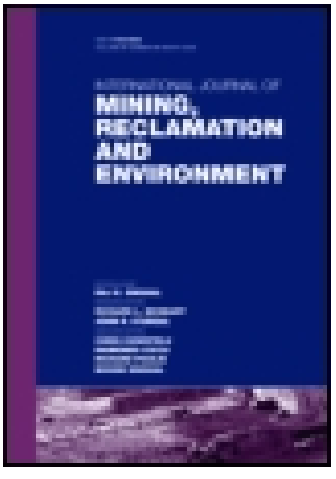

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Mine water: policy perspective for improving water management in the mining environment with respect to developing economies

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Mine water: policy perspective for improving water management in the mining environment with respect to developing economies

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Mine water is a resource and potential nuisance at the same time and its management is a major challenge for the worldwide mining industry. Its quality and quantity relates to the ore and mining type, and might result in environmental pollution if not properly used or managed. The entire water management and conservation needs to be addressed by all stakeholders involved and it has to be a bottom-up, rather than a top-down approach, taking into consideration site-specific conditions. We propose that some key policy areas, if implemented into practice, will provide direct benefits to mine operators and consequently mine water management can be improved at different levels. In the future, the concerns of the community and social welfare must not be ignored for any reason whatsoever. This technical analysis therefore stresses upon results-oriented pragmatic efforts for mine water resources development and management, which gives direction to green mining and sustainable development of mining areas. *Best Practice Water Management* and *Intelligent Mine Water Management* can be considered the best solution, maintaining an acceptable standard of living – now and in the future. This paper, meant for the benefits of the mining industry of developing countries in particular, discusses key mine water areas in a policy perspective. To obtain satisfying environmental protection, mine water management should be jointly enforced by the industry, regulators and stakeholders.

Keywords: mine water; water; policy; water management; mining environment

1. Introduction

In the current market, water is a precious commodity, comparable to oil and gold. Water in general and mine water in particular is integral to virtually all mining activities [1–3]. Undoubtedly, many mining companies recognise its importance as a critical commodity, but water use, which ultimately depends on the needs, the area, quantity and availability, has immense implication for the present as well as for the future. Water can be a risk issue for mine sites also and therefore its reliability in terms of scientific evaluation may be questioned [4]. Thus, water management becomes important and thorough planning and integrated water use throughout the life cycle of a mine is essential and one of the best ways to manage mine water would be reducing the total water consumption [5,6]. Consequently, this paper will revisit some important key mine water areas. With regard to its applicability and from a water management perspective,

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there are challenges that need to be optimised and improved. Adequate policy and water management procedures, if in place, will help to mitigate risks and issues. Over and above, in the modern technological age, a *holistic approach* on these issues is required [7].

2. Mine water areas that need consideration

An ample amount of usable water is available as mine water [8]. Reliable figures of mine water amounts are not available but it will be in the billions of cubic metres in various operative and abandoned mines [2]. A 2005 evaluation for the US alone gives an estimated daily ground water and surface water use of 15.2 Mm^3 for mining purposes [9]. Mine water is a renewable resource for miscellaneous needs, e.g. industrial or agricultural/irrigational, and can be made even potable by new and modern water management techniques, philosophies/policy tools and available preservation steps [2]. Despite widespread research and development by the industry and involved institutions, a lot still needs to be done in the context of cost-effective mine water management and better conservation methodologies of this precious commodity. In developing countries, e.g. India or South Africa, water is one of the most crucial elements in industrial developmental planning [10]. Any country that prepares itself to enter the twenty-first century intends to develop, conserve, utilise and manage this important resource and thus has to be guided by proper policies and national perspectives.

Hitherto, social and economic conditions in developed and developing countries in respect to the approach as well as social and techno-economic constraints differ greatly. Therefore, some scientific and industrial areas require more attention compared to others. Based on the authors' experience, some broad key areas that are of importance for the mining environment with respect to developing, mineral-based economies are delineated in the following paragraphs. This paper's basic approach is improving the resource utilisation and environmental conditions by improving water management.

2.1. Organisation policy and financial outlay

A clear and transparent corporate policy provides a direction for implementation plans and programmes [11]. This effectively controls the cost component as well and expresses the desire of the organisation to achieve the aims fixed towards improvement of water management. If any organisation policy recommends for better water utilisation and sound water management then it is also essential that companies must have ingenuity for its effective implementation. Commonly, policies do exist in developing countries, but the desire for their implementation is often lacking. This is particularly the case in small- and medium-sized companies in unorganised sectors having lacks of financial resources. One of the difficulties, mining companies or the mine management focuses, with regard to policy formulation, is also the lack of proper equipment, machinery, expert knowledge or financial resources for executing the policy.

In any financially improvised company, which has sound policies for water management, conservation and effective utilisation of water in place, administrators and mangers try to escape from the core issues of water management by referring to financial bottlenecks. In many cases, the lack or cutting of funds results in less stringent handling or management of water in mines. Whether these reasons are admitted or not admitted by the management; it is commonly observed practice in case of profitability-conscious private mining companies, such as small-scale mines of developing countries

in the unorganised private sector. It should also be noted that this loophole may be less important for a rich country, but substantial as well as practical for developing countries. Furthermore, the organisation policy and the national water policy should be in tune with each other. In brief, adequate funds are essential for the implementation of plans and ideas.

2.2. Focus on core issues

Research and academic studies together with various reviews reveal the deficiencies in certain aspects of water-related policies [12]. Especially, the necessity, potential or prevalence as well as management of using surface water as well as groundwater and concentration on core issues is missed many times. In this context, the following aspects are noteworthy:

- Water wastage
  (a) In semi-urban and rural areas, its importance is often neglected.
  (b) Lean period of water wastage when water availability is not of much importance or when water availability in a designated area is sufficient.
- Long-term aim or goal of conserving groundwater.
- Penalty and procedure for misuse and overexploitation.

In general, the framing of water resource policies at national level focuses on urban areas; and, the specifics of semi-urban and rural areas where mineral resources are exploited are often overseen or even neglected. Hence, it is obvious that a large water resource area is not addressed adequately by policy-makers. The handling of mine water, managing and conservation practices require expertise, hence valourisation of mine water, groundwater research initiatives in developing countries (which has fund paucity), technology options for core issues, fostering knowledge creation and the promotion of better public understanding could be a possible practical solutions for filling the existing gaps. For the growing small- and middle-sized companies engaged in mineral extraction in developing countries, such steps will be important [13].

It should be emphasised here that water policy usually focuses on water in general and not in particular on mine water [14]. This becomes especially complicated when the water policies and the mineral resources policies are managed by different departments or regulatory bodies [15]. Thus, mine water is a special case and has to be projected into the national mineral policy or mining company policy. By following this procedure, focus on site-specific core issues can be accounted for in relation to water management. If required, emphasis on mine water can be taken into consideration through a separate documentation, guideline or legislation. Such steps or practices will entail the mine operator to improve the water management on site.

2.3. Transition of mineral resource regions from Europe to other continents

Europe was once the most important mining region in the world and nearly all European countries have remnants of historic and even prehistoric mining sites [16]. As of now, Asian, South American and African countries are the principal mining regions [17]. This transition of mineral resource regions requires an interdisciplinary national policy outlook towards mine water because of the growing number of abandoned mine sites and new developing mine areas, which poses great environmental challenges

[18,19]. Policy decisions at appropriate national as well as international level are therefore needed to reduce these environmental challenges (damages and dangers) through mine water-related technological interventions [20,21,23,24]. One potential pathway to follow are the 'Berlin guidelines' published by the United Nations [25–27] and briefly discussed in Wolkersdorfer, 2008 [2]. They describe the prerequisites for mining and the sustainable management of mining operations, including water management and monitoring. In addition, the Equator Principles need to be taken into account in modern mining operations, which ensure that projects 'are developed in a manner that is socially responsible and reflect sound environmental management practices' [28]. Proper international funding, thus, helps in sustaining a sound environment around mine sites, even if some entities are critical with regard to the Equator Principles [29].

2.4. *Planning and machinery used*

Mine water and its management is a vast and interdisciplinary area that requires the knowledge about different aspects of mine planning. For better planning, a thorough understanding of the hydrogeological aspects is imperative. Though this is known on operational level and with regard to technical questions, a lack of knowledge and understanding can often be observed when it comes to policy formulation. In order to obtain sound regulations, further education is needed [30].

In the framework of site-related water management, the machinery used has direct linkages with production and operating cost. Machinery used with respect to the mine water obviously involves pumps and pumping systems. In developing countries, availability of machinery and spares commonly poses practical difficulties. Both electrical and mechanical engineering knowledge and workforce availability at the operation stage leads to failure of planning and ineffective machinery utilisation. With proper machine selection and adequate planning, pits can be kept dry during most of the year and made available for mineral production. Inadequacy in planning and machinery knowledge or utilisation can lead to higher risk and higher cost of water handling as well as management. Hence, to save additional management efforts, this aspect needs attention. If addressed properly, both water quantity and water quality can be managed adequately.

2.5. *Drainage system and mine water discharge*

Mine water drainage is an integral part of planning and if done improperly, can pose a serious threat to existing ecosystem functions, receiving water bodies and human health [30]. Water quality deterioration and water accumulation in the pit is the net result if water drainage and discharge is not taken care of [31]. Hence, finding both short-term and long-term sustainable solutions for an adequate mine water discharge is imperative. The importance of drainage becomes even more critical in metallic ore deposits, where potentially toxic metals in addition to acid mine drainage might pollute downstream watercourses. Hydrochemical evaluations of mine water at the point of discharge have to be conducted in order to install an appropriate mine water treatment solution. Whichever solution is chosen, they are usually cost-intensive and need adequate operation and maintenance. Adequate drainage and discharge of mine water can be considered a proactive prevention strategy for environmental protection. Local geological and geotechnical conditions and the source of water need to be duly considered and discussed in this context to achieve the objectives outlined here.

In any surface mine, the sump design and proper location of the sump in the mine provides a maximum solution for drainage and discharge-related problems and issues. Site-specific practical considerations (e.g. elevations of different locations) are imperative in this regard [32].

Discharge means *disposal* and disposability refers to what purpose the water is used for and whether or not it needs to be discharged. The chemical composition of the mine water discharge and the mineral being excavated correlate with each other and differ on a case-to-case basis [5,33,34]. The vicinity of major river systems or groundwater bodies might conflict with inadequate mine water management and is of important significance in this context. To deal with the above-described issues, best practices in water management are the most adequate remedial measures which can be implemented on a given mine site for gainful results [35].

2.6. Alternate uses of mine water

Mine water has a large range of alternative usages [2], ranging from energy production to recreational or drinking water, depending on the water's quality. If the mine water is polluted or too highly mineralised, its alternate use is still possible, provided the quantity available is adequate. This is called valourisation and encompasses a large range of potential usages. In some mines, mine water is used for miscellaneous purposes, such as coal washing, agricultural/irrigational use [36] or community water supply. During the periods of water shortage, mine water can have tremendous practical applications [37]. For improving mine water management, alternate uses of water must be promoted through the scientific community. In addition, policies must be set up and enforced by the mine, depending on the onsite and climatic conditions.

2.7. Ore processing, tailings and waste disposal

To extract metals from the ore, the ore needs processing. This mechanical and metallurgical process produces residues that are commonly stored in mine tailings disposal sites, commonly referred to as tailings dams. Thus, tailing and waste management including its disposal is an important area that needs attention with respect to mine water and its management [1]. Some tailings may contain natural as well as added chemicals with potential toxicity [38]. Since a detailed inspection of deposits at the exploration stage is often not conducted by small- or medium-sized operations, the detailed geological and mineralogical composition of the deposit in developing countries is commonly revealed during the operational stage. For the mining industry, this has direct implications with regard to potential mine water pollution and thereby might have an impact on receiving water bodies from both metal and coal mines as they might result in metal enriched acid mine drainage.

Inappropriate waste handling and waste disposal can have adverse effects on the environment. It certainly depends on the type of deposit mined and the host rocks, which chemical composition the mine waste might have. Thus, the adopted methods and procedures are the key in the pollution abatement strategies. Applicable policy-level intervention at organisational level concerning the parameters to be selected and considered is therefore important. In this context, industry-specific standards are helpful and desirable. It should be noted that several subsectors of mining especially, but not conclusively, have such standards [66].

2.8. Mine water treatment solutions

Robust, reliable and economically feasible technological solutions for treatment of mine water from different types of mines and applications are available [2,3,39]. A clear and transparent company policy can make the treatment solutions cheaper as well as easier to implement. The available applications can be used for drainage water from underground mines, surface water in open pit mines and excess water from tailing storage facilities or waste rock piles [40]. These technologies (e.g. advanced membrane systems, nanofiltration systems, advanced oxidation systems), also called 'Intelligent Mine Water Management System' [41], ensure that, even under varying conditions, environmental discharge requirements can be met by providing good quality of discharged water for disposal. As the spectrum of potentially harmful components varies from mine effluent to mine effluent, the defined discharge requirements (by local environmental authorities) become even more stringent. In this context, an in-depth review of water analysis data and operating conditions must be conducted to determine a suitable mine water treatment system design. Practical experience in mine water treatment (e.g. landfill leachate) is an advantage to design sustainable and dependable systems for mining and mine water treatment solutions. In addition, understanding the intricate relationships between physical, chemical and biological processes of mine water technically and then formulating a precise and appropriate policy is a key to the effective development strategies for water management [10,21–23,42–49]. It is essential to formulate applicable approaches to enhance the use of recycled water after mine water treatment [8].

2.9. Pollution and its cost

Environmental pollution is a result of various sources and the costs for remediation, including monitoring during and after the action, can be substantial. In industry, the unpredictability of these costs comes not only from the different kinds of pollution dealt with, but also from the method used to calculate these costs. Since the notion of cost is quite complex, a practical way is needed to tackle industrial mine water e.g. by national standards for water-related aspects for mines and ancillary industry. Guidelines that can be followed are especially helpful for small- and medium-scale mines, whilst the large international companies commonly use well-established consulting houses to solve their mine water-related questions.

As a general rule of thumb, the cost of industrial pollution should be minimised and in order to do so, pollution prevention is the favourable solution. If pollution arises, it should be dealt with scientifically sound, e.g. mine waste on land may give rise to acid rock drainage and leaching (dissolution of metallic content in mine water). Thus, the pollution cost should be kept controlled if appropriate pre-cautions are taken at early stages of a mining operation. If pollution arises besides all precautions, accepted principles of 'the polluter pays' must be enforced.

2.10. Community action and statutory compliance

Since water is everybody's concern, an adequate involvement of stakeholders i.e. community action can solve a number of operational problems before they occur. Over the past decades, the global mining industry has witnessed a number of community-related social reactions [50]. This condition is quite important for developing countries and the mining industry of any country must not ignore this issue. The corporate social responsibility (CSR) has emerged out as a policy tool for such purposes and necessary

for the company to commit to the community and not ignore the importance of this commitment [29,51,52].

Another important community-related problem of mining projects in general and mine water in particular that needs to be properly addressed are the concerns of the tribal communities in remote rural areas where minerals are often excavated. Due policy intervention for protection of tribes, local and indigenous peoples' interest for water-related matters, which could be either pro or against the mining company, must be in place to guarantee smooth operation of the project. This has clearly been outlined in the 1992 Rio Declaration [53].

In addition to such community action, the role of the different statutory organisations and administrative agencies becomes important in enforcing safety and pollution-related aspects of mine water. Rules, regulations, acts and standards, which are designed specifically for the mining industry and which has legal statutes, are the most practical, non-expensive and easy way for control and abatement. They shall be enforced by the regulatory institutions [45]. So far, prescribed penalties for non-compliance are either not clearly allocated or not adequately enforced in India or other emerging countries. The authors feel that both at the national level and corporate policy level, legal clauses that exist must be implemented rigorously as such provisions are essential. Penalties and procedures should be clearly defined and strictly adhered at various levels. They should be adequate and substantial to ensure that the operators follow the rules in order to avoid penalties.

3. Education and academic training

Education and academic training is the key to appropriate mine water management and to improving the skills of personnel involved in this subject. It can be achieved by short courses or by higher education curricula. Yet, as has been highlighted by Hancock and Wolkersdorfer [30], the demand for experts in this field is substantially higher than the number of qualified personnel educated. Based on the experience in reviewing papers for conferences and international peer-reviewed journals, it is evident that many colleagues in developing countries do not have access to the information and knowledge necessary to evaluate potential problems in mine water management. This can lead to either wrong decisions or a very long decision process, as external experts have to be consulted before decisions are made. In addition, an academic career, which would be necessary to improve the skills for qualified mine water personnel, in many developing countries is less attractive than starting to work in a consultant company or legislative body. Though gaining experience while conducting projects in those positions, the basic knowledge should be gathered during academic studies, in-house skills trainings or attendance of workshops and seminars. South Africa, for example, recently announced that the number of PhDs awarded through higher education does not meet the demands for a growing economy. In order to meet the demands of the industry and academic institutions, the numbers have to be increased from 1800 to 6000 annually [54]. This situation is not unique for South Africa and other developing countries might consider optimising the education for mine water management as well.

4. Best practices in mine water management

The basics of mine water and its management lies in a small acronym: UTS – *Use, Treat and Store*. It means that mine water needs to be treated and stored (conserved) for future

use and should be dealt with according to its prospected use and availability in the present context. The next step is to consider the water quality and its disposability. Water quality together with its quantity are two broad areas which can be managed scientifically, but disposability, to some extent, depends on the pursued procedure whether, or not, the water be discharged outside the mine area, so as to remain free from pollutants. Best practices in mine water management is a single solution that can prevent pollution if planned comprehensively. In addition, a bottom-up, rather than a top-down, approach, taking into consideration site-specific conditions, has to be considered [42].

Best practices in mine water management imply continuing improvement of the water environment and practices to maintain an acceptable level of protection as well as maximum performance of the measures implemented. This incorporates the integration of economic, environmental and social considerations in a manageable and applicable way. A sound water management is essential to achieve environmental best practices. For a sound mine water management, selected international and national documents as well as guidelines available for the mining industry worldwide are:

- Best practice environmental management in mining – EPA, Australia [55].
- US EPA practices for water management in coal mining areas [56].
- Water policy and its management in India [44].
- Global Acid Rock Drainage (GARD) guide (www.GARDGuide.com).
- South African Best Practice Guideline H4: Water Treatment [57].
- Berlin Guidelines of United Nations [25–27].
- Equator Principles [28,29].
- NMA's and SME's Hard rock Mining and Beneficiation Environmental Management System Guide [58].

Best practice in mining together with mine planning classifies the different water sources and prioritises its usage. It is an essential prerequisite for developing the mine water management strategy, which encompasses dewatering, discharge of potentially acidic and polluted effluent water and the overall management of water sources in mining areas.

Prime water management in mining operations requires an understanding of the hydrological cycle as well as knowledge about the physical and process elements of the applied water management system. Detailed frameworks of how a best practice water management plan be implemented are some basic needs for mine operators. Yet, mine operators neglected those prerequisites far too often. These frameworks are necessary for the different water management issues pertaining to different stages during the life cycle of a mine. Water management and best practices therefore require practical approaches and any mine water management system must account for physical, chemical and climatic changes relevant for mine water. These require the combination of site-specific factors, e.g. mine process factors, to ensure its usability. As water is essential in most operational aspects, the companies' commitment to integrated water management is a critical precondition for a sustainable operation [59].

Based on the discussion above, the following issues are essential for improving water management in the mining environment in developing countries. For all of these considerations, the key aspect is to implement best practice water management:

(1) Integrated environmental planning is a fundamental component of best practice water management.

(2) Reliable mine water technology [4] and intelligent mine water management, an approach meant for improving current mine water management technologies [41], are the future practical approach.
(3) Poor management of water results in decreased production as well as reduced safety, health and environment. It can even have far-reaching consequences, which lead to an increase in operational costs and financial damage to mining companies. Therefore, cost-effective scientific management of water is the best practical and long-term solution.
(4) Water quality within mines and mining areas, including effluent discharge (if any), should be managed effectively and practically by tightening the monitoring and enforcement mechanism. This can be implemented into a code of practice by regulators and administrators.
(5) As initial mine planning is commonly based on limited data, it is important to have detailed water-related data at the operational phase and adjust the water management system to minimise the risk of polluted water impacting the environment.
(6) Reduced oxidation of tailings, less leaching of metals of concern and anaerobic or aerobic treatment of acid mine drainage or acid rock drainage is the most cost-effective practical way to decrease the pollution level in particular for fauna and also for living organisms in the mining or nearby areas.
(7) Mine water treatment solutions using new and innovative technologies for a sustainable development of mine sites should be applied whenever economically viable.
(8) When the surface mines ceases to operate, pit lake development is an effective and pragmatic end use for mine water [32,60].
(9) Mine voids can be used as water storages to feed populated areas when there are shortages of surface or ground water [61–63]. It can be considered an eco-friendly approach for serving two important purposes: effective end use of mine water and effective environmental protection of mining areas. Both, during operation and mine closure, this method can be applied and implemented. Yet, the public acceptance of this water and potentially harmful concentrations of constituents need careful consideration [64].

Thus, in our technological age, existing mine water technologies can be helpful to implement best management practices. Researching new technologies using new materials and new sensors, including the valourisation of mine water techniques, can be considered the future of mine water management in the mining industry. In rural industrial areas, where raw materials commonly are extracted, the management and development of water is manageable, a direct employment generator and less capital-intensive compared to heavily industrialised areas [65]. Site-specific planning and a sound development strategy are the most practical approaches for both large-scale mines and small-scale mines.

5. Conclusions

This experience-based study concludes that the gaps which exist in the management and development of mine water can be solved effectively through policy intervention and by improving the enforcement mechanism at various levels. Since the demand for water is rising constantly, mine water can help in ensuring water availability in regions

where mining dominates the local economy. Considering the fact that the sustainable development of mine sites is a substantial part of water resource policy management, the participation at all levels of management i.e. at corporate, at site and at operations management level is desired. Practical measures, according to the site conditions, societal set-up, people involvement and compliance of formal regulations will play an important as well as effective role in mine water conservation. With sound policy and improved technical methods, water management can be ensured for a wide range of applications, including process and drinking water.

The best practice water management and intelligent mine water management system, if implemented in practice, will be a way to promote sustainable use of mine water and thereby maintain an acceptable standard of living and social welfare in mining communities, now and in the future. If those measures are implemented and supported by a thorough education and skills improvement programme, mine water management in developing economies will very likely ensure future sustainable operation of mines.

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