ENVIRONMENTAL IMPACT ASSESSMENT OF PIT LATRINES USING REMOTE SENSING AND MULTI-CRITERIA SPATIAL ANALYSIS IN ULAANBAATAR (GER AREA), MONGOLIA

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KEYWORDS: Pit Latrine, Remote sensing, Multi-criteria spatial analysis, Environmental impact assessment, Ulaanbaatar city.

ABSTRACT:

This study aimed to analyze the environmental impact of pit latrines of ger-sprawl district areas (low rise sprawl area with detached "ger"- nomad's mobile tent surrounded by fences or with handmade dwellings) in Ulaanbaatar capital city of Mongolia using remotely sensed data and multi-criteria spatial analysis. Within the last two decades, the residential areas without infrastructure have been significantly expanded and changed due to the migration of people from rural areas. 50.1% of the total population of Ulaanbaatar city is lives in ger district areas. Due to the formation of unstructured residential areas, pollution from pit latrines poses a risk to the urban environment and human health by infiltrating shallow water, being carried by floodwaters, and being released into the air. Therefore, to reduce the number of pit latrines in ger areas, the total number and location of pit latrines in the city were determined using high-resolution satellite imagery. In addition, spatial multi-criteria analysis methods were used to assess the negative impact of pit latrines on the environment and human health and categorize them into four zones. A total of 144,992 pit latrines were counted in Ulaanbaatar, with 9,443 pit latrines in Zone IV, 43,377 pit latrines in Zone III, 71150 pit latrines in Zone II, and 21,022 pit latrines in Zone I. The results of this study are important for implementing management measures to reduce soil pollution, such as restricting and banning the use of pit latrines in ger areas, installing toilets that meet MNS 5924: 2015 standards, and carrying out disinfection.

1. INTRODUCTION

Mongolia, as is the case with many countries of the developing world, has a problem with rapid urban expansion and the growth of population in the main cities (Amarsaikhan *et al.*, 2009). Ulaanbaatar is the capital and largest city of Mongolia. The city is situated in the central part of Mongolia, on the TuulRiverr, at an average height of 1350 m above sea level and the area of residential areas in Ulaanbaatar is 37 thousand ha and the total area of ger districts (low rise sprawl area with detached "ger"- nomad's mobile tent surrounded by fences or with handmade dwellings) is 17.5 thousand ha (Amarsaikhan *et al.*, 2015). About 60 percent of all ger districts are located in the mountainous areas north and northwest of Ulaanbaatar. In the eastern part of the city, in the lower reaches of the Selbe, Uliastai, and Tuul rivers, about 30 percent of ger districts are located, and in the southwestern part of the city, on the southern terrace of the Tuul River, about 10 percent. Nalaikh district is located 45 km southeast of Ulaanbaatar and has a total ger area of 478 hectares. In recent 30 years, ger areas (residential areas without infrastructure) have expanded without urban planning due to a sharp increase in the number of people migrating from rural areas to Ulaanbaatar. Ger districts in Ulaanbaatar are home to 22.38% of Mongolia's population. 44.6% of Mongolia's total population (3.4 million) live in Ulaanbaatar. 50.1 percent of Ulaanbaatar's total population (1.5 million) live in ger areas (Mongolian Statistical Year Book, 2021).

One of the main reasons for the increase in urban pollution caused by pit latrines is the creation of residential areas that are not connected to the water supply and sewerage system and do not have an infrastructure. Bacterial contamination is high in ger areas of Ulaanbaatar, around large markets, and near landfills. Bacteria and fungi were detected in 88% of the total samples, 12% were free of bacterial contamination, 53% were mild, 24% were moderate and 11% were highly contaminated. Types of soil microbial contamination and their share in the total sample: E.coli 65.2%, Proteus 27.3%, Citrobacter 12.2%, Pseudomonas 3%, Enterococcus 7.6%, anaerobic microorganisms: Cl.perfringens 21.2%, intestinal pathogenic bacteria of the group: Salmonella 9.1%, fungi 42.4%. Ammonia is also a relatively volatile contaminant and is associated with human, livestock,k and animal feces. 88.4% of all soil sampling points in Ulaanbaatar are contaminated with ammonia and 11.5% are non-contaminated. Ammonia levels are highest in the city's densely populated shopping centers. For example, the maximum ammonium content in the soil sample taken from the back door of the Narantuul market was 21.07 mg/kg, which is 10 times higher than the background rate.

Due to the formation of unstructured urbanization of residential areas, pollution from pit latrines poses a risk to the urban environment and human health by infiltrating shallow water, being carried by floodwaters, and being released into the air. Therefore, to reduce the negative impact and lump sum of pit latrines in ger areas, the total number, and location of pit latrines in the city were determined using high-resolution satellite imagery. In addition, spatial multi-criteria analysis methods were used to assess the negative impact of pit latrines on the environment and human health and categorize them into four zones.

2. MATERIALS AND METHOD

2.1 Study area

Ulaanbaatar is located in the southwestern part of the Khentii Range, between the mountain forest-steppe and dry steppe zone, in the northern part of the Tuul River valley, Chingeltei (1949.7 meters a.s.l), in the south Bogdkhan, and the west Songino Khairkhan (1652.3 meters a.s.l), to the east, Bayanzurkh (1845.5 m, a.s.l) is surrounded by mountains and stretches from east to west. The mean altitude is between 1300-1400 meters above sea level, the lowest point is about 1200 meters along the Tuul River near Songino valley, and the highest point is the Tsetse Gun peak of Bogd Uul mountain at 2256.3 meters above sea level.

Ulaanbaatar has nine official districts, and the study considered at ger districts in seven central districts. Table 1 shows the area of seven districts and ger districts in Ulaanbaatar. The 'Ger area' (residential sprawl are semi-detached to plot nomadic tent with enclosed fences) which are mostly adversely possessed all vacant land of the urban fringe area (B.Bayanjargal, 2020) Figure 1 shows the location map of the study area.

In Ulaanbaatar, the soils are exposed to strong anthropogenic impacts. In the districts dominated by gers, the initial soils are overlain by the deposits of anthropogenic and natural (diluvial and pluvial) origin (Batkhishig, 2013). Kastanozem and alluvial soils are prevalent in Ulaanbaatar's residential areas (Batkhishig, 2013). The humus layer of anthropogenic effect low humus soil is 20-30 cm thick, organic content is 2.6-6.3%, the reaction is neutral or weakly alkaline (pH 7.1-7.8), has a loam texture composition and water permeability is 6.8-28.6 mm/h. The thickness of the humus layer of alluvial soil is 20-40 cm, organic content is 5-10%, the soil reaction is neutral (pH 6.5-7.0), loam or sandy loam composition, and water permeability is 5.2-72.6 mm/h. However, the anthropogenic effect of urban soils in Ulaanbaatar's areas varies widely. For example, the soil reaction (pH 5.7-10.6), organic content 0.1-41.4%, EC 0.0-15.8 dS/m, SO_4 0.0-73.3 mg-eq/ 100g, N-NH_4 0.0-73.3 ppm, NO_3 1.0-9.9 ppm.

№	District	Total district area, hectare	Ger district area, hectare	Ger area in district area, %
1	Sukhbaatar	21119	3338	15.8
2	Chingeltei	9171	2723	29.6
3	Bayangol	2440	435	17.8
4	Khan-Uul	50185	1222	2.4
5	Bayanzurkh	123603	3477	2.8
6	Songinokhairkhan	120005	5836	4.8
7	Nalaikh	68803	478	0.7
	Ulaanbaatar city	477000	17509	100

Table 1. Area of districts and ger area of Ulaanbaatar city

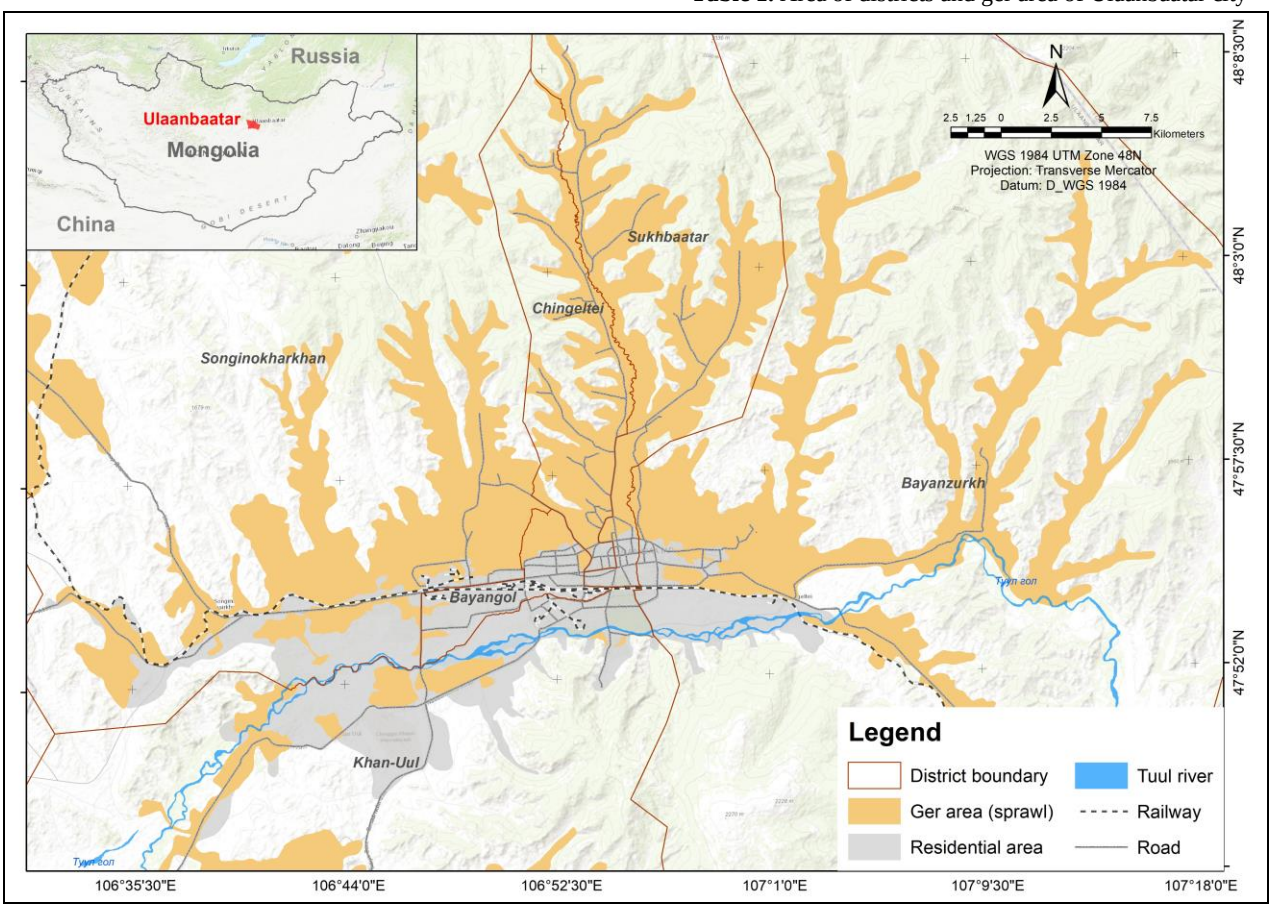

Figure 1. Location map of the study area (sprawl), Ulaanbaatar city, Mongolia

2.2 Pit latrine inventory methodology

The location and counting of pit latrines in Ulaanbaatar's ger area was based on high-resolution satellite images of 2021 on the Google Maps platform of the European Space Agency's Copernicus program, CNES / Airbus, US Maxar Technologies, and map data. Using those satellite images, each pit latrine in the ger area was created using a point in Arc GIS 10.8, and GIS data such as coordinates and elevation in the attribute was automatically calculated using the Arc GIS-Tools field calculation menu. In addition, cadastral information from ger area households was used to generate land use information, such as plots and pit latrines location, address, and tenure, and information from each point was automatically linked using the ArcGIS-Analysis Tools-Split tool. Figure 2 shows an example of the location of a pit latrine in a ger area using satellite imagery.

Figure 2. Pit latrines in a ger area

2.3 Methodology for assessing and zoning the impact on the environment and human health

Multi-criteria spatial analysis methods were used to assess the environmental and human health effects of pit latrines in ger areas. Depending on the spatial location of each pit latrine, nine criteria are defined (groundwater level, surface water, drinking water source, surface slope, soil infiltration, land use, population density, pit latrine density, flood risk zone) and each indicator was rated on a scale of 1 to 5 for impact intensity.
The principles of pollution index – PI (Hakanson, 1980) and pollution load index - PLI (Tomlinson *et al.*, 1980) were used to assess the negative impact of pit latrines**.** Pit latrines in Ulaanbaatar's ger areas will have a PI of 1-5 for each of the nine spatial criteria and a total pollution load index of 1-5 (PLI) compared to the total number of n estimates. The PLI is calculated by the following formula:

$$PLI = (PI_1 \times PI_2 \times PI_3 \times \ldots \times PI_n)^{1/n}$$

Therefore:

n - number of criteria
PI – pollution index

The PLI index is the sum of the negative effects of pit latrines on environmental and human health: PLI = 3.0-5.0 is very high or zone IV, PLI = 2.6-2.9 is high or zone III, PLI = 2.1-2.5 is classified as moderate negative or zone II, and PLI = 1.0-2.0 is classified as low negatively affected or zone I. Table 2 shows multi-criteria of environmental and human health effects of pit latrines.

Criteria	Unit of measurement	Rate				
		Very high 5	High 4	Moderate 3	Low 2	Very low 1
Groundwater level	meters	0-2	2-10	10-30	30-60	60-100
River water protection zone	meters	0-50	50-100	100-200	200-300	300-500
Flood risk zone	index	5	4	3	2	1
Source of drinking water	meters	0-200	200-400	400-600	600-800	800-1000
Surface slope	degrees	15<	10-15	5-10	2-5	0-2
Sedimentary rocks and permeability	sediments	Gravel	Sand	Sandy loam	Loam	Clay
Land use	1-5	5	4	3	2	1
Population density	person/ha	120<	90-120	60-90	30-60	0-30
The density of pit latrines	number/ha	51-91	36-50	21-35	6-20	1-5

Table 2. Assessment of multi-criteria of environmental and human health effects of pit latrines

3. RESULT AND DISCUSSION

3.1 Pit latrine inventory

There are a total of 144,992 pit latrines in the seven central districts of Ulaanbaatar. In each district: Songinokhairkhan 49022, Bayanzurkh 32147, Sukhbaatar 19628, Chingeltei 22739, Khan-Uul 11373, Bayangol 5308 and Nalaikh 4775 pit latrines were counted.
Ulaanbaatar's ger area pit latrines are divided into four zones according to their impact on the environment and human health. In Ulaanbaatar, there are 9443 pit latrines in Zone IV, 43377 in Zone III, 71150 in Zone II, and 21022 in Zone I, which prohibits the use of pit latrines.

№	Districts	Number of pit latrines	Zone			
			IV	III	II	I
1	Songinokhairkhan	49022	1199	13387	25015	9421
2	Bayanzurkh	32147	3263	9746	15447	3691
3	Sukhbaatar	19628	783	4676	11409	2760
4	Chingeltei	22739	1902	6511	10337	3989

5	Khan-Uul	11373	327	3918	6063	1065
6	Bayangol	5308	1952	3174	182	0
7	Nalaikh	4775	17	1965	2697	96
Ulaanbaatar city		144,992	9,443	43,377	71,150	21,022
		100 %	6.5 %	29.9 %	49.1 %	14.5 %

Table 3. The total number of pit latrines in districts.

3.2 Negative environmental impact

In the ger areas of Ulaanbaatar, soil contamination occurs throughout the four seasons of the year. In the vicinity of Ulaanbaatar, the soil is frozen from the last ten days of October to mid-April, and pit latrines in ger areas are not able to absorb liquid waste, so household waste is dumped in the open spaces in the streets and accumulates on the soil surface. It thaws in mid-April to mid-April and is absorbed into the soil and surrounding environment, causing contamination. From June to August, Ulaanbaatar's climate is relatively dry and with little precipitation, which poses a risk to the environment through airborne pollutants released into the air by machinery and human activities. Ulaanbaatar receives the highest annual precipitation (55.4-58.9 mm) in July and August. During this period, floods occur in some areas of the ger areas, and organic contamination of pit latrines is a source of surface and groundwater contamination through the soil. For example, the average depth of maximum microbial contamination (Batkhishig and Donati, 2017) in the ger areas of Ulaanbaatar is 2.8 meters (Figure 3). This depth is close to the bottom level of the pit latrine. The maximum bacterial contamination value was found to be PLI = 3.46. Depending on the soil structure and density, the minimum depth of bacterial contamination is 4-9 meters. The minimum depth of soil bacterial contamination is 6.3 meters on average. In general, no microbial contamination of soil below 10 m was detected.

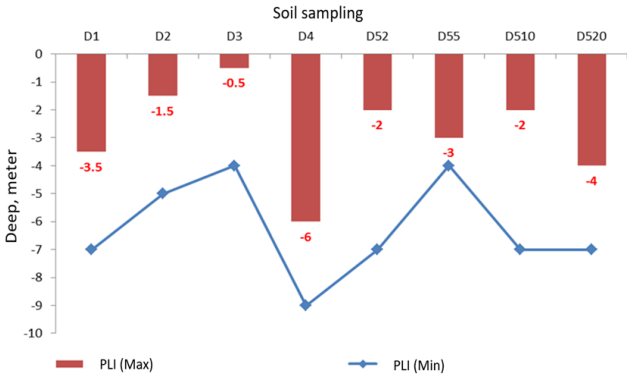

Figure 3. Vertical (Deep in pit latrines) distribution of soil microbial contamination in ger areas

The highly contaminated groundwater in urbanized areas of Ulaanbaatar, especially in highly populated peri-urban areas without municipal sanitation facilities, may have an impact on the public health risks associated with ground-water sources (Batsaikhan *et al.*, 2021). Groundwater in urbanized areas is highly contaminated by nitrate (and Cl^-, SO_4^{2-} and TDS), with the exceedance of the WHO drinking water standard for nitrate in 28% of total samples (Batsaikhan *et al.*, 2021). Water supply in ger areas is mainly provided by the Water and Sewerage Authority of Ulaanbaatar city (WSA) integrated water distribution points in Ulaanbaatar. WSA is also responsible for water quality control. A small number of residents use private wells and hand wells in the middle of the ger area. In this study, samples were taken from three wells in the ger area of the study to determine the level of microbial contamination in the groundwater. The 3 wells samples have different depths: the well in the 27th khoroo of Bayanzurkh district is 1.5 meters deep, the water level is close to the surface, the 2 drilled wells in the 12th khoroo of Chingeltei district are 47 and 74 meters deep. Water from a 74-meter-deep well in the middle of the ger area is free of microbial contamination. E.Coli bacteria was slightly detected in the water at a depth of 47 meters. E.Coli and proteus bacteria were highly contaminated in 1.5 meter deep wells near the surface. It can be concluded that microbial contamination of pit latrines in areas close to the groundwater level has a direct impact on groundwater quality.

3.3 Multicriteria spatial analysis

Geographical information systems (GIS) provide the decision-maker with a powerful set of tools for the manipulation and analysis of spatial information (Carver, 2007). Multi-criteria decision analysis (MCDA) emerged as a formal methodology to face available technical information and stakeholder values to support decisions in many fields and can be especially valuable in environmental decision-making (Huang, Keisler and Linkov, 2011). In the study, the nine criteria have been defined, for instances groundwater level, surface water, drinking water source, surface slope, soil infiltration, land use, population density (Huang, Keisler and Linkov, 2011), pit latrine density, and flood risk zone (Huang, Keisler and Linkov, 2011) (Figure 4). The depth of pit latrines in ger areas in Ulaanbaatar varies depending on the location and is 1-2 meters deep in river valleys with a lot of groundwater, 2-3 meters deep in low-lying flat areas, and a maximum of 5-6 meters deep. The risk of contamination from groundwater infiltration from pit latrines is 5 if there is water at a depth of 0-2 m, 4 if there is water at a depth of 2-10 m, 3 if there is water at a depth of 10-30 m, 2 if there is water at a depth of 30-60 m, 60-100 m If it has deep water, it is rated 1. Groundwater levels were calculated using groundwater borehole data and a 1: 100,000 scale hydrogeological map of Ulaanbaatar.

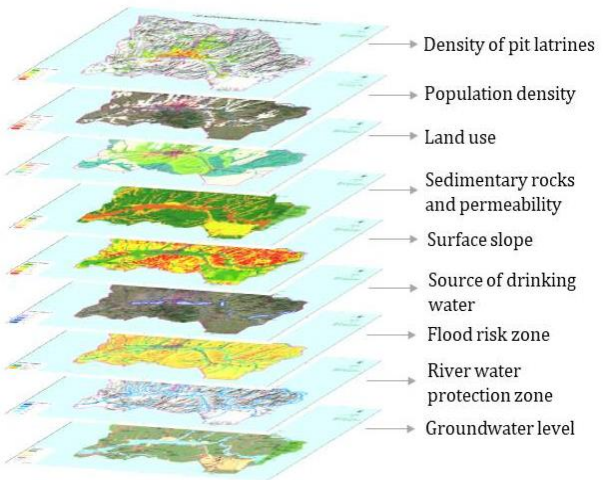

Figure 4. Multi-criteria of the study

The location of pit latrines close to river water carries a high risk of the spread of pollution during heavy rainfall and adverse effects on livestock, animal, and human health through the flow of contaminated river water. Therefore, we rated the location of the pit latrine at a distance of 0-50 m from the river water, 5, 50-100 m, 4, 100-200 m, 3, 200-300 m, 2, and 300-500 m, 1. Ulaanbaatar's ger districts are often flood-prone.

There is a high risk that pit latrine contamination will cause surface runoff through floodwaters, surface contaminants will be exposed to surface water, and contaminants will be released into the air through the respiratory tract and the respiratory system. Therefore, pit latrines located in flood risk zones were rated on a risk scale of 1-5. The intensity of groundwater infiltration from pit latrines is directly related to the mechanical composition of the subsoil and the geological-sedimentary rocks. Therefore, we used a 1: 25000 scale soil map of Ulaanbaatar to assess the mechanical composition of the soil as gravelly-5, sandy-4, sandy loam-3, loam-2, and clay-1. Also, a 1: 100,000 scale geological map of Ulaanbaatar was used to determine the intensity of liquid infiltration of pit latrines. Red-yellow clay, gravel, and sand loosely bound conglomerate gravelly sandstone sediments are 3, Cretaceous and Upper Middle Carboniferous shale sands of various grains, gravesite, conglomerate, and siltstone predominant sediments are 2, deep rock or late Triassic - Early Jurassic rocks and granites are 1. Ulaanbaatar's drinking water wells are located adjacent to large ger areas in an alluvial aquifer with an average thickness of 30-40 meters. This means that the contamination of pit latrines in the ger areas can lead to long-term pollution of drinking water sources (e.g. nitrogen compounds). Therefore, the distance from the drinking water source is 0-200 m for 5, 200-400 m 4, 400-600 m 3, 600-800 m 2, if 1000 m and more further is 1.

Slope or slope angles and lateral lengths are also important factors in soil and vegetation formation and ecological development. The Digital Elevation Model (DEM) was used to determine the slope of the pit latrines in the ger districts of Ulaanbaatar's central districts and the height above sea level. The DEM has been generated using the data of the European Space Agency's Copernicus program Sentinel 1B Synthetic Aperture Radar (SAR) satellite data acquired on August 7, 2020, with an accuracy of 10 meters**.** The Sentinel 1B satellite flies at an altitude of 693 km, has a lifespan of 7 years, has a C-SAR sensor (C-band SAR instrument) and it acquires in the range of 5.405 GHz and C channel (5.55 cm). The interferometric SAR images of the Sentinel 1B satellite have been used, and as a result of the interferometric SAR technique, a DEM with a 10m x 10m pixel resolution has been generated from the Sentinel-1 satellite data for the study area (Erdenebaatar and Damdinsuren, 2020). The greater the slope of the surface, the more intense the lateral process. For example, according to the kinematics of the fluid, surface and groundwater and moisture are rapidly transported to the lower side, along with sediments and soil elements, and the greater the slope of the surface, the faster the lateral process (Б.Баянжаргал, 2020). Therefore, we rated the slope of 15 degrees or more as 5, 10-15 for 4, 5-10 for 3, 2-5 for 2, and 0-2 for 1.

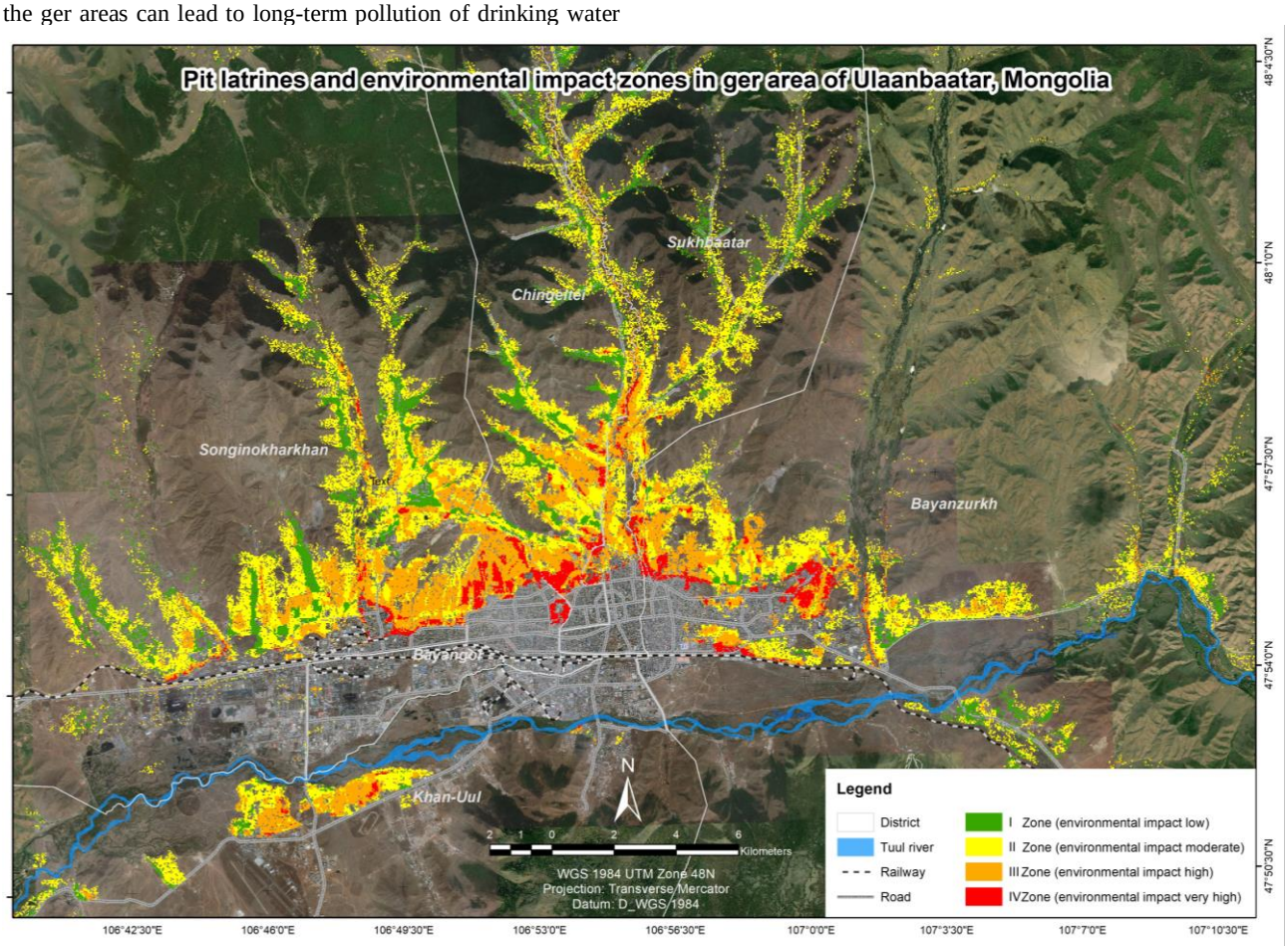

Figure 5. Pit latrines and environmental impact zones in ger area of Ulaanbaatar, Mongolia

The land-use zoning assessment uses a 1: 350,000 scale zoning map of the calculation land fee in the capital city of Ulaanbaatar and depending on the location of the pit latrine in the ger area, the socio-economic significance was rated in reverse order:

Zone 1 is 5, Zone 2 is 4, Zone 3 is 3, Zone 4 is 2, Zone 5 is 1. The population density map of the chorus in 7 central districts of Ulaanbaatar's ger districts is generated using satellite images and GIS tools. Therefore the area and boundaries of each ger residential area have been defined. The size of the khoroo's residential area (ha) was calculated using the 2020 population statistics as per capita. The density of pit latrines in ger areas in Ulaanbaatar ranges from 1 to 91 in terms of density per hectare. Therefore, we rated 1 hectare as 1-5 for 1, 6-20 for 2, 21-35 for 3, 36-50 for 4, and 51-91 for 5. Eventually, Ulaanbaatar's ger area pit latrines are divided into four zones according to their environmental impact using GIS-MCDA (Figure 5).

4. CONCLUSION

This study aimed to analyze the environmental impact of pit latrines of ger district areas in Ulaanbaatar capital city of Mongolia using remotely sensed data and multi-criteria spatial analysis. Inventory and registration of pit latrines in ger districts of Ulaanbaatar were determined using remotely sensed high-resolution satellite imagery, and the geographic information system's database was created.

A total of 144,992 pit latrines were counted in Ulaanbaatar. In each district, there are 49022 pit latrines in Songinokhairkhan, 32147 in Bayanzurkh, 1962 in Sukhbaatar, 22739 in Chingeltei, 11373 in Khan-Uul, 5308 in Bayangol and 4775 in Nalaikh. Ulaanbaatar's ger area pit latrines are divided into four zones according to their environmental impact. In Ulaanbaatar, there are 9443 pit latrines in Zone IV, 43377 in Zone III, 71150 in Zone II, and 21022 in Zone I, which prohibits the use of pit latrines.

The results of this study are important for implementing management measures to reduce soil pollution, such as restricting and banning the use of pit latrines in ger areas, installing toilets that meet hygiene norms MNS 5924: 2015 standards, and carrying out disinfection.

5. RECOMMENDATION

Implement multifaceted measures such as destruction of 9443 pit latrines in Zone IV of ger districts of Ulaanbaatar soon (1-4 years), replacement of eco-latrines that meet sanitation guidance MNS 5924: 2015 standards, and further connected to the sewer line.

There's have to implement legal measures such as banning, imposing taxes and fines on 43,377 pit latrines located in Zone III, which hurt the environment from the pit latrines in the ger districts of Ulaanbaatar, and take measures to replace them with eco-latrines that meet sanitation guidance MNS 5924: 2015 standards.

Have to limit 71150 pit latrines in Zone II, which will hurt the environment, halt to the appearance of new pit latrines in that zone, replace old pit latrines with eco-toilets that meet MNS 5924: 2015 standards, and provide public economic support to residents and households who use eco-latrines. Implement long-term multilateral measures such as providing low rate mortgages, local eco-movement incentives, and policy support for green loan financing.

Take hygiene measures to disinfect 21022 pit latrines in the first zone of Ulaanbaatar's ger district from adverse environmental impacts, not to create new pit latrines in the zone, and to carry out regular disinfection during the warm season (during May-September).

In case of granting new land ownership rights to citizens and enterprises in the residential area of the capital city of Ulaanbaatar, whether they are connected to the sewerage system or meet the MNS 5924: 2015 standard of pit latrines and sanitation pits. Require technical compliance to pit latrines of a plot to be legally transferred. Refusal to grant land possession rights if this requirement is not met.

To set conditions and requirements for citizens to install pit latrines and wash pits that meet MNS 5924: 2015 standards when doing legal registration to sell or transfer their land ownership rights to others.

To impose fines and restrict measures on enterprises that own land in Ulaanbaatar's residential areas and use pit latrines, and pollute the surrounding soil with organic and inorganic substances and solid-liquid waste.

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REFERENCES

Amarsaikhan, D. *et al.* (2009) 'Applications of remote sensing and geographic information systems for urban land-cover change studies in Mongolia', *Geocarto International*, 24(4), pp. 257–271. doi:10.1080/10106040802556173.

Amarsaikhan, D. *et al.* (2015) 'Applications of multitemporal rs images for the evaluation of urbanization process in Mongolia', *ACRS 2015 - 36th Asian Conference on Remote Sensing: Fostering Resilient Growth in Asia, Proceedings*, (July), pp. 1–5.

Batkhishig, O. (2013) 'Soil pollution of Ulaanbaatar city', *Proceedings of the Mongolian Academy of Sciences*, 53(01), pp. 15–19.

Batkhishig, O. and Donati, P. (2017) 'Soil pollution penetration and depths', *Mongolian journal of soil science*, 2, pp. 132–141.

Batsaikhan, B. *et al.* (2021) 'Groundwater contamination assessment in Ulaanbaatar City, Mongolia with the combined use of hydrochemical, environmental isotopic, and statistical approaches, *Science of the Total Environment*, 765. doi:10.1016/j.scitotenv.2020.142790.

Carver, S.J. (2007) 'Integrating multi-criteria evaluation with geographical information systems, *http://dx.doi.org/10.1080/02693799108927858*, 5(3), pp. 321–339. doi:10.1080/02693799108927858.

Erdenebaatar, N. and Damdinsuren, A. (2020) 'Geographical analysis of forest types based on a digital elevation model generated from synthetic aperture radar', *Proceedings of the Mongolian Academy of Sciences*, pp. 43–54. doi:10.5564/PMAS.V60I4.1504.

Hakanson, L. (1980) 'An ecological risk index for aquatic pollution control.a sedimentological approach', *Water Research*, 14(8), pp. 975–1001. doi:10.1016/0043-

1354(80)90143-8.
Huang, I.B., Keisler, J. and Linkov, I. (2011) 'Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends', *Science of the Total Environment*, pp. 3578–3594. doi:10.1016/j.scitotenv.2011.06.022.

Tomlinson, D.L. *et al*. (1980) *Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index*.

APPENDIX

The photo below shows a street and a pit latrine in a ger area of Ulaanbaatar (Figure 6,7,8).

Figure 6. Pit latrines in ger area of Ulaanbaatar, Mongolia

Figure 7. Street of ger area of Ulaanbaatar, Mongolia

Figure 8. Street of ger area in the winter

B. Bayanjargal, E.A. (2020) 'Integrated assessment of environmental factors of Mongolian landforms', Geographical and geoecological issues of Mongolia, 41, p. 119.

Б.Баянжаргал, Э.А. (2020) 'Монгол орны газрын гадаргын хотгор гүдгэрийн экологийн хүчин зүйлсийн нэгдсэн үнэлгээ', *Монгол орны газарзүй, геоэкологийн асуудлууд*, 41, p. 119.