting from the maximum potential (red colour code) for the low-Vs30 values to the minimum potential for the highest observed Vs30-values – as the lower Vs30 values will mark a stronger contrast with respect to the underlying bedrock which is typically characterized by higher shear wave velocities (generally Vs>1000 m/s).

- *Assessment of other natural hazards*

According to the national standard, the assessment of other natural hazards was conducted according to seven main indicators which identified threats from 7 types of natural disasters (floods, high winds, intense snowfalls, rising of the water table, landslides, snow avalanches, riverbank erosion). The field study has been developed under the leadership of the Ministry of Emergency Situations of the KR.

Each of the 48 education institutions were evaluated for the level of threat from each of the seven types of natural hazards in three levels of the index, where assignment to level "0" was applied when there was no threat from this type of hazard, level "1" was applied when there was a moderate level of threat from this type of hazard and level "2" was applied when there was a high level of threat from this type of hazard.

- *Assessment of Geotechnical hazard*

This type of hazard was evaluated according to two indicators: minimum groundwater level and soil resistance (product of their multiplication). In addition to these

indicators within assessing the geotechnical hazard for each of the 48 education institutions, the geological and lithological characteristics of the soil and the maximum depth of penetration of the zero isotherms were also evaluated. These data were obtained by studying the open pits and boreholes and were used as additional information for a general qualitative assessment of the geotechnical conditions of each site and institution. The field study has been developed under the leadership of the Kyrgyz Institute of Geological and Engineering Survey (KyrgyzGIIZ).

4) *Assessment of vulnerability*

- *Structural vulnerability*

This type of vulnerability was evaluated by two groups of indicators. Within the first group of indicators were evaluated: the main construction materials and details of the foundation and within the second group: the construction materials of the walls. The field study has been developed under the leadership of the Kyrgyz Research and Design Institute of Earthquake-resistant Constructions. Within the first group of indicators were evaluated: building material of the foundation (where level "2" was applied for foundations which were built from concrete & modular reinforced concrete blocks, "1" built from stones and concrete and "0" when construction was built without foundation), depth foundation in the ground and total height of the foundation. Within the second group of indicators were evaluated: building material of walls (where level "1" was applied for walls which were built from compacted clay, "2" built from burnt bricks, "2" built from wooden panels, "2" built from reinforced concrete).

- *Structural mitigation and retrofitting*

It is important to note that after the collapse of the Soviet Union (1991), in the Kyrgyz Republic the quality of state control over all design work in civil engineering and the quality of construction and repair work of social facilities was significantly reduced. In addition, due to the subsequent economic crisis, budget allocations for the construction and repair of all social facilities were reduced everywhere. This situation created the prerequisites for the development of inefficient construction projects when many social facilities were designed, built or renovated with low quality and/or without respect for important building codes.

Because the target area is in a region of high seismic activity, this type of assessment was developed for indication the impact of conducted mitigation and retrofitting activities on the seismic-resistant characteristics of the buildings. The field study has been developed under the leadership of the Kyrgyz Research and Design Institute of Earthquake-resistant Constructions and in collaboration with the Aga Khan Foundation, Local Government, School Administrations and MES.

The evaluation was carried out in accordance with the six levels of index, where the index "0" was applied, if no structural mitigation and retrofitting was performed. From "1" to "3" was applied if such activities gave an average effect of increasing the seismic stability of buildings, and from "4" to "5" if the best effect of increasing the seismic stability of building structures was achieved.

- *Disaster education*

Many studies show that DRR education critically

improves the level of disaster preparedness and increases safety and resilience [47,48,49]. At the same time in Kyrgyzstan, as in any other regions, women and children are the most affected groups in the community during the disasters because of the time they are spending in more hazardous rural areas such as in houses located in flood or landslide prone zones [4,50]. Because of the high-level of exposure of children to decision-making [51,52] special attention should be paid to their DRR education.

As the results of the evaluation showed, during the standard course of training in educational institutions of the Chong-Alai district, the DRR topic is not taught, or it comes in a very limited version. However, a more extensive course of DRR training (theoretical and practical) was introduced in some educational institutions in the framework of DIPECHO projects implemented by local NGOs in partnership with the local department of Ministry of Emergency Situations of KR, local authorities and administrations of educational institutions. Without considering the quality of the DRR training that could be evaluated in a more specific study, within this multi-risk study, we assessed only the quantitative factor (the percentage of children trained in effective methods of DRR). The field study has been developed under the leadership of MES and in collaboration with the Aga Khan Foundation, Local Government and School Administrations.

- *Fire safety*

This type of vulnerability was evaluated according to national fire safety assessment procedures and seven criteria: access to fire water supply, availability of fire barriers in the construction of buildings, installation of fire alarms, installation of electric wiring according to standards, availability of fire-extinguishing means, flame retardant, access to the second emergency exit.

In many cases, a fire can be a secondary hazard resulting from seismic or other natural and man-made hazards and many criteria of this type of vulnerability are important for the effective evacuation of children under any other emergency and disasters. The field study has been developed under the leadership of MES and in collaboration with the Aga Khan Foundation, Local Government and School Administrations. The evaluation was carried out according to four levels of the index, where the index "0" was applied if the level of the criterion was evaluated as heavily vulnerable, "0,5" as vulnerable, "1" as moderately vulnerable and "2" as mildly vulnerable.

5) *Assessment of exposure*

The United Nations International Strategy for Disaster Reduction defines exposure as "people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses" [1]. In our evaluation under exposure we considered the total number of students and teachers in each of the 48 educational institutions.

IV. RESULTS OF MULTI-RISK ASSESSMENT

The results of multi-risk assessments (i.e. all evaluated, normalized and calculated values of all risk indicators, summary measures and multi-risk values for all 48 target institutions) were addressed to the wide group of multidisciplinary specialists involved in the DRM system at local and national levels and therefore were presented by diverse forms of narrative, statistical and visual information. Table V shows one of the versions of the synthesis table of multi-risk assessment information.

TABLE V: MULTI-RISK SUMMARY TABLE (INFORMATION ABOUT SCHOOLS)

#	Village	MULTI H	MULTI V	[Exposure] Ex	MULTI RISK
1	*2*	*3*	*4*	*5*	*6*
	Schools:				
1	Daroot-Korgon	0,50	0,46	0,60	0,21
2	Jarbashy	0,27	0,52	0,80	0,17
3	Daroot-Korgon	0,40	0,68	1,00	0,41
4	Chak	0,63	0,82	0,60	0,47
5	Jash-Tilek	0,53	0,86	0,40	0,28
6	Kulchu	0,70	0,76	0,20	0,16
7	Kyzyl-Eshme	0,27	0,60	0,40	0,10
8	Kara-Kabak	0,67	0,62	0,20	0,13
9	Achyk-Suu	0,50	0,70	0,60	0,32
10	Jayilma	0,47	0,58	0,20	0,08
11	Kabyk	0,33	0,42	0,20	0,04
12	Kashka-Suu	0,67	0,82	0,80	0,66
13	Kara-Teit	0,73	0,80	0,40	0,36
14	Jekendi	0,63	0,74	0,60	0,43
15	Karamyk	0,80	0,54	1,00	0,65
16	Shibe	0,80	0,88	0,40	0,43
17	Chuluk	0,70	0,82	0,20	0,17

Figure 9 demonstrates the geographical dependencies, as well as a geographical significance of multi-risk values.
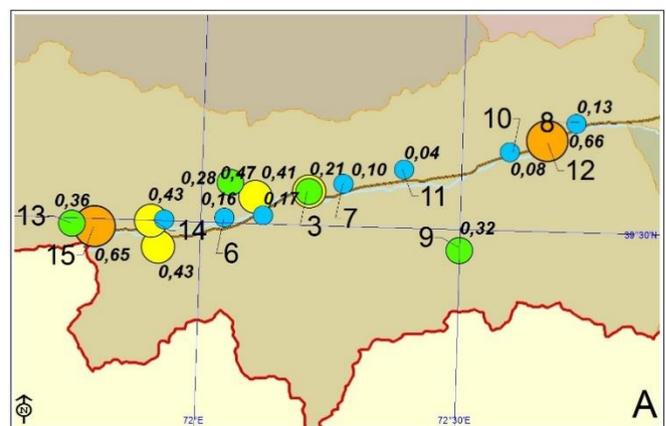

Fig. 9. Risk map (information about schools)

According to the results of the assessment, three institutions (6%) are evaluated with the highest rank of multi-risk. Nearly half of the institutions (46%) are evaluated with the lowest rank of multi-risk and another half (47%) is marked by average ranks of multi-risk. In terms of people (teachers and pupils): 2% - located in institutions with the highest rank of multi-risk, 27% - in institutions with the lowest rank of multi-risk and a large portion of the population belongs to institutions with average ranks of multi-risk (71%). Table VI shows information about institutions and people distributed by risk ranks.

TABLE VI: RISK ASSESSMENT RESULTS

Risk ranks	Institutions		People	
	#	%	#	%
Maximum:	3	6	128	2
High:	5	10	1519	19
Medium:	5	10	2081	26
Low:	13	27	2036	26
Minimum:	22	46	2178	27
Total	48	100	7942	100

Concerning the general analysis of assessment outcomes, the red code (which indicates the highest level of danger) on the multi-risk summary table (see Table V) dominates on the part related to vulnerability, rather than the hazard. It means that: (1) in the overall scheme of risk, the vulnerability values of assessed institutions were high and comparatively higher than hazard values and (2) in most cases, the higher values of risk due to higher vulnerability values (rather than high hazard values). That is encouraging because unlike a hazard, the high values of vulnerability could be decreased by relevant DRR actions and this would eventually help to reduce the risk values, even if hazard values would not be changed. Furthermore, effective DRR actions could reduce and maintain relatively low vulnerability values and that is very important for constraining risk values on minimal ranks, even if disasters become more powerful and more frequent in the future.

Considering the general high seismic hazard level of the target region, practically all studied institutions are exposed somehow to natural hazards. Our approach was based on the differentiation between the hazard and risk affecting those institutions. Therefore, when we speak of 'low' level, it means a low level at regional scale – but it should be considered that the corresponding risk level might still be higher than, for example, for 99% of educational facilities in Europe. Therefore, the issue of DRR for all assessed institutions is critical, because these institutions located in a mountainous, hazardous natural environment with high variability, where emergencies, disasters and catastrophes can strike quickly.

V. RECOMMENDATIONS

The quantitative approach in multi-risk assessment could be also applied to specific DRR actions, to the assessment of resilience, climate change adaptation, and improvement of disaster insurance programming:

1) The resilience is defined as the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions [1]. The multi-risk assessment approach will be particularly effective for the development of a local, community resilience action plan and can be calculated by the following conceptual equation [53]:

$$Risk = \frac{Hazard\ (H)\ x\ Vulnerability\ (V)\ x\ Exposures\ (Ex)}{Resilience\ (Rs)} \quad (3)$$

The equation for calculating multi-risk would employ the same principle as Eq. (2) above (including prior calculation of total values of multi-hazard and multi-vulnerability) and would be:

$$Multi-risk = \frac{\sum(H_{n1p1}+H_{n2p2})\ x\ \sum(V_{n1p1}+V_{n2p2})\ x\ Exposures\ (Ex)}{Resilience\ (Rs)} \quad (4)$$

Where: n – the number of hazards and vulnerabilities types and p – the priority coefficient.

Resilience can be evaluated and integrated into a quantitative scheme by applying the Local Government Self-Assessment Tool for Disaster Resilience (LGSAT) [53]. The LGSAT constitutes a multidimensional questionnaire specifically designed to assess community disaster resilience. Using this tool, local governments and communities can set legitimate priorities in budget allocations for specific DRR actions and justify needs for resources from the regional and central government. The LGSAT already includes a measurement system for converting qualitative information into a quantitative format, which is also based on a five rates system.

2) Another possible direction for the improvement of the multi-risk assessment approach is the integration of climate change estimation. As Olson et al. [54] have argued, "(…) climate change has multiple and varied effects on the initiating or trigger hazard (H) variable, which then has ripple effects across the rest of the equation (R = H + Ex x V) to yield, ceteris paribus, a much higher risk of emergencies, disasters, and even catastrophes." Integrating the climate change factor into the multi-risk assessment method could affect the increased probability of estimated values of risk, but a larger challenge in implementing probabilistic approaches for extreme events and climate change, however, lies in their relative infrequency [55]. In future studies, attention might be focused on finding a solution to how effectively integrate the climate change factor into a holistic system and quantitative approach of the multi-risk assessment.

3) The quantitative multi-risk assessment procedures can also be effectively integrated into disaster risk financing systems and particularly into disaster insurance programs. Thus, disaster insurance programs occupy an increasingly important place in the structure of DRR because they are strengthening financial resilience (ensure that national financial system and population are financially protected in the disaster events) and because they reduce dependence on post-disaster external aid (or improve the effectiveness of governance). Unfortunately, the disaster insurance sector is one of the least developed DRR mechanisms in CA. In modern times (after the breakdown of the Soviet Union in 1991), in the KR the national disaster insurance program was only initiated in 2015 [56].

The quantitative multi-risk assessment approach integrated into disaster insurance programs could organize an insurance system based on a targeted approach (index-based insurance policy). This will create the basis for the transition from generalized to individual insurance principles, where each individual insurance object could be considered according to specific risk conditions. In general, improvement of quality and diversity of insurance products

will increase demand, which means that it will create stable preconditions for the development of this important sector of the economy and DRM. Effective disaster risk insurance programs also can improve awareness of disaster risk and increase the motivation of people to invest in reducing vulnerability, improving capacity and building resilience. This factor would be very important for the successful implementation of the Government's ambitious reform aimed at the development of a disaster insurance system, which is essential for the improvement of the ability to anticipate, prevent, prepare for, respond to and recover from economic shocks of disasters and catastrophic events by emerging resilient with reduced vulnerability and disaster risk.

Development of an index-based insurance policy is very important in developing countries with limited resources, weak governance, systemic corruption, and high poverty, where big differences in incomes between different socio-economic groups and geographical areas exist and the Kyrgyzstan is one of those regions, where these environmental and socio-economic issues are particularly acute.

VI. CONCLUSION

The disaster risk assessment is the central part of DRM. The outcomes of such analysis provide an opportunity for the improvement of DRR planning, through the justified selection and directing DRR actions to the most vulnerable and most exposed to the disaster risk objects.

The developed multi-risk assessment approach was approved by the decision of the Scientific and Technical Council of the Inter-Ministerial Commission for Civil Protection of the Kyrgyz Republic and was recommended to be adapted to the local and national system of disaster management [57]. This experience may contribute to the improvement of DRM practice in KR, which is still mainly based on old paradigm of disaster risk, where the risk concept is still considered equal to the concept of hazard (Disaster Risk ≈ Hazard) and this explains why most of the national DRM activities still focused on assessing separate hazards and, as usual, without a systematic consideration of vulnerabilities and resilience. Thus, the hazard in KR is still considered as the main (and often the only) causal factor of disaster and as a result, DRM actions are mainly directed towards disaster recovery and response and not so much towards disaster risk reduction and mitigation.

The conducted multi-risk assessment was developed in collaboration with researchers, disaster managers, local authorities and the people living in the target area. The multi-risk assessment identified the mechanisms and individual values of risk for each of the 48 educational institutions, for their facilities and 7,942 people (teachers and pupils) that make up 30% of the total district population. The results of the conducted multi-risk assessment also were validated by outcomes of regional hazard assessment, developed by other research that was dedicated to regional hazard zonation of Pamir and Pamir-Alai [41]. Thus, calculated multi-risk values of evaluated education institutions correspond nicely with the regional hazard survey of the target area.

Identified risk parameters are not constant, they could be changed in the future due to various reasons, including environmental, social or technical factors (disasters, climate change, industrial activities, the change in DRR education, reconstruction, wear and tear of the facilities, etc.). Therefore, to assess the real status of risk, it would be important to repeat multi-risk assessment (after each stage of conducted DRR actions, following disasters or at specific time intervals). The quantitative multi-risk assessment approach also clearly illustrates the interaction between physical, environmental and social factors of disaster risk and how they are contributing to the risk values. Thus, outcomes of research also contributed to raising awareness that the disasters could, in fact, be reduced, if not even prevented [58] and created a suitable basis for formulating effective strategies for mitigation of their impact on people, communities and economies.

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