Article

Herd It in the Gobi: Deserting Pastoralism?

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Abstract: Global drylands host more than USD 1 trillion in resource extraction investments, which serve to reconfigure communities and landscapes. In Mongolia's Gobi Desert mega-mining brings social challenges and environmental changes that question if nomadic herding and mining can co-exist. Whilst company and community conflict are common, nascent frameworks and mediation models suggest alternate ways to resolve the mining–community conundrum. Here we investigate environmental transformations that herders encounter in the presence of the Oyu Tolgoi mega-mine in Mongolia's Khanbogd *soum* (district). Using socio-economic and physical data collected through interviews, field studies and climate records, we assessed local engagement and adaptation to large-scale mining. Combining qualitative and quantitative methods enabled us to examine the implications of mining for herder lives and lands in an integrated way. This study presents a holistic assessment of the roles of herders, governments and mines in reshaping pastoralism. In our chosen case study, we find that—contrary to common narratives—mining and herding can, and do, coexist in Khanbogd *soum*, though ongoing challenges exist which deserve critical attention.

Keywords: drylands; herder livelihoods; pastoralism; mining; dust; Mongolia; Gobi

1. Introduction

Mongolia's Gobi Desert was filled with "extraordinary illusions" according to Marco Polo, was mapped by Mercator, explored by von Humboldt and collectivised by the Soviets [1]. Throughout these epochs, nomadic pastoralism and animal husbandry have been the principal livelihood in rural Mongolia. A history of grazing in the region since the Bronze Age documents herding as a resilient and environmentally sustainable livelihood in the desert's severe landscape [2]. Mongolian herding transitioned from a quasi-feudal structure to the state-controlled *Negdel* (Soviet era collective) and now to an independent, market economic-based system [3,4]. As technology, vehicles and development have transformed herding, the environment has remained a desert.

Since its transition to democracy in the early 1990s, Mongolia has embraced large-scale mining and pastoralism shifted to a neoliberal system. Livestock numbers have fluctuated dramatically, from 20 million in the 1990s to more than 80 million in the 2010s, and today settling at ~60 million [5]. Whilst herding provides work for half a million people and 13% of national GDP, mining represents 21% of GDP, 85% of exports and >30% of the country's budget [6].

These changes reflect the dramatic economic shifts in Mongolia, including severe economic crises that followed the collapse of the Soviet Union. Optimism was high when the contract with Ivanhoe Mines (owned by Rio Tinto [7]) was signed in 2009 for the Oyu Tolgoi (OT) mega-mine. As the fulcrum for the Mongolia extractive debate, Oyu Tolgoi's USD 12 billion development costs and USD 7 billion expansion in Khanbogd *soum* (district) are a crucible to understand herding in the presence of a mega-mine [8,9]. The rapid rise in mineral extraction in the last decade has raised the previously unthinkable question, "can herding survive mining?" [10,11].

The Mining–Herding Conundrum

Being host to large deposits of copper and gold that are mined as key commodities, Mongolia is representative of drylands that host >USD 1.1 trillion resource extraction investments [12]. Across the Gobi Desert, large-scale mining brings social challenges and environmental changes [13] that have resulted in many stakeholders (especially those unfamiliar with pastoralist livelihoods) questioning the viability of nomadic herding. This is particularly salient given that herding in the Gobi is set against a backdrop of water scarcity, extreme winters (*dzud*), insect invasions and marginal environments [14]. Regional topicality is magnified by neighbouring China's Belt and Road Initiative (BRI), which promises >USD 1 trillion global infrastructure investment, including the Mongolian Economic Corridor [15]. Internationally, Mongolia's community–mining dilemma repeats across the Global South from Africa and Latin America to Central Asia [16,17], where issues such as insecure tenure of small-holders, corruption and political marginalisation of rural peoples leave little room for truly participatory decision-making in developmental land acquisition.

Although research on herding in Mongolia is well developed, it remains fragmented between social science, focused on pastoralism, livelihoods, development and governance (e.g., Ahearn and Bumochir, 2016; Ulambayar et al., 2016 [18,19]), and physical science, investigating climate, vegetation and water (e.g., Shinoda 2012; Middleton et al., 2015 [20,21]). Such fragmentation is problematic because climate and nature strongly frame herding dynamics in drylands: pastoralists engage with environmental scarcity through adaptation, mobility and effective livelihood strategies [4,22]. When a large mine is brought into the mix, it becomes difficult to map out the complex dependencies at play.

Prior research on mining in Mongolia has tended to focus mostly on the physical and environmental impacts of mineral extraction on the steppe [23,24]. These impacts include modified landscapes, new infrastructure, pasture fencing and fragmentation and potential degradation of soil, water and land [11]. Agriculture may be displaced and livestock and biodiversity affected, and an increase in dust and pollutants are often recorded following the introduction of a mine. Greater mega-mine impacts include greenhouse gas emissions from mining and mineral transport [25].

Perhaps less explored are the social perceptions of environmental changes that frame herding in the desert region [26,27]. These include changes in access to land and water, job opportunities and income losses, altered land tenure, herder resettlement and evictions [28] and disruption to customary lives and governance. Fisher et al. (2018, p1 [29]) frame the extractive process as "assymetrical conflicts over natural resources in the Global South". The benefits are often viewed as accruing to governments in the form of revenue and rent-seeking, whilst adverse factors affect human well-being and landscape viability, particularly in the vicinity of the mines. Notable studies have sought to critically assess the socio-political impacts of mining (e.g., Suzuki, 2013; Lechner et al., 2017; Jackson, 2018; Lezak et al., 2019 [30–33]). Combining the most salient parts of these evaluations with physical science studies is crucial for painting a fuller picture of the mining–herding conundrum.

In this paper we draw upon interdisciplinary fieldwork centred at Rio Tinto's Oyu Tolgoi (OT) mine (Oyu Tolgoi was once labelled as the world's largest new copper and gold mine and "a cash machine in the Gobi Desert" [34]. Rio Tinto Corporation took control of the mine and the 80 km^2 fenced Mine License Area in 2011. The mega-mine has contributed >USD 2.8 billion to the national treasury, making it the country's largest corporate taxpayer [35]. The contract, governance and political implications remain contentious [36]), Khanbogd *soum*, Omnogovi Province, Mongolia. Our study of OT's impact seeks to combine physical science and social science methods to holistically examine the impact of mega-mining on the physical and social geography of Khanbogd *soum*. We evaluated the perceptions and resilience of mobile pastoralist livelihoods when they encounter the constellation of environmental and infrastructural hazards in the region. Moving beyond the fatalistic discourse of "can herders survive mining?", we used results from this fieldwork to pose a more holistic and politically salient challenge: with the advent of large-scale

mining across Mongolia, can society and government establish environmental practices and safeguards to support its rural population?

Our work reveals that an interdisciplinary approach that couples natural and social science methods is needed to understand the dynamics of changing environments. Rigorous investigation and participatory methods are key to establishing baseline dynamics and identifying mining-induced transformation. When resource extraction is complete, herders will continue to be the stewards of the Gobi, and should be supported in that role by the best available research.

2. Methodology

2.1. Study Region

The rolling arid landscape of Khanbogd *soum* (Figure 1a), where this study is focused, is situated at an altitude of 900–1300 m in the Gobi Desert, the world's coldest desert. The Mongolian word *soum* refers to the administrative district (>13,000 km^2), while the *soum* centre refers to the only town (population > 3000; 43.20° N, 107.19° E). Khanbogd is a traditional camel breeding region, and has seen a dramatic rise in population in recent decades, with the number of households in the *soum* increasing more than threefold between 2003 and 2018 (see Figure S1 in the supplementary Information).
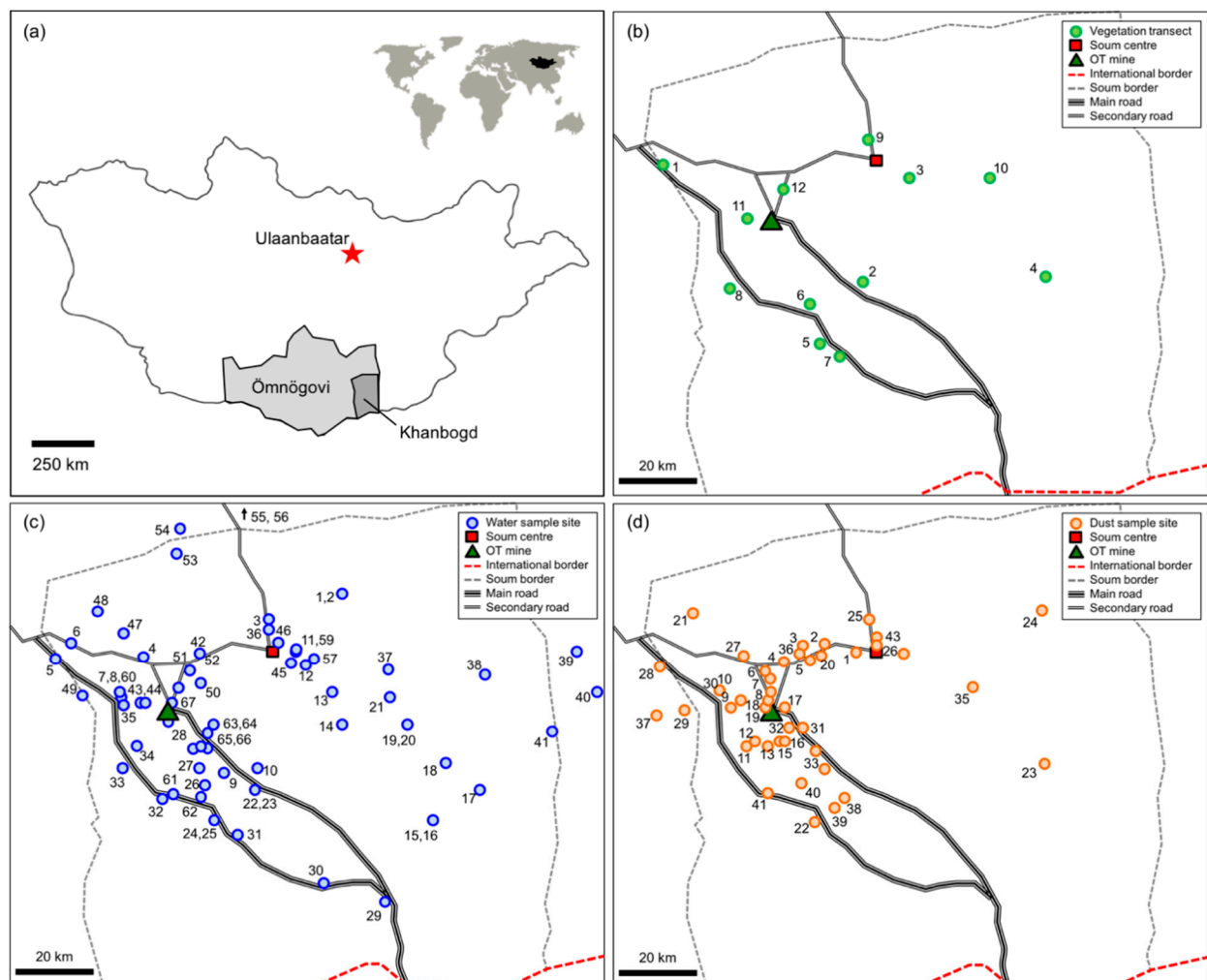

Figure 1. (**a**) Location map showing Khanbogd *soum* within Mongolia; (**b**) vegetation transect locations; (**c**) water sampling site locations; (**d**) dust sampling site locations.

Extreme temperature variability and climatic change characterises the *soum* (and the Gobi Desert more widely). Khanbogd is the warmest *soum* in the country, with an

average annual temperature of 7–8 °C, but temperatures can vary by up to 70 °C across the year [35,37]. Precipitation averages 95.3 mm per year (see Figure S1 in the Supplementary Information). Conditions in Khanbogd are similar to climate trends across the country, with the *soum* experiencing a 40-year warming trend and a slight increase in annual precipitation (see Figure S2 in the Supplementary Information). Negative precipitation anomalies suggested drought episodes in the 1960s, 1980s and early 2000s (see Figure S3 in the Supplementary Information).

Khanbogd *soum* is centred on one of the world's largest (at 1500^2 km) alkali granite massifs which is part of a sedimentary and volcanic landscape radiating from the caldera into the vast steppe [38]. The surrounding desert is characterised by a dry, gravel and rock-strewn landscape with poor soils. Water is scarce in the region, with only the Bor Ovoo spring (now desiccated by mining activity) identified as a surface source. Yet shallow aquifers are present at $\geq$2 m depth, particularly in dry river beds, and deep aquifers of up to several hundred metres are known to exist. The landscape hosts wildlife such as wild ass, saiga antelope and the rare Gobi bear, but livestock dominates, particularly cashmere goats and camels.

Other recent infrastructure unrelated to the OT mine, including the China-bound export road of Tavan Tolgoi (one of the world's largest coal mines), the unfinished Tavan Tolgoi railroad and a Qatari bird and wildlife reserve (an extensive fenced exclusion zone east of the *soum* centre) have contributed to land fragmentation and loss of pasture in the *soum*.

2.2. Data Collection

Our interdisciplinary research took place as part of an independent expert research project within the International Finance Corporation's Compliance Advisor Ombudsman (CAO) complaint resolution process in 2016, and follow-up qualitative research was conducted in 2019. Key themes in the herder complaint lodged to the CAO [39] included mining impact on water supply, pasture degradation and resultant dust impacts upon human and livestock health. In addition, herders identified concerns regarding the ability to practice traditional livelihoods, thus another aspect of the study was focused on understanding the socio-economic dynamics and changes in land use since 2003.

2.2.1. Pasture

Vegetation cover was examined using twelve 1 km vegetation transects located at or near water sources, which themselves were selected to be co-located with herder households and key points of interest relating to the mine. We chose the twelve vegetation transect sites to cover as large an area as possible across the *soum*, and at various distances from the mine itself (Figure 1b).

For each transect, vegetation measurements were taken at 25 m, 50 m, 100 m, 200 m, 500 m and 1000 m from the water source to identify cover as a function of distance from a well. At each distance, a 50 m section of pasture was examined [40]. Percentage of plant basal cover for each meter along the line was recorded as a measure of plant density. At each site, plant species growing along the transect were collected to establish species composition and animal palatability (see Table A1). It should be noted that May–July 2016 was a particularly rainy period, including several days in May and June when fieldwork was conducted. This would be expected to lead to greater cover than drier years.

2.2.2. Access to Water

To evaluate water resources available to herder livelihoods, we examined the distribution, quality and access to water sources at 67 locations across the *soum* (Figure 1c). As explained above, the water source field sites were selected based on their collocation with herder households and key points of interest relating to the mine.

Water quality was assessed at all sites by measuring the pH, total dissolved solids (TDS) and electrical conductivity (EC) using a Hanna HI meter (model 98129), which

provides an approximate indication of relative water quality in the field. Sensafe strips were also used to test for heavy metals at each site. Depth was documented by lower rope that was then tape-measured for distance.

2.2.3. Dust

Dust impact was monitored by placing 43 dust traps (composed of a simple cardboard structure holding an absorptive sponge (100 × 60 × 30 mm) throughout the *soum* during May 2016 (Figure 1d). Dust traps were placed in areas covering both the 20 km "exclusion zone" around OT, as well as sites further from the mine itself, including along major roads, at herder camps, *bagh* centres, water sources and in the *soum* centre. Placement included sites deemed most relevant to the herder community, such as along roads and near *gers* (mobile tent homes).

Due to significant logistical difficulties, including long distances, the absence of roads and constrained research schedules, traps were placed and collected on different dates, but all traps remained in situ for 1–2 weeks. As noted above, the unusual occurrence of rain during the fieldwork period may have potentially impacted dust collection and retention at different sites.

Given the construction of the dust traps and the timings of their distribution, we consider the dust trap data to be valuable as a relative measure of dust deposition between samples, rather than an absolute measure that could be directly compared to other methodologies. While fairly simplistic, our methodology does allow us to identify broader-scale spatial patterns of dust emission across the study period.

In support of our dust trap data, we extracted aerosol optical depth (AOD) measures for the study region from remotely sensed MODIS imagery [41]. We downloaded publicly available data from the NASA MOD-4 Aerosol Product [42] over the years 2002–2016 to establish a historical dust record for Khanbogd *soum*. This dataset provided additional contextual information to support findings from the more granular dust trap data.

2.2.4. Interviews and Focus Groups

We assessed herder perceptions and land use practices by conducting 106 interviews with herder households registered across four *baghs* in Khanbogd *soum*. The households were randomly selected from a list provided by the local government of herder households registered in the *soum*. Interviews were conducted in herders' ger homes, outdoors and in community centres at times and places convenient for herders. This enabled us to speak with herder households across the territory, including households who had been resettled from the Oyu Tolgoi license area and others who lived more than 100 km from the mine site. Ariell Ahearn and Tsendsuren Purevsuren conducted all of the interviews together in the Mongolian language. A set question list was used with herders in a semi-structured approach. Additionally, a select number of Oyu Tolgoi and local government representatives were interviewed. A diversity of herder experiences were captured, but only the major trends are noted in Section 3.2 on socio-economic dynamics.

Seven focus groups were also conducted as part of the wider CAO complaint resolution process. Participants included mine staff/representatives, local government officials and herders and participant observation. In 2018–2019, an additional 98 follow-up interviews were conducted in order to develop a preliminary set of longitudinal data. All interviews were transcribed into the Mongolian language and translated into English, and coded using NVivo software.

3. Results

3.1. Environmental Dynamics

3.1.1. Pasture

Transect data revealed there was at least some vegetation cover across the 12 *soum* sites (Figure 2). Average coverage at each site ranged from 2.0% (site 5, south of the Tavan Tolgoi road) to 13.6% (site 9, north of the *soum* centre). In general, vegetation cover was

relatively homogenous in the zone 25–200 m from each water source (varying from 5.9 to 6.3%), and tended to increase slightly with increased distance from the water source. This suggests that isolated water points lead to a concentration of livestock and thus higher grazing and trampling damage to plants.
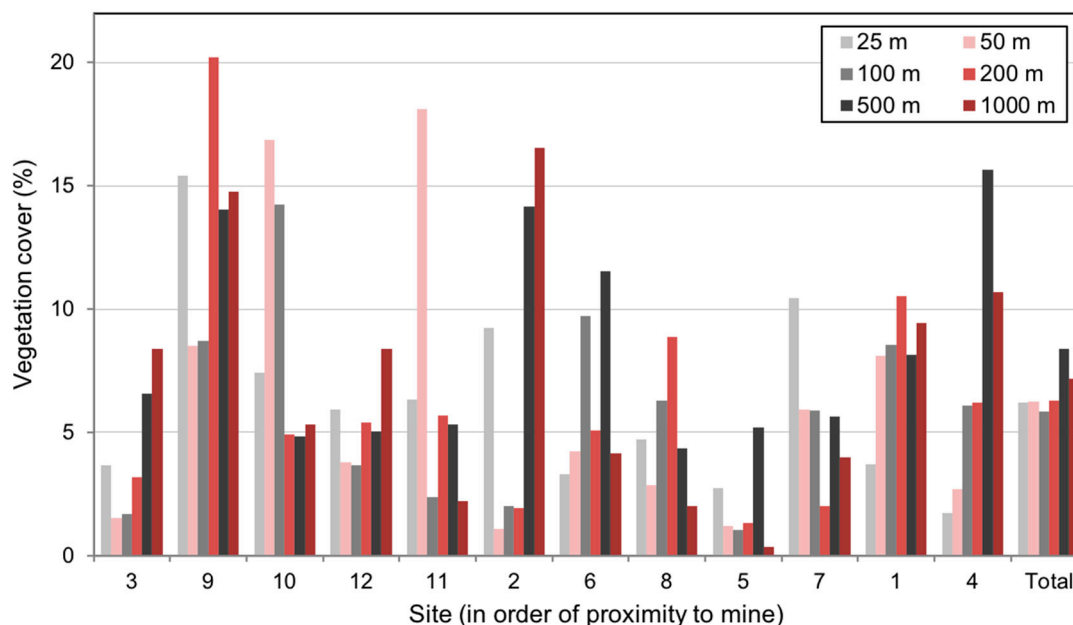

Figure 2. Vegetation cover at 12 experimental transects in Khanbogd *soum*, at increasing distance (m) from a given water source. Sites are ordered by proximity to mine (site 3 is closest and site 4 is furthest).

The vegetation transects ranged in distance from the mine from ~5 km to ~70 km, but we found no clear relationship between the proximity of the vegetation transects to the mine and the level of vegetation cover. Transects closest to the mine (transects 11 and 12) had similar coverage to those further away (transects 3, 7 and 8), and the least vegetated transect (transect 5) was distant from the mine. Whilst our transects were not designed to provide data on volume or biomass, most of the identified plant types were found to be palatable for animals (see Appendix A). Vegetation covers reported here are relatively lower than previous assessments [43–45], which report average cover of 8–25% across selected sites.

3.1.2. Access to Water

In the Gobi, surface water is limited and the majority of herders rely on wells for their water supply. Examinations of 67 water sources across the *soum* showed that, of all the surveyed sites, 46 sources (69%) were shallow hand wells, 14 sources (21%) were motorised deep wells, 5 sources (7%) were surface sources, and 2 sources (3%) consisted of water delivered by Oyu Tolgoi (Appendix B). Of the hand wells that were surveyed, almost 80% had water depths shallower than 2 m below ground level (Table 1), and of the surveyed deep wells, 85% were locked and only accessible by key. Locked wells are highly unusual in Mongolia; typically, water is openly available to anyone in the region and well maintenance is the responsibility of local governments (Jackson 2018).

The impact of mining on the drawdown of surface level water and shallow groundwater was not ascertainable, as water levels suggest well viability. The absence of well baseline data at mining initiation prevented comparison over time.

The majority of surveyed water sources were of good to satisfactory quality, in terms of pH (μ = 8.2), TDS (μ = 583 mg L^{-1}) and EC (μ = 1149 μS cm^{-1}) (see Figure S3 in the Supplementary Information for detailed site-specific data). All sites had relatively low

heavy metal presence (<20 µg L^{-1}). Seven sites had particularly high (>1000 mg L^{-1}) TDS levels, and three sites near Khanbogd town had relatively high (>9.0) pH levels.

Table 1. Water levels in all surveyed hand wells.

Water level (m Depth from Surface)	Proportion of Hand Wells (%)
x < 1	26.1
1 ≤ x< 2	52.2
2 ≤ x< 3	9
3 ≤ x< 5	4.3
x ≤ 9	4.3
unknown	4.3

3.1.3. Dust

The levels of dust measured using the dust traps in May 2016 varied significantly across the *soum* (Figure 3). The highest levels were observed at two sites on the Khanbogd road, yet other sites on the same road recorded up to 85% fewer dust particles. High amounts of dust were also recorded in the *soum* centre and at an isolated site near a powerline. Several sites related to mining construction and operation were examined; in fact, the old OT airport, paved sections of road and areas 250 m off the unpaved Khanbogd road had the lowest dust concentrations, suggesting that traffic on the unpaved road had a limited impact on dust beyond its immediate vicinity. In general, it was found that variables such as wind, weather conditions and environment were more relevant to measured dust volume than proximity to potential spot locations for dust emissions, such as the OT mine, the old airport, the paved road or herder camps.
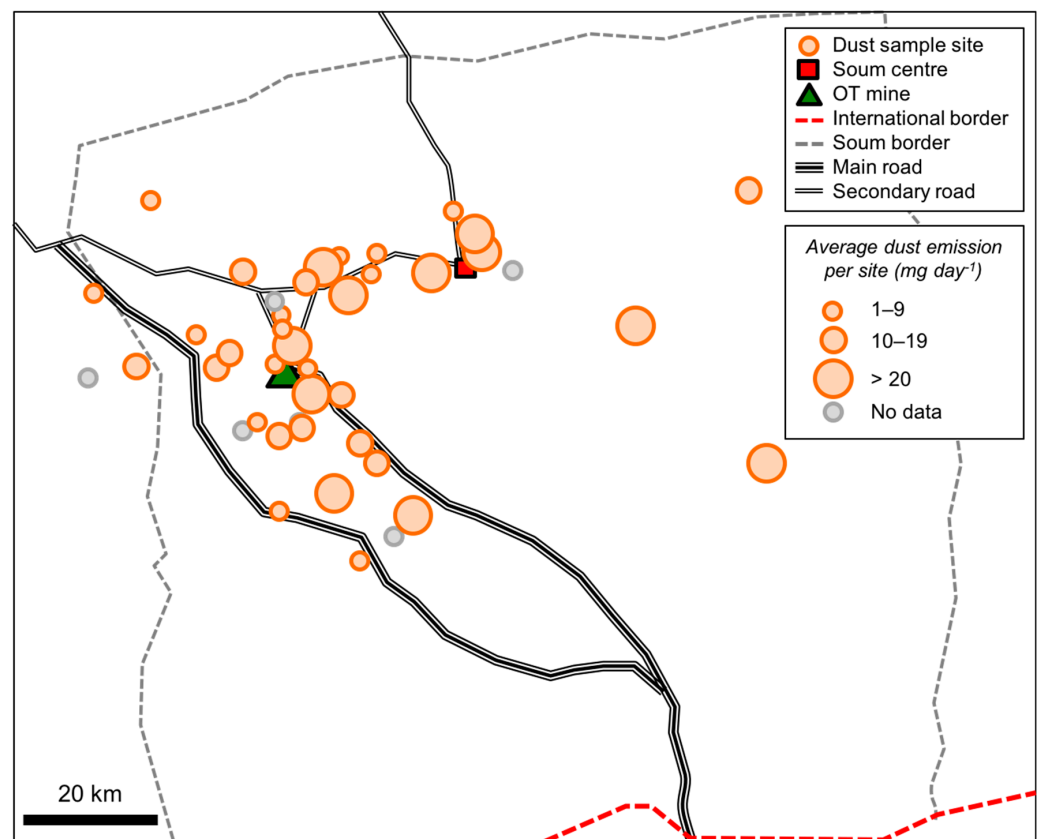

Figure 3. Distribution of dust emissions (mg day^{-1}) across the survey sites in Khanbogd *soum*.

In general, dust was more prevalent at our sites in Nomgon *bagh* than in Javalant or Gavaluut *baghs* (which are closest to the mine). Driving tracks were as much as 75 m wide in Javalant *bagh* and 55 m wide in Bayan *bagh* as vehicles choose alternate tracks depending on conditions. In the absence of paved roads, traffic creates multiple "braided" tracks across the landscape. In comparison, the (then unpaved) OT-Khanbogd road is 11 m wide with 2–4 m soft edges. Heavy truck traffic on the road to China (particularly coal transport) on dirt tracks, creation of new tracks and digging up of riverbeds for local construction material can instigate erosional processes and provide source material for dust transport. Our methods do not allow the initial source of the dust to be ascertained, but it is likely that several other potential dust sources exist beyond mining and road traffic: quarries and dirt pits, construction of a railway and new powerline, dry riverbeds and areas of livestock concentration. Moreover, large-scale dust events also occur, which can have landscape-wide impacts. An example during our field season is that the local Khanbumbat airport was temporarily closed due to dust storms on 22 May 2016.

Results from the aerosol optical depth (AOD) analysis (Figure 4) show high variability in dust presence throughout the 2000s. This may be associated with mine site development and transport from Tavan Tolgoi on unpaved roads. High dust levels were observed in the *soum* from 2005 to 2010 ($\mu = 0.22$, $\sigma = 0.11$), which may be linked to operational developments at OT, and this was followed by a steep decline after the autumn of 2010 ($\mu = 0.17$, $\sigma = 0.06$). There is significant intra-annual variability resulting from local wind patterns and strengths, with higher dust levels occurring in spring (MMA, $\mu = 0.28$, $\sigma = 0.07$) and lower levels in autumn (SON, $\mu = 0.13$, $\sigma = 0.03$). On NASA's scale of 0.1 being very clear and 0.4 being very dusty [42], dust levels in the past few years have largely remained at satisfactory levels, though levels reach higher in late 2015. Whilst evaluating the impact of specific dust sources on human health was beyond the scope of the investigation, it is in any case difficult to assess "additionality" to dust-based illnesses since residents of arid environments often grow up in dusty conditions [46].
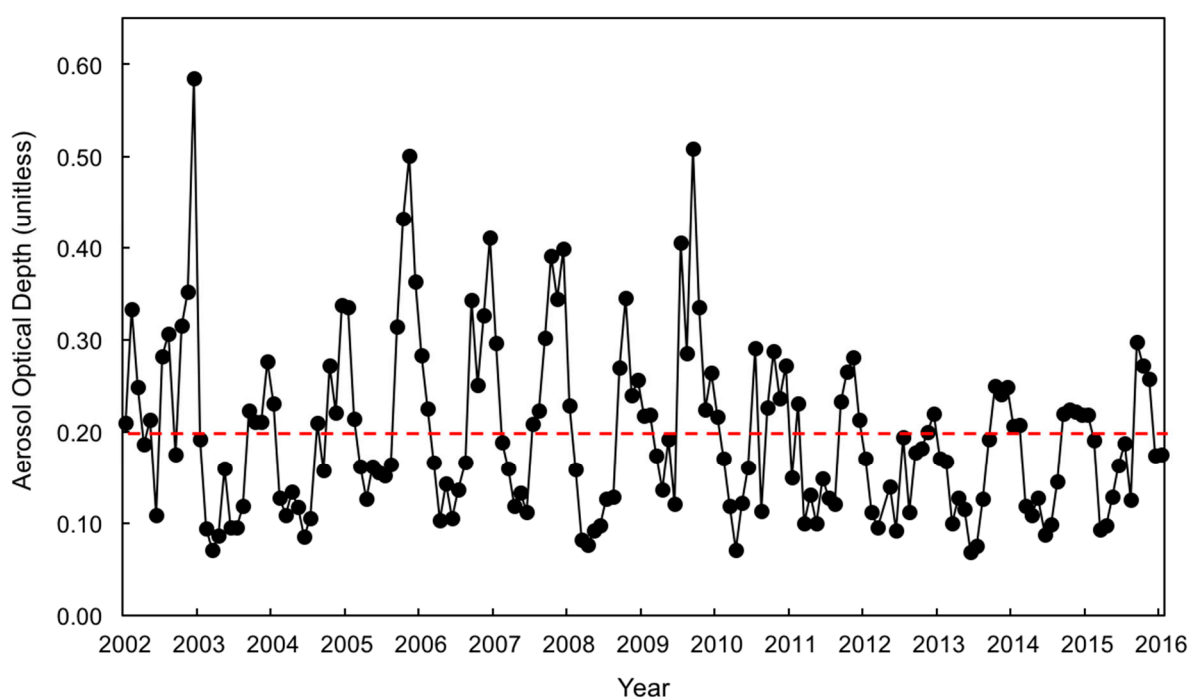

Figure 4. Remotely sensed dust assessment, derived from MODIS aerosol optical depth (AOD) data from 2002 to 2016. Low values represent a clear atmosphere, and high values represent a dusty atmosphere. A value of 0.2 (red dotted line) represents a satisfactory level of atmospheric dust [42]. Year tick marks are placed on the month of July of each year.

3.2. Socio-Economic Dynamics

Several factors were identified that affected herding in Khanbogd from 2003 to 2016, some of which are common features of social change in rural Mongolia. The market system, including financialisation of education, veterinary services and health care, has increased herder household reliance on short-term bank loans [18]. New patterns of herder household organisation reflect changing socio-economic conditions. As an example, lowered school enrolment age and the need to provide childcare to children attending school in town initiates household splitting practices that reduce children's opportunities to learn herding skills at a young age. Herders often identify, as a major change in herding practice, the use of new technology such as motorcycles and cars to herd livestock, which contributes to higher livelihood costs. While these issues are also apparent in Khanbogd, the rapid shift (within a decade) from land use dominated by mobile pastoralist systems to one of extraction and export has had particular effects. Large-scale mining in the region and the issuance of licenses for further mineral exploration in the *soum* has involved loss of pasture land, displacement of households, the development of an industrial landscape and further population from migration into Khanbogd *soum*.

Pasture fragmentation, loss of pasture access, reduced usufruct grazing rights, dust, herder land disputes, new infrastructure and overgrazing were pressing concerns (Table 2). Such factors led to a sense of insecure land rights and unmet expectations. Local government was ineffective at resolving problems. The local government's role in assigning winter camps, maintaining wells and resolving problems was perceived as poorly executed. The government was not trained or supported by the central government to deal with the great community transformation spurred by the mine. Herders believed the mine should resolve problems directly as the government was ineffective. State-level authorities were regarded with suspicion and thought to be interested in primarily benefitting their own private interests.

Table 2. Pasture challenges identified by herders.

Pasture
Land occupied, used, fragmented by Oyu Tolgoi mine license area, old and new airport sites, OT-Khan Bogd road, Tavan Tolgoi coal road, railroad construction, 30 quarries, Qatar Wildlife Reserve, other mines, power station & lines, restricted infrastructure and areas
Pasture crowded by winter camps 'owned' by herder households
Loss of summer pastures due to OT mine
Livestock overgrazing an area
Pasture covered in dust
Lack of rain for pasture
Pasture unused—lack of water for livestock
Use of vehicles for herding degrades land
Packs of wild dogs and wolves

3.2.1. Resettlement and Competition for Pasture

As a result of the resettlement of herders by Ivanhoe Mines during the initial construction of Oyu Tolgoi (2004) and again during Rio Tinto's development (2011) of a water pipeline, an airport and energy infrastructure, herders were displaced from their original territories. These mine-directed resettlement and compensation programmes compacted herder camp locations. The OT resettlement action plans recognised compensation primarily for herder winter camps which had been officially registered with the local government within a specified distance from a piece of fixed infrastructure. These so-called impact zones did not correspond to herder mobile land use practices. Officially registered spring camps located inside the impact zones were also included to some extent, but unevenly. This methodology was not able to adequately capture mobile livelihood practices, thereby excluding many herders who relied on grazing their livestock on pastures within an "impact zone" but did not have a registered winter or spring camp within the zone. This

resettlement approach created confusion and resentment amongst herders who were not recognised as having legitimate land claims in this process. Nonetheless, OT has provided compensation to herders who qualify based on their definition of mine impacts based on a mediated community settlement ("An example to All", *The Guardian*, 2019 [47]) and has provided temporary employment to some households as part of this scheme.

These displacements compounded competition for pasture and conflict between herders. Mobility, the key coping strategy, now encounters restricted water points and assigned winter camps that may limit options and impede migration routes as not all land in the *soum* is suitable or accessible for livestock grazing, or lacks sufficient water. Many herders who moved away from Oyu Tolgoi into new territories were called "sell outs" by herders present in those areas and chased away. In 2016, an elderly widow reported during an interview, "Households which lack water and pasture due to the activity of Oyu Tolgoi are pushed out. When they arrive at the new place, local people accuse them of selling off their land to outsiders and ostracize them. My children must have felt it fully when we moved to the north. Since then my children say that it is not worth moving anywhere, because everywhere we went there was pressure and gossip. I feel that it is difficult to carry that burden. When we move somewhere else we experience a lot of such pressure".

The OT mine contributed to these livelihood pressures but was not the only source. For example, the vast Tavan Tolgoi coal mine 140 kilometres to the north constructed a road through Khanbogd *soum* for export. The road's constant stream of trucks driving to the Chinese border and the roadside trench barriers have fragmented common pasture and have created obstacles for livestock to move across the landscape to reach grazing areas. A railroad development project and new industrial activities including quarries also contributed to the wider transformation in the *soum*. Mineral royalties, which could contribute to local improvements, go to the central government. Payments are not directed to herder issues; inadequate funding returns to the *soum* for investment or amelioration of extractive impacts.

3.2.2. Pressure on Resources

Key issues were over access to water, pasture and winter camps. The challenge of water availability for livestock vis a vis the amount consumed by the mine was a major complaint. Responsibility was commonly attributed to the OT mine; for example, almost all households interviewed perceived their water shortage problems as caused either entirely or partially by OT mining activities. Yet various non-mine-related social, infrastructural and physical changes have also modified herder livelihoods over time.

There has been a loss of customs and conventions related to pressures on water resources and grazing pasture driven by development of infrastructure and a transition in land use and tenure rights. For many households, lack of sufficient labour at the household level compromises the capacity to hand-milk livestock, which in turn affects the production of traditional livestock-based products.

In a notable judgement of herding viability, not all herders want their children to become herders because of perceived and experienced economic and environmental insecurity. For current and future herders, major challenges are the presence of mines and government shortcomings in planning and lack of structure that protects herders' customary rights. Importantly, these include access to pasture and functioning water wells and the ability to continue mobile herding with migration privileges. A herder living in Javkhlant bag explained, "Although today they are building us some buildings, brought electricity and a road, they robbed us of our future. There is no pasture and water here and therefore there is no future. When the groundwater is pumped out we no longer will have pasture and all life will become strange."

Mine impact, locked wells, the increase in livestock, slow well recharge and a lack of shallow groundwater were common issues cited with various causes (Table 3). The Bor Ovoo spring was lost to the OT mine license area; wells are slow to recharge; there is a lack of wells in areas with good vegetation; there are fewer migrating herders, who rely

on wells for longer periods of time. Such changing patterns increase pressure on limited water sources.

Table 3. Water issues identified by herders.

Water Issues		
Oyu Tolgoi activities impacting shallow groundwater		
Oyu Tolgoi impact on cascading boreholes cause shallow aquifers drain to deep aquifer		
Area around Bor Ovoo spring (inside mine) no longer available		
Wells are being locked		
Too many herders with >1000 livestock		
Bagh sub-district		
Javkhlant	Slow recharge of wells	
	Locked wells	
	Disappearance of springs & standing water	
Gaviluud	Slow recharge of wells	
	Locked wells	
	Loss of operational wells	
	Disappearance of springs & standing water	
Bayan	Lack of water in highland areas	
	Not enough wells in areas of good pasture	
Nomgon	Lack of shallow groundwater	
	Slow recharge of wells	
	Not enough wells in areas of good pasture	
	Need for more deep wells: shallow wells take 24 hours to recharge	

"Long ago, we used to move a lot. The water and pasture were enough. The Bor Ovoo [spring] water was spread everywhere in all of Javkhlant bagh. We did not use a bucket [to get water], we only used the water spread on the ground"—Javkhlant bagh herder.

"If we don't move and stay in one place, our herds will not grow. Also, the well pump is expensive too. So many expenses. In the places we move to, people sometimes have good attitude, sometimes a bad attitude. Some people let us drink their water, some won't"—Bayan bagh herder.

Customary land tenure enables mobility across land; this is now compromised by exclusive use given to companies, rail construction and incoming industries. Herders' rights to use land (more secure when pastoralism was the main economic practice) are subordinate to these private leases issued by government authorities. Traditional land tenure systems, protected vaguely by law, appear to be ineffective as the national and local governments issue extractive licenses. In Khanbogd, wealth is customarily measured by number of livestock with large animals (horse, camel, cattle) of greater value and cashmere goats generating cash each spring. An increase in livestock at the household or district level is the best available assessment of expanding economic activity. When the land tenure systems clash there is evidence that more wealthy households attempt to secure their rights to use pasture through additional investments such as property ownership, permanent buildings and obtaining more than one winter and spring camp site. One household (with 991 livestock) reported having three winter camps and two spring camps. More than 90% of herders report that climate (i.e., weather, amount of precipitation) and infrastructure (mining-related infrastructure, the presence of other household camps) are the primary impacts on pasture availability.

3.2.3. Herders Remain Semi-Nomadic

Findings stressed that Khanbogd *soum* herders remain semi-nomadic, moving to varying degrees from camp to camp (Table 4). The OT mine land take, though severe (mine license area is 80 km^2), accounts for a small proportion of *soum* pasture land. In principle, with government organisation, it is possible for herding to continue despite the

mine's presence. The failure of mining operators to collect baseline data from the project
initiation meant that water impact cannot be sufficiently addressed or quantified. It was
recognised that the increase in the number of livestock and changing practices affected
pasture viability. Herders expressed anger and frustration about the changes that have
affected their lives and communities due to the mega-mine and other processes. A sense
of powerlessness in influencing the transformation was conveyed, especially by elder
residents. These psychological impacts are evidenced in the feelings of an older herder,
who explained, "But recently my mind is not at peace. Whenever I go out and have a look
or herd my animals there is dust everywhere and trucks drive past. Then I am not able to
see my animals in the dust. Nobody will be happy about that and I get frustrated about it.
I have no faith in the future and worry what will happen. Considering what is happening
to the water now, once the factory [OT] starts to use water more, then I think we will be
badly affected. That's why psychologically we are under great pressure. I was thinking of
turning my children into herders and they will rear livestock and carry on this heritage. I
don't know what will happen. I have almost nothing left to hope for."

Table 4. Number of herder moves per year by number of livestock.

Number of Livestock	Number of Moves per Year
>100	0–2
100–250	1–10
250–500	2–6
500–800	3–12
800+	to 20

3.2.4. Changing Herding Practices

Herding practices have changed in the district since 2002. Herders are moving less,
with several active pastoralists (17%) now living in a fixed dwelling located at a seasonal
camp (Table 5). There are growing wealth inequalities, more family separations take place
and debt is widespread. Often loans are for vehicles that are expensive to buy and run.
Herders cited petrol as a major expense, with estimates of 50 litres used per week. Some of
these shifts are due to the presence of the mine; others reflect patterns common across the
country, including changes in herder preferences and choices. Other recent developments
in the district, including the coal road, the railway, small-scale mining and the fenced
Qatari Wildlife Reserve, fragment pasture and affect mobility. Some herders are prospering
and finding new opportunities for employment and business. Yet many are struggling.
There was no clear pattern that linked success or problems systematically with the mine.
However, herders attributed most of their problems to the mine.

Table 5. Herder households by type of dwelling—ger (tent yurt) or fixed house.

Sub-District	House		Ger		Live in Town		Total
	#	%	#	%	#	%	#
Nomgon	7	12	46	78	6	10	59
Gaviluud	21	20	85	79	1	1	107
Javkhlant	9	10	69	73	17	18	95
Bayan	23	26	63	72	2	2	88
TOTAL	60	17	263	75	26	7	349

In aggregate, livestock numbers of Khanbogd herders have increased threefold from
2003 to 2015 (Figure 5). As noted, in Mongolia, livestock are a key measure of wealth. How-
ever, an aggregate count conceals a more significant change regarding wealth inequality
in the region. In 2010, the livestock census in Khanbogd indicated that 6 households out

of 647 each own more than 800 livestock. These 6 households owned 5.92% of the total number of livestock. By 2015, the number increased to 15 (11.37% of the total number of livestock) and by 2018 the number of households with more than 800 livestock increased to 41 households (25% of the total number of livestock). These numbers present an interesting picture, as they demonstrate a growing number of families with significant livestock holdings in Khanbogd. In 2018, two families had over 1500 head of livestock. Calculating wealth profiles for pastoralists is complex and there is increasing attention to qualitative measures, including self-reports of wellbeing, as potential avenues to capture changing dynamics [48].
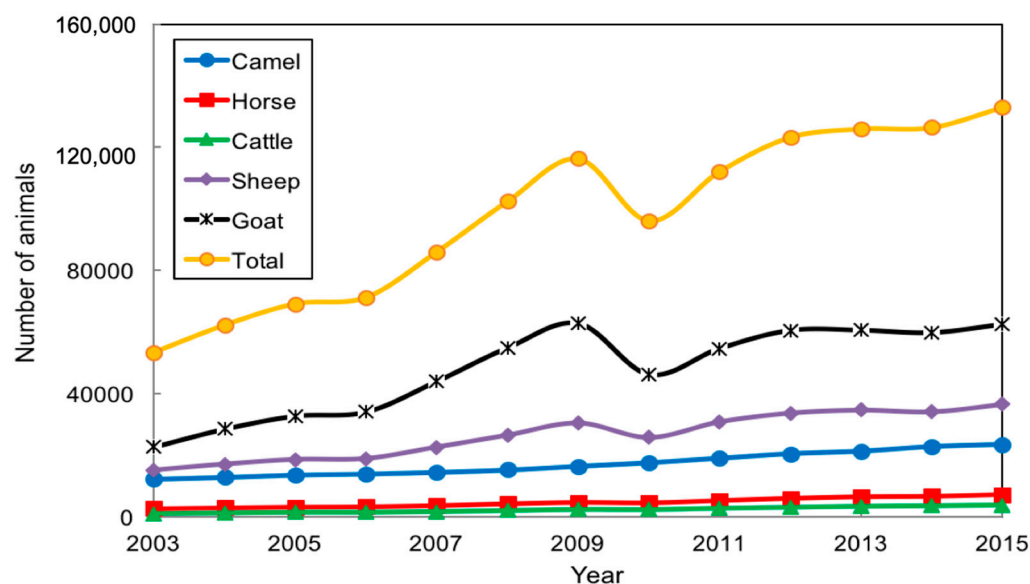

Figure 5. Change in numbers of animals kept by herders in Khanbogd *soum*, from 2003–2015 [49].

The impact of OT varied with potentially negative and positive outcomes. The mine created work opportunities for some residents through full- and part-time work. Whilst locals had limited specialist skills, some had local jobs in construction, cleaning, food service, maintenance and driving.

4. Discussion

4.1. The Social and Physical Environment

Effective integration of environmental data with herder perspectives presents a strong narrative of mining impact on the Gobi pastoral environment. Herder social-ecological reports and ground truthing are consistent on several points. Many interview statements were supported by testing and observation. Yet different data collection techniques between interviews and physical investigation provide data that may at times not be comparable. Here, findings may corroborate comments or add complexity and understanding to vital issues. What develops is an in-depth account of the pastoral landscape in Khanbogd *soum* from two distinct methodologies. Results manifest the practical, perceptual and physical challenges in Khanbogd *soum*'s pastoral landscape. These shape the viability and vulnerability of herding that confronts and co-exists with mega-mining.

Interviews reveal a changing environment and demanding physical parameters that are integral to herding; environmental investigation provides physical data on the topics (Table 6). Some key points are comparable across methods—vegetation cover, fragmentation, locked wells. Other issues are complimentary, for example, an identified problem (water) and resolution (high potential for shallow wells), yet government or private funding and initiative are needed to resolve the issue. Findings highlight shared knowledge perceptions and data documentation on pasture and water. There are also differences; dust was perceived more negatively than testing presented. The concurrence on *soum*

environmental issues builds a platform for the local government, mine and residents to understand the environment and potentially mitigate detrimental practices and ameliorate pastoral conditions.

Table 6. Comparative results from herder interviews and environmental investigation on key issues.

		Herder Data	Environmental Data	Method
Theme	**Issue**			
Water	Quantity	Decrease	Shallow groundwater	Measurement
	Quality	–	Good	Testing
	Availability	Decrease	–	–
	Locked wells	Yes	Yes	Observation
	Distance between wells-kms	Yes	Yes	Observation
Pasture	Low vegetation cover	Yes	Yes	Transects
	Plant palatability	–	Yes	Plant identification
	OT impact	Soum-wide	Mine license area+	Observation
	Infrastructure impact	Yes	Yes	Observation
	Limitations-physical	Yes	Yes	Observation
	Restrictions-social	Yes	–	–
Dust	Overall	Bad	Acceptable	Remote sensing, dust traps
	OT-Khan Bogd road	Bad	Acceptable	Dust traps
	Improvement over time	–	Yes	Remote sensing
Fragmentation	Roads	Yes	Yes	Observation
	Fencing	Yes	Yes	Observation
	Railroad	Yes	Yes	Observation
	Wildlife reserve	Yes	Yes	Observation
Mobility	Changing practices	Yes	-	–
	Governance, policy	Yes	-	–
	Infrastructure	Yes	Yes	Observation

4.2. Deserting Herding in the Gobi?

The presence of mining operations, particularly the vast OT and Tayan Tolgoi mines, is a central point of conflict for the herders of Khanbogd *soum* [36]. Their significant implications for the physical environment and livelihoods have raised the question, "can herding survive mining?" in Mongolia [10]. Our study shows that in 2016, mega-mining and herding did co-exist in the region, that environmental conditions were a result of diverse causes with mining being significant, and that resource extraction represented a rapid transformation of the pastoral landscape. This has potential beneficial, mixed or detrimental impacts in Khanbogd. We find that climate and natural forces, mining activities, herder behaviour and the decisions and (in)actions of the government combine to define the social-ecological systems in the *soum*.

Some environmental changes, such as lower water levels and sparse vegetation, could prima facie be related to mining. Key drivers of physical changes, such as climate and pasture resources, are not directly attributable to the mine. The data results and spatial variability across our study sites for dust, water and vegetation identified impacts but not an exclusive link between mining operations and environmental impact across the *soum* in 2016. Conditions may have been different during the construction of the mine (disruptive impact

of construction); herding adjustments may have mitigated detrimental effects to water sources and pasture and mine-sponsored compensation may have satisfied some herder complaints. Less tangible forms of damage to customary rangelands, livelihood stress and new uncertainty may reflect impacts from OT; these are distinct from environmental factors. The clear, consistent responses of the herders highlight the tensions that the mine has provoked in terms of their decision-making and perceptions of environmental potential for livestock raising.

Our findings on water access in the *soum* (see Table 1) highlight three key issues. First, the main source for water was shallow hand wells. Second, access to existing water has been reduced through physical (locked wells) or social (herder winter camp delineation; need for permission) means of control. Third, the use of motorised pumps is changing the way that water is accessed by herders. A customary assessment of well water—how long the well takes to refill—is no longer a suitable measurement when using motorised pumps and may skew herder perceptions of water abundance/scarcity over time. There is also a potentially significant problem that surrounds the possible connection between shallow and deep aquifers resulting from boreholes drilled on behalf of OT. This was repeatedly mentioned in interviews and in public documents [49,50]. Yet the question of deep borehole construction quality and potential surface-to-deep aquifer leakage would require further examination that is beyond this investigation.

Whilst the OT mine has had direct environmental impacts, including built infrastructure (airport, roads) and loss of pasture and fragmentation, herder behaviour and societal change (development, increase in livestock and vehicles) has also affected pasture and water demand and resources. These pressures are exacerbated by poor maintenance of wells by the local authorities, and efforts by some herders to control resources through locked water points and winter camp registration, a form of implied tenure rights. Nevertheless, the overall increase in animal numbers suggests that herding has so far remained viable in the *soum*.

The Gobi context presented evokes Franks et al.'s (2014) [51] mining–community conflict rubric about large-scale actors' role in socio-ecological system (SES) change. Without OT, Khanbogd *soum* would be similar to other Mongolian regions; part of the influence of the mega-mine has been to reconfigure basic conceptions of herding practice and sustainability. As Horrocks-Taylor (2018) [52] points out, in Kyrgyzstan, mining's apparent economic benefits come at a risk to environments and livelihoods. In addition to detrimental mining effects (fragmentation, land take), potential overgrazing, increased livestock density and intensification (e.g., at water points) present significant pasture pressures. The situation in Mongolia maps on to Fernandez-Gimenez et al.'s [53] ecological and cultural resilience trajectories for the country. Whilst cyclical, Khanbogd *soum* shows OT herders occupying shared territory, something of an achievement in such a contentious space. This is in part due to the herder's IFC complaint and OT's resultant engagement [17,49]. Ostrom (2009) [54] would insist on focused monitoring and enforcement for SES value. In fact, the gradual herder–OT–government tripartite engagement offers hope for SES amelioration, or at least continued viability [32].

Recognising social complexity, minimising environmental risk, reducing infrastructure conflict and costs (to USD 20 million/week) exemplified in Khanbogd are challenges across mineral-rich regions [31]. In acknowledging an asymmetrical conflict [29] and engaging with the community—albeit later than desirable—Mongolian society has been able to take value from customary practices notwithstanding OT's presence. This is timely as China's Belt and Road Initiative, mimicked by the Mongolian Economic Corridor, comes to the greater steppe region [55]. Power imbalances, weak state governance, poor environmental standards and a lack of transparency suggest planned mining expansion in Mongolia will present a great challenge for herders and the country to cope with, manage and address. Attention to cumulative impacts of mining and related infrastructure in policy-making and directed development of supporting industry would aid in social and environmental safeguarding. Strengthening local government capacity to manage and

monitor development and facilitate citizen participation in decision-making remains a crucial issue that could be addressed with additional personnel and resources.

Interactions between the herders of Khanbogd *Soum* and their environment is changing rapidly and will face increasing pressure in the coming decades. The continuing evolution of herding away from a subsistence livelihood adds new layers of decision-making and complexity that lead Mongolian pastoralism into an uncharted future. As socio-economic forces predominate and mining expands, the environment becomes an input rather than the defining feature. In Khanbogd *Soum*, physical limitations of water and pasture productivity are recognised by data and herders. These have major ramifications for the future of herding, especially if animal numbers continue to increase or extractive footprints expand. A point may soon come where traditional mobile pastoralism in the Gobi gives way to more settled livestock raising. This new reality would make the Gobi environment unrecognisable to Marco Polo, von Humboldt and, indeed, the authors of this paper.

5. Conclusions

Khanbogd *soum*'s location in an arid desert environment forms an important backdrop to herding activities in the area. Precipitation throughout the year is low and displays significant interannual variability. Customary herding is based on adaptation to such a harsh landscape, and resource extraction adds a new layer of complexity. The presence of the vast OT mine is a central point of conflict for the herders of Khanbogd *soum*. Mining-related exclusion zones and infrastructure have impacted, displaced or inconvenienced herders, and road traffic poses a risk to animals over large distances. Dust production from mining activities appears to have relatively limited impact, but unresolved water access issues continue, particularly regarding the potential connectivity between shallow and deep aquifers resulting from borehole construction. This remains a justified fear to local herders and represents an ongoing conflict with the OT mine. Looking to the future, OT's environmental impact (i.e., water, vegetation, dust, fragmentation) identifies mega-mining outcomes at multiple levels—for the community, investors, researchers and development trajectories.

Concurrently, the perceptions, decision-making and behaviour of herders have transformed pastoralism in the *soum* from a subsistence livelihood into an economic activity. This has led to changes in practice, land use, motivation and conception, whilst the community participates in the domestic development trajectory. The doubling of livestock numbers whilst the OT mine has been operating documents that, contrary to common narratives, mining and herding do coexist in Khanbogd *soum*. Pastoral praxis and performance have transitioned; in doing so, the herding environment has been reconfigured into a workable contemporary representation, home to both pastoralism and mining. Herding has not been deserted in the Gobi.

Appendix A

Table A1. Vegetation composition at all transects.

Site	Latin Name	Mongolian Name	Palatability		Life Form	Growth
Khanbogd 1	Peganum nigellastrum		palatable	camel, goat, horse, sheep	perennial	forb
Khanbogd 1	Oxytropis myriophylla		palatable	camel, goat, horse, sheep	perennial	shrub
Khanbogd 1	Cleistogenes squarrosa		palatable	camel, goat, horse, sheep		
Khanbogd 1	Achnatherum splendens		palatable	camel, goat, horse, sheep		
		Sandaal Sarmar				
Khanbogd 2	Ptilotrichum canescens		palatable	goat, horse	perennial	forb
Khanbogd 2	Peganum nigellastrum		palatable	camel, goat, horse, sheep	perennial	forb
Khanbogd 2	Zygophyllum xanthoxylon		palatable	camel, goat, sheep		shrub
Khanbogd 2	Amygdalus pedunculata		palatable	camel, deer, goat, sheep		shrub
Khanbogd 2	Lespedeza dahurica		palatable	cattle, goat, horse, sheep	perennial	forb
Khanbogd 3	Cleistogenes squarrosa		palatable	camel, goat, horse, sheep		
Khanbogd 3	Oxytropis myriophylla		palatable	camel, goat, horse, sheep	perennial	shrub
Khanbogd 3	Dracocephalum foetidum					
Khanbogd 3	Artemisia santolinifolia		palatable	camel, cattle, goat, horse, sheep	perennial	shrub
Khanbogd 4	Iris bungei		palatable	camel, cattle, goat, horse, sheep	perennial	forb
Khanbogd 4	Oxytropis aciphylla		palatable	camel, goat, horse, sheep	perennial	shrub
Khanbogd 4	Peganum nigellastrum		palatable	camel, goat, horse, sheep	perennial	forb
Khanbogd 4	Echinops gmelinii		palatable	camel, horse	perennial	forb
Khanbogd 4	Artemisa anethifolia		palatable	camel, goat, sheep	annual/biennial	forb
Khanbogd 4	Nitraria sibirica		palatable	camel, goat, sheep		shrub
Khanbogd 4	Convolvulus ammanii		palatable	goat, sheep	perennial	forb

Table A1. *Cont.*

Site	Latin Name	Mongolian Name	Palatability		Life Form	Growth
Khanbogd 5	Iris oxypetala		palatable		perennial	
Khanbogd 5	Artemisia santolinifolia		palatable	camel, cattle, goat, horse, sheep	perennial	shrub
Khanbogd 5	Peganum nigellastrum		palatable	camel, goat, horse, sheep	perennial	forb
Khanbogd 5	Pedicularis abrotaniflolia		palatable	camel, goat, horse, sheep		
Khanbogd 5	Achnatherum splendens		palatable	camel, goat, horse, sheep		
Khanbogd 5		Sandaal				
Khanbogd 5		Sarmar				
Khanbogd 6	Iris bungei		palatable	camel, cattle, goat, horse, sheep	perennial	forb
Khanbogd 6	Arnebia guttata		palatable	camel, goat, sheep	perennial	forb
Khanbogd 6	Ptilagrostis pelliotii				perennial	
Khanbogd 6	Stipa gobica		palatable	camel, cattle, goat, horse, sheep		grass
Khanbogd 6	Raemuria soongorica		palatable	camel, goat, sheep	perennial	shrub
Khanbogd 6	Tournefortia sibirica		palatable	camel	perennial	forb
Khanbogd 6	Artemisia santolinifolia		palatable	camel, cattle, goat, horse, sheep	perennial	shrub
Khanbogd 6	Iris oxypetala		palatable		perennial	
Khanbogd 6	Amygdalus pedunculata		palatable	camel, deer, goat, sheep		shrub
Khanbogd 6	Kalidium foliatum		palatable	camel		shrub
Khanbogd 6	Olgeae leucophylla				perennial	forb
Khanbogd 6	Zygophyllum rosovii		palatable	cattle, goat, horse, sheep	perennial	shrub
Khanbogd 6	Scorphularia incisa					shrub
Khanbogd 6	Artemisia scoparia		palatable	camel, cattle, goat, horse, sheep	biennial	forb
Khanbogd 6	Zygophyllum xanthoxylon		palatable	camel, goat, sheep		shrub
Khanbogd 7	Raemuria soongorica		palatable	camel, goat, sheep	perennial	shrub
Khanbogd 7	Peganum nigellastrum		palatable	camel, goat, horse, sheep	perennial	forb
Khanbogd 7	lom		palatable	camel, goat, horse, sheep		shrub
Khanbogd 7	Artemisia scoparia		palatable	camel, cattle, goat, horse, sheep	biennial	forb
Khanbogd 7	Nitraria sibirica		palatable	camel, goat, sheep		shrub
Khanbogd 7	Oxytropis aciphylla		palatable	camel, goat, horse, sheep	perennial	shrub
Khanbogd 8	Elymus paboanus		palatable	camel, cattle, goat, horse		grass
Khanbogd 8	Amygdalus pedunculata		palatable	camel, deer, goat, sheep		shrub
Khanbogd 8	Stipa gobica		palatable	camel, cattle, goat, horse, sheep		grass
Khanbogd 8	Convolvulus ammanii		palatable	goat, sheep	perennial	forb

Table A1. *Cont.*

Site	Latin Name	Mongolian Name	Palatability		Life Form	Growth
Khanbogd 8	Salsola passerina		palatable	camel, goat, horse, sheep		shrub
Khanbogd 8	Raemuria soongorica		palatable	camel, goat, sheep	perennial	shrub
Khanbogd 8	Olgeae leucophylla					forb
Khanbogd 8	Zygophyllum xanthoxylon		palatable	camel, goat, sheep		shrub
Khanbogd 9	Elymus chinensis		palatable	camel, cattle, goat, horse, sheep	perennial	grass
Khanbogd 9	Amygdalus pedunculata		palatable	camel, deer, goat, sheep		shrub
Khanbogd 9	Peganum nigellastrum		palatable	camel, goat, horse, sheep	perennial	forb
Khanbogd 9	Caragana leuncophloea		palatable	camel, goat, sheep		shrub
Khanbogd 9	Eurotia ceratoides		palatable			shrub
Khanbogd 9	Convolvulus ammanii		palatable	goat, sheep	perennial	forb
Khanbogd 9	Arnebia guttata		palatable	camel, goat, sheep	perennial	forb
Khanbogd 9	Nitraria sibirica		palatable	camel, goat, sheep		shrub
Khanbogd 9	Salsola passerina		palatable	camel, goat, horse, sheep		shrub
Khanbogd 9	Oxytropis aciphylla		palatable	camel, goat, horse, sheep	perennial	shrub
Khanbogd 10	Suaeda corniculata		palatable	camel, goat, horse, sheep	annual	forb
Khanbogd 10	Elymus paboanus		palatable	camel, cattle, goat, horse		grass
Khanbogd 10	Raemuria soongorica		palatable	camel, goat, sheep	perennial	shrub
Khanbogd 10	Peganum nigellastrum		palatable	camel, goat, horse, sheep	perennial	forb
Khanbogd 10	Ptilotrichum canescens		palatable	goat, horse	perennial	forb
Khanbogd 10	Nitraria sibirica		palatable	camel, goat, sheep		shrub
Khanbogd 10	Convolvulus fruticosus					shrub
Khanbogd 11	Scorzonera pseudodivaricata		palatable	goat, sheep		shrub
Khanbogd 11	Zygophyllum xanthoxylon		palatable	camel, goat, sheep		shrub
Khanbogd 11	Iris bungei		palatable	camel, cattle, goat, horse, sheep	perennial	forb
Khanbogd 11	Stipa gobica		palatable	camel, cattle, goat, horse, sheep		grass
Khanbogd 11	Panzeria lanata		palatable	goat, horse, sheep		forb
Khanbogd 11	Peganum nigellastrum		palatable	camel, goat, horse, sheep	perennial	forb
Khanbogd 11	Raemuria soongorica		palatable	camel, goat, sheep	perennial	shrub
Khanbogd 11	Nitraria sibirica		palatable	camel, goat, sheep		shrub
Khanbogd 11	Atriplex sibirica				annual	forb
Khanbogd 11	Bassia dasyphylla		palatable	camel	annual	shrub

Table A1. *Cont.*

Site	Latin Name	Mongolian Name	Palatability		Life Form	Growth
Khanbogd 12	Stipa gobica		palatable	camel, cattle, goat, horse, sheep		grass
Khanbogd 12	Eurotia ceratoides		palatable			shrub
Khanbogd 12	Peganum nigellastrum		palatable	camel, goat, horse, sheep	perennial	forb
Khanbogd 12	Anabasis brevifolia		palatable	camel	perennial	forb

Appendix B

Table A2. Water quality and well characteristics.

Site	pH	TDS	EC	Heavy Metals (Semi-Qualitative)	Water Level (m)	*Bagh*	Well Type
W1	7.8	840	1585	10	~	Bayan	Hand pump
W2	6.3	775	1570	10	2.4	Bayan	Hand pump
W3	7.7	350	690	20	~	Bayan	Deep, motor, locked
W4	7.88	2000	4000	10	~	Gavalut	Delivery tank
W5	8.07	2000	4000	20	~	Gavalut	Deep, motor, locked
W6	8.3	404	680	20	8	Gavalut	Hand
W7	7.8	1075	2180	10	1	Gavalut	Hand
W8	7.9	415	820	10	~	Javalant	Deep, motor, locked
W9	8.2	307	616	20	1	Javalant	Hand
W10	8	338	678	10	~	Javalant	Hand pump
W11	9.2	155	318	10	0	Nomgon	Surface
W12	9.2	277	530	10	9	Nomgon	Hand
W13	8.99	254	507	10	2	Nomgon	Hand
W14	8.8	520	1040	10	~	Nomgon	Deep, motor, locked
W15	8.9	328	655	10	3	Nomgon	Deep, motor, locked
W16	8.65	221	444	10	~	Nomgon	Deep, motor
W17	8.6	1892	3785	10	6	Nomgon	Deep, motor, locked
W18	8.5	744	1492	10	~	Nomgon	Deep, motor
W19	8.45	592	1180	10	2	Nomgon	Hand
W20	8.35	582	1159	10	2	Nomgon	Hand
W21	8.6	362	722	10	1.9	Nomgon	Hand
W22	8.38	673	1040	10	2	Javalant	Hand
W23	8.64	684	1362	10	2	Javalant	Hand
W24	8.84	519	1036	10	1	Javalant	Hand
W25	8.68	396	793	10	1	Javalant	Hand, tire well
W26	8.85	459	911	10	2	Javalant	Hand
W27	8.62	340	664	10	2	Javalant	Hand
W28	8.8	223	445	10	1	Javalant	Hand
W29	8.53	202	401	50	0	Hairan	Surface
W30	8.54	122	247	10	0	Javalant	Surface
W31	7.9	1907	3761	10	0.5	Javalant	Hand
W32	8.38	485	971	20	2	Javalant	Hand
W33	8.4	321	643	10	1.5	Javalant	Hand
W34	8.62	306	618	10	2	Javalant	Hand
W35	8.53	595	1210	10	1	Javalant	Hand
W36	8.38	315	631	20	1.2	Javalant	Hand
W37	8.28	217	431	10	2	Bayan	Hand pump
W38	8.45	95	188	10	0	Bayan	Surface
W39	7.98	313	628	10	~	Bayan	Deep, motor, locked
W40	7.74	797	1587	10	~	Bayan	Hand pump
W41	8.24	127	256	10	3	Bayan	Hand
W42	7.04	1003	1997	20	2	Javalant	Hand
W43	7.8	2000	4000	20	~	Gavalut	Delivery

Table A2. *Cont.*

Site	pH	TDS	EC	Heavy Metals (Semi-Qualitative)	Water Level (m)	*Bagh*	Well Type
W44	8.08	579	1230	10	1	Gavalut	Hand
W45	8.02	233	470	10	0	Nomgon	Surface
W46	7.7	178	356	10	2	Javalant	Hand
W47	8.3	440	879	20	2	Gavalut	Hand
W48	8.1	722	1441	20	11	Gavalut	Deep, motor, locked
W49	8.2	892	1790	10	1.5	Gavalut	Hand
W50	7.8	638	1277	50	~	Javalant	Deep, motor, locked
W51	8.38	507	1011	10	32	Javalant	Deep, motor, locked
W52	8.05	455	906	10	~	Javalant	Deep, motor, locked
W53	8.12	362	7.65	10	5	Gavalut	Hand
W54	8.06	540	1076	10	2	Gavalut	Hand
W55	7.9	637	1275	20	75	Bayan	Deep, motor, locked
W56	7.9	788	1571	20	2	Bayan	Hand
W57	7.85	260	520	20	3	Nomgon	Hand
W58	8.5	158	318	20	2	Nomgon	Hand
W59	8.1	542	1081	10	1.5	Nomgon	Hand
W60	8.46	411	822	10	1	Gavalut	Hand
W61	7.51	664	1306	10	1.1	Javalant	Hand
W62	8.09	586	1156	20	1	Javalant	Hand
W63	8.06	560	1158	10	3.5	Javalant	Hand
W64	7.58	539	1079	20	1.8	Javalant	Hand
W65	7.58	813	1623	20	1.2	Javalant	Hand
W66	7.92	411	821	10	1	Javalant	Hand
W67	8.47	669	1340	10	1	Javalant	Hand

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