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Visual inspection results and evaluation of Akhtala tailing safety based on tailing management facility safety methodology

K. Sahakyan✉, A. Sarukhanyan

National University of Architecture and Construction of Armenia, Yerevan, Armenia

✉sks091279@gmail.com

Abstract. *Relevance.* Mining sector is one of the leading branches of the industry in Armenia. Therefore, effective government regulation of the sector based on a sound legal basis is a necessity. Accidents at tailing management facilities are posing a high risk to people and environment especially in their near vicinity and often have a transboundary impact. The tailing management facility safety methodology elaborated under the auspices of the German Environmental Agency is an efficient tool for quick assessment of the technical condition of the tailing management facilities. ***Aim.*** To present the results of application of the tailing management facility methodology in Armenia, which was applied to the operated Nahatak tailing management facility of the Akhtala Ore Dressing Combine (Lori region, Armenia). ***Objects.*** Tailing management facility methodology was applied to the operated tailing management facility Nahatak of the Akhtala Ore Dressing Combine, for which all documentation was checked. Enrichment wastes were stored at the tailing management facility during processing copper ore from the Shamlug mine and polymetals from the Akhtala mine. The main visual inspection was carried out in three parts of the tailing management facility: main dam, drainage canal and secondary dam. Special attention was drawn to the main dam conditions. The video recorded by a drone was used to explore the dam bottom-line. ***Methods.*** The tailing management facility methodology includes the following elements: the method of evaluation of Tailings Hazard Index; the tailing management facility checklists including the questionnaire for visual and documentation inspection, the evaluation matrix for the tailing management facility safety level; the measures catalogue for taking actions to improve tailing management facility safety. The questions of each tailing management facility checklist are stated in a way to encompass the minimum set of the requirements, critical for tailing management facility safety, which allows evaluating the tailing management facility conditions. Questions in all groups of the checklist are sorted by the tailing management facility lifecycle and each subsection contains relevant questions applied to a specific stage (design, construction, operation, re-cultivation, closure). Application of the tailing management facility checklist is supported by a measures catalogue with short-, medium- and long-term safety measures. ***Results.*** The tailing management facility methodology was used/tested for the operated tailing management facility in Armenia for the first time. The main problems of the Nahatak tailing management facility were identified and analyzed, and appropriate recommendations were provided based on them. Based on the obtained results it can be concluded that the main problems are related to the drainage system and the management of water flows, some parts of the primary dam that require restoration, as well as the improvement of monitoring systems. At the same time the experience of application of the tailing management facility methodology in Armenia, allowed improving this methodology and making it the most effective working tool for quick and efficient visual inspection of tailing management facilities and for thorough inspection of relevant documentations. The user-friendly tailing management facility safety methodology (with questionnaires of visual and documentation checking) is an efficient tool for quick assessment of the technical condition of the tailing management facilities, as well as for training staff both in the governance bodies and in mining enterprises.

Keywords: mining sector, tailing management facility safety methodology, checklists, tailing management facility safety level

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Результаты визуального осмотра и оценка безопасности Ахталинского хвостохранилища на основе методологии безопасности хвостохранилищ

К.С. Саакян[✉], А.А. Саруханян

Национальный университет архитектуры и строительства Армении, Республика Армения, г. Ереван

[✉]sks091279@gmail.com

Аннотация. Актуальность. Горнодобывающий сектор – одна из ведущих отраслей промышленности Армении, поэтому эффективное государственное регулирование отрасли на прочной правовой основе является необходимостью. Аварии на хвостохранилищах представляют высокий риск для людей и окружающей среды, особенно в непосредственной близости от хвостохранилищ, а также часто имеют трансграничное воздействие. Методология безопасности хвостохранилищ, разработанная под эгидой немецкого агентства по охране окружающей среды (Umweltbundesamt), эффективна в качестве инструмента для оперативной оценки технического состояния хвостохранилищ. **Цель:** представление результатов применения методологии безопасности хвостохранилища в Армении, которая была опробована на действующем хвостохранилище Нахатак Ахталинского горно-обогатительного комбината (Лорийская область, Армения). **Объекты.** Методология хвостохранилища была применена к действующему хвостохранилищу Ахталинского горно-обогатительного комбината Нахатак, для которого была проверена вся документация. Отходы обогащения на хвостохранилище складированы при переработке медной руды Шамлугского рудника и полиметаллов Ахталинского месторождения. Основной визуальный осмотр был проведён на трех участках хвостохранилища: основная дамба, дренажная канава и вторичная дамба. Особое внимание было уделено состоянию основной дамбы, и для исследования нижней линии плотины была использована видеозапись с дрона. **Методы.** Методология безопасности хвостохранилища включает следующие элементы: метод оценки индекса опасности хвостохранилища; контрольные списки хвостохранилища, включая анкету визуального и документального контроля; матрицу оценки уровня безопасности хвостохранилища; каталог мер по повышению безопасности хвостохранилища. Вопросы контрольных списков сформулированы таким образом, чтобы охватить минимальный набор требований, критических для безопасности хвостохранилища, позволяющий оценить состояние хвостохранилища. Вопросы контрольных списков отсортированы по жизненному циклу хвостохранилища, и каждый подраздел содержит актуальные вопросы, относящиеся к определенному этапу (проектирование, строительство, эксплуатация, рекультивация, закрытие). Применение контрольного списка хвостохранилища поддерживается каталогом мер с краткосрочными, среднесрочными и долгосрочными мерами безопасности. **Результаты.** Методология безопасности хвостохранилища была опробована на эксплуатируемом хвостохранилище в Армении впервые, в результате чего были выявлены и проанализированы основные проблемы хвостохранилища Нахатак, и на их основе даны соответствующие рекомендации. В ходе полученных результатов можно сделать вывод, что основные проблемы касаются дренажной системы и управления водными потоками некоторых участков первичной плотины, требующих восстановления, а также совершенствования систем мониторинга. В то же время опыт применения данной методологии в Армении позволил усовершенствовать методологию и сделать ее наиболее эффективным рабочим инструментом для быстрого и оперативного визуального осмотра хвостохранилищ и тщательной проверки соответствующей документации. Удобная в использовании методология безопасности хвостохранилищ (с анкетами визуальной и документальной проверки) является эффективным инструментом для оперативной оценки технического состояния хвостохранилищ, а также для обучения персонала как в органах управления, так и на горнодобывающих предприятиях.

Ключевые слова: горнодобывающий сектор, методология безопасности хвостохранилищ, контрольные списки, уровень безопасности хвостохранилища

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Introduction

Accidents at tailing management facilities (TMFs) are posing a high risk to people and environment in their near vicinity and often have a transboundary im-

pact. Accidents at TMFs, particularly in the countries with economies in transition, including Armenia, can result in catastrophes not only at local, but also at national and transboundary levels. The UNECE Conven-

tion on the Transboundary Effects of Industrial Accidents provides a legal basis for the countries in their efforts to prevent industrial accidents. It also promotes enhancing of international cooperation among the neighbouring countries in case of emergencies. The UNECE Safety Guidelines and Good Practices for TMFs (2014) were elaborated under the auspices of the German Environmental Agency (Umweltbundesamt) [1]. The user-friendly TMF safety methodology developed on this basis (with questionnaires of visual and documentation checking) is an efficient tool for quick assessment of the technical condition of the TMFs, as well as for staff training both in the governance bodies and in mining enterprises [2–14].

General information about TMF methodology. The successful experience of applying the TMF methodology in Armenia (within the framework of project on “Assistance in safety improvement of tailings management facilities (TMF) in Armenia and Georgia” [3, 11, 13]), where numerous TMF sites are located, allowed improving this methodology and making it the most effective working tool for quick and efficient visual inspection of TMFs and for thorough inspection of relevant documentations. The TMF methodology was applied to an operated TMF for the first time in Armenia [4].

The *TMF Methodology* includes the following elements:

1. The Method of evaluation of Tailings Hazard Index (THI Method).
2. The TMF Checklist including:
 - The Questionnaire (three groups of questions).
 - The Evaluation Matrix for the TMF safety level.
 - The Measures Catalogue for taking actions to improve TMF safety.

The *Tailings Hazard Index (THI)* is the index that demonstrates the measure of specific potential hazards/risks posed by tailings facilities to the environment, infrastructure, and humans. The THI is calculated by summing up the major TMF parameters that significantly effect the level of its safety. These are:

- volume of tailings;
- toxicity of substances in tailings;
- TMF management status;
- natural conditions (geological, seismological, and hydrological conditions) specific to the TMF site;
- dam safety.

Tailings Hazard/risk Index can be calculated in two ways depending on the availability of data on TMFs:

1. *Basic THI* is a simple calculation approach by using the data on two major parameters – volume and toxicity of tailings material

$$THI_{Basic} = THI_{Cap} + THI_{Tox}$$

where THI_{Cap} is the measure of hazard/risk caused by the volume of tailings stored in TMF (TMF capacity);

THI_{Tox} is the measure of hazard/risk caused by toxicity of substances contained in tailings.

2. Extended THI is a detailed approach by using the data on two major parameters of basic THI and additionally three other parameters clarifying TMF status, natural conditions and dam safety

$$THI_{Extended} = THI_{Cap} + THI_{Tox} + THI_{Manag} + THI_{Site} + THI_{Dam}$$

where THI_{Manag} is the measure of hazard/risk related to improper management of facilities; THI_{Site} is the measure of hazard/risk related to specific geological and hydrological conditions at the TMF site [5, 6]; THI_{Dam} is the measure of dam failure hazard/risk related to structural and component items of the dam, its integrity and functionality.

The *TMF Checklist* includes three groups of questions called as follows:

- “Basic Check” (Group A);
- “Detailed Check” (Group B);
- “Check of Inactive Sites” (Group C).

Each group includes two subgroups – the first subgroup is intended for visual inspection and the second subgroup is elaborated to work with documentation. Visual inspection is mandatory for all groups.

The questions of the TMF Checklist are formulated in a way to encompass the minimum set of the requirements, critical for TMF safety, which allows evaluating the TMF conditions. Questions in all groups of the Checklist are sorted by the TMF lifecycle and each subsection contains relevant questions applied to a specific stage (design, construction, operation, re-cultivation, closure).

During “Detailed Check” evaluation can be performed based on the analysis of available design information and operator records, reinforced with additional studies and tests clarifying all TMF parameters performed by external experts if required and using information received during site visit to the TMF company and interviewing TMF staff.

- The tasks of the “Detailed Check” group comprise:
- assessment of all TMF systems and technical components;
 - assessment of all risks/hazards, impacts and potential impacts, linked with TMF construction, operation, closure, and rehabilitation;
 - determination of the needs and priorities for taking short-, medium-, and long-term measures aiming to improve the TMF safety level.

Evaluation of the TMF safety level within the Checklist is performed with the Evaluation Matrix (EM), which is the matrix of numerical values of answers to the Checklist questions. The matrix elements are calculated by special procedures depending on the scope of the check.

The developed Evaluation Matrix of TMF safety level offers an assessment of TMF, checked for com-

pliance with applicable safety requirements, formulated in the Questionnaire. The Evaluation Matrix unifies the answers to the questions; it includes both overall and categorial evaluations using specific categories, which allows a thorough check of all TMF elements. Besides, the Matrix enables evaluating uncertainties, caused by the lack of data on the inspected TMF.

Table 1. Identification of TMF safety level after evaluation

Таблица 1. Определение уровня безопасности хвостохранилища после проведения оценки

TMF safety level Уровень безопасности хвостохранилища	Criteria Критерии
Acceptable Приемлемый	90% of minimum set of safety requirements are met (MSR>90%) Соблюдается 90 % минимального набора требований по безопасности (МНТ>90 %)
Unacceptable Неприемлемый	Less than 90% of minimum set of safety requirements are met (MSR<90%) Соблюдается менее 90 % минимального набора требований по безопасности (МНТ<90 %).

An application of the TMF Checklist is supported by a Measures Catalogue with short-, medium- and long-term safety measures. The developed short- and medium-term measures should be based mainly on organisational and low cost measures; the long-term measures should be the goal to reach and therefore part of an investment plan meeting international safety standards.

Visual inspection at Nahatak TMF. TMF methodology was applied to the operated TMF of the Akhtala Ore Dressing Combine (Lori region, Armenia), for which all documentation was checked and thoroughly studied.

The Akhtala ore dressing combine operated in 1967–1988, with processing copper-bearing ore of Shamlugh mine and Akhtala polymetallic deposit.

The plant operation was suspended on 01.07.1989 according to the decision of USSR Cabinet of Ministry no. 66/317 justified by the fact that the reserves of the Akhtala mine have been exhausted [7].

In 2001 the Institute of Mining and Metallurgy of the Republic of Armenia developed and implemented a new design for the retrieve of the Akhtala ore dressing combine, which provided processing of only copper-pyrite ore of the Shamlugh mine. In 2009 the design was modified with enlargement and reconstruction of the Nahatak TMF; according to this document the TMF in the Nahatak river gorge was re-commissioned. Its operation restarted in 2011 [8].

Currently, the plant is recycling the Shamlugh copper ore, which is delivered from the underground mine to the plant by carriages or is unloaded at the storage near the underground gallery exit and transported by trucks to the plant. Besides, the ore is transported by trucks from the open casts. The copper content in the ore varies from 0,5 to 1,3% [9].

The TMF dimensions are following:

- maximum length is 993 m;
- maximum width is 446 m;
- smallest width is 101 m.



Fig. 1. Location/view of the Nahatak TMF of the Akhtala ore dressing combine

Рис. 1. Расположение/вид хвостохранилища Нахатак Ахталинского горно-обогатительного комбината

A visual inspection showed that the tailing dump was more than 80% full, and the surface of the lake was approximately 8 ha.

The total reclamation area of the tailings, including the area of the dam slopes, is estimated at approximately 17 ha. Full reclamation of the tailings is provided after the introduction/organization of storage of dry tailings in the worked-out section of the quarry [15–18].

The operating TMF “Nahatak” has the tailings of upstream type; it has been operated since 2011. The design capacity amounts 3.75 million m³. Tailings material deposition is performed by the zenith method. The starter dam is stone-filled of 7.0 m height; the height of the TMF dam with clayey sand material is 64 m.

It was to note, that from the end of 2019 the company use a new method for tailings disposal with dry tailings; in this case the TMF extension or construction of a new TMF is not planned [10].

TMF site visit. The visit to the Nahatak TMF site was carried out on July 2019. The site visit included the most important TMF parts. To explore the TMF and a dam bottom-line, a video recorded by a drone was used. The main study was carried out in three parts of the TMF: main dams, drainage canal, and secondary dam. Special attention was drawn to the main dam conditions.

Check of the documentation. As a result of these activities, the questionnaire on documentation checking was fully applied. The results of the documentation check were included in the Excel file, which was updated according to the updated version of the TMF methodology (answers to 259 questions of Subgroup C2; with short justification in column “S” of the Excel file).

Evaluation of the results. The updated version of the TMF methodology (2019) for the TMF safety was applied to evaluate the safety level of the Nahatak TMF. The key novelties were (1) the equivalence of the evaluations obtained for visual and document checks, (2) introduction of the critical questions of doubled weight in comparison to general ones in both subgroups B1 and B2, and (3) more detailed categorial evaluation for visual check. The results of TMF safety evaluation are given in Table 2 and in Fig. 2, 3. The visual inspection provided answers to 35 questions of Subgroup B1 “Detailed visual inspection” with relevant justification/comments in column “S” of the Excel file, as well as to 259 questions of Subgroup B2 “Detailed Document Check”. The evaluation matrix was filled in at the TMF site during a week after the field reconnaissance. The measures were proposed after checking the answers/evaluation matrix and having insight into the drone footage.

Table 2. Overall evaluation results of the Akhtala ore dressing combine TMF*

Таблица 2. Общая оценка хвостохранилища Акталинского горно-обогатительного комбината*

Group of participants Группа участников	Checklist questions Вопросы контрольного списка	Not applicable Не применимо	Yes Да	Mostly yes В основном да	Mostly no В основном нет	No Нет	Minimum set of requirement (MSR) Минимальный набор требований (МНТ)	Credibility Достоверность
Main dam Основная дамба	Subgroup B1 Подгруппа B1	14.3	22.9	31.4	17.1	14.3	59.1	43.3
	Subgroup B2 Подгруппа B2	5.4	75.2	12	3.5	3.9	89	83.6
	Group B (B1+B2) Группа B (B1+B2)	6.5	68.9	14.3	5.1	5.1	74	63.5
Drainage canal Дренажный канал	Subgroup B1 Подгруппа B1	11.4	17.1	28.6	20	22.9	47.1	45.2
	Subgroup B2 Подгруппа B2	5.4	75.2	12	3.5	3.9	89	83.6
	Group B (B1+B2) Группа B (B1+B2)	6.1	68.3	14	5.5	6.1	68.1	64.4
Secondary dam Вторичная дамба	Subgroup B1 Подгруппа B1	11.4	28.6	34.3	8.6	17.1	61.6	51.6
	Subgroup B2 Подгруппа B2	5.4	75.2	12	3.5	3.9	89	83.6
	Group B (B1+B2) Группа B (B1+B2)	6.1	69.6	14.7	4.1	5.5	75.3	67.6

*The table shows only the final results, because the details of the calculations are quite extensive, based on the answers to 294 questions (B1+B2). For this, a separate settlement document in Excel format was created with the ability to import the relevant data, which is an integral part of the TMF Methodology/В таблице показаны только окончательные результаты, поскольку детализация расчетов достаточно обширна и основана на ответах на 294 вопроса (B1+B2). Для этого создан отдельный расчетный документ в формате Excel с возможностью импорта соответствующих данных, который является неотъемлемой частью Методология безопасности хвостохранилища.

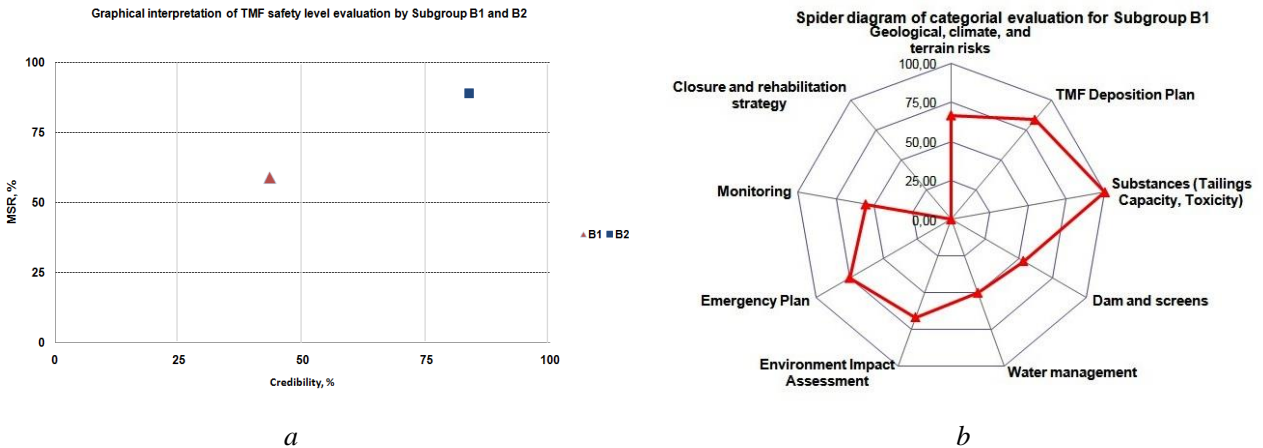


Fig. 2. Safety evaluation results for the main dam: a) overall evaluation; b) categorial evaluation for visual check
Рис. 2. Результаты оценки безопасности главной плотины: а) общая оценка; б) категориальная оценка визуального осмотра

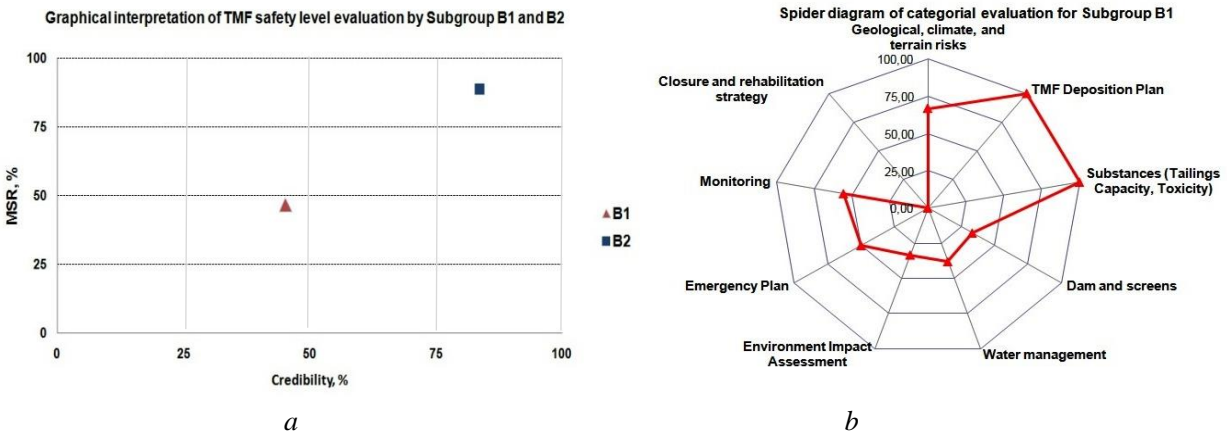


Fig. 1. Safety evaluation results for the drainage canal: a) overall evaluation; b) categorial evaluation for visual check
Рис. 3. Результаты оценки безопасности дренажного канала: а) общая оценка; б) категориальная оценка визуального осмотра

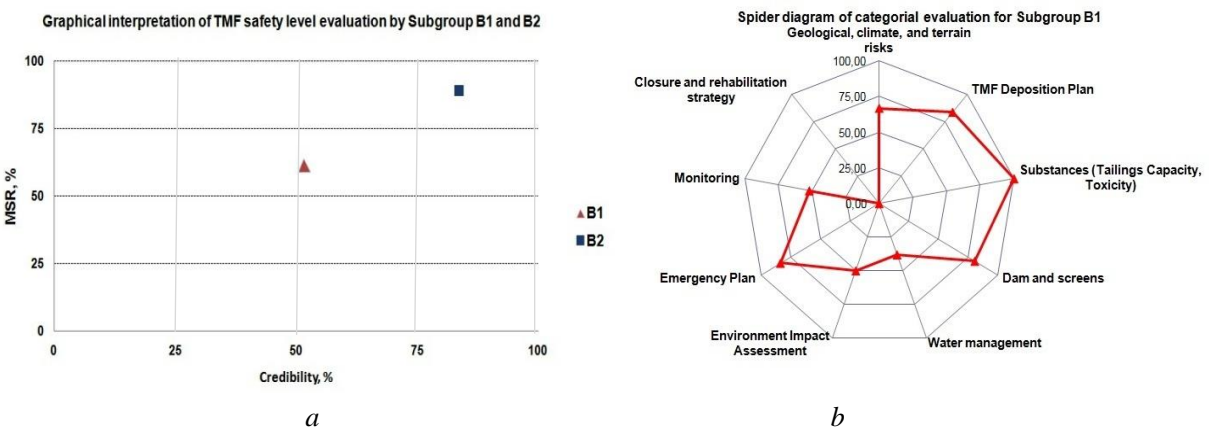


Fig. 2. Safety evaluation results for the secondary dam: a) overall evaluation; b) categorial evaluation for visual check
Рис. 4. Результаты оценки безопасности вторичной плотины: а) общая оценка; б) категориальная оценка визуального осмотра

Spider diagram of categorial evaluation for Subgroup B2

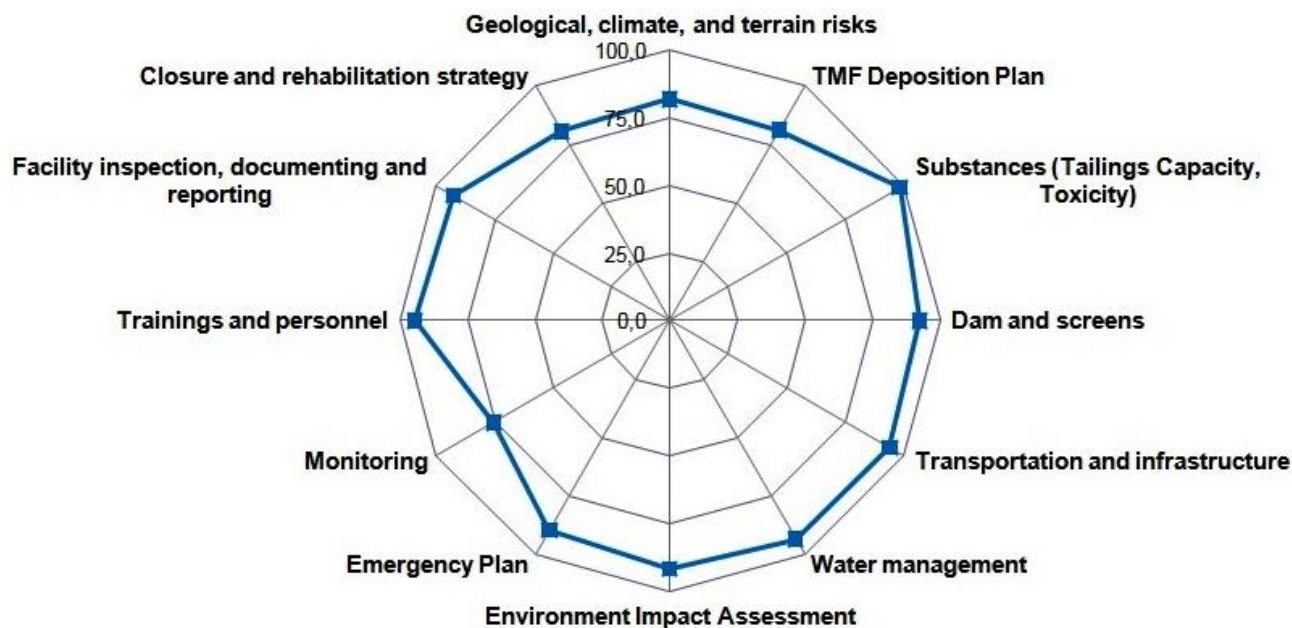


Fig. 5. Safety evaluation results obtained by document check

Рис. 5. Результаты оценки безопасности, полученные при проверке документации

Measures recommended with direct using of Measure Catalogue of TMF methodology. As a result of the implemented studies, the following priority improvement measures were proposed:

- **Short-term measures:**
 - increase through put of TMF drainage facilities (cleanse it of vegetation; remove plants in the diversion channel and check its integrity);
 - permanently monitor drainage water streams using automatic analyzers;
 - assess the possible dam failures and dam stability;
 - equip the TMF with facilities preventing unauthorized access;
 - develop a risk management strategy based on the assessment of risks posed by the abandoned TMF.
- **Mid-term measures:**
 - strengthen the dam using grouting and/or drainage curtains:
 - rehabilitation with covering the tailings pond with soil and vegetation as long-term measures;
 - support ballast made of rocks and boulders to prevent from possible landslides at bottom line;
 - equip the TMF with emergency spillways and additional tanks and ponds for collecting emergency overflows;
 - detect locations of piping, water pathways/leakage through the dam body and locations of slope instability;

- create accumulating ponds for catching water in case of severe floods;
- equip the TMF site with additional wells and checkpoints for monitoring basic parameters (see Recommendations to TMF monitoring);
- carry out technical upgrading of checkpoints.

Conclusions

In spite of the fact that the TMF methodology (questionnaire of group B) was used/tested for the operated TMF in Armenia for the first time, the main problems of the TMF were identified, analysed, and appropriate recommendations were provided based on them, which were taken into account by the company management.

Based on the results it can be concluded that the main problems are related to the drainage system and the management of water flows, some parts of the primary dam that require restoration, as well as the improvement of monitoring systems.

The entire questionnaire B (including the questions B2 for the documentation check) was proposed to use not only for active, but also for temporarily suspended TMFs.

The results of applying TMF methodology also served as the basis for the international community to pay more attention to solving problems arising in the mining industry [19, 20].

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Information about the authors

Kristine Sahakyan, Cand. Sc., Assistant, National University of Architecture and Construction of Armenia, 105, Teryan street, Yerevan, 0009, Armenia sks091279@gmail.com; <https://orcid.org/0000-0003-4639-4837>

Arestak Sarukhanyan, Dr. Sc., Professor, Head of the Department, National University of Architecture and Construction of Armenia, 105, Teryan street, Yerevan, 0009, Armenia sks091279@gmail.com; <https://orcid.org/0000-0003-4928-9960>

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Информация об авторах

Кристине Суриковна Саакян, кандидат технических наук, ассистент кафедры геоэкологии и жизнеобеспечения Национального университета архитектуры и строительства Армении, Республика Армения, 0009, г. Ереван, ул. Теряна, 105. sks091279@gmail.com; <https://orcid.org/0000-0003-4639-4837>

Арестак Арамаисович Саруханян, доктор технических наук, профессор, заведующий кафедрой водных систем, гидротехники и гидроэнергетики Национального университета архитектуры и строительства Армении, Республика Армения, 0009, г. Ереван, ул. Теряна, 105. asarukhanyan51@mail.ru; <https://orcid.org/0000-0003-4928-9960>

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