

Dealing with sand in the Arctic city of Nadym

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Abstract Sand plays an important role in the Arctic urban development as construction material and stable ground. Significance of its studies increases in face of permafrost degradation and coastal erosion and for understanding human capacities to restore natural landscapes after anthropogenic disturbances. This paper examines changing human interactions with sand in the city of Nadym, northwest of Siberia. The study utilizes an interdisciplinary approach which includes remote sensing and GIS analysis, field observations, and interviews with local residents and stakeholders. Analysis of spatial and social characteristics of sand demonstrates different roles of sand as part of the landscape, a resource, and as a mediator in urban and infrastructure development. Understanding the diversity of sand qualities, its uses, and perceptions is relevant for studies of landscape disturbances, resilience, vulnerability, and adaptive capacities of Arctic cities.

Keywords Disturbed landscapes · Infrastructure · Nadym · Sand · Social practices · Urban development

INTRODUCTION

Sand plays an important role in the Yamal region infrastructure and in its extractive industrial development. The region is the key player in Russia in terms of natural gas reserves and production: almost one third of all national resources of natural gas are located there. At the same time, Yamal is a leading region in Russia by area of disturbed land (105.4 thousand hectares) (National report 2021). Most of the linear objects, such as oil and gas pipelines and roads, use sand for construction. The total area of these linear objects is larger than the area of extraction sites themselves. Each spring, road section is washed away

requiring extra resources for road maintenance and causing additional landscape disturbance.

Walker et al. (2010) noted poor quality of sandy areas for vegetation which leads to difficulties with re-vegetation once they are disturbed by oil and gas exploration along the Yamal Peninsula. Less than 7% of these lands have been revegetated (Likhanova and Archegova 2014). According to experts in the field of ethnoecology, the spread of sand in tundra after poor-quality reclamation deteriorates the reindeer forage base. Combined in their stomach together with food, sand can cause some diseases and even death (Martynova 2013). Increased reindeer population and related trampling are also considered as contributors to landscape disturbance (Moskalenko 2006). Moreover, climate change-induced greening of tundra also brings unpredictable changes in the Arctic environment (Ezau and Miles 2016; Lara et al. 2018).

As Anna Tsing (2015) successfully demonstrated, the ruins for one can be life for others in human-modified landscapes. While she explored disturbance-based life despite capitalism, the question remains how these relations assemble beyond capitalism? Literature critically assessing human–environment interactions in the Soviet and Russian Arctic has two, quite opposite directions. Most of the research has been dedicated to studies of traditional ways of life where humans partner with animals to survive and make the most of tundra and forest-tundra landscapes. In particular, Nenets and Khanty, Indigenous peoples of the region, rely on reindeer for livelihoods, food and identity (Degteva and Nellemann 2013; Forbes 2013; Golovnev 2017). Disturbance of their traditional livelihoods by hydrocarbon exploitation was examined in a number of works (Forbes et al. 2009; Kumpula et al. 2010). At the same time, Arctic cities became exemplary for studies of the Soviet practices of “mastering the North” (Slavin

1982) or “conquering permafrost” (Chu 2020). But eventually, as Bruno (2016) demonstrates, these efforts have been unsuccessful, and nature was recognized as an important actor that “both enabled industrial livelihoods and curtailed socialist promises” (p. 7). This recognition would logically lead to greater appreciation of nature in social life in the Arctic, especially given deficiencies of resources and insufficient infrastructure development that both rural and urban communities face (Vakhtin 2017). However, understanding the human–environment relations in the process of urban and infrastructure development, especially during Gulag expansion, remains limited with a few exceptions (Gritsenko and Kalinin 2010; Mikhailova 2012; Orttung et al. 2016; Gritsenko 2018; Streletskiy et al. 2019).

This paper aims to address this gap of knowledge by focusing on changing human interactions with sand and its role in location and construction of built and social environments in the Arctic city of Nadym. We discuss these results in the context of human–sand relations and conclude by emphasizing the need for more interdisciplinary research on human–sand interactions.

THEORETICAL CONSIDERATIONS

As Vince Beiser (2018) persuasively documented, sand is deeply ingrained in human culture and plays an important role in urban construction and infrastructure development by providing a solid base for mobilities in the form of cement, concrete, asphalt, glass, fiber-optics, and silicon for high-tech industry. As the most exploited solid material in the world sand is directly or indirectly related to all 17 Sustainable Development Goals (UNEP 2022). Sustainability issues of sand extraction are related not only to depletion of the resource, but also to the environmental impact of extraction and issues of social justice and economic prosperity (e.g., Bendixen et al. 2019). The high importance of sand for multiple aspects of human life allowed William Jamieson to call for development of granular geography (2020) or even granular geographies to conceptualize the specific character of relations between capital and nature (Kothary 2021). Researchers note increasing global demand for sand while its replacement by other materials is hardly possible in the near future (Torres et al. 2017; Habert et al. 2020). There is limited understanding for how sand mining affects ecosystem services (Koehnken et al. 2020). Even less scholarly work has been produced about the effects of sand extraction on local livelihoods (Lamb et al. 2019).

While sand’s societal benefits are acknowledged, so too is its societal capriciousness (Reynolds et al. 2007; Beiser 2018). Special efforts are also applied to stabilize actively

moving sand dunes (Huggett 2017). Meanwhile, restoration of sand dunes for specific natural habitats is also becoming an issue (Prach et al. 2021). Characteristics of bare sands in the high latitudes remains understudied. The best known are the Kobuk sand dunes in Alaska (Fernald 1964; Dijkmans and Koster 1990), in the interfluvium of the Athabasca and Richardson rivers in the northeast of the Canadian province of Alberta (Allen et al. 2003), on the coast of Lake Athabasca in the northwest of the Canadian province of Saskatchewan (Jonker and Rowe 2001), and in the areas with limited vegetation of Western and Eastern Siberia (Pavlova et al. 2017; Zykina et al. 2017).

All these uncertainties surrounding human–sand relations make Nadym built mostly on bare sand an especially intriguing case for considering sand as an actant (important agent and/or mediator) in social relations (Latour 2005). Actor-network theory has already been successfully utilized in geography in general (Murdoch 1998) and in urban studies in particular (e.g., Farias 2010). Continuing this line of thought, studies of sand’s participation in urban and infrastructure development are important for understanding how human–environment relations are re-assembled in Arctic conditions. We are interested in instances when and where residents appreciate, utilize, fight, or otherwise deal with sand’s qualities while building the urban and social fabric.

STUDY AREA: NADYM, CITY BUILT ON SAND

Sandy landscapes are quite widespread in the Yamal region, composing large river terraces and the most elevated watershed areas where they underlie peatlands. Generally, one can distinguish two different sandy landscapes. Sandy landscapes that were not subject to cryogenic weathering on contemporary floodplains, river terraces, etc. are composed of coarse and fine-grain sand. Sandy landscapes of watersheds formed in the Pleistocene and have undergone long periods of freeze/thaw cycles that led to formation of silty sands. According to some researchers, this type of sand has accumulated during a series of marine transgressions (Melnikov 1983; Trofimov 1987; Velichko et al. 2011). According to others, sand has accumulated during the Neopleistocene glaciations (Astakhov 2006; Fredin et al. 2012; Pavlova et al. 2017; Zykina et al. 2017; Galanin et al. 2018). While these discussions are continuing, for the purposes of this paper, it is important to note the variety of sandy landscapes in the study area with different granularity of sands.

There are a few archaeological sites in the study area that prove human presence in the Neolithic period (end of 6000—beginning of 5000 B.C.) and during the Iron Age (800 B.C.—400). Nenets traditionally living in the area

have some specific relations with sandy landscapes. In particular, tundra Nenets reindeer herders on their nomadic routes avoid sandy terrain as unsuitable for reindeer forage. At the same time, many animals, including reindeer, like to wallow on sand to clean their skins. Reindeer herder camps are also usually located on the sandy river terraces where the soil is well drained (Kosintsev 2013).

Settlers, who have lived in the area for several generations, have also devised ways to cultivate sandy landscapes. Available archaeological findings demonstrate their preference for sandy landscapes over tundra and forest in an ancient Nadymsky town in the floodplain of the Nadym River, 25 km from its mouth (N66.059484° E72.000715°) (Kardash 2009). This most prominent settlement existed in the thirteenth–eighteenth centuries, 60 km northwest of the modern city of Nadym, and served as a small post combining trading with military and defensive functions. Archaeologists note that the Nadymsky town could have been founded by Russian pioneers from Velikiy Novgorod (Kardash 2009). From the fifteenth century, most of its population was formed by Ugric tribes (ancestors of the modern Khanty), and the Samoyeds (ancestors of the Nenets) (Slepchenko et al. 2020). The town had a diversified economy, which included hunting, reindeer breeding, dog breeding, gathering, and crafts. In the 17–eighteenth centuries, Ostyaks (Khanty) and Samoyeds (Nenets) lived in the lower banks of the Nadym River. In the 19th–early twentieth century, the population of the modern Nadymsky district became more multi-ethnic and included Nenets, Khanty, Komi-Zyryan, and Russians (Kardash 2006).

At the early twentieth century, local mostly Russian residents successfully grew barley, potatoes, and other garden crops as well as kept horses, cows, sheep, and chickens on sandy banks of the Nadym River at the Ivlevskiy Peski area (Dmitriev-Sadovnikov 1917). Many camps and the town of Obdorsk in the Ob River basin have been located on the river's lower terraces with coarse sand.

Both local communities and forest Nenets historically have been dependent on fishing. The fishery grounds are often distinguished based on the specific geographic location of sandy shorelines and riverbeds. In the archival documents from the 1920s, fishing grounds often carried the names related to specific sandy areas and well-known fishermen such as Pesok Babikova (Babikov's Sand) (Gritsenko 2018). While some of these areas are utilized for winter fishing, others are more appropriate for summer fishing (Kosintsev 2013; Kvashnin 2009; Volzhanina 2021).

The thick layer of sand of the lower river terraces provides stable ground in areas underlain with permafrost, which usually hinders urban development and multiplies expenses for housing construction in the Far North. The area of Nadym was first chosen as a station during the

Gulag Chum—Salekhard—Igarka railroad construction in 1949–1953 (Gritsenko and Kalinin 2010). The Gulag prisoners used different kinds of sand to build the railroad, and in the Nadym area, they had to stabilize the silty sand with iron grids. Prisoners were forced to extract sand manually year around. Since most of the year the ground is frozen, major efforts were applied to thaw it before extraction by burning wood near the extraction site (from an interview with a local resident, male 65, Nadym, 2022). Sand was also utilized for other purposes in the camps: a layer of wood chips and manure was piled on it to grow vegetables and store them underground (Gritsenko 2018).

After the project was abandoned, the area was used for housing of workers serving on maintenance of the telegraph line between Salekhard and Igarka cities (Gritsenko 2018). With discovery of rich gas reserves of Medvezhye in 1967, the territory was chosen as a base for a shift-workers' camp and in 1972 it was transformed into a permanent city (Nadymskiy rayon v tsifrakh, 2020). Thousands of migrants moved to the region raising the need to construct a large number of the multi-storey buildings for housing of increased population and develop infrastructure for production and transportation of natural gas and oil. About a third of the territory of the city (32.9%) was built on bare sands (Sizov et al. 2022). Most importantly, the urban core was built on barren land of aeolian dunes on the second terrace of the Nadym River (Fedorov et al. 2021).

The influx of newcomers mostly from temperate latitudes of the former Soviet Union transformed the ethnic structure of the region. As of 2020, 64,572 people lived in the territory of the Nadymsky district, including Russians (64%), Ukrainians (8.2%), and Tatars (4.4%), while Nenets formed only 2.91% of the total population (Federal State Statistics Service 2020).

MATERIALS AND METHODS

Understanding sand–human interactions in the region requires answering two interrelated questions: what is the role of humans in sand's distribution and what is the role of sand in urban and infrastructure development? To answer the first question we identify origins of bare sands in the region, and sand blowouts as the easiest way to understand sand's movement in natural conditions. For the second question, we study granular composition of sands from different quarries, their main usage, and local perceptions and practices of dealing with sands of different granularity.

This research is based on a mix of methods of remote sensing, cartographic, fieldwork observations, and interviews necessary for holistic understanding of sand–human

relations. In general, it is possible to distinguish spatial and social characteristics of sand.

Studies of sand's spatial characteristics

For understanding spatial characteristics of sandy areas, we utilized multiple sources of data (Table 1). For mapping *bare sands* and understanding their anthropogenic or natural origins, data were selected using the Google Earth Engine cloud platform for July–August months. A mask of bare sands was obtained using the ISODATA unsupervised classification method (15 initial classes were set in the settings) (Ball and Hall 1965). The resulting bare mask was edited and verified using visual interpretation: we removed areas of sandbanks (river valleys, coastal strip of lakes, coastline of the sea), areas of dense lichens because they have a similar spectral signature, and objects with an area of $< 400 \text{ m}^2$ —at least four pixels ($10 \times 10 \text{ m}$ each) to avoid confusion with noise. While there are no historic maps indicating bare sands, their location in areas distant from roads and anthropogenic objects can serve as an indication of their natural origin. The bare sands on road slopes, dirt roads, industrial sites, and old quarries and surroundings were qualified as bare sands of anthropogenic origin. The work was carried out using tools and capabilities of the Google Earth Engine cloud platform.

Creation of a map of sand quarries near Nadym and a graph of the dynamics of quarries and building construction required several stages. First, we identified the main objects including the type of linear infrastructure (roads, railways, pipelines) and quarries (type, area and year of its formation) directly in ArcGIS based on Sentinel-2 data (in the EO Browser service (EO Browser 2022) and the World Imagery layer in ArcGIS Online mapping service (ArcGIS Online 2022)). We manually digitized objects in the buffer zone of 2 km identified as quarries according to specific attributes: the presence of a sandy surface, a local anomaly of vegetation, presence of access roads, and a characteristic regular shape. The obtained objects were verified using several sources. On topographic maps, the largest quarries are shown by corresponding symbols. On the digital elevation model (DEM), quarries are distinguished by height

and steep slopes from local depressions and lakes with more gentle banks. During the field work in July 2022, a control sample of 15 objects was used for ground validation. The resulting map of quarries was compared with the map of sand deposit types created by A.E. Babushkin (1982). Plot boundaries were reconfirmed using Sentinel-2 data. To determine the age of quarries, we used the public archive of Landsat-4/5/7/8, Sentinel-2 and Corona images (survey period 1968–2018) in EarthExplorer (2022). The years of buildings construction were obtained from the GIS Housing and Communal Services reference system (GIS ZHKH 2022). Editing and formatting results for maps, spatial measurements, and statistical processing of the results were conducted in ArcGIS 10.8 software.

Studies of sand's social characteristics

Qualitative studies were conducted with the purpose to understand social practices and narratives about sand. They were gathered via Zoom (2 interviews) in 2020 and in-person during the field studies in Nadym in 2021–2022 when 27 interviews and participant observations were also conducted. The respondents were recruited using a “snowball” approach initially based on existing social networks of the project team’s partners in the local branch of the Arctic Research Center of the Yamal-Nenets Autonomous Okrug. Later, the circle of interviewees expanded to include respondents of different age, gender and occupation, including students, teachers, workers of local cultural institutions, Gazprom workers, retired former workers of local municipality, and builders of the city. While young interviewees were born in the city, generation of 40–50-year-old residents were brought here in childhood or came in search of work as adults, and retired interviewees have usually spent most of their adult lives in the city and participated in the city construction. The authors were able to meet with the interviewees at their workplaces, in their homes, in cafes, while driving around the city and its surroundings, and while walking over sandy areas. The structure of interviews was a combination of standardized guide and open questions that varied depending on the area of the expertise of the interviewees. The main focus of

Table 1 Data analyzed for studies of sand's spatial characteristics

Objects	Data	Date	Resolution, m	Source
Bare sands, quarries	Sentinel-2	2016–2020	10	Copernicus Open Access Hub (2022) and Google Earth Engine (2022)
Quarries	Corona/KH-4b	1968.08.21	≈ 2	US Geological Survey
Quarries	Landsat-4/5/7/8, Sentinel-2	1984–2018	Various	US Geological Survey
Quarries	Arctic digital elevation model (DEM)	2012–2018	2	Maxar/PGC (Arctic DEM 2022)

interviews was on personal accounts of human–environment relations. The topic of sand persistently appeared in these conversations and especially during the trips around the city. In 2022, questions about sand and its role in urban development were included in the guides of interviews. All the interviews were transcribed, and using NVivo we extracted the fragments of interviews that discussed sand and analyzed their content.

RESULTS

Sand as a part of the regional landscape

Based on analysis of documents and satellite images, we found 404,675 plots classified as bare sands, with a total area of 2228.17 km² (Fig. 1). Their occurrences are observed at all types of relief across the north of West Siberia. The expansion of the areas with bare sands quite often serves as visible evidence of environmental disturbance. For instance, the largest share of bare sand is found within the oil deposits of the Purovsky region (Barsukovskoye, Sporyshevskoye, Muravlenkovskoye, etc.).

Our analysis shows that bare sands of natural origin are more widespread and occupy larger areas than the ones of anthropogenic origins (Table 2). However, on average, the naturally formed areas have a smaller size. Their large distribution is rather provided by a few areas of larger size, but those that are large can occupy as much as 33.52 km².

Sand as a resource

For the city of Nadym, sand is the fourth major natural resource after oil, gas, and gas condensate with an estimated 57.7 million cubic meters deposited in the region. Sand extraction in inland Siberia is hardly a lucrative industry: transportation logistics are too complex, and no supply chain or infrastructure is built to support it. However, its role in local urban development is hard to overestimate.

For construction purposes, coarse sand has been extracted from quarries and bottoms of the lakes. In sum, 159 quarries with an area of about 524 hectares along 11,448 km of linear oil and gas infrastructure facilities were identified on the satellite images (Fig. 2). The biggest quarries are the remains of those created during the northern railroad construction by the Gulag system. Quarries along the pipelines are also widespread. Finally, a number of large quarries were created in proximity to the city for its construction. Extraction sites in the areas with predominantly silty sand are located at a distance from the city and main infrastructure development. When access to coarse sand is difficult, areas with silty sand are used for

extraction along the infrastructure objects, such as the gas pipeline along Levaya Kheta river.

The history of sand quarries formation reflects urban and infrastructure development in the study area. Initially, builders utilized sand quarries created during the Gulag era, because they were the most available for exploitation due to the previous drudgery work by camp prisoners. After the Gulag, sand for construction purposes was extracted using heavy machinery. The largest number of quarries was created in 1986—the time of the intensive city construction (Fig. 3).

Sand extraction from the lakes transformed their shapes and depth. In particular, the Lake Yantarnoie was made deeper and larger while one of its inlets disappeared as a result of sand extraction and housing and infrastructure construction (interview with male, 60, Nadym, 2022). Two sand dugouts within city limits created during the development of the city were filled with water from surrounding wetlands and creeks and became artificial lakes, unofficially called Second Yantarnoye and Prodolgovatoye. The depth of these dugouts is over ten times deeper than that of natural lakes (Fedorov et al. 2021).

Sand as mediator in urban and infrastructure development

Interviewees distinguish different kinds of sand based on their personal experiences of dealing with it in the city when it is more than just an underneath foundation: silty sand from dunes and blowouts and coarse sand from river and lake bottoms and shores. One of the respondents remarked on the sand's enormous presence and emphasized its difference from sands elsewhere:

The sand here is of a different quality. In Siberia, there is sand with a little clay or something. You sprinkled it and it trampled down and the paths are stable, but here no matter how much we trample, it is still loose. The sand properties are different. There was a dredger that extracted sand from the river bottom. They dug quarries for sand extraction. That was sand for construction, but this one under your feet, on top, I don't know what it's for (female, 70, Nadym, 2022).

Sand as a part of urban landscape

Silty sand was on the surface of some areas where builders started the city construction. Sandy tracks were laid for cars before concrete and asphalt roads along the urban streets. As in the desert areas, this sand on surface has been unsuitable for construction purposes: too fine and round-shaped, and easily washed away by rain and melting snow. Wind would easily lift its light particles into the air:

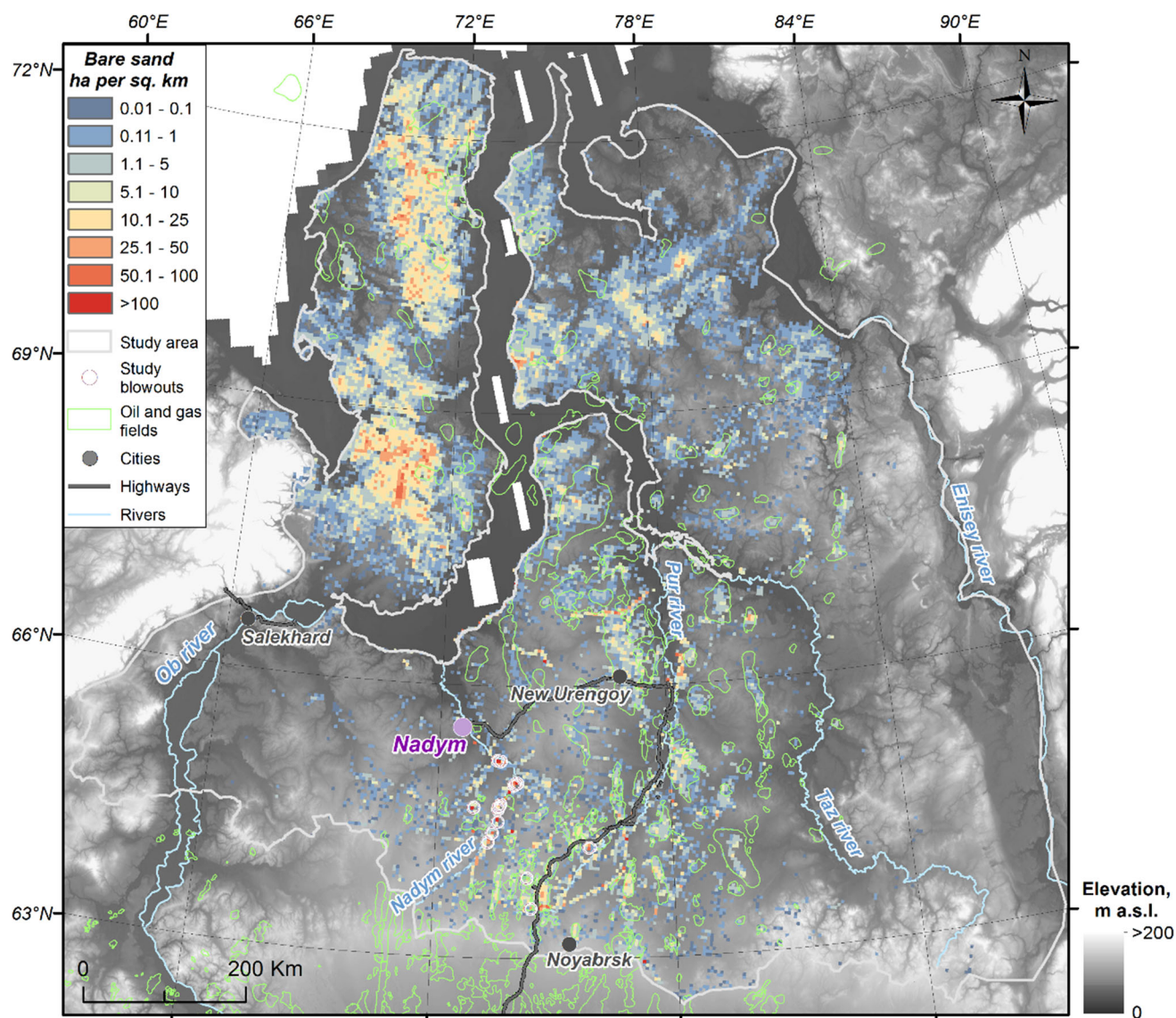


Fig. 1 Distribution of bare sands in northern West Siberia (total area) (Source for basemap: The TanDEM-X 90 m DEM(c)DLR)

Table 2 Areas with barren sand by origin

Origin	Number of plots	Average plot area (ha)	Maximum area (km ²)	Number of objects over 1 km ²	Total area (km ²)
Natural	394,129	0.44	33.52	55	1929.15
Anthropogenic	10,546	2.84	4.26	8	299.03

Here is the kindergarten Solnyshko. What is green around it has also grown for the last 30–40 years, because there was a lot of sand. Especially when the wind blew in the summer, you would walk down the street and have sand on your lips painted with lipstick, sand in the hair. It was the greening of the city

that was actively carried out so that the sand would not fly so much (female, 40, Nadym, 2021).

Stabilization of sand is one of the primary topics in the interviews with the residents who either were involved in building the city or were born and raised during the city construction and development in 1970–1980s. Built on silty sands, the road connecting Nadym with the city of Novy Urengoy was impassable by ordinary vehicles during warm seasons. Dealing with this kind of sand was described as an issue that residents faced every day at home, work, and on the streets:

There used to be a lot of sand. Now no one puts rags near apartments. Previously, it was like a law, because you pick it up from the street, come in carrying sand, and it will be all over the apartment. And

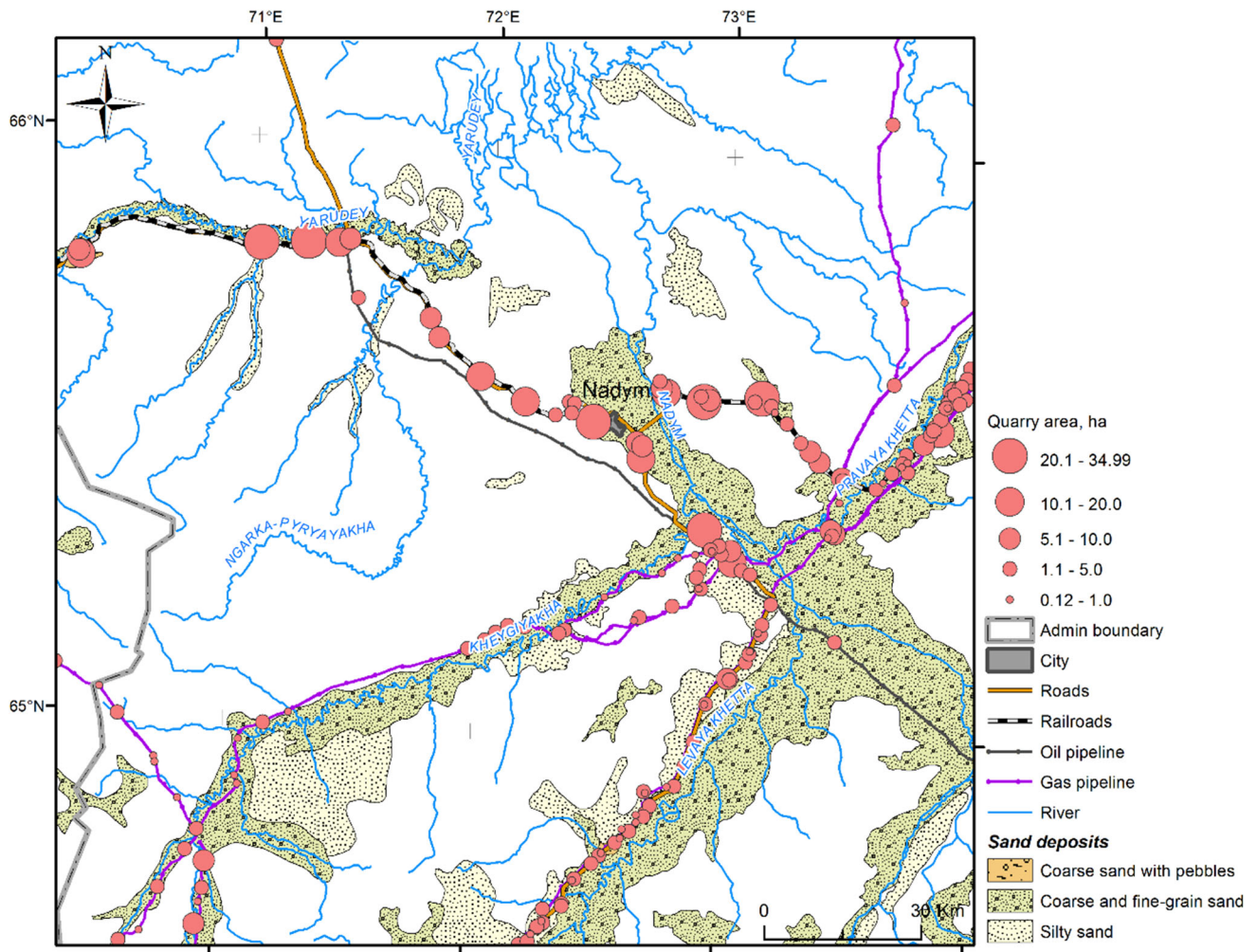


Fig. 2 Distribution of sand deposits and quarries. It is visible that most of the sand deposits and quarries, respectively, are located near the city and infrastructure objects

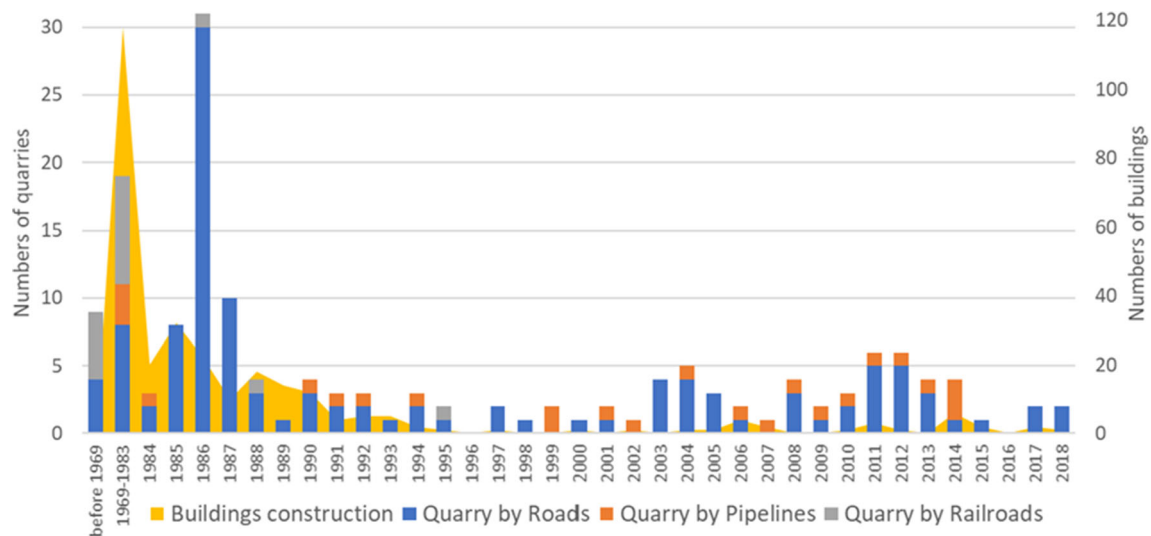


Fig. 3 Years of sand quarries creation and building construction. Before and during the peak of the building construction, sand was extracted from quarries near the railroad built by Gulag. Later on, more quarries were created along the roads. Since 1995, building construction has occurred occasionally while infrastructure development related to oil and gas extraction was quite stable

at the industrial premises, tubs with water were always set. Before entering you dipped your sole in the water so that the sand fell to the bottom. Otherwise, the sand is brought in (male, 60, Nadym, 2022).

In less than a decade, by the end of the 1970s—early 1980s, the landscapes with silty sand were almost completely covered with buildings, asphalt and concrete roads, sidewalks, other paved areas, lawns, and other elements of urban infrastructure.

Previously, Leningradsky Prospekt was watered and washed, then a truck was brought with a vacuum cleaner, because there was so much sand. And there were Soviet spinners that swept sand. They had to constantly remove and wash away sand from the road. I remember, water trucks would stop by and sprinkle the park (male, 60, Nadym, 2022).

Silty sand acted as a hindrance for mobility not only on land, but also in the river: during the Soviet time, the dredgers worked to remove it and deepen the riverbed to provide passage for cargo ships delivering food and goods to the city.

Only recently have dunes and blowouts with silty sand around the city started to serve as recreation areas. On the river and lake shores, it is used for camping, fishing, barbecue, sunbathing and so on. Interviewees born in the 1990s have not witnessed problems with sand and rather perceive it as a recreation resource. Sand dunes attract bike and ATV riders as well as fans of hang gliders.

Sand as a foundation

Sandy areas are appreciated by local planners and urban residents for available construction materials and easy water drainage. The latter is especially important in tundra landscapes with underlying permafrost. Large amounts of sand were used for stabilization of the building foundations in swamplands. Builders poured sand and watered over it, compacted the mix, and let it freeze over the winter before setting up foundations of the buildings in the area.

Stabilization of the ground has been practiced also on the scale of individual dacha plots, mostly located in forested areas. To build dachas there, the owners first must clear land of existing vegetation. In contrast with other forested regions, the procedure of clearing is more elaborate. Since the area is swampy, people do not remove large tree roots. Instead, these roots serve as additional stabilizers of land. Smaller trees are cut and laid under the ground to create drainage systems and protect new residents lower layers of permafrost from thawing. After the ground is stabilized, the issue is to pour sand and cover it with fertile soil for gardening. Residents have “greened” some areas in

their garden plots by bringing silt and turf from the Nadym River floodplain for that purpose:

We have now covered the area with sand: people make sand cushions, and then add peat with soil. And you pour and pour sand in. Since we bought this plot, we have already invested 100,000 rubles in sand. Just sand to fill it up, so something can be grown on this site (female, 35, Nadym, 2021).

Other cases of sand use as a foundation include the base to pour under the slabs for road construction, sprinkle over icy roads, and filling the ground for creating hockey courts in the winter, and soccer and ping pong in the summer. While participation in building houses would require some skills and knowledge, one could argue, that creation of sports grounds was rather for building relations among new residents.

Sand as a construction material

During the first years, construction of the city was constrained by the amount of building materials. Gravel in limited quantities was delivered to Nadym during the summer navigation period from Kharp, the closest settlement, about 400 km away. To solve this supply problem, builders started to use sand concrete (another version of the name is “fine-grained concrete”) as a building material. Production of sand concrete was exclusively based on sand as a filling material and required twice as much cement as for regular concrete, but still was cheaper due to transportation costs of gravel. Based on this resource, construction of a large-panel building plant (ZKPD) was started in 1976 and was completed in 1980.

In addition to its availability, advantages of sand concrete as a building material included its high strength, lightness, slight shrinkage, and frost and moisture resistance. Sand concrete was used for manufacturing building blocks and slabs, pouring foundations, leveling floors, making staircases, etc. As a result, most buildings (about 81%) in the city are made of sand concrete (Fig. 4a). Beyond construction of buildings, sand concrete had a variety of uses in the city: for paving roads, making fences (Fig. 4b), building garages (Fig. 4c).

At the same time, builders found that slabs made of sand concrete had a higher thermal conductivity compared to slabs with stone or expanded clay, so additional efforts were needed to keep apartments warm. To address the issue, they used expanded clay concrete slabs for the outer panels of houses and additional heating of buildings. Later, a small brick factory was opened where sand and clay from nearby quarries were used for brick production which had better insulating properties.



a)



b)



c)



d)

Fig. 4 Examples of uses of sand in urban development: **a** view of the city with buildings made of sand concrete (photo by O. Sizov, 2020); **b** fences made of sand concrete (photo by V. Kuklina, 2021); **c** garages made of sand concrete (photo by V. Kuklina, 2021); **d** sandbox in a sandy courtyard (photo by R. Fedorov, 2022)

Even for playgrounds, coarse sand had to be brought from quarries in sandboxes to the local courtyards, because fine-grained sand was found unsuitable for children's building sandcastles (Fig. 4d). Sand served as a main playing material for children:

For sandboxes they brought sand from quarries. Every kindergarten has their own sandbox. They would make a “mushroom” (roof) over these sandboxes (to protect from rain). It was like a building material for children. Adults would bring water, moisten it, so children could work with it. It was in every kindergarten. Twelve groups - twelve sandboxes ... We have a very long winter, snow, snow, snow, and then, sand! They were always happy with the sand. There were troubles - sprinkled, got into the eyes, children could not do without pranks. But in general, the children loved playing in sandboxes. And sandboxes were constantly replenished with new sand. Q: Where did the sand come from, do you happen to know? A: Well, the sand

was brought from quarries. Then, when they were dredging here (in the lake) (female, 70, Nadym, 2022).

In the village of Stary Nadym, an artificial sandy beach was created for children on the banks of the river despite abundant sand on dunes nearby:

We still remember how in childhood, sailors on ships poured sand and created the beach for us on the river shore because the quarries with sand were not particularly for children (female, 30, Nadym, 2021).

In summertime, sand festivals with contests for the best sand figures began to be held in Nadym. Coarse sand for this purpose is brought from the floodplains.

DISCUSSION

Human–sand interactions in Nadym and its surroundings can be summarized as follows (Table 3). In Arctic and

Table 3 Role of sand in different kinds of human–sand interactions

Role of sand	Rural dwelling	Urban and infrastructure construction	Urban and infrastructure maintenance
Ecosystem services	Reindeer herding pathways Farming plots Fishing grounds	Construction material for sand-concrete Support for foundations on permafrost	Topsoil for green areas Protection from slippery ice Ground for recreation and children play areas Material for creative works
Ecosystem disservices	Source of environmental disturbance Disruption for reindeer forage	Source of dust Hindrance for human and vehicle mobility	Source of dust

Colors of font indicate: blue—coarse sand, red—silty sand, purple—both

remote conditions, sand provides some ecosystem services and disservices that differ from temperate regions, such as support on frozen ground and slippery ice (UNEP 2022). Specific forms of interactions prevailed during different stages of urban development and some have changed their character. Manual frozen sand's extraction and transport were an instrument of prisoners' exhaustion during the Gulag era. After they were replaced by mechanical heavy machinery, sand became an ally for stable construction on permafrost. While respondents of older age could witness the whole variety of different roles of sand, for younger generations, only roles associated with recent stages of development are relevant.

Careful examination of human–environment relations requires combination of methods of physical and social sciences. An analysis of satellite and GIS data and interviews revealed the important role of sand in both environmental disturbances of the region and urban and infrastructure development of Nadym. It allows to see bare sands in Arctic conditions both as a pre-condition and result of human activity. While areal extent of human-

caused bare sands is smaller than the natural ones, further studies of changes in volume and the impact on wildlife are needed.

Also, our research reveals local specificities of understanding of disturbance. While beyond the city limits it is an important point of discussions, in the city dramatic landscape and topography transformations are considered as inevitable part of urban development. From one side, these findings support Jamieson's call for granular geography (2020), from another—illustrate another form of landscape disturbance that was explored by Anna Tsing (2015).

Construction of such a large city and infrastructure in the Arctic has relied on moving, distributing, stabilizing, cementing, and molding large amounts of sand. As such, it, in alliance with humans, has participated in disturbances of natural landscapes and animals. It brings a geographical dimension to Vince Beiser's (2018) detailed account of diverse qualities of sand as a commodity or as an enemy depending on sand's location, granular size, and texture. Using actor-network terminology, one could say that sand

became more than just a resource, but an important actant in the urban and infrastructure development.

CONCLUSIONS

As in many other Arctic and remote regions, the interviewees refer to southern regions of Russia as the “Earth” and “mainland.” This discourse has a double meaning in Nadym as a city built on a sandy “island” surrounded by tundra and taiga. Not surprisingly, discussions about sand prevail among senior citizens who witnessed or participated in the city’s construction when the discourses of “mastering nature” and “conquering permafrost” were dominating. At the same time, based on first-hand experience, these residents provide more detailed descriptions of sand, including its quality and uses. From interactions with sand people gained locally specific knowledge of its granularity relevant for urban and infrastructure development. This knowledge is utilized for further transformations of natural landscapes, but also as a shared experience, it becomes part of local identity. Based on these findings, it is possible to say that sand has participated in building social cohesion through its own circulation as a part of landscape, filling or building materials, and provider of infrastructure, such as roads, playgrounds, etc. However, creation of livable environment for urban dwellers results in disturbed landscapes for rural communities, disruption of mobilities, and pasture lands of reindeer herders and animals.

Such disturbance-based human–environment relations will be even more prevalent with growing extractive industry in the Arctic and can easily lead to disruptions on human and animal well-being. Moreover, with climate change-induced growing instability of grounds on thawing permafrost and coastal erosion on the shores in the Arctic, sand adds additional considerations for urban and infrastructure sustainability planning. Therefore, understanding the diversity of sand qualities, its uses, and perceptions is relevant for studies of landscape disturbances, resilience, vulnerability, and adaptive capacities of Arctic cities.

While importance of Indigenous knowledge has already been proved in Arctic research, the local knowledge of urban residents can also offer more nuanced understanding of complex disturbance-based systems. It also has policy implications related to more careful planning and environmental and social-economic impact assessments that would take into account both direct and indirect effects of urban and infrastructure development on landscapes and people.

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Declarations

Conflict of interest The authors state no conflict of interest.

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