Global Environmental Change 44 (2017) 109–124

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

The exposure of global base metal resources to water criticality, scarcity and climate change

Stephen A. Northey[a,b,*], Gavin M. Mudd[a,1], Timothy T. Werner[a], Simon M. Jowitt[c], Nawshad Haque[b], Mohan Yellishetty[a], Zhehan Weng[a]

[a] Faculty of Engineering, Monash University, Clayton, VIC, Australia
[b] CSIRO Mineral Resources, Clayton, VIC, Australia
[c] Department of Geoscience, University of Nevada, Las Vegas, 4540 S Maryland Pkwy, NV 89154-4010, USA

ARTICLE INFO

Keywords:
Base metal mining
Copper
Lead-zinc
Nickel
Water risk
Climate change

ABSTRACT

Mining operations are vital to sustaining our modern way of life and are often located in areas that have limited water supplies or are at an increased risk of the effects of climate change. However, few studies have considered the interactions between the mining industry and water resources on a global scale. These interactions are often complex and site specific, and so an understanding of the local water contexts of individual mining projects is required before associated risks can be adequately assessed. Here, we address this important issue by providing the first quantitative assessment of the contextual water risks facing the global base metal mining industry, focusing on the location of known copper, lead, zinc and nickel resources.

The relative exposure of copper, lead-zinc and nickel resources to water risks were assessed by considering a variety of spatial water indices, with each providing a different perspective of contextual water risks. Provincial data was considered for water criticality (CRIT), supply risk (SR), vulnerability to supply restrictions (VSR) and the environmental implications (EI) of water use. Additionally, watershed or sub-basin scale data for blue water scarcity (BWS), the water stress index (WSI), the available water remaining (AWaRe), basin internal evaporation recycling (BIER) ratios and the water depletion index (WDI) were also considered, as these have particular relevance for life cycle assessment and water footprint studies. All of the indices indicate that global copper resources are more exposed to water risks than lead-zinc or nickel resources, in part due to the large copper endowment of countries such as Chile and Peru that experience high water criticality, stress and scarcity. Copper resources are located in regions where water consumption is more likely to contribute to long-term decreases in water availability and also where evaporation is less likely to re-precipitate in the same drainage basin to cause surface-runoff or groundwater recharge.

The global resource datasets were also assessed against regional Köppen-Geiger climate classifications for the observed period 1951–2000 and changes to 2100 using the Intergovernmental Panel on Climate Change's A1FI, A2, B1 and B2 emission scenarios. The results indicate that regions containing copper resources are also more exposed to likely changes in climate than those containing lead-zinc or nickel resources. Overall, regions containing 27–32% (473–574 Mt Cu) of copper, 17–29% (139–241 Mt Pb + Zn) of lead-zinc and 6–13% (19–39 Mt Ni) of nickel resources may have a major climate re-classification as a result of anthropogenic climate change. A further 15–23% (262–412 Mt) of copper, 23–32% (195–270 Mt) of lead-zinc and 29–32% (84–94 Mt) of nickel are exposed to regional precipitation or temperature sub-classification changes. These climate changes are likely to alter the water balance, water quality and infrastructure risks at mining and mineral processing operations. Effective management of long-term changes to mine site water and climate risks requires the further adoption of anticipatory risk management strategies.

1. Introduction

The mining industry spans all hydrological contexts and climate regions, with these contexts influencing the water risks facing mining operations and the potential for the industry to impact surrounding ecosystems, industries and communities. Access to water is a potential

* Corresponding author at: Faculty of Engineering, Monash University, Clayton, VIC, Australia.
E-mail addresses: stephen.northey@monash.edu, stephen.northey@csiro.au, stephen.northey@gmail.com (S.A. Northey).
[1] Present address: Environmental Engineering, RMIT University, Melbourne, Australia.

http://dx.doi.org/10.1016/j.gloenvcha.2017.04.004
Received 17 October 2016; Received in revised form 22 March 2017; Accepted 10 April 2017

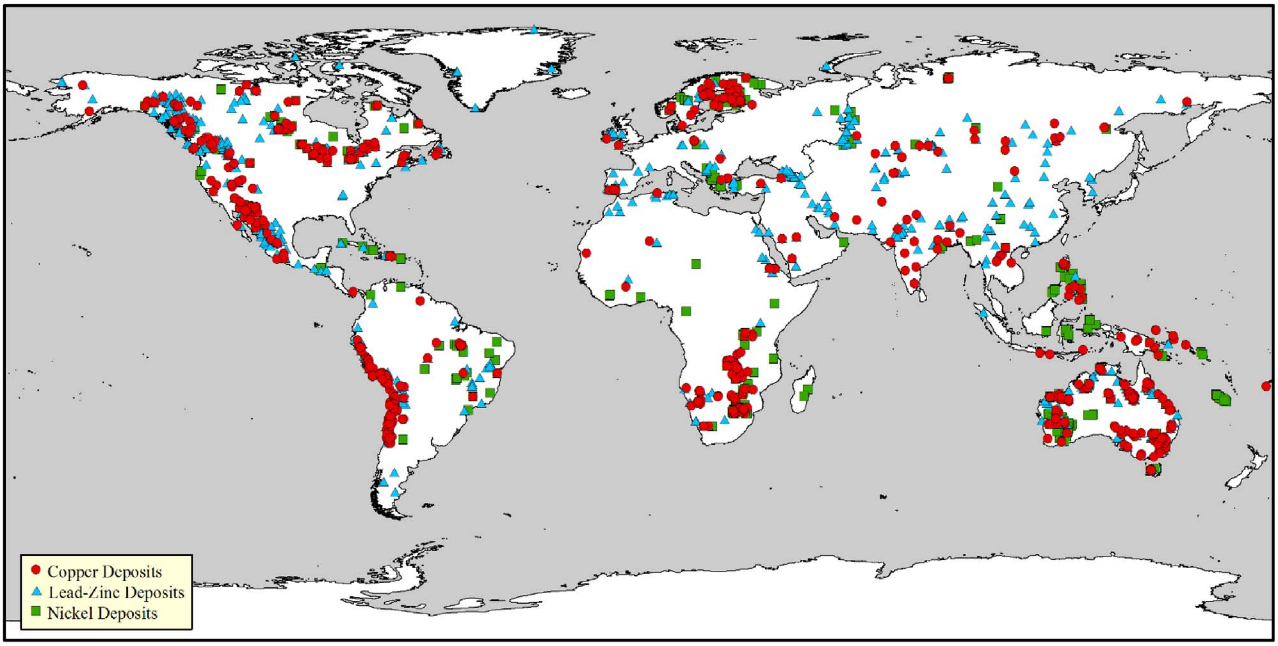

Fig. 1. Location of copper, lead-zinc and nickel resources considered in this study. Maps showing mineral deposit types and operating status are shown in electronic supplementary Figs. S.1–S.5. Raw data provided in supplementary Tables S.24–S.26 and in Google Earth format (.kmz).

constraining factor on mineral resource development, regardless of the climate and absolute water scarcity of a region. The presence of other competing water users, such as agriculture, may limit the ability to allocate water resources to the mining industry (e.g. Shang et al., 2016). Concerns over water may also change community support and reduce a mine's perceived social license to operate (Wessman et al., 2014). Assessing these risks requires the use of systems approaches that can integrate mine site water balances, catchment hydrology and the water use requirements of regions.

Mine sites utilise water in a range of processes, such as mineral processing and dust suppression, and the overall water requirements are highly variable due to factors such as: the local climate, ore mineralogy and grade, the scale of infrastructure and ore processing, and the extent of tailings dewatering and water recycling (Gunson et al., 2012; Mudd, 2008; Northey et al., 2013, 2014a, 2016). The local nature of mine site water use impacts has impeded the ability to produce global scale assessments of the water risks associated with the industry. Previous research has outlined global estimates of the water withdrawals associated with non-fuel mining (Gunson, 2013), however drawing meaningful conclusions requires understanding where this water use occurs. Improving the outcomes of these studies requires knowledge of how the spatial distribution of the mining industry relates to local contexts and environmental pressures. Global assessments have been conducted to assess the distribution of the mining industry in relation to biodiversity and conservation areas (Durán et al., 2013; Murguía et al., 2016). However, to date there have been no quantitative global assessments of the contextual water risks facing the mining industry.

This article presents a detailed assessment of the spatial distribution of known base metal resources in relation to a variety of water risk and impact indices. The assessment focuses on copper, lead-zinc and nickel resources as these metals are vital for modern infrastructure and are expected to have continued or growing demand into the future (Daigo et al., 2014; Elshkaki et al., 2016; Kleijn et al., 2011). The exposure of regions containing these resources to climate change has also been assessed by considering regional data for Köppen-Geiger climate classifications and how these may evolve with climate change (Kottek et al., 2006; Rubel and Kottek, 2010). The information and data provided by this study may form a basis for further assessment of the global base metals industry to understand climate change adaptation requirements, water footprint or life cycle impacts, and expected changes to mine site water balance, water quality and infrastructure risks.

2. Methods and data sources

2.1. Copper, lead-zinc and nickel resource datasets

This study utilises datasets for individual copper (Mudd et al., 2013), lead-zinc (Mudd et al., 2017) and nickel (Mudd and Jowitt, 2014) resources that were developed over several years and are primarily based upon the mineral resource reporting of individual exploration and mining companies. Typically these resource disclosures are made as part of a company's statutory or financial reporting obligations. The copper dataset includes resource data for 730 deposits containing 1781 million tonnes (Mt) of copper (363,270 Mt ore @ 0.49% Cu; Mudd et al., 2013). The lead-zinc dataset includes resource data for 852 deposits representing a combined resource of 837 Mt lead-zinc (50,882 Mt ore @ 1.64% Pb + Zn; Mudd et al., 2017). While, the nickel dataset includes data for 476 deposits containing 293 Mt of nickel (61,365 Mt ore @ 0.48% Ni; Mudd and Jowitt, 2014). Individual deposits in these datasets have been classified according to primary and/or dominant mineral deposit types (e.g. Jowitt et al., 2013). Individual resources in the datasets have also been classified as being either an undeveloped deposit or a recently operating mine-site, based upon the status of the deposit for the year the dataset was compiled (Copper: 2010; Lead-Zinc: 2013; Nickel: 2011). The datasets provide minimum estimates of known resources and so the results presented represent the minimum exposed resource to the various water and climate risks.

Coordinate data (latitude and longitude) for individual deposits within the datasets have been added and crosschecked from a range of sources, including government geological organisations (the United States Geological Survey, the British Columbia Geological Survey, Geoscience Australia, Geological Survey of Finland, etc.), online resources (company websites, mindat.org, dmgeode.com, etc.), consultant databases (e.g. SNL database), scholarly literature (journals, conference proceedings, books, etc.), and company technical reports