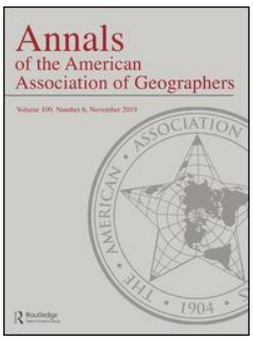

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A Transboundary Political Ecology of Volcanic Sand Mining

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Sand, the main ingredient of cement, glass, and asphalt, is being mined for urban development and global production at a pace that exceeds natural renewal. Yet research on the sustainability of sand mining has concentrated on extraction rates and socioecological impacts in rivers and coastlines. The potential of active volcanoes to generate a renewable supply of sand through cyclical or intermittent eruptions has been understudied, as have the asymmetrical power relations that animate around this dangerous but financially lucrative industry. This article uses a transboundary political ecology framework to examine the geographically dispersed development interests that drive volcanic sand mining on Mount Merapi, Indonesia's most active stratovolcano. I argue that to make Mount Merapi's volcanic sand trade more sustainable, collaborative forms of environmental governance are needed to bridge critical gaps in knowledge about industry practices that create environmental impacts extending well beyond the volcano's slopes. I develop this argument through three sets of transboundary political ecology themes centered on (1) knowledge boundaries that inform differentiated place-based practices; (2) the transboundary governance dilemma posed by disconnects between upstream mining practices and downstream environmental impacts; and (3) the potential of cross-border governance networks to collaboratively address these policy deficits.
Key Words: environmental governance, extraction frontiers, political ecology, sustainability.

Sand scarcity is a global sustainability challenge. With construction industry demands tripling over the past two decades (Cousins 2019) and an estimated 32 billion to 50 billion metric tons of sand used for glass, concrete, asphalt, and electronics annually, sand and gravel are among the most extracted materials in the world (Bendixen, Best, et al. 2019). Sand and sediment shortages, combined with accumulating evidence of the damage to local ecologies and ecosystem services generated by the removal of large volumes of sand and nutrients from the world's rivers and coastlines, has inspired a search for sustainable alternatives (Torres et al. 2017; Bendixen, Overeem, et al. 2019).

Very little is known about the sustainability of sand mining on active and frequently erupting volcanoes relative to riverbed or beach sand mining. Studies of volcanoes are dominated by volcanologists and other physical scientists whose emphasis on geophysical processes rarely encompasses the "social volcanology" (Donovan 2010b) of sand mining. Although pyroclastic materials released through cyclical or intermittent eruptions have been proposed as a sustainable resource (Okwadha and Ngengi 2016), empirical studies are lacking. Existing research is mainly confined to community-level perceptions that volcanic quarrying using controlled sediment extraction techniques could, or does, provide an effective disaster mitigation strategy in regulating the volume and location of sediment unloading (Ikhsan, Sulaiman, and Fujita 2008; Rianto 2009; Ikhsan, Fujita, and Takebayashi 2009; Otani and Suharyanto 2012).

This article aims to increase social scientific knowledge of the diverse development interests that drive this understudied industry. The same political and economic factors that produce sand scarcity in riverbeds and on beaches are now leading the exploration of new frontiers for resource exploitation in volcanic landscapes. Global demand for renewable sand supplies is moving the construction industry ever closer to the summits of active volcanoes extending from Indonesia (along the Sunda Arc) to the Philippines (Mount Pinatubo), Montserrat (Soufrière Hills Volcano), and Kenya (the Great Rift Valley; Schuessler 2016; Wardhani, Sartohadi, and Sunarto 2017; Zuluaga et al. 2017; Kavilu 2018). When capital-driven development processes encroach on remote and rural volcanic landscapes, they transform resource-dependent livelihoods and

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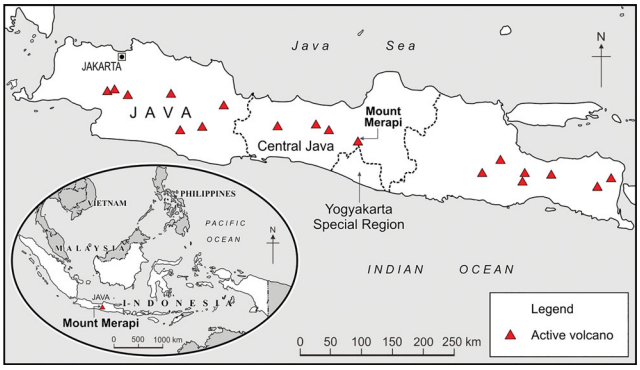

Figure 1. Active volcanoes on Java Island, Indonesia (adapted from Bani et al. 2013).

traditional ways of life. On Indonesia's most populous island of Java, where there are eighteen active volcanoes (Figure 1), the construction industry's reliance on large volumes of granular black volcanic sand is creating new forms of risk and vulnerability that bring local artisanal miners and rural communities into growing tension with outside companies.

Drawing from research conducted on and around Indonesia's most active stratovolcano, Mount Merapi (*Gunung Merapi*; Fire Mountain), this article argues that a collective politics of environmental action is required to forge more sustainable mining pathways that are inclusive of rural resident miners and to formulate effective disaster mitigation responses to volcanic threats and crises. I develop this argument using transboundary political ecology frameworks established by Salisbury, López, and Vela Alvarado (2011) and Salisbury, de Melo, and Tipula (2012), which are attentive to the importance of boundaries of resource use, control, and access in shaping patterns of authority and redistributive inclusions and exclusions at particular organizational scales of governance. Theoretically, the article brings transboundary political ecology into conversation with recent work in political ecology and political geography on the expanding scalar agency of capital-driven social relations in reconfiguring resource extraction frontiers (Pangsapa and Smith 2008; Spiegel 2017; Eilenberg 2018; Rasmussen and Lund 2018). I treat these boundary relations as fluid and dynamic because the parameters of human-resource connections are continually shifting in extractive industries (Wayland 2019) as ecological rhythms and political economic processes repattern the spatiosocial distribution of environmental costs and benefits.

Here, I define Merapi sand as a *transboundary* resource rather than a *transnational* commodity because it is consumed exclusively across subnational administrative borders on the island of Java. By contrast, sand extracted from rivers and islands elsewhere in Asia is mostly sold internationally (Lamb, Marschke, and Rigg 2019). Volcanic sand flows off Mount Merapi naturally in addition to being transported for human consumption across second-tier (provincial) and third-tier (district) jurisdictions. This has transboundary governance implications when the overexploitation of volcanic sand by outside construction companies with heavy earth-moving equipment introduces new forms of unpredictability in the form of altered flows of hot pyroclastic currents and noneruptive cold lahars, or rapidly moving mud torrents. The leakage of these transgressive impacts across overlapping areas of governmental authority and responsibility creates issues for cross-border cooperation among neighboring administrations, damaging the very urban infrastructures that volcanic sand is designed to strengthen.

Although these transboundary impacts do not flow across national borders, they do introduce a transnational dimension into Merapi's volcanic sand industry. Japan is the sole international sponsor of around 300 sabo (Japanese term for erosion control) dams designed to capture and contain approximately 70 percent of sediment, debris, and lava flows off Mount Merapi (Japan International Cooperation Agency [JICA] 2004, 2018b). Using its investments in these disaster mitigation infrastructures, the Japanese government has sought to augment its ad hoc decision-making role in regulating volcanic sand mining for sustainable development and participatory disaster governance (Na et al. 2009; JICA 2014a, 2016). It has revisited this strategy in recent years, however, as excessive sand mining has damaged or destroyed the foundations of many sabo dams, placing significant populations in two provinces at the base of Mount Merapi at heightened risk of downstream disasters in future eruptions (Maharani 2018).

To explore the transboundary political ecology of volcanic mining, I use qualitative methods suited to evaluating perceptions of in situ mining practices and experiences of environmental impacts. The research draws from participant observation in disaster simulation activities in a Code River community and forty-two semistructured interviews conducted on and around Mount Merapi in November 2013, June 2016, and January 2017. Purposive (selective) sampling was used to interview seven government

officials from provincial and district offices of Indonesia's Disaster Mitigation and Planning Agency (*Badan Penanggulangan Bencana Daerah* [BPBD]) and six representatives of nongovernmental organizations (NGOs) involved in posteruption, disaster mitigation, and livelihood transition programs. A combination of purposive (selective) sampling and snowball sampling (recruiting people recommended by interviewees) were used to interview twenty-six active and retired volcanic sand miners and three sand suppliers in Yogyakarta. All interviews are anonymized due to the politically sensitive nature of volcanic mining research in Indonesia. Where possible, I triangulate these findings using a combination of document analysis (newspaper and journal articles, Indonesian legislation, government reports, and NGO statements) and consultations with Merapi environmental activists and geographers based at Yogyakarta's Gadjah Mada University. I do not seek to romanticize the idea of a noncapitalist rural economy (Harrison 2020) or to present the local knowledge of Merapi resident miners as science. Rather, my concern is with bridging knowledge gaps that pose ongoing barriers to cooperation in the interests of making a more ecologically and socially sustainable set of industry practices.

A Transboundary Political Ecology Framework

Transboundary political ecology is useful for analyzing the dynamism of human–nature relations in crossing borders and in borderland places, where people are "viscerally part of the social construction of multiple scales by their very border location" (Salisbury, de Melo, and Tipula 2012, 109). The framework is conceptually allied with scholarship on regional political ecology, which tends to be polarized both in Asia and globally between detailed ethnographies and more generalizable policy research. The literature on political ecologies of extractivism similarly emphasizes either the macroeconomic or elite drivers of resource extraction or the micropolitics of mining conflicts (Spiegel 2017; Bebbington, Fash, and Rogan 2019; Wayland 2019). Transboundary political ecology can similarly be scaled up to the supranational or regional level or down to the subnational scale of governance. In focusing on the border as a "launching place for transboundary political ecology to contribute to the political ecology of scale" (Salisbury, de Melo, and Tipula 2012, 109), however, the framework is also suited to bridging these macro- and microscalar differences. It does so by showing how cross-jurisdictional and knowledge boundary dynamics determine environmental outcomes at specific organizational scales of governance. This is important in the administratively bordered context of Mount Merapi, both in identifying existing barriers to developing sustainable industry practices and in formulating collaborative governance responses to shared volcanic threats and crises.

The transboundary political ecology framework thus has utility in reading the scalar politics of environmental governance by showing how differentiated place-based practices shape social and ecological outcomes. These scalar politics are written into knowledge boundaries (including receding boundaries of place-based ecological knowledge that inform traditional livelihoods and cultural practices) and administrative boundaries that partition the governance of shared and overlapping resource interests. In addition to highlighting the politics of scale in these bordered human-resource geographies, the framework contributes to critical political ecology work on the materialities of resources themselves that shape their cross-border governance. Sundberg (2011) advanced recent thinking about the agency of nonhuman actants in unsettling and disrupting everyday practices of boundary enforcement through her study of cats and the Sonora Desert that pose challenges to United States–Mexico border security. Volcanic sand has a similarly transgressive potential in its ability to shift shape to form flows of transboundary environmental harm (Mason 2008; Miller 2020). Flowing off Mount Merapi on trucks as well as naturally via its fifteen rivers, volcanic sand and sediment undergoes a fundamental transformation from the point of its extraction as a raw material through to its movement into urban areas, where it is processed and consumed mainly as concrete. Yet volcanic sand can, and periodically does, become an agent of environmental harm when it responds to the multiple stressors inflicted by uncontrolled mining by turning into cold lahars (viscous mud slurries) that cause tremendous downstream damage in densely populated riverine communities. When this happens, the extraction of volcanic sand becomes counterproductive, as it destroys the very urban fabric it is intended to fortify.

Transboundary power relations shape and are reconstituted by these flows of volcanic sand and sediment. The remainder of this section examines these boundary relations through three sets of transboundary political ecology themes centered on (1) knowledge boundaries that inform differentiated place-based practices; (2) the transboundary governance dilemma posed by disconnects between upstream mining practices and downstream environmental impacts; and (3) the largely unexplored potential of cross-border governance networks in bridging policy gaps between multisited knowledge production and in situ activities. These themes, which build on previous transboundary political ecology scholarship, are used here to highlight the governance dimensions of Mount Merapi as a frontier of contested development with social and environmental impacts extending well beyond its slopes.

The first theme of knowledge boundaries relates to political ecology's central concern with the social construction of knowledge in determining environmental outcomes (Bryant 1998; Ahlborg and Nightingale 2018). Since the late 1990s, political ecology has grappled with the expanding ecological reach of urban demands into agrarian societies as rural economies become absorbed into urban-capitalist circuits of production and consumption (Birkenholtz 2012; Angelo and Wachsmuth 2015; Newell and Cousins 2015). Land-use change accompanies these processes as people who move into extraction and agricultural frontier spaces bring with them knowledge of resource management that differs from practices already in place (Rindfuss et al. 2007). We see how this destabilizes place-based knowledge in the inability of Merapi residents to intervene when outside mining operations adversely affect them—despite their conceptual preparedness to work toward sustainability goals through controlled mining practices—due to their marginal position within broader sets of power relations and economic processes. Precarious mobilizations of labor tend to follow this receding rurality of place-based knowledge, creating borderland spaces of environmental deregulation, social dispossession, and fractured traditional livelihoods and ways of life (Pangsapa and Smith 2008; Gallent et al. 2015; Swyngedouw 2015).

Second, upstream–downstream disconnects in environmental governance are thematically underpinned by the social production of scale, the primary means by which ecology is rendered political (Blaikie and Brookfield 1987; Neumann 2009; Rangan and Kull 2009). Governments invoke scalar politics to delimit the boundaries of their activities, to absolve responsibility for ecological disruptions within their own jurisdictions, or to explain environmental transformations that fall outside their administrative borders or fields of expertise. Yet urban processes "bleed" back and forth across rural boundaries to create "new political ecologies of scale" (Salisbury, de Melo, and Tipula 2012, 152; see also Woods 2009). For instance, urban demands for volcanic resources incubate environmental impacts in remote and rural parts of Mount Merapi that then boomerang back into the heart of surrounding urban settlements, where they are felt as flash floods, cold lahars, and debris avalanches.

The third theme highlights the productive potential of transboundary governance networks in sharing knowledge about sustainable development practices and building resilience to future perturbations. These networks might be spatially stretched and even temporally distant, as in the case of Japan's geo-economic investments in critical disaster mitigation infrastructures in Mount Merapi's river systems that date back to the early 1970s (JICA 2014b). When successful, such transboundary environmental networks can transform place-based governance arrangements in ways that facilitate the coproduction of ecological knowledge and create opportunities for collective learning through coordinated activities (Miller et al. 2020). Conversely, sustainable resource initiatives often fail when governance regimes neglect the instrumental role of social relationships in determining environmental outcomes (Crona and Hubacek 2010).

Shifting Resource and Geo (Political) Boundaries

Borders or boundaries in transboundary political ecology are fluid, flexible, and continually shifting as human-resource connections transform each other (Sundberg 2011; Margulies and Karanth 2018). The boundaries of volcanic resource extraction frontiers fluctuate according to the "ebb and flow of past and present resource booms" (Salisbury, López, and Vela Alvarado 2011, 149) that are adjusted by construction industry growth cycles and changing sand prices. Ecological timescales such as cycles of seasons and eruptions also alter the temporal availability of

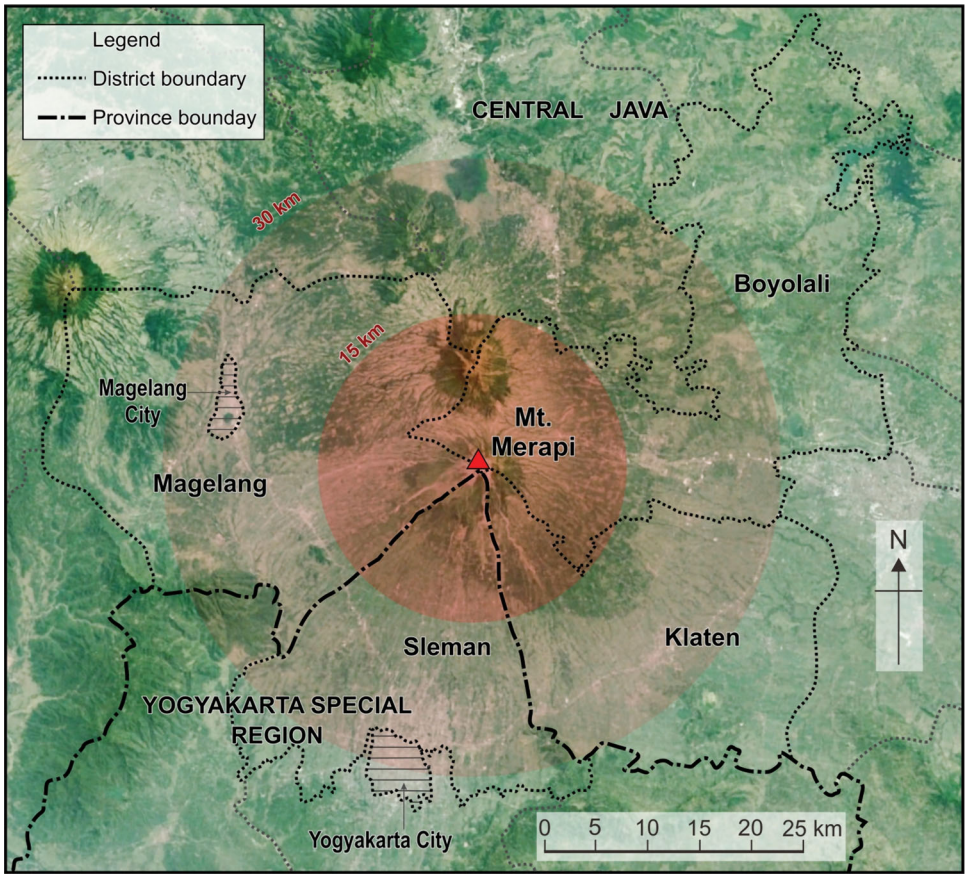

Figure 2. Provincial and district administrative boundaries traversing Mount Merapi.

volcanic sand, its economic value, and the health risks associated with mining. For instance, volcanic sand is mainly mined in the dry season months of June to September because "when it rains, flash floods can bury [sand] trucks within a few minutes and not even early warning systems like *om telolet om* [musical car horn culture, used for communication between mining trucks] can save us" (interview, June 2016). The boundaries of volcanic sand mining also sharply contract for about one year after major eruptions due to lingering ground heat and heightened respiratory risks associated with inhaling airborne ash high in crystalline silica and other toxic tephra emissions (interviews with miners, November 2013 and BPBD officials, June 2016).

Expanding urban demands further reconfigure these shifting resource boundaries. Mount Merapi straddles the provinces of Central Java and Yogyakarta Special Region (Figure 2) that are home to more than 38 million people (Badan Pusat Statistik 2015). The more-than-urban development processes that shape and sustain these populations require massive volumes of sand, the main ingredient of glass, asphalt, and concrete. The island of Java alone consumes over half of Indonesia's annual volume of cement production, with around 70 percent of total demand driven by the property sector (Global Cement 2019; Singapore Business Review 2019). In Java's construction industry, Mount Merapi's grain-sized black sand is especially prized because it is said to make denser and more durable concrete than sand quarried in rivers and on private lands (interviews with sand suppliers, Yogyakarta, 2016 and 2017). Most of the sand and gravel removed from Mount Merapi is sold in cities in Central Java and Yogyakarta city, the capital of Yogyakarta Special Region (JICA 2003). Wholesalers in Yogyakarta, some 30 km away from Merapi's summit, calculate that the financial benefits of selling volcanic sand and sediment outweigh any risks. Merapi sand is more expensive, is difficult to obtain, and incurs higher overhead costs in petrol and truck repairs than river sand or beach sand because it is extracted in remote mountainous areas with unpaved degraded roads. Despite this, sand suppliers say that "Merapi sand always sells straight

Figure 3. Sand trucks on Mount Merapi.

away, but river sand can sit here [in the shop] for a week or longer" (interview, January 2017). Andesite, an extrusive igneous rock quarried alongside Merapi sand, also supports a thriving artisanal stone masonry industry in surrounding towns and cities (interview, January 2017).

For around 400,000 predominantly rural residents living in more than 540 villages within a 20-km radius of Mount Merapi's summit (Mei et al. 2013), however, these encroaching development demands are moving the boundaries of economic exclusion and environmental risk to their detriment. With as many as 500 lorries and excavators winding up and down the volcano each day during the dry season, the sheer volume of traffic creates deep potholes that frequently render access roads impassable, except by motorbike or Jeep (Figure 3). Road damage periodically restricts the movements of Merapi residents, potentially compromising their capacity to evacuate in the event of eruptions. Local residents have complained to a sympathetic mass media that their homes, communities, and farms have become more exposed to irrigation inefficiencies (as mining holes as deep as 20 m cause wells to dry up; *Jakarta Globe* 2015), flash floods, and noneruptive cold lahars linked to excessive and unregulated mining (Wismabrata 2013; Parwito 2014; Sajarwo 2015; Ige 2016; Munte 2019).

Governance shifts have changed subnational administrative boundaries in ways that have exacerbated these tensions. The provinces of Central Java and Yogyakarta Special Region that intersect Mount Merapi are further divided into five municipalities (the districts of Sleman, Magelang, and Boyolali and the cities of Klaten and Yogyakarta; Figure 2). A nationwide democratic decentralization process that came into effect in 2001 after four decades of centralized authoritarian rule (1967–1998) awarded

provincial governors, regents, and mayors considerable discretionary powers to grant mining permits that had previously been issued at the ministerial level (McCarthy, Vel, and Afiff 2012). This pushed the boundaries of capital-driven development ever deeper into remote and rural parts of Mount Merapi as outside construction companies leveraged their influence with local government officials to expedite in a few months the issuance of mining permits that normally took around one year to process. As these decentralized patronage networks jostled around the spoils of Merapi resources, spaces for the protection of intergenerational knowledge about sustainable mining practices and rural livelihoods became increasingly fragmented and attenuated.

An unintended consequence of Indonesia's neoliberal trajectory of democratic decentralization has been the hardening of subnational political borders (Miller 2013). The decentralized system has encouraged competition between neighboring administrations over loans, funding opportunities, and access to wider markets (McCarthy, Vel, and Afiff 2012). Legal ambiguities regarding the boundaries of state, private, communal, and customary (*adat*) resource rights have added to this contestation over natural resources (Lund and Rahman 2018). In the case of Mount Merapi, interjurisdictional competition has come at the expense of cross-border cooperation in regulating overlapping volcanic resource interests and cogoverning the negative externalities generated by unsustainable sand mining practices.

The implications of this lack of cross-jurisdictional cooperation are elaborated in subsequent sections. It is worth noting here, however, that the hardening of subnational borders has affected higher scales of governance. Specifically, Indonesia's longstanding geo-economic relationship with the Japan International Cooperation Agency (JICA), the government agency responsible for Japan's overseas development assistance, has come under strain in recent years. Although JICA's activities on Mount Merapi have historically focused on the construction of sabo (erosion and sediment control) dams that are not directly related to volcanic mining, these disaster mitigation infrastructures have proven vital in containing its excesses (Ikhsan, Fujita, and Takebayashi 2010), just as they have been increasingly damaged by unregulated sediment extraction (Maharani 2018). Although JICA has financially and logistically supported Indonesia's democratic decentralization process, its Merapi programs have suffered from the conflicting agendas of decentralized government agencies and the competing business interests of local state officials (JICA 2016, 2018a). These vested interests ultimately thwarted JICA's plans to protect its infrastructural investments on Mount Merapi by establishing a Sand Mining Management Institution (SMMI) to develop sustainable volcanic mining capacities. Moreover, the tremendous difficulties JICA faced in "coordinating various conflicting interests" (JICA 2016, 13) among divided and disunited local government agencies prevented it from obtaining official safeguards against the future destruction of its sabo dams, thereby adding to these unresolved tensions.

Knowledge Boundaries

There is a sustainability narrative linked to Mount Merapi's volcanic sand trade that is popular among environmental NGOs, rural Merapi communities, and JICA. This narrative is rooted in an awareness that there are tremendous variations in the ways in which pyroclastic materials, water, and debris move through, and interact with, landscapes that have been exposed to uncontrolled mining versus responsible quarrying that is carefully managed in terms of location and volume. Proponents of this narrative argue that if volcanic sand is properly regulated, it could provide a sustainable source of development as Mount Merapi generates on average 1.2 million cubic meters of sediment annually (Susanto 2013; Cho, Won, and Kim 2016). Merapi residents have historically mined their mountain using sustainable extraction techniques in between eruptions that occur every eight to fifteen years (Mei and Lavigne 2012). Their mining methods serve two purposes: (1) to sustain a financially profitable, if intermittent, sand economy; and (2) to mitigate the destructive impacts of volcanic flows. As one manual miner explained:

> We need to be careful about where we collect sand and put some back on riverbanks so that lava and rainwater don't destroy our homes and cows. This is our children's future. (Interview, June, 2016)

Unsustainable extractive practices by outside construction companies using heavy earth-moving equipment are threatening these rural livelihoods and traditional ways of managing volcanic threats and crises. To make the volcanic sand trade more

sustainable in the longer term, the locally based knowledge of Merapi residents must be formally integrated into decision-making processes and governance programs.

This sustainability narrative, compiled from a combination of secondary sources and interviews, is underscored by a worldview that is incompatible with capital-intensive development. Merapi residents have traditionally maintained a spiritual relationship with their volcano's sacred (*keramat*) properties as an eternal giver and taker of life that replenishes what it destroys in the form of nutrient-rich soil and groundwater that sustains agricultural livelihoods (Dove 2007; Donovan 2010a; Sulistiyanto 2014). In this way, manual miners see linkages between their volcanic resource dependencies and their daily social and spiritual lives (Lavigne et al. 2008).

This logic of reciprocity makes Merapi's resident miners mindful about where and how much volcanic sediment they extract. A recurring theme among interviewed miners was their emphasis on collecting sand and sediment in sites at least 100 m upstream or downstream of some 300 sabo dams located in Merapi's rivers. These concrete sabo dams, built between 1985 and 2001 with JICA funding and technologies, replaced earlier makeshift dams constructed by Merapi residents themselves (JICA 2016). They have proven effective in preventing around 70 percent of sediment loss and regulating its downstream flow while channeling water into communities where it is used for drinking and crop irrigation (Ariyanti, Yulinsa, and Tiamono 2017; JICA 2018b). To maintain this delicate balance in human–volcano interactions, resident miners say they mainly rely on manual technologies (pickaxes and shovels) to control the quantity of sand extracted from these strategic 100-m buffer points. They claim their attention to volume and location helps to optimize the regulatory functions of Merapi's sabo dams without disrupting natural hydraulic flows of water and nutrients required for riparian revegetation (Ikhsan, Fujita, Takebayashi, et al. 2009). This in turn mitigates downstream disasters such as debris avalanches and cold lava flows that cause extensive damage in urban riverbank settlements at the base of the olcano. There is a strong moral dimension to these place-based practices, which manual miners argue make their work sustainable in ways that mining undertaken by outside construction companies is not. As one manual miner who has intermittently worked on Mount Merapi since the mid-1980s put it:

> Those greedy people [with heavy earth-moving equipment] only care about profits, not the life of our mountain. I hope the volcano finishes them off in the next eruption. (Interview, January 2017)

Set against this sustainability narrative is the hegemonic counternarrative used by urban developers and construction industry bosses who measure the sustainability of volcanic sand in terms of its physical durability and economic growth. This narrative is ideologically aligned with the Indonesian government's long-term plans to boost economic development through mining, agricultural expansion, and infrastructure investments in "'remote and underdeveloped' borderlands" and "unexploited resource frontiers" (Eilenberg 2018, 180–81). Unlike Merapi resident miners, who are ethically opposed to, or cannot afford to buy mechanized earth-moving equipment, outside construction companies use backhoes, loaders, and excavators that are capable of inflicting a significant amount of environmental damage in a short time period. Many of these companies work illegally or possess mining licenses obtained through political connections with government officials in surrounding urban centers. These factors, combined with their lack of any cultural attachment to the volcano or its residents, make construction companies less likely to invest in Merapi's social and environmental futures. Their deep dredging in unsafe areas causes riverbank erosion or collapse and landslides that destroy or damage the foundations of sabo dams, bridges, and dykes while heightening the risk that hot pyroclastic materials will be channeled into farmlands and villages in future eruptions (Maharani 2018). Despite the imposition in 2000 of a blanket ban on mining near bridges on Mount Merapi after the floor of the Srandakan Bridge on the Progo River collapsed (Mananoma and Wardoyo 2009), illegal in-stream mining has persisted due to a combination of weak legislation and the perpetuation of financial benefits that accrue to those invested in its overexploitation.

Artisanal migrant miners who come from both rural and urban areas elsewhere in Java have proven equally insensitive to the need for regulated mining. The majority of these migrant workers, who lack mining permits, target refined and readily accessible "sweet sand" (*pasir manis*). This softer sand, found in hillsides, cliffs, and escarpments, cleaves easily from

partially eroded vertical landforms and its extraction using basic mining technologies (pickaxes and shovels) often triggers landslides and debris avalanches, especially during the monsoon season. As one migrant miner from West Java explained:

> Yes, it is dangerous to mine for sweet sand, but mining is dangerous. What is more dangerous? To have no money to eat, or to eat [using profits from] sweet sand? (Interview, June 2016)

Knowledge boundaries about (un)sustainable mining practices are not always clear in practice. This confusion became apparent after November 2010, when the biggest eruption of Mount Merapi since 1872 (Jenkins et al. 2013) generated 140 million cubic meters worth of pyroclastic materials, killing 386 people, destroying 2,847 homes, and displacing almost 400,000 people for 1.5 months (Mei et al. 2013; Maly and Nareswari 2015). This landmark event reconfigured the dividing lines between Merapi resident miners and outside construction companies into more fluid and networked power relations in one of two ways. First, for over a year after the major eruption, residual surface heat prevented manual mining using pickaxes and shovels, tools that rural resident miners have claimed reduce environmental damage and are associated with a culture of strategic extraction by volume and location. After the 2010 eruption, however, Merapi residents whose homes and farms were buried beneath the debris needed to obtain land reclamation permits to hire earth-moving equipment from construction companies in nearby towns and cities to find and unearth their properties. For farmers who had lost their crops and livestock during the eruption, mechanized sand mining provided an alternative source of income and an opportunity to collect the raw materials for (re)building concrete homes. One former dairy farmer who turned to mechanized mining after the 2010 eruption remembered that:

> Thistles grew out of the ash instead of grass, which made cows produce less milk, so it wasn't financially worth keeping [dairy] cows anymore. Everyone went into mining so we could feed our families until the grass grew back. (Interview, November 2013)

Although illegal, this commercial use of heavy machinery was tacitly endorsed by village heads, government officials, and construction company bosses in nearby cities, who each retained a percentage of the miners' profits. Although many rural residents eventually returned to manual mining, conditions were so harsh following the 2010 eruption that they needed to wear protective clothing for up to three years afterward in the form of "two pairs of long pants, two pairs of socks, rubber boots, gloves, a hat, scarf and sunglasses" (Interview, June 2016).

A second process by which knowledge boundaries eroded was through the experience of rural displacement and involuntary urban resettlement. After the 2010 eruption, it became illegal for Merapi residents to live in the "High Hazard" exclusion zone located 5 km from the summit at an altitude above 1,500 m (Thouret et al. 2000; Nugraha et al. 2019). Deprived of electricity, school teachers, and other public services, these residents comprising manual miners and farming families felt they had no choice other than to move into 2,516 housing units in government-sponsored permanent settlements (*Hunian Tetap*, commonly known as *Huntap*) in surrounding periurban areas (Fajarwati et al. 2016; see also Figure 4). Among this group, disaster displacement and resettlement fragmented rural knowledge and weakened the once inviolable belief in Mount Merapi's properties of reciprocity. This belief system was further unsettled by the death of Merapi's eighty-three-year old spiritual gatekeeper in the 2010 eruption and his replacement by his son, a university lecturer said to be "out of touch" with the volcano (interviews, November 2013). Physically and culturally removed from Mount Merapi, men and women who had previously worked as manual miners began to diversify their livelihoods, seek out alternative income-generating opportunities, and learn new skills that promised more secure urban futures. Although some of these relocated Merapi residents later returned to manual mining, many others, who could afford neither trucks nor petrol to transport sand off the volcano, sought dry seasonal employment with construction companies or left the mining industry entirely (Miller 2018).

These shifting knowledge boundaries have contributed to the creation of new hybrid sociospatial forms, each with its own networked governance arrangements. The partial but incomplete absorption of Mount Merapi's manual mining labor force into construction companies has generated pockets of hard resistance against nonresident miners in some communities but a thinning of knowledge boundaries elsewhere. For example, in one Huntap, a chandelier hanging over a tiny front porch became the focal

Figure 4. Huntap Pagerjurang at the base of Mount Merapi.

point of community resentment as the homeowner, a former manual miner, had gained employment with a large construction company. His disaffected neighbors, all manual miners, decided to air their grievances by approaching environmental activists based in Yogyakarta in the hope that the urban connections and university-level education of the latter would advance their cause to evict construction companies from their mountain and obtain socioecological justice. In this way, the configuration of Mount Merapi as an arena of contested development has ushered in the emergence of new spaces for environmental action. To coordinate a more sustainable set of industry practices that are inclusive of manual miners, however, the diverse stakeholders involved in Merapi's mining sector would need to work at overcoming epistemic barriers to knowledge coproduction that underpin their differentiated extractive activities and generate cascading downstream impacts.

Upstream–Downstream Disconnects in Governance

Mount Merapi's mining operations incubate upstream environmental problems that flow downstream to penetrate the heart of urban settlements. Although hot and cold lava flows, flash floods, and debris avalanches delineate the ecological boundaries of volcanic risks and impacts, these flows have not yet been mapped onto a cohesive system of governance. In spatial terms, transboundary volcanic flows drain downward and outward from the single source of Mount Merapi's summit. They are distributed via its fifteen rivers among five municipalities in two provinces. Noneruptive cold lahars, and, far less frequently, hot pyroclastic materials, destroy or damage homes, disrupt public services, and pollute water supplies in Magelang district (which receives on average around 54 percent of volcanic flows), Klaten and

Figure 5. Average distribution of volcanic flows off Mount Merapi by district (adapted from Maharani 2018).

Boyolali districts in Central Java (18 percent), and Sleman and Yogyakarta city in Yogyakarta Special Region (28 percent; see Figure 5).

All of these administrative units have a long history of dealing with volcanic hazards, but the spatial terrain of sand mining impacts is only beginning to be understood and has not been properly assessed in aggregate terms or integrated into disaster governance regimes. In part, this is because heavy rainfall (around 40 mm within a two-hour period) rather than the slow onset hazard of unregulated mining provides the immediate trigger for the rapid onset

hazards of noneruptive cold lava flows and debris avalanches (Lavigne et al. 2007). In the first monsoon season after the 2010 eruption of Mount Merapi (October 2010–May 2011) there were 240 cold lahars (Bélizal et al. 2013) and over the next five monsoon seasons an additional 180 cold lahars were recorded, overwhelming riverside settlements up to 20 km away (Gob et al. 2016). According to a BPBD official in Sleman district, the monsoon season prevalence of cold lahars adds to the widespread tendency to misdiagnose these disasters as occurring separately from, and unrelated to, unregulated upstream mining (interview, June 2016). This upstream–downstream disconnect is exacerbated by localized assessments of property damage and livelihood disruptions along individual rivers that conceal the transboundary effects of uncontrolled volcanic sand mining. The compound health effects of cold lava flows, which contaminate drinking water and lead to outbreaks of dysentery, typhoid, and Hepatitis A, are similarly reported and treated in isolation from their underlying causes (interview, June 2016).

Occasionally, local governments have taken the initiative of attempting to mitigate the transboundary impacts of unregulated volcanic sand mining within their jurisdictions. In 2013, the administration of Sleman issued a district-wide decree banning volcanic sand mining within its borders in a bid to reduce cold lava torrents and restore the ecological health of Merapi's rivers (Susanto 2013). Village-level state authorities along Merapi's evacuation routes have also risked incurring substantial economic losses by periodically banning sand mining in their areas. These bans have tended to follow public demonstrations about noise pollution, dust, and increased crime rates after the arrival of outside construction companies, as well as extensive road damage caused by overloaded sand trucks and earth-movers (Na et al. 2009; JICA 2016; Harianjogja.com 2019).

In recent years, the excesses of Merapi's volcanic sand trade have also tested Indonesia's geopolitical relationship with JICA. The Japanese government, which provided RP780 billion (US$56.8 million) in Official Development Assistance to rebuild or repair sabo dams damaged by the 2010 major eruption of Mount Merapi, has voiced growing concerns about the harmful impacts of unregulated mining. With its mandate of approaching overseas aid through a "development and humanitarian nexus" (Tanaguchi 2018), JICA has previously acknowledged the material benefits of selling excess sediment from around sabo dams to establish linkages between its disaster mitigation infrastructures and Indonesian state development objectives (JICA 2014a). JICA's position has gradually hardened, however, as damage to the foundations of its sabo dams has accumulated. With the restoration of one sabo dam alone costing around RP10 billion (US$728,000), the chief consultant for JICA in Indonesia threatened in 2018 to discontinue funding to Indonesia on the grounds that "it would be useless to build sabos which would subsequently be destroyed by sand miners" (Maharani 2018).

That unregulated mining has persisted despite such warnings points to the underlying problem of vested economic interests that frustrate decentralized policy reforms. At least officially, there are clear guidelines in place that restrict mining to designated safe areas, just as there are exclusion zones that strictly prohibit mining near the volcano's summit and in the Mount Merapi National Park. Decentralized government agencies for "one door investment and integrated services" designed to improve citizen access to local services in Central Java and Yogyakarta have issued volcanic mining licenses in accordance with these sustainability standards, specifying where and how much sand can be quarried within a given time frame. In practice, however, these rules are rarely enforced as local government officials, the police, and legislators own much of the heavy machinery used in illegal mining (Susanto 2013). Protected by these decentralized patronage networks, nonresident miners and their construction company bosses have continued to work unobstructed irrespective of their permit status. Some have even staged protests following raids on illegal mining sites by law enforcement officials (personal communications, 2017 and 2018). Others have launched "campaigns of terror" using earth-movers and other intimidation tactics against Merapi residents who have complained about outside miners in their areas (Tribunjogja.com 2015). Yet there is no incentive for migrant miners to pursue alternative livelihoods because "the government doesn't offer miners alternative jobs and many miners come from other parts of Java and don't live around here" (personal communication, December 2017). This problem of low levels of political will among the financial beneficiaries of volcanic sand mining has

eroded Indonesian state authority from within. In this context, the role of coordinating upstream and downstream disaster mitigation activities has been largely left to those communities whose proximity to volcanic risks means that they bear the cumulative socioeconomic burden of unregulated mining impacts.

The Unrealized Potential of Transboundary Governance

Indonesia's decentralized democracy has afforded rich opportunities for local governments to pursue pro-growth policies by incentivizing interjurisdictional competition. A critical oversight of this system has been its failure to anticipate the need for institutional mechanisms to facilitate coordination among the various stakeholders involved in resource governance. The lack of such mechanisms has made it extremely difficult to cogovern overlapping resource interests and to coproduce ecological knowledge that could inform policy reforms around sustainable industry practices (Phelps et al. 2014). In governing Mount Merapi, the neighboring provinces of Central Java and Yogyakarta Special Region have concentrated on fortifying development within their own borders at the expense of cooperatively delivering public services and dealing with the transgressive impacts of unregulated volcanic mining. This lack of coordination in tackling shared externalities is visible along Mount Merapi's evacuation road at the border between Yogyakarta Special Region, where the road is deeply potholed, and Central Java, where the road surface is smooth and well maintained.

The hardening of borders under the decentralized system goes well beyond interjurisdictional competition, as it extends to include a lack of coordination within and among government agencies. For instance, a survey of 100 respondents representing twenty-eight institutions involved in recovery from the 2010 Merapi eruption reported chronic miscommunication and poor coordination due to a lack of trust between decentralized government agencies, NGOs, and volunteer organizations (Pratama and Nurmandi 2020). More often than not, proposals aimed at enhancing interagency and interjurisdictional cooperation are regarded with suspicion by local departmental heads who fear ceding control over key budgets, losing competitive funding opportunities, or forfeiting strategic business partnerships if they participate in joint activities. These conflicting interests are rife in Merapi's lucrative mining sector where governors and regents routinely circumvent Indonesia's decentralized licensing system to fast-track mining permits. Under these conditions, the prospect of cross-border cooperation poses a threat to preexisting opportunities for personal enrichment.

On the other hand, democratic decentralization has empowered civil society actors to mobilize across administrative boundaries and collaborate with NGOs in supporting government agencies around participatory forms of disaster governance. For example, the grassroots volunteer network, Jalin Merapi (*Jaringan Informasi Lingkar Merapi*; Information Network around Merapi), which was established in 2006 following a major earthquake in Yogyakarta city, uses shortwave radio communication networks to disseminate real-time disaster information between districts, support state emergency services, and coordinate the distribution of aid among affected communities (Tasic and Amir 2016). Riverbank communities in Yogyakarta city work with Jalin Merapi and local emergency services to build preparedness for cold lava flows by co-organizing disaster mitigation simulations (*simulasi mitigasi bencana*) in cooperation with the police, fire department, and BPBD officials (participant observation, November 2013). These hybrid simulations take the form of interactive disaster theater and have a carnival atmosphere. Adults and children alike adorn fake blood and bandages and take turns using two-way radios and riding in emergency vehicles to a disaster simulation evacuation site, where the exercise culminates in a community feast (see Figure 6).

JICA's efforts to tap into Indonesia's rich social capital by collaborating with Merapi communities around sustainable development activities have been less successful. These grassroots collaborations have centered on riverbed regeneration, participatory volcanic sand mining workshops, and the installation and management of early warning systems. Merapi residents have generally welcomed JICA's support, especially when their complaints about unregulated mining have been ignored or downplayed by local government officials with business interests in the construction industry. Yet JICA ultimately failed in its effort to establish the SMMI, which was rejected at the advanced planning stage by Indonesia's decentralized government agencies that directed "more

Figure 6. Disaster simulation in Yogyakarta.

attention to community development instead of establishing SMMI" (JICA 2016, 13). Although district governments agreed to take responsibility for SMMI sand mining manuals and training programs, a follow-up JICA survey found that its piloted sand mining programs in three villages were never adopted in other areas, where "illegal mining is still prevailing," risking further "damage to sabo facilities caused by those actions" (JICA 2016, 43). Although JICA subsequently warned Indonesia's Public Works and Housing Ministry to "promptly come to grips with [the] establishment of an effective sand mining management system" (JICA 2016, 45) to put an end to ongoing sabo dam destruction, its own capacity-building programs were never designed to comprehensively address this problem. A key weakness of JICA's community-based pilot projects was that they only targeted rural villagers, many of whom already possessed intergenerational knowledge of controlled sediment extraction techniques. Construction industry representatives were excluded from a series of participatory volcanic sand mining workshops funded by JICA involving research collaborations between Japan (Kyoto University) and Indonesia (Gadjah Mada University) that limited participation to Merapi residents (Na et al. 2009; Na and Okada 2013).

With efforts to build knowledge of sustainable mining practices currently restricted to small-scale and short-term programs, the potential for a collaborative system of governance around the sustainable development of Mount Merapi remains a theoretical proposition. Urban developers and construction industry bosses who hold the balance of power in the volcanic sand industry continue to prioritize fast profits over the advantages of working in a safer environment under conditions of enhanced social stability. In the absence of enforceable legislation, public advocacy could potentially be mobilized in

the service of safeguarding manual mining practices and protecting Merapi communities from threats and intimidation by outside companies. Merapi residents and local authorities have previously used social media and formal news channels to achieve small-scale successes in banning mechanized mining from particular localities. A second way in which a collective politics of environmental action could be fostered is by actively engaging JICA in wider cogovernance partnerships. With its institutional knowledge of sustainable sand mining practices and investments in Merapi disaster mitigation infrastructures, JICA's continued exclusion from formal Indonesian governance processes represents a missed opportunity to harness international technologies, funding, and support for the development of a more locally sustainable sand mining industry. The alternative to nurturing such collaborations in the near to medium term would be to wait until the transboundary impacts of unregulated mining become so disruptive that coproduced knowledge and coordinated forms of redress become not only desirable, but necessary, to deal with the accumulating social, health, and economic costs of increasingly frequent volcanic threats and crises.

Conclusions

Mount Merapi's volcanic sand mining industry is an arena of contested development set within a geographically dispersed set of relationships. This article has argued that a collective politics of environmental action is needed to bridge knowledge gaps about volcanic sand mining and to develop more sustainable industry practices that are actively inclusive of resident manual miners. The transboundary political ecology framework used here provides a means of reading the scalar politics that are written into knowledge boundaries and cross-jurisdictional barriers to environmental cooperation. Taking these boundaries as the focal point of enquiry is useful for identifying opportunities to forge collaborative pathways for governing overlapping resource interests and shared environmental threats at particular organizational scales.

The transboundary political ecology framework offered in this article consists of three thematic parts that contribute to recent scholarship concerned with understanding connections across scales in the political economy of resource extraction frontiers. First, a transboundary reading of the political ecology of knowledge boundaries shows how differentiated place-based practices shape environmental outcomes. It also highlights the diverse ways in which rural societies and economies become integrated into capital-driven power relations and what this means for the receding boundaries of place-based knowledge, traditional livelihoods, and rural ways of life.

Second, transboundary political ecology adds insights into the social production of scale in shaping upstream–downstream disconnects in extractive resource industries. Although governments tend to invoke scalar politics to demarcate and delimit the boundaries of their own environmental responsibility, the transboundary terrain of volcanic sand mining impacts warrants a corresponding rescaling of environmental governance. We see how provincial and district governments absolve responsibility for the destructive effects of uncontrolled volcanic mining within their own jurisdictions, while working to retain control over the right to issue mining permits. The patronage networks that animate around this decentralized licensing system frustrate efforts to coordinate governance reforms, with clear implications for the capacity of proximate Merapi residents to build resilience to future volcanic threats and crises.

Third, transboundary political ecology highlights the still largely unexplored potential of interjurisdictional and interdepartmental cooperation in integrating local articulations of ecological knowledge, adaptation innovations, and disaster mitigation strategies into higher scales of governance. This does not mean that grassroots knowledge and practices are necessarily progressive, but, rather, that resource development cannot be regarded as sustainable unless it is inclusive of the diverse range of stakeholders. Unresolved contestations about the meaning of sustainable development exacerbate societal tensions and create operational confusion. A transboundary politics of collective action around volcanic sand mining is urgently needed on Mount Merapi, both to build consensus around what sustainable volcanic sand mining means and also to redistribute the benefits and risks associated with volcanic resource extraction in ways that are more equitable and socially inclusive in the longer term.

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