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REVIEW ARTICLE

Prospective Review of Mining Effects on Hydrology in a Water-scarce Eco-Environment

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ABSTRACT

Water scarcity has become one of the most challenging problems in many countries around the world, and many aspects can be attributed to economic development activities including the emerging industrial operations and competition associated with such activities among companies in the mining industry. The effects of drought due to the uneven seasonal distribution of water resources also play an important role in water scarcity. The main objective of this review is to discuss the eco-environmental problems associated with mining in water-scarce mining area, and to propose a system that can provide the best solution to the scarcity-associated issues in different water-scarce environments, taking an example of the north-western region of China. Existing literature on water scarcity and its associated problems, environmental damages induced by mining activities such as drawdown of water level and reduced or dried up surface water, dried up soil, dead vegetation and desertification were consulted and summarized. A Four-Set-up System (4-SuS) is proposed as a future prospect, and was designed using different Software such as Adobe Illustrator, CAD and GIMP. The system is composed of water trading, the use of traded water in the underground space in synergy with pumping filtrated water back to the surface, backfilling the dried-up aquifers, and then the use of stone-layer-trapped water (SLTW) for different activities on the surface. The 4-SuS system is convertible to a Three-Set-up System (3-SuS) in case the area is too arid to possess SLTW or when the stone layer lies deep underground in such a way that it is not easy to drill for SLTW. The proposed 4-SuS system proves that, if correctly implemented considering all necessary aspects of the water-scarce environment, it is possible to trade water from phreatic zone to the water-scarce mining area, and may serve as the best solution to water scarcity challenges around the world.

Keywords

Water scarcity; Water trade; Water use; Aquifer backfilling; Stone layer-trapped water

1. Introduction

1.1 Generalities on water scarcity

Water an inevitable resource is constantly and always on a high demand considering its applications in everyday life including: domestic use, industrial use, artificial snow production, agriculture, ecological flow requirements, and hydropower production[1], yet its supply is a challenge in a water-scarce eco-environment. In a world facing increasing water scarcity and droughts, many industries, especially the mining companies face water-related operational risks and capital expenditures that threaten the financial performance, and even the social license-to-operate[2,3]. Similarly, there exist troublesome manifestation effects on the ecosystem and socio-economic development and sustainability in water-scarce areas[4]. Scarcity has stranglehold on most of the discourse of the polite society, to the point where it is simply taken for granted just like every social "problem" is, at root, a problem that arises from scarcity in an eco-environmental system[5]. Nevertheless, after Budds' interpretation, society and nature cannot be separated, and communities rely on and closely relate to water[6]. The mining industry in particular accounts for water[7], and faces the challenge of increasing water management costs and growing public scrutiny of the often-irreversible effects of mining on local land and water resources, i.e., hydrology. For this reasons, the evaluation of groundwater footprint[8] in mining operations and the accurate assessment of water deficit and related uncertainties in water-scarce areas are imperative in the various fields of water resources management[9], whether during extractive and post-closure stages[10], especially during mining. It is significant to know the water-positive and water-negative vis-à-vis the overall water balance in the mining site, the quality of water required for the mining operations and risks associated as well as carefully considering the geological situation and hydrological conditions with respect to climate change impacts in the area [11,12]. This area is herein defined as water-scarce environment due to different reasons impacted by mining operations. North China mostly relies on vast irrigation systems and underground aquifers to support its agriculture[13], and this encouraged and increased the water trade owing to its vast semi-arid and arid regions facing water-scarcity challenges.

Water scarcity arises as a result of lack of fresh water resources to meet the standard water demand. Two types of water scarcity have been defined: (i) physical water scarcity- where there is not enough water to meet the demands of the ecosystem[14] (this may be induced by both natural phenomena (e.g., aridity, drought) and human influences), and (ii) economic water scarcity- due to the lack of investment in infrastructure or technology to draw water from aquifers, rivers, or other sources, or insufficient human capacity to satisfy the demand for water[15,16]. It is also believed that water scarcity can arise from unequal power relations[5]. **Cai et al., (2019)**, emphasized that taking China as an example, explains the virtual water flows as the root of intensifying water scarcity, while hydrological droughts have diverse range of effects on water resources[17] and as such affects water quality and quantity in different ways. The increase in water demand and decrease in freshwater availability can also cause water scarcity leading to human health damage, ecosystem quality, and natural resources[18]. Concerning virtual water flows, **Cai et al., (2019)**, gave an example using the China National development strategies like the "Western Development" and

"Revitalization of the Northeast" that led to more virtual water exports from Northeast and Northwest which in turn intensified the regional water scarcity. Implying that the Northeast and Northwest regions in their implementation of the strategy paid greater attention to economic benefits than to environmental protection. This intensified the water scarcity because these regions chose to sacrifice their scarce water resources in exchange for increase in GDP and to satisfy the water demands of richer regions like Beijing, Shanghai, Guangdong, Shandong, amongst others, thereby turning the two water-scarce regions from net importers to virtual water exporters[19].

1.2 Water and mining

In their research, **Salem et al., (2018)**, explained that mining projects face community opposition in various parts of the world, and water is often perceived as a primary reason for such opposition, especially in regions that suffer from water scarcity. They also mentioned that, despite the proliferation of community conflicts at mine sites, there is a dearth of documented evidence to ascertain the factors that engineers these conflicts, but it is worth nothing that, quantity and the availability of water are the main drivers of those water-related social conflicts with mining companies. While other drivers including the absolute size of mining investments, the amount of tax revenues being redistributed to the regions, and the corruption perception index are the core significant predicting factors.

Mining operations require access to a secure and stable water supply because they are highly associated with water risks[3] (i.e. (i) dryness: having insufficient water to meet production needs, and (ii) wetness: having too much water leading to discharge during high rainfall events[20]) that may be due to water accessibility and surrounding water quality, especially where mines operate in water scarce regions, or upstream of communities that rely on the same water source for consumption or agriculture.

Water scarcity and droughts are not the only challenges, but also pollution is another problematic environmental concern as thousands of kilometers of rivers are heavily polluted by drainage from abandoned coal and hard rock mines[10] hence leaving a serious land degradation and negative effects on the eco-environment, of which the hydrology is a slight target of the harm.

1.3 Laws and enforcements on environmental protection

In an eco-environment where water-based mining operations are being performed under the premises of water scarcity, the enforcement of laws and standards on environmental protection, and license-to-operate requirements are not easy to get by. Obtaining water use and discharge licenses have become increasingly challenging for mining companies in many resources' rich jurisdictions; which can be partly attributed to the competing water usage in water scarce regions and the pollution caused by existing and legacy mines. The quality of a law alone is not necessarily indicative of the level of risk associated with water use in any one country. Political or administrative discretion, respect for the rule of law, and the capacity of a state to monitor and enforce water and environmental regulations are often the crucial factors in determining investment risk related to water use by mining companies[3].

1.4 Surface protection: afforestation, rehabilitation, streetscapes

In the wake of restoring the natural environment as a result of the new industrialized urban growth in a hostile harsh arid region, the greatest challenge is either to waste scarce water resources available or adopt a strategy to managing water use in order to develop the needed streetscapes that can cope with the environmental situation. Thus, it is imperative to adapt a sustainable approach that develops and maintains (saves) water, protects resources and meets the demand of users. These can be achieved by addressing the major challenges related to water issues, climatic conditions, as well as design and planning situations[21].

All the reviewed literature provided a general understanding of water scarcity as a major problem and its effects on eco-environment in the semi-arid and arid regions. Therefore, the aims of this paper is to (i) give a brief overview of the problems associated with mining in a water-scarce eco-environment, (ii) summarize the hydrology and its stability characteristics in a water-scarce eco-environment and (iii) suggest the 4 most "holistic"[22] remediation approaches that can be adopted to address water negatives in a water-scarce mining area.

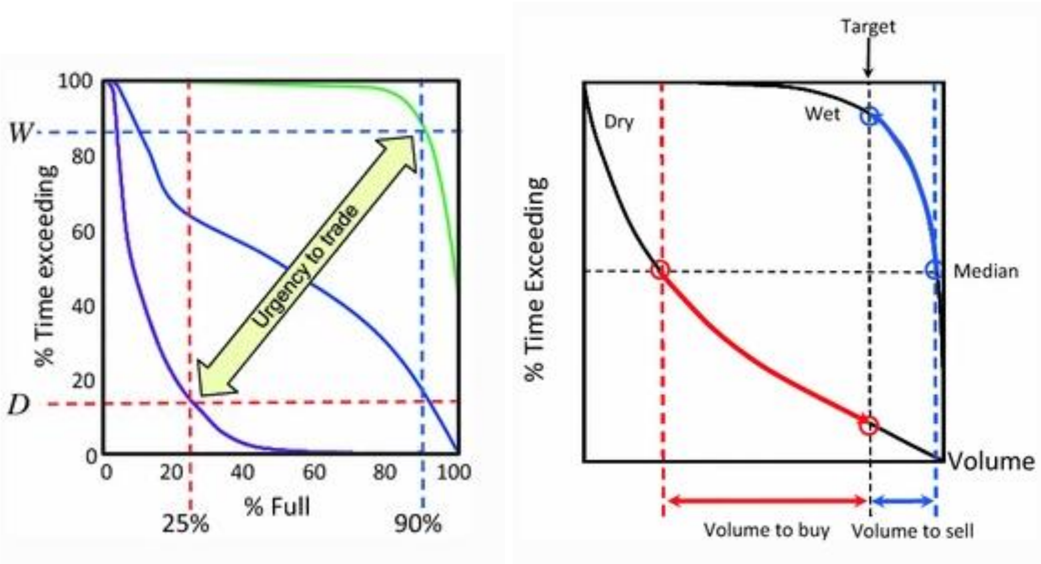
2 Methods for possible solutions to water scarcity problems

The negative effects caused by mining in the water-scarce areas can be remediated by the 4-SuS system. In this 4-SuS system, worked water can be traded among mining companies until it reaches the water-scarce mining area where it would be stored underground, filtered and used during mining operations underground, and can also be pumped back to the surface as fresh-water for surface ecosystem activities. The last setup is a system of stone layer trapped water use, which consists of the possible use of water trapped as aquifers or natural reservoirs which are located near the surface for easy drilling and channeling. The 4-SuS can be converted to a 3-SuS in case the area is too arid to contain stone layer trapped water. This would address the problem of water scarcity which lies at the root of dried soils, dead vegetation, desertification and many other challenging problems. With regards to subsidence, backfilling the dried-up aquifers can be an effective control measure.

2.1 Worked water trade

If mining operations are to continue and water is one of the major needs for its life, then it is crucial to set up measures to protect both the surface and underground ecosystems. This would be possible in the case where water is stored in the underground reservoirs, cleaned or sterilized for the underground use in the mine and/or pumped back to the surface for eco-environmental compliance as shown in Fig. 3*(a)*. To arrive at a consistent system, sometimes mines located in arid or semi-arid regions, such as the Western regions of China, would need to adopt the worked water inter-operability to satisfy the needs of water and to combat the water scrutiny as proposed by **Barret et al., (2010)**. Therefore, a description of worked water set-up is given to understand the desired abidance by the eco-environmental mining impacts remediation in arid and semi-arid regions as shown in Fig. 6 describing the water exceedence situation.

Barret et al., (2010), showed that a site that often becomes too dry has as high risk of losing production due to insufficient water. Conversely, a site that is most often too wet risks penalties associated with discharge. Another pathological case is a site where the storage capacity is not matched to the local climate variability (e.g., too little storage capacity) and rapidly switches from too dry to too wet (or vice versa) as the climate changes. A desirable system is one that is infrequently too wet (i.e., 90% full infrequently) and also not too dry (i.e., not 25% full too frequently).



(a) Worked water exceedence graph *(b) Worked water tradability*

Fig.1: Urgency to trade between mines[23]

In Fig. 1*(a)*, the concave curve (purple) represents a site that is too dry, most often, the convex curve (green) stands for a site that is too wet, most often, and the curve running from top left to bottom right (blue) is from a site that has its water supply and water demand requirements in balance. The 'urgency to trade' water between mines is depicted as the distance on the exceedance graph between the wetness, W, and dryness, D, indices for any pair of sites[23].

Fig. 1*(b),* depicts a schematic diagram of the sale and purchase of water between two mines. For simplicity, it is assumed that both mines have the same volume of storage capacity. The solid black lines show water exceedence curves for a 'dry' and 'wet' mine. The median storage is defined as 50% of the volume of the worked water store 50% of the time (horizontal dashed black line). 'Wet' mines sell water (blue arrow) until the volume drops to the target storage value (vertical dashed black line). 'Dry' mines purchase water (red arrow) until the volume reaches the target value. In this case, the volume to buy is greater than the volume to sell and additional trades are needed to fully satisfy the demand for water by the 'dry' mine as explained by **Barret et al., (2010)**.

The relationship between the wetness W_i (worked water storage is about 90%) and the dryness D_j (for a storage is ≤25%) is depicted and the "urgency to trade" U_{ij}, the site's "need to sell" S_{ij} and "need to buy" $B_{ij}$are defined as follows:

The "urgency to trade" $U_{ij} = |W_i - D_j|$ (1)

where i and j represent two different sites where mines are operating.

The "need to sell" $S_{ij} = W_i U_{ij}$ (2)

The "need to buy" $B_{ij} = D_i U_{ij}$ (3)

The basis for establishing the priority or order in which water trades can occur among sites provided enough water is available to trade is hence provided. However, the further mines are to each other the less likely to trade. So, the 'propensity to trade' index among mines, P_{ij}, which takes into account the need to sell and buy water as well as the Euclidean distance, d_{ij}, between mines are considered;

$$P_{ij} = S_{ij} B_{ij} / \| d_{ij} \| \quad (4)$$

where S_{ij} and B_{ij} represent an individual mine's water status with respect to every other mine within a region. From the above formula, an operating target value for the mine worked water storage must be set. This can be determined individually for each mine depending on local requirements and management approaches[23].

2.2 Water use in underground and/or on surface

While operating in the water-scarce mining area, different activities to be conducted both on the surface and underground require great amounts of water. As proposed by **Kunz and Moran, (2016)**, the worked water can be used for dust suppression in underground and open cut mining, for the relocation of tailing and their reclamation which involves processed infiltrated rainwater, runoff water, water with feed, and third-party water supplies (perennial rivers, etc.) from the surrounding community's environment. There is also dewatering which can be observed from the evaporation, surface water discharge, losses and ground water seepage.

The present and future water scarcity in Switzerland was studied by **Brunner et al., (2019)**, and they revealed the potential for alleviation of scarcity through reservoirs and lakes, and then proposed the supply-demand set-up where it is possible to locate shortage or surplus water volumes depending on seasons as depicted in Fig. 2. The extremes are cases of harsh conditions where shortage is more evident with the need to trade water from the reservoirs and tanks or from the phreatic areas and a surplus situation where dewatering is needed with immediate effect.

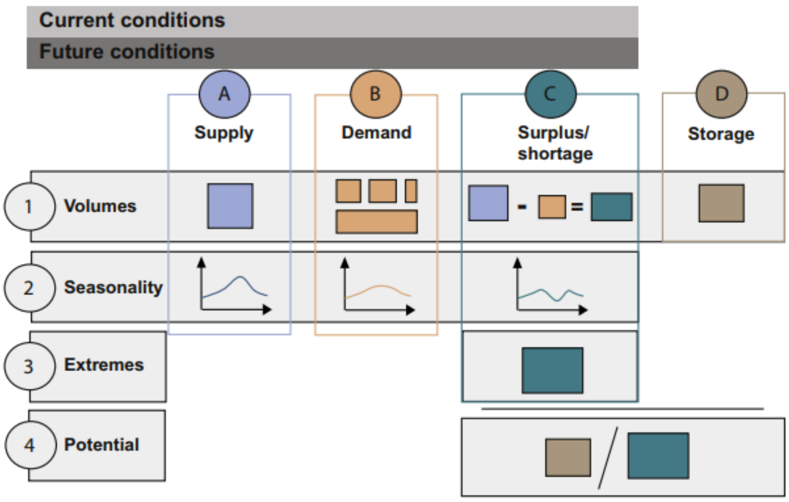


Fig. 2: Study framework: The four elements A) water supply, B) water demand, C) water surplus/shortage, and D) storage capacity is analyzed with respect to 1) volume and 2) seasonality. They are used to assess 3) extremes and 4) the potential of natural lakes and reservoirs for alleviating water shortages[1]

2.3 Dried-up aquifer backfilling

For the dried-up aquifer backfilling, the waste rocks from underground (gangue) are often piled on the surface, and can be mixed with other additives to produce the backfilling materials. Those materials are then sent underground to fill up the voids left when aquifers dry up by the cemented backfilling method. A typical cemented backfill material has the proportion of dry material composed of 35% fly ash, 10% white ash, 2% cement, 53% gangue (as presented in Fig. 3*(a)*), and 79% solid content of slurry[24].

2.4 Stone Layer Trapped Water

Although the mining environment is reclaimed, the landscapes would lack greenery and requires revegetation per the existing environmental situation. Therefore, in-depth understanding of the ecological characteristics of the site is key to effectively reclaim and overcome the scarcity of water and the lack of greenery. Most arid regions are advantaged with the formation of aquifers and stone layers underneath, which can trap some useful water. This can attributed to sedimentary rock layers (about 1-2 meters) under the top soil that holds rain water and the leakages from public water piping system[25] thereby preventing water from seeping deep underground or evaporating due to climate change heating and drying. It is therefore incumbent on the authorities and companies in charge to locate and utilize the trapped water resources in the revegetation process. By so doing the reality of water scarcity that stems from harsh climatic conditions can be overcome, and the revegetation can be achieved by applying the four (4) unique solutions and/or techniques proposed by **BaHammam, (2013)**.

These solutions and/or techniques are:

(i) Planting native or drought tolerant plant species.

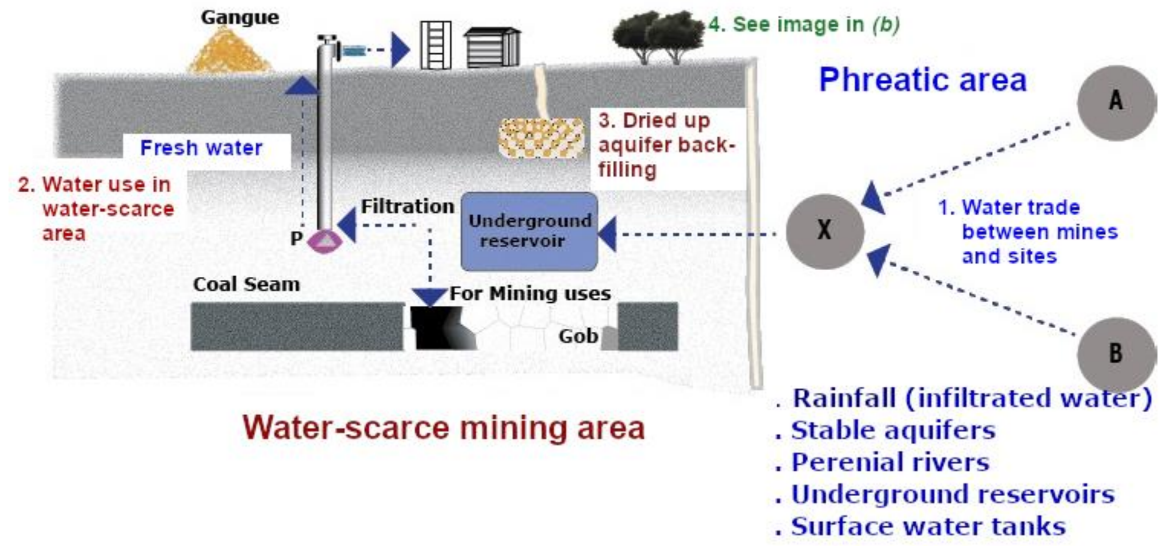
(ii) Relaying on tree form plants in most of its planting projects, for their characteristics in consuming less water.

(iii) Applying modern water conserving techniques such as drip irrigation systems throughout the region’s planting projects.

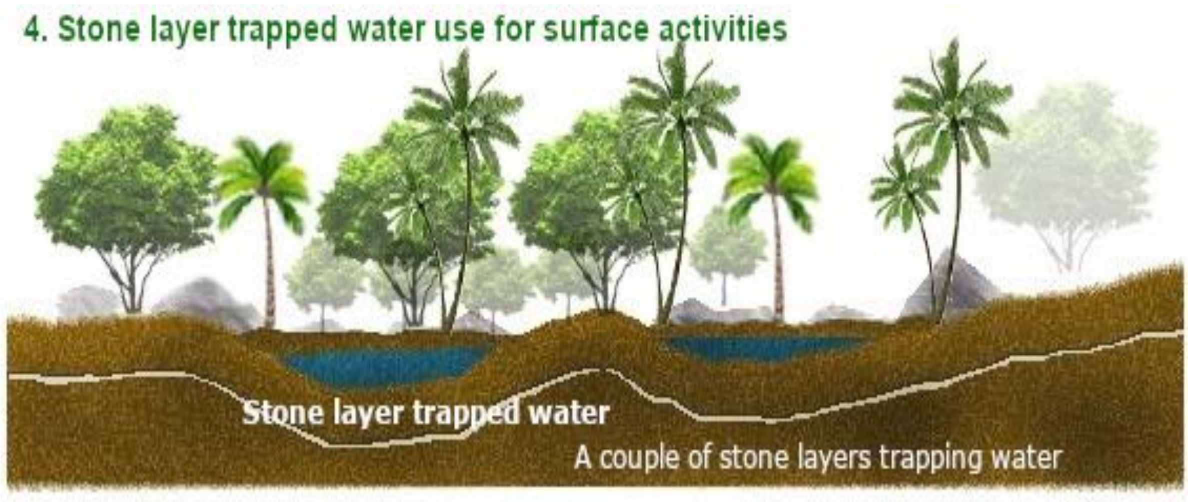
(iv) Utilizing the trapped water near the surface for irrigation, and other uses of positive impacts on the livelihood of humans and ecosystem on the surface.

2.5 The 4-SuS System applied in the water-scarce environment

The 4-SuS system is composed of the 4 different activities that can be executed to complete the full cycle of supplying water and using the supplied water in the water-scarce environment. Those activities, of which the first three are summarized in Fig. 3*(a)* and the fourth in Fig. 3*(b)*, are the following: (1) Trading water from mines located in phreatic area to a designated location X; (2) Supplying water to the water-scarce environment for use, which involves pumping the water to the underground reservoir, filtering before channeling to the working face, and pumping to the surface for surface environment revitalization activities. The underground water reservoir can be designed according to the method developed by **Li et al., (2018)**, for the construction of a Goaf Groundwater Reservoir; (3) Backfilling the dried-up aquifers that are a result of void spaces in the underground space created after the scarcity has caused water to infiltrate and leave an empty space which can later cause subsidence and other unpredicted disasters; and (4) The use of stone layer trapped water as proposed by **BaHammam, (2013)**, in the modified image presented in Fig. 3*(b)* for irrigation and restoration of surface landscapes.



(a) The Three principal activities in the 4-SuS System



(b) The fourth activity is the stone layer-trapped water use: A couple of stone layers trapping water to be utilized on the surface activities, modified from[21]

Fig. 3: The Four-Set-up System (4-SuS)

3 Hydrological compositions in the mining area

The hydrology of a mining area is composed of surface waters (rivers, lakes…) and groundwater (aquifers and aquicludes). The hydrology in a water-scarce mining area is always on track, especially the dry which turns into dried soils, dead vegetation and desertification as a result of problems associated with mining in a water scarce eco-environment. The severity of aridity in the area would suggest the collective measures needed to be taken by mining companies combined with the mining-induced effects; for environmental compliance and ecosystem protection.

3.1 Water sources uneven distribution in water-scarce environment

It is necessary to map up the variation of water-scarcity and discuss the relationship between hydrology and mining in water-scarce environment, as well as the incurring effects on the ecology in the same mining environment.

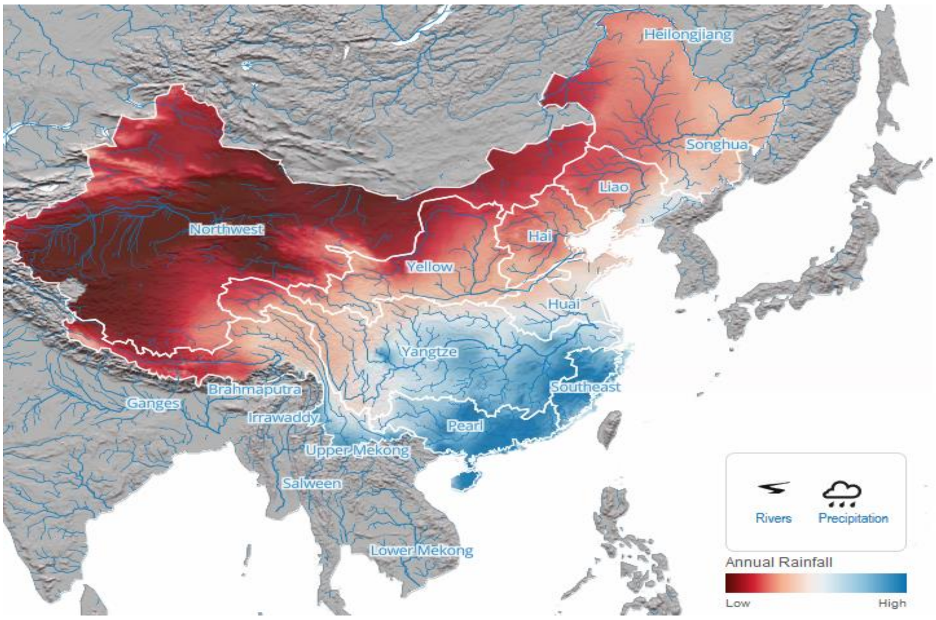


Fig. 4: China's Water Sources[26]

Due to the distribution of precipitation (Fig. 4), it is clear that the zones with high-to-low concentration are water-scarce zones (highlighted red) and those regions highlighted with blue are the phreatic zones. Mining in water-scarce zones would impact the ecology and environment in both negative and positive ways. On one hand, negative effects would be defined in dead vegetation, dried surfaces, intense desertification, and subsidence resulting from the sinking of strata overlying the dried aquifers (Fig. 8, D) and/or poorly supported/backfilled gob. On the other hand, positive impacts would result from good management by mining company owners and the enhanced cooperation with other companies operating in phreatic areas as described in Fig. 6. The positive impacts would include pumping water back to the ground surface for community use, backfilling the dried-up aquifers to prevent subsidence and dewatering, restoration of the ecosystem in the water-scarce zone, and economic upgrades through the trade of water with the phreatic companies.

3.2 Water availability and Virtual water scarcity risk (VWSR)

Fig. 5 shows the flow changes from *a* to *c*. In 2002, the Central and the Northeast regions were the main virtual water exporters whereas the South Coast and Beijing-Tianjin regions were the major importers. By 2007, the Northwest regions had replaced the Central regions and had become the major virtual water exporters; whereas the East Coast changed from major virtual water exporter in 2002 to importer in 2007. By 2012, the position of the major virtual water exporters of the Northwest and Northeast regions further strengthened while the major importers changed from East coast to the South and North coast regions[19].

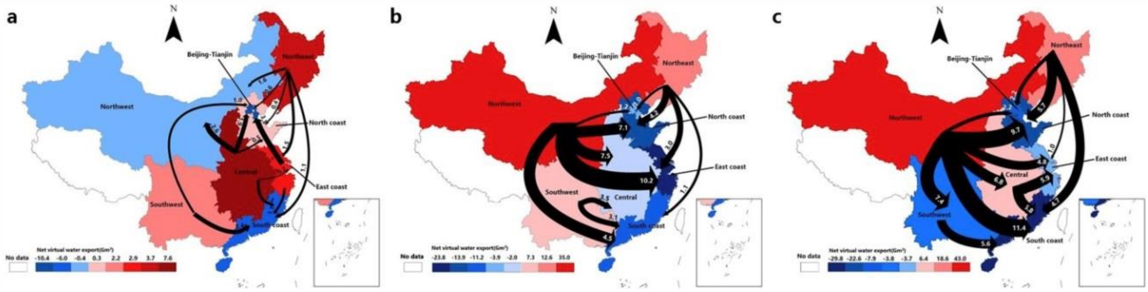


Fig. 5: Virtual water balance per economic region and the largest net virtual water flows are shown in China at 2002 (a), 2007 (b) and 2012 (c). Note that, only net water export of >0.2 Gm^3/y are labeled in (a) and >0.1 Gm^3/y are labeled in (b) and (c). (After **Cai et al., (2019)**)

The virtual water flows between different provinces from 2002 to 2012 intensified the water scarcity situation of the less developed central and western regions, which were also the major water exporters. Water scarce provinces, i.e., Xinjiang and Heilongjiang, were the two major virtual water exporters. These two provinces (Xinjiang and Heilongjiang) exported 48.2% and 23.8% of the respective provincial water withdrawal in 2002 and the shares increased to 64.6% and 78.3% in 2012, respectively. Also, other water-scarce provinces including Hubei, Hebei and Anhui were also major exporters in 2002, 2007 and 2012. In 2002, Beijing, Gansu and Hainan were the major virtual water importers, which accounted for about one-fifth of the total virtual water imported. The major virtual water importers changed to Shandong, Zhejiang and Guangdong in 2007 and 2012 and these three provinces accounted for more than 27% of the total virtual water imported. There were more than eight provinces facing water scarcity that benefited from the virtual water flows during the study period (i.e., nine in 2002, eleven in 2007 and eight in 2012).

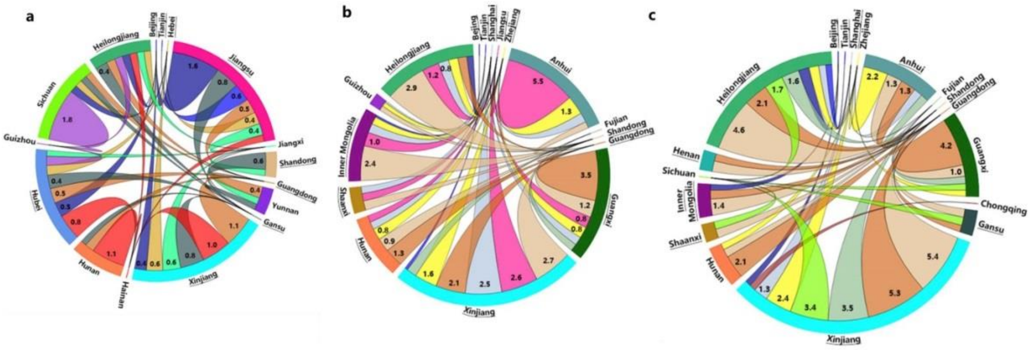


Fig. 6: Virtual water flows between provinces in 2002 (a), 2007 (b) and 2012 (c). The numbers refer to net virtual water exports in Gm^3[19]

The regions with the same color in the circle are net importers, while the others are net exporters. The underlined regions faced water scarcity issues. Only net water exports of >0.4, >0.6 and > 1.0 Gm3/y are labeled in (a), (b) and (c), respectively[19] without color interpretation.

Globally, water availability data of nations under the future climate change are often sourced using the Water Resource Institute (WRI)[27] based on the CIMP5 Model which covers average water resource changes from a baseline period in the past to the future period under two types of climate change scenarios of Representative Concentration Pathways (RCP) as stated by **Zhao et al., (2019)**. The First scenario is RCP 8.5 also known as Business As Usual (BAU) scenario and the second being the RCP 4.5 referred to as the

Optimistic scenario. Total blue water in all catchments in each country are summed up, and then overlaps in water supply across different basins are deducted based on the basins' identification in the set of data available. The determination of average water availability in the future period in each country, the water availability volume of each catchment is divided according to the area of different catchments accounted for in different countries. For the existing water availability data, the **FAO AQUASTAT, (2015)** indicators of total renewable water resources, and that studied by **Hoekstra et al., (2012)**, are collected for water scarcity measurements to reflect environmental requirements.

The fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) concluded that climate change would have a significant impact on global water resources. Therefore, the risk of loss in production due to water scarcity can be transmitted through international trade to distant economies downstream the supply chain. The only way to stabilize the hydrology in water-scarce regions is to improve water efficiency in critical sectors, such as mining in an environment with higher VWSR, which is essential for increasing the resilience of the global economy against climate change-induced water scarcity[28]. They also cited some nation-sectors with the largest VWSR, such as Petroleum, Chemical and Non-metallic Mineral Products in Syria, Pakistan, Kazakhstan, India, Uzbekistan, Iran and China exports while in Saudi Arabia, US, Russia, Germany, Italy, and China have high water demand due to the scarcity of water with respect to climate change. Therefore, the trade between those regions is defined in Fig. 7 by presenting the world map of climate change-induced VWSR export and import, which demonstrates the transmission of water scarcity risks via international trade under the BAU Scenarios.

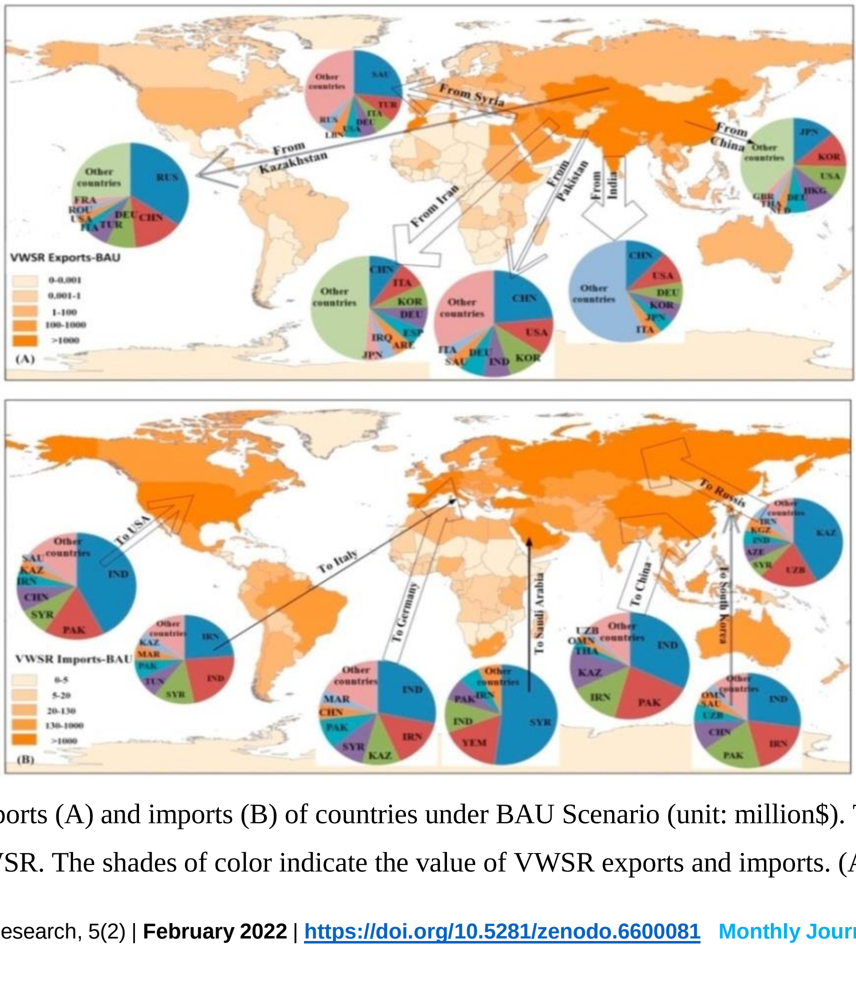


Fig. 7: VWSR exports (A) and imports (B) of countries under BAU Scenario (unit: million$). The arrow width is proportional to the VWSR. The shades of color indicate the value of VWSR exports and imports. (After **Cai et al., (2019)**)

4 Problems associated with mining in an eco-hydrological environment

4.1 Drawdown of water level and reduced or dried up surface water

After mining in an area, sometimes groundwater (aquifers) seeps into the gobs through fractured zones, thereby causing in-rush accidents due to the mining operations' inability to provide efficient support for the overburden. Through the same fractures, surface waters including lake and river levels experience a drawdown while some dry up thereby bringing about water scarcity[23].

4.2 Dried-up soil, dead vegetation and desertification

An example is taken from the Alcoa of Australia bauxite mines for the production of alumina located in the Western Australia's Darling Ranges extends from the east of Perth to Collie. **Grant and Koch, (2007)**, reported on the technical advices and recommendations provided to Alcoa's bauxite mining operations on the hydrology and stream zone ecology so as to successfully attain the following objectives for the protection of vegetation in the mining areas and as an emphasis on enhancing the main mechanisms for minimizing mine rehabilitation impacts on stream flows:

(i) Minimize salinity risks associated with mining in the intermediate rainfall zone, where clearing of the natural vegetation could cause secondary salinity if not properly managed, and

(ii) Minimize impacts of mine rehabilitation on catchment water yields and riparian ecosystems caused by high water use of dense, regrowth forests. This issue has exacerbated the severe decline in water inflow to Perth's water supply dams experienced in recent years due to the drying climate [29].

All those risks and negative impacts caused by mining operations that do not consider damages such as surface runoff, dried soil, intensified desertification and subsidence form a great challenge to the development of the mining industry and to the wellbeing of the ecological environment.

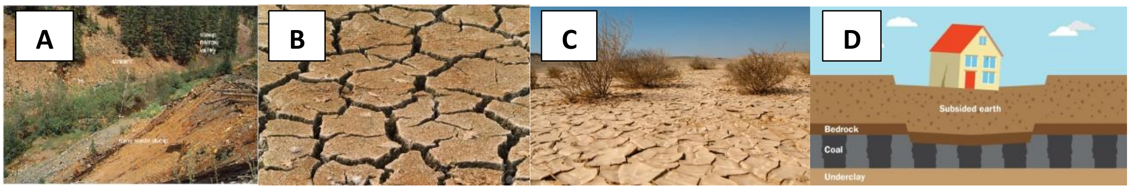


Fig. 8: Negative effects of mining on the eco-environment of water-scarce areas[30]

The picture in Fig. 8 A represents a typical abandoned mine waste dump at Rocky Mountains in the U.S. Oxidized ore and soil developed from mine waste material form a steep slope in a narrow valley drained by a perennial stream. Surface runoff water from solids on the dump and infiltration into the dump adds sediments and dissolved metals to the stream. The underground mine in Fig. 8A exploited tungsten skarn deposit that was last worked in 1955. The remaining pictures in Fig. 8B, C and D depict dried soil, intensified desertification and subsidence, respectively.

5 Conclusions

After reviewing the existing literature on water scarcity and studying possible methods that can be used to revitalize the life of any water-scarce mining eco-environment, conclusions were made according to the approach proposed and relevant to the conditions of the ground environment of the mining area as follows:

It is possible to fight water scarcity using the water trade strategy, which consists of trading water between mines and sites, by safely storing the traded water in the underground and/or surface reservoirs to be used for different activities in the underground and on the surface.

The traded water, once supplied to the water-scarce environment, is filtrated to make it fresh for use in different human-led daily life activities in the area using different filtration and pumping methods.

In the water-scarce mining area, aquifers dry up after some time leaving voids in the underground space; which can cause damages and disasters to the actual setting of the area. Therefore, it is possible to backfill dried up aquifers using different backfilling methods such as the cemented backfilling developed and applied by[24].

Even though aquifers dry up due to the severity of aridity in the water-scarce mining area, there is the possibility to find stone layer trapped water which can be located closer to the surface layers or deep in the underground. In this case, the closer stone layer-trapped water can be drilled and used for irrigation and other different surface uses.

All the activities involved in the 4-SuS system proposed in this review are costly. Since no cost consideration was made in this paper, we expect to conduct a deep detailed study on the financial structure for the 4-SuS system to bring it to the possible applicability in not only water-scarce mining areas but also in any water-scarce area including deserts where resources are discoverable but difficult to exploit.

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Disclosure of Conflicts of interest

Authors of this article declare no conflict of interest.

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