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How Should Mine Reclamation Design Effectively Respond to Climate Change? A Mini Review Opinion

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Abstract

Climate change is a growing concern with each of the last three decades being successively warmer than preceding decades. Mine wastes are mandatory required to be reclaimed after mine operation due to their high risks of contaminating environment and huge volumes occupying large useable land resources. However, most traditional mine reclamation plans are designed with an assumption of unchanged, consistent conditions of environment, climate and hydrology conditions, which may not work properly under the global climate change. This paper discussed the previously ignored problem that is how mine reclamation design should effectively respond to climate change. Through reviewing the current responding strategy to the climate change during mine reclamation and closure, this mini review was structured, and the opinion is concluded that the more active the designers consider the factors of climate change, the more manageable, predictable and sustainable the reclaimed ecosystem and landscape are. Nature-based solutions can act as the general guidelines when considering climate change with mine reclamation, and the six-step framework aims more specifically on mine reclamation. The two methods can work together to help designers and regulators to effectively respond to climate change when planning mine reclamation and closure.

Keywords

Climate Change, Mine Reclamation, Mine Closure, Nature-Based Solutions, Six-Step Framework

1. Introduction

Climate change is a growing concern with each of the last three decades being successively warmer than preceding decades, resulting in impacts from climate

change are being observed globally (Woodward et al., 2014). In some tropical regions the impacts of climate change take the form of more severe weather events such as hurricanes and tropical storms intense precipitation events, and longer periods of drought. These impacts in turn affect various component of environment and sectors of economy. For examples, changing precipitation patterns are observed by means of altering the hydrologic systems, affecting the quality and quantity of water resources. The increasing frequency and severity of hurricanes and tropical storms are another concern, resulting in significant environmental and economic damages. Moreover, the changing climate can impact communities in many ways and adds to the challenges of high and often fluctuating costs of infrastructure, energy and water supply, and promoting sustainable development that balances consideration of environmental, social and economic well-being.

Reclamation aims to maintain environmental quality and enhance land management capacity, implying a fundamental recovery of eco-friendly systems (Haigh, 2007; Xie & van Zyl, 2020). What mine reclamation does is converting disturbed mining lands and surfaces of mine wastes to a natural or economically usable state after mine closure or tailings facilities decommissioning. Due to the devastating effects by mining activities and the importance of recovering mine environment, mine reclamation should be planned before mining and implemented after mine operation and facilities decommissioning. One of objectives of mine reclamation is the development of an aesthetic appearance on the surface of the mine wastes, usually by establishing vegetation (Ritcey, 1989).

However, most traditional mine reclamation plans are designed with an assumption of unchanged, consistent conditions of environment, climate and hydrology conditions, which may not work properly under the global climate change (Rooney, Robinson, & Petrone, 2015). The influence of climate change on mine reclamation has been largely ignored by scientists, designers and regulators, even though thousands of hectares of land resources need to be restored during mine reclamation with a long timeframe. Most current research focuses on the global policies of climate change, but the impacts on and responses from the mining industry are limited. While some leading mining companies are taking actions to make sophisticated and integrated approaches to help them response and manage risks, there are still considerable challenges being embedded management of climate change impacts across the industry, especially the process of mine reclamation and closure.

This review introduces how climate change is influencing the mine reclamation and how mining companies should response to the consequences of climate change. Apparently, the more active the designers consider the factors of climate change, the more manageable, predictable and sustainable the reclaimed ecosystem and landscape are. The objective is to introduce two practical and helpful methods for strategy-designing when designing mine reclamation and closure plan adapting to climate change on through literature review. Nature-based so-

lutions can be act as the general guidelines when considering climate change with mine reclamation, and the six-step framework aims more specifically on mine reclamation. The two methods can work together to help designers and regulators to effectively respond to climate change when planning mine reclamation and closure.

2. Mine Reclamation Design

2.1. Traditional Mine Reclamation Design

Traditional mine reclamation design commonly involves combining covers on top of mine wastes following mine closure. Three independent types of cover for reclamation measures have been classified by former researchers: physical cover, chemical cover and vegetation cover (Wang et al., 2017). Physical cover by enclosing with coarse rock, soil or other materials with low-permeability to form a cover will result in the reduction of water infiltration, gas diffusion or capillary (Rogers et al., 1984; Waugh et al., 2015). Chemical cover that allows interaction with the fine tailings to form a hardpan or that aim to convert the toxic components so that they are resistant to weathering and leaching, thus minimizing the environmental problems, including migration of acid mine drainage and transport of heavy metals (Ritcey, 1989; Zeng, 2017). Vegetation cover is planting on the mine wastes that can result in a protective barrier from wind and water erosion and for the reduction of drainage downward and heavy metals transport, and as well as an aesthetic landscape for the sites (Chen et al., 2018; Leroy, 1973).

Actually, since tailings facilities or mine wastes dumps are usually quite large and occupy a large area of land resources, recovering the mine wastes surface to an aesthetic landscape for future land uses becomes the most significant and the ultimate purpose for mine wastes reclamation (Ritcey, 1989). Therefore, establishing revegetation on the upper layer of the tailings storage facilities or mine wastes dumps has the potential to achieve the objective of achieving aesthetic appearance and a long-term self-sustainable system (Farmer & Richardson, 1981). Especially the entire landscape design for reclamation involves ecological and hydrological aspects integrated with each other in large mine reclamation projects.

2.2. Conflicts with Climate Change

Unfortunately, most reclamation plans are designed with an assumption of unchanged, consistent conditions of environment, climate and hydrology conditions, which may not work properly under the global climate change (Rooney et al., 2015). Typically the mine reclamation always needs to recover thousands of hectares of land resources and have a very long timeframes, but the potential effects of climate change has been neglected by designers and regulators. Even in academia, the influence of climate change on mine reclamation has been largely ignored by scientists, with only few exceptions (Alam et al., 2018; Devito et al., 2005; Foote, 2012; Rooney et al., 2015; Vo et al., 2014).

Wang et al. focuses on the process and mechanism of migrant–reclamation in Northeast China in response to climatic disasters over the past 300 years (Wang, & Yang, 2001). Ye et al. use comparative analysis of key interlinked factors in this response involving drought/flood events, population, cropland area, farmer revolts, administrations establishment, and land reclamation policies (Ye et al., 2012). Mid-point characterization models were preferred over damage-oriented (end-point) characterization models because of their high levels of uncertainties (Ditsele & Awuah-Offei, 2012). Carbon storage in biosolids-amended and conventionally reclaimed mine soils several years were compared after closure (Trlica & Teshima, 2011). Wastewater reclamation and reuse also were studied for providing a thorough understanding about the consequences of the climate change (Vo et al., 2014). Obviously there is limited research about impacts of climate change on reclamation, and also research gap on policies and strategies that mine reclamation designs should response to the changing climate.

3. Responses to Climate Change

In order to tackle with the challenges caused by climate change, the World Bank firstly introduced the concept the Nature-based solutions in 2000 to migrate the impacts on biodiversity and ecosystem, which can act as the general guidelines for customizing the mine reclamation designs to the changing climate. There are different technical terms regarding the recovery of mine environment: restoration, reclamation, remediation and rehabilitation (Lima et al., 2016), whereas all of them can be conducted and planed under the guideline of Nature-based Solutions as long as involving revegetation and ecosystem establishment. Another set of framework was introduced by researchers from University of Waterloo that is a six-step framework to improve the success chances for mine reclamation projects and control mine closure costs with long-term climate change. This framework targets closely on mine reclamation, which is a more useful and handful tool for designers and regulators to assess and mitigate the impact of climate change.

3.1. Nature-Based Solutions

The concept of "Nature-based solutions" (NbS) was introduced towards the end of the 2000s by the World Bank (Mackinnon et al., 2008) and IUCN (2009) to highlight the importance of biodiversity conservation for climate change mitigation and adaptation (Pauleit et al., 2017). Nature-based solutions (NbS) are solutions to societal challenges that involve working with nature to deliver benefits for people and biodiversity. They include the protection, restoration or management of natural and semi-natural ecosystems; the sustainable management of productive land and seascapes; or the creation of novel ecosystems in and around cities (Cohen-Shacham et al., 2016). Moreover, it is noticeable that NbS can be cost-effective and that benefits range from environmental protection to creating jobs and stimulating innovation for a green economy (Pauleit et al.,

2017). Well-designed NbS can contribute to tackling climate change and biodiversity loss, whilst supporting many other sustainable development goals, but poorly designed schemes can have adverse impacts (Seddon, 2021). Seddon et al. developed four evidence-based guidelines for delivering successful, sustainable NbS with long term benefits for people and nature in 2021 (Seddon et al., 2021):

- NbS are not an alternative choice for the rapid phase-out of fossil fuels and should not postpone urgent action to decarbonize our economies.
- NbS contain the protection, restoration and/or management of a wide range of natural and semi-natural ecosystems on land and in the ocean, the sustainable management of aquatic systems and operating lands, or the introduction of novel ecosystems in and around cities or throughout the broader landscape.
- NbS are designed, implemented, controlled and monitored by or in corporation with Indigenous peoples and local communities through a process that completely respects and champions community rights and knowledge, and generates community benefits.
- NbS support or promote biodiversity that is the diversity of life forms from the level of the gene to the level of the whole ecosystem.

3.2. A Six-Step Framework

There are so many environmental issues caused by climate change that may have serious effects on the ecosystem established on reclamation land, e.g.: storm, drought, flood, wildfire, habitats conditions changing, etc. In order to take into account the effects of climate change, researchers at the University of Waterloo suggested a six-step framework to improve the success chances for mine reclamation projects and control mine closure costs with long-term climate change. Rooney et al. stated the workflow can also help reconcile the government-mandated mine closing procedures because regulators currently do not require mining companies to incorporate predictive modeling into reclamation designs (Manning, 2015).

The six-step workflow includes three steps to aim on being capable of adapting to the changing climate and other three to ensure that targets at the habitat patch and landscape levels resemble natural analogues (Rooney et al., 2015). If integrated, this workflow should be able to provide a more scientifically approach to adjust reclamation targets that are not only natural-looking and being integrated with surrounding lands, but would be self-sustainable under the changing climate conditions. These six steps are:

- Step 1: Climate model is to identify future capability of regional climate being envelopes with multiple scenarios and models to seize uncertainty under climate change.
- Step 2: Hydrological model is to estimate effects of various climate pathways on hydrologic processes and then to establish the water budget for reclamation.
- Step 3: Bioclimate classification is the combination of climate variables such

as timing of snow melt, length of growing period and hydrologic variables such as precipitation to potential evapotranspiration ratio. The bioclimate classification identifies reclamation targets that would be self-sustainable and capable of integration with restored land.

- Step 4: Landscape model is to locate low-disturbance regions currently within that climate envelope possessing similar geomorphology and soils to the mined area, and then to characterize their habitats composition and configuration as reference landscapes.
- Step 5: Habitat model is to characterize the biotic and abiotic conditions of habitats or ecosystem within reference landscapes to identify various levels of targets.
- Step 6: Closure plan design is to integrate climate-suitable habitat patches in a configuration property of reference landscapes to produce climate-suitable reclamation targets, at the landscape level, which would have a natural appearance and be self-sustainable within the constraints of the water budget.

3.3. Recommendations

Except for the above two useful methods, other components are also recommended to be considered to establish adaption strategies to climate change during decision-making of mine reclamation and closure.

1) Interact with stakeholders, such as local communities and mining companies to understand their concerns to climate change, and to develop concrete adaption plans to the consequences of climate change. Factors needed to be considered include environment, ecosystem, financial cost, end land uses, local benefits, post-closure strategies, water management, emergence response capabilities etc.

2) The government establishes climate adaption development into initiatives or regulations, which is helpful for the sustainable local benefits. As every mine site has different situations, climate conditions, and the end closure goals, it is important that the mine reclamation and closure plan would be required by regulations to clarify how the closure project can response specifically to the climate change in the local region.

3) Refer to the experiences from cross-industry communications of the local regional climate adaption plan. Climate change may have impacts on global as well as regional areas and be faced by multi-industries, so the adaption strategies should also exist in any industry such as energy, agriculture, construction, transportation, etc. Sharing information of the complimentary work and exploring opportunities to collaborate cross various industries provide a valuable way to seek the best practices for climate adaption when it comes to design the locally specific mine reclamation and closure plan.

4. Conclusion and Future Perspectives

The impacts of climate change on mine reclamation and its long-term ecosystem

restoration should be actively considered during the planning stage. The more active the designers consider the factors of climate change, the more manageable, predictable and sustainable the reclaimed ecosystem and landscape are. Nature-based solutions can act as the general guidelines when considering climate change with mine reclamation, and the six-step framework aims more specifically on mine reclamation. The two methods can work together to help designers and regulators to effectively respond to climate change when planning mine reclamation. Thus, the mining industry can play a critical role in contributing environmental protection and mitigation of climate change. Climate adaption strategies of mine reclamation and closure plan may vary from mine to mine, given the diversity of geographies and various closure end purposes by the stakeholders. However, wherever the mine site is located, integrating well-considered climate adaption strategies into the mine reclamation and closure plan can make a significant difference to the mining environment and the industry.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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