Investigating the Environmental Impacts of Landmines in the Maidan Sub-district through GIS-Based Mapping

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Abstract

Landmines and explosive remnants of war (ERW) create serious threats to human safety and the environment. Decades of armed conflict have resulted in widespread landmine contamination in Iraq, severely affecting ecosystems and land use. The Maidan sub-district in particular remains heavily contaminated and requires detailed spatial analysis to assess both the extent and the environmental consequences of landmine presence. This study used a GIS-based mapping approach to identify and visualize the spatial distribution of contaminated areas in the Maidan sub-district. Data provided by the Mine Action Agency (MAA) of the Kurdistan Regional Government (KRG), collected using Garmin GPS and Trimble devices, were integrated into ArcGIS Pro for analysis. The total contaminated land area (in square meters) was calculated, and mine-affected sites were classified into categories to support statistical and spatial interpretation. The findings revealed that landmine contamination has significantly degraded local ecosystems by restricting vegetation regrowth, fragmenting habitats, and preventing the safe use of land for agriculture, grazing, and various forms of human activity. Several previously productive agricultural zones are now unusable due to persistent contamination. Furthermore, environmental degradation was observed in the form of reduced biodiversity and limited natural land recovery in affected areas. GIS mapping proved effective in delineating mined zones, quantifying contaminated land, and visualizing patterns of environmental impact. This spatial analysis enables more targeted mine clearance operations and supports post-conflict recovery efforts. Ultimately, the study demonstrates how GIS-based environmental assessment can inform land-use planning, ecological restoration, and policy decision-making in post-conflict regions like Maidan.

Keywords: Landmines, environmental impacts, GIS, Maidan sub-district.

پوختە

مین و پاشماوە تەقینەوەکانی جەنگ (ERW) کاریگەرییەکی گەورە لەسەر سەلامەتی مرۆڤ و ژینگە دروست دەکەن. لە عێراقدا چەندین دەیە شەڕی چەکداری بووە هۆی مینڕێژیی زەوی بە ڕێژەیەکی زۆر، ئەمەش بەتوندی

کاریگەریی زۆری کردە سەر ئیکۆسیستەم و کشتوکاڵ. ناحیەی مەیدان بە شێوەیەکی بەربڵاو مینرێژکراوە و پێویستی بە شیکاری شوێنی ورد هەیە بۆ ئەوەی هەڵسەنگاندنی بۆ بکرێت بۆ هەردوو ڕێژە و دەرئەنجامە ژینگەییەکانی پیسبوون بە مین لەناوچەکەدا. ئەم تویژینەوەیە ڕێبازێکی نەخشەسازی لەسەر بنەمای GIS بەکارهێناوە بۆ دەستنیشانکردن و وێناکردنی دابەشبوونە شوێنییەکانی ناوچە مینرێژراوەکان لەناحیەی مەیدان. ئەو داتایانەی کە لەلایەن دەزگای گشتی کاروباری مینی حکوومەتی هەرێمی کوردستانەوە وەرگیرابوون، کە بە بەکارهێنانی ئامێرەکانی Garmin GPS و Trimble کۆکرابوونەوە، لە نێو سۆفتوێری ArcGIS Pro یەکخران بۆ شیکاری ورد. کۆی ڕووبەری زەوییە مینرێژکراوەکان (بە مەتر چوارگۆشە) پێوانەکرا، و شوێنە کارتێکراوەکانی مینیش پۆلێن کران بۆ گرووپی جیاواز بۆ پشتگیریکردن لە لێکدانەوەی ئاماری و شوێنی. دەرەنجامەکانی توێژینەوەکە دەریانخست کە ناوچە مینرێژکراوەکان بە شێوەیەکی بەرچاو ئیکۆسیستەمی ناوچەکەی شێواندووە بە سنووردارکردنی دووبارە گەشەسەندنی ڕووەکی و دابەشکردنی شوێنی نیشتەجێبوونی گیانداران و ڕێگریکردن لە بەکارهێنانێکی تەندروستی زەوییەکان بۆ کشتوکاڵ و لەوەڕاندن و جۆرە جیاوازەکانی چالاکیی مرۆڤ. چەندین ناوچەی کشتوکاڵی کە پێشتر بەرهەمدار بوون ئێستا بەهۆی پیسبوونی بەردەوامەوە بەکارناهێنرێن. جگە لەوەش، تێکچوونی ژینگە لە شێوەی کەمبوونەوەی جۆراوجۆری زیندەوەرەکان و سنووردارbوونی زیندبوونەوەی ناوچە زەوییە سرووشتییەکان لە ناوچە زیانلێکەوتووەکاندا بەدیکرا. نەخشەسازییە بەکارهێنانی GIS کاریگەر بوو لە هێماکردنی ناوچە مینرێژکراوەکان، ڕووپێوی و دیاریکردنی زەوییە مینرێژکراوەکان، و وێناکردنی شێوازە کاریگەرییە ژینگەییەکان. ئەم شیکارییە شوێنییە یارمەتی پرۆسەی پاککردنەوە ئامانجدارەکانی مین دەدات و پشتگیری لە هەوڵەکانی چاکبوونەوەی دوای ململانێی جەنگی دەکات. لە کۆتاییدا، توێژینەوەکە نیشانی دەدات کە چۆن هەڵسەنگاندنی ژینگەیی بەبەکارهێنانی GIS دەتوانێت پلانداناانی بەکارهێنانی زەوی، گەشەپێدانی ئیکۆلۆژی و بڕیاردانی دروست لە ناوچەکانی دوای ململانێی جەنگی وەک مەیدان بخاتەڕوو.

وشەی سەرەکی: ناوچە مینرێژکراوەکان، کاریگەرییە ژینگەییەکان، GIS، ناحیەی مەیدان.

ملخص البحث

تُشكل الألغام الأرضية ومخلفات الحرب القابلة للانفجار تهديدات خطيرة على سلامة الإنسان والبيئة. في العراق، أدت عقود من النزاع المسلح إلى انتشار واسع النطاق للألغام الأرضية، مما أثر بشدة على النظم البيئية واستخدام الأراضي. ولا تزال ناحية الميدان، على وجه الخصوص، ملوثة بشدة، وتتطلب تحليلاً مكانياً مفصلاً لتقييم مدى وجود الألغام الأرضية وعواقبه البيئية. اعتمدت هذه الدراسة على نهج رسم الخرائط القائم على نظم المعلومات الجغرافية لتحديد وتصوير التوزيع المكاني للمناطق الملوثة في ناحية الميدان. دُمجت البيانات التي قدمتها وكالة مكافحة الألغام التابعة لحكومة إقليم كردستان، والتي جُمعت باستخدام أجهزة Garmin GPS وTrimble، في برنامج ArcGIS Pro لتحليلها. حُسب إجمالي مساحة الأرض الملوثة (بالأمتار المربعة)، وصُنفت المواقع المتضررة بالألغام إلى فئات لدعم

التفسير الإحصائي والمكاني. كشفت النتائج أن تلوث الألغام الأرضية قد أدى إلى تدهور كبير في النظم البيئية المحلية من خلال تقييد نمو النباتات، وتفتيت الموائل، ومنع الاستخدام الآمن للأراضي للزراعة والرعي ومختلف أشكال النشاط البشري. أصبحت العديد من المناطق الزراعية، التي كانت منتجة سابقًا، غير صالحة للاستخدام بسبب التلوث المستمر. علاوة على ذلك، لوحظ تدهور بيئي تمثل في انخفاض التنوع البيولوجي ومحدودية استعادة الأراضي الطبيعية في المناطق المتضررة. وقد أثبتت خرائط نظم المعلومات الجغرافية فعاليتها في تحديد المناطق الملغومة، وتحديد كميات الأراضي الملوثة، وتصور أنماط الأثر البيئي. يُمكّن هذا التحليل المكاني من إجراء عمليات إزالة ألغام أكثر دقة، ويدعم جهود التعافي بعدالصراع. وفي نهاية المطاف، توضح الدراسة كيف يُمكن للتقييم البيئي القائم على نظم المعلومات الجغرافية أن يُسهم في تخطيط استخدام الأراضي، والاستعادة البيئية، وصنع القرارات السياساتية في مناطق ما بعد الصراع مثل ميدان.

الكلمات المفتاحية: الألغام الأرضية، الآثار البيئية، نظم المعلومات الجغرافية، ناحية ميدان.

1. Introduction

Over 100 million buried landmines are thought to have polluted 3,000 km² of land globally (Kasban et al., 2010). Landmines and unexploded ordnance (UXO) are examples of explosive remnants of war (ERW), which are among the most deadly and enduring effects of armed conflict. Because they limit access to vital resources like water, pastureland, agricultural fields, and forests, landmines in mine-affected areas continue to endanger civilian lives and livelihoods. Beyond their direct humanitarian effects, landmines have a significant—yet usually disregarded—impact on protecting the environment. The harm or death of wildlife is the most obvious example of this influence, but it also affects more general elements of the natural environment, such as soils, water systems, and physical landscapes. These abiotic elements have inherent significance as the principal targets for environmental conservation and are necessary for the maintenance of many biological processes (Alegría et al., 2017; Kiernan, 2007).

Landmines not only promote disease but also lead to poverty and starvation. In Angola, a country with rich agricultural land and copious amounts of rainfall, starvation is killing thousands of people because of landmines. Because they fear losing their lives or limbs to landmines, they avoid cultivating areas with fertile soils. Thus, landmines have a greater harmful impact than drought and natural calamities, leading able-bodied people to starve even in the face of an abundance of fertile soil (Oppong & Kalipeni, 2005).

Anti-personnel landmines have contaminated large areas in over 60 nations, according to the Geneva International Centre for Humanitarian Demining (GICHD) (Popov et al., 2022). Iraq is regarded as one of the nations most severely impacted by landmines worldwide (Iraq, 2023). The Gulf War in 1991, the Iran-Iraq War in 1980–1988, and the U.S.-led invasion in 2003 are the main causes of the widespread contamination. Among the mined sites are minefields along Iraq's borders with Iran and Saudi Arabia. Furthermore, the contamination issue has been worse since 2014 when improvised explosive devices (IEDs) began to litter regions that were formerly under the control of the Islamic State group (Impact – Iraq, 2025).

In post-conflict areas across the world, an estimated 60 million landmines are still buried, resulting in about 25,000 fatalities or injuries annually. People who work on contaminated property or are minors make up the majority of the victims. Many players have started extensive initiatives to lessen this disaster through mine clearance, victim aid, and public awareness campaigns, including governmental agencies, humanitarian groups, and armed units (Kranitzle, 2000).

In demining operations, geospatial technologies are becoming more and more important. Over the past 20 years, groups like The HALO Trust have used Global Navigation Satellite Systems (GNSS) and Geographic Information Systems (GIS) to improve the accuracy and security of explosive ordnance disposal (Speed, 2024). Prioritising clearance operations requires the use of these technologies' high-resolution mapping, data-driven planning, and spatial analytic capabilities.

This study tackles the pressing issue of widespread landmine contamination in the Sulaymaniyah Governorate, Iraq's Maidan sub-district, where decades of armed conflict have severely degraded the environment and rendered vast regions unfit for human usage. There is still a dearth of thorough, geographically explicit data to direct efficient demining and ecological restoration operations, despite continuous clearing efforts. The primary research issue is the lack of thorough mapping and environmental impact assessments of landmine-affected areas, which makes it more difficult for decision-makers to set priorities for clearance efforts and create sustainable land use plans. In order to close this gap, the study uses GNSS-gathered field data and GIS-based mapping to categorise mine-affected areas, quantify contaminated land area, and assess the environmental effects of landmine presence.

Two hypotheses serve as the foundation for the study: (H1) landmine contamination is spatially clustered, with higher concentrations close to areas that were once involved in conflict, like the Iranian border; and (H2) areas with higher contamination levels show more environmental degradation, such as vegetation loss and altered land use. Through testing these theories, the study aims to show how integrated geospatial technologies might help with ecological recovery, mine clearance operations, and sustainable land-use planning in post-conflict environments.

2. Study area and Methodology

Study area

The study investigates Maidan sub-district in Khanaqin district at Diyala province of Iraq, as indicated in Fig. 1. The Maidan sub-district is an agricultural and semi-mountainous place which has a fairly suitable climate. The land is located in the southeastern of Sulaymaniyah city. The land is bordered on the north by the Bamo sub-district, on the south by the Qoratoo sub-district, on the east by Iran, and on the west by the Sheikh Tawel and Pebaz sub-districts. The Maidan sub-district is located between the latitude and longitude of 34.9182 north and 45.6197 west. The area of the Maidan sub-district is 556.8 km^2 and the population number is 4911 individuals, consisting of 915 families (Sabir et al 2022).

After the 1991 Iraqi uprisings, Maidan sub-district is governed by Garmian administration by KRG (Khanaqin, n.d.; Sabir et al 2022). A high rate of landmine have been buried in a number of villages in the Maidan sub-district by Ba'athist regime in order to hurt and kill the Kurdish villagers. As a result, since General Energy have started working in the area, they have continuously tried to clean the area for the people, beside their main jobs, in order to ensure that they can live in safety and away from any danger (Yarwais 2013).

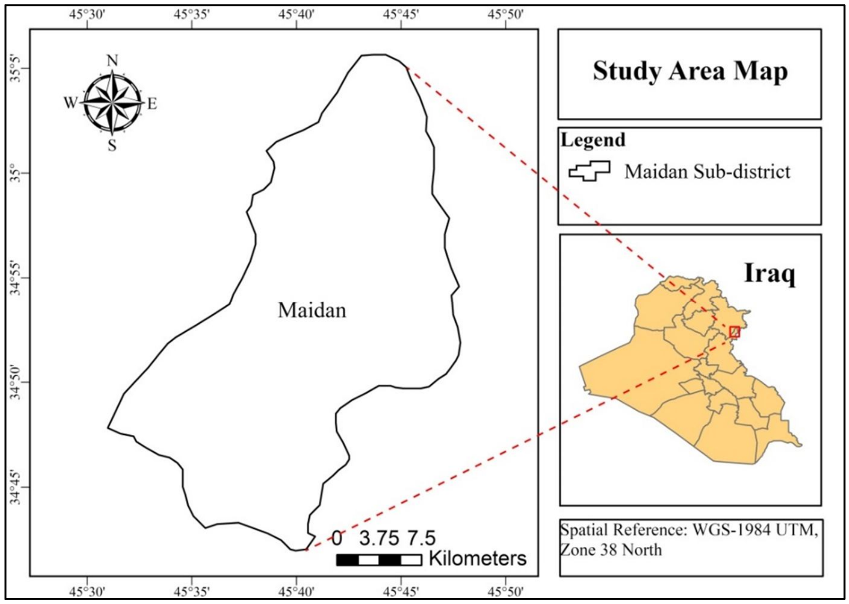


Figure 1. Geographic location of the study area.

2.2 Structure of Landmines

Three parts make up each landmine: the case, which can be made of metal, wood, plastic, or a combination of these materials; the explosive material, which can be Tetryl, mixed RDX/TNT, TNT, or other high explosives; and the initiator, which can be an electronic sensor, a pressure sensor, or any other type of sensor. Landmines can be categorized based on their targets or design (Kasban et al. 2010).

2. 2.1 Classification According to Design

Three primary categories can be used to classify landmines based on their design: Blast, Bounding (bouncing Betty), or Fragmentation landmines (Abujarad 2007).

2.2.1.1 Blast Landmines

Blast landmines are often buried at the soil's surface and are set off by handling or disturbing them, or by pressure (such as stepping on or driving over them). For pressure-activated mines to detonate, roughly 5–16 kg of pressure is needed. These landmines' primary objective is to demolish whatever is around, such a person's foot or leg. The intended object is intended to be broken up into pieces by a blast landmine, which may result in secondary harm like infection or amputation (Abujarad, 2007).

2.2.1.2 Bounding Landmines

Only a tiny portion of the initiator of these landmines often protrudes from the ground after they are buried. To injure a person's head and chest, the initiator raises the mine approximately one meter into the air when it is activated, setting off a propelling charge. (Abujarad 2007).

2.2.1.3 Fragmentation Landmines

These landmines have the ability to shoot fragments in all directions or in a single direction. At closer range, these landmines can kill and injure people up to 200 meters away. Glass or metal particles are utilized in these landmines (Abujarad 2007).

2.2.2 Classification According to Target

According to the potential target, buried landmines can be divided into two main categories: AT and AP landmines (Bhuian et al. 2006). Table 1 shows how the two main categories differ from one another. In addition to landmines, past battlegrounds may also contain unexploded ordnance (UXOs), which are misfired shells or unexploded bombs that remain buried in the ground (Paik et al. 2002).

Table 1. Comparison of Anti-Personnel (AP) and Anti-Tank (AT) Landmines.

Type	AP landmines	AT landmines
Weight	Light (100g-4 kg)	Heavy (6kg-11kg)
Size (diameter)	6-20 cm	20-50 cm
Target	Human	Vehicle
Case material	Plastic, metal, wood	Plastic, metal
Operating pressure	500g	120 kg

2.2.2.1 AT Landmines

AT landmines are usually set on roads or railway tracks and are designed to explode when a big car passes over them. It is possible to activate them with an electrical cord (Lee, C. 2004). Tanks, armoured personnel vehicles, army trucks, and the men inside are all intended to be destroyed. There are several types of AT landmines, according to Kasban (2008). AT landmine examples are seen in Figure 2, and their specifications are listed in Table 2.

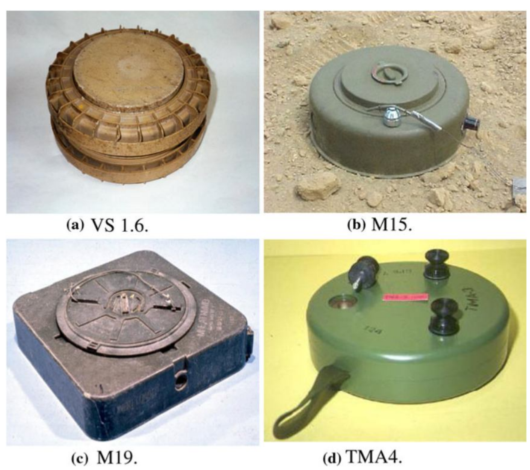


Figure 2. Examples of Anti-Tank (AT) Landmines.

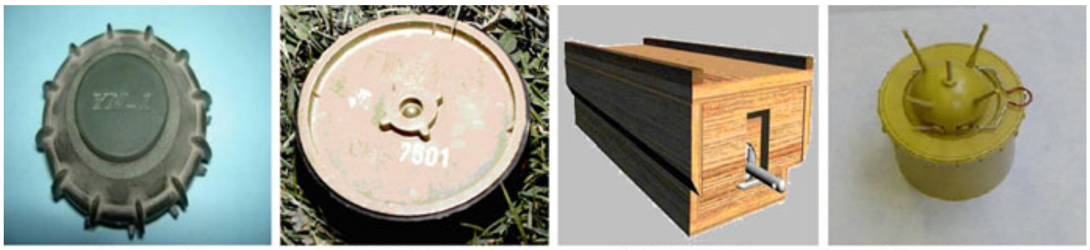
Table 2. Technical Specifications of Anti-Tank (AT) Landmines.

Type	VS 1.6	M15	M19	TMA4
Case	plastic	Metal	Plastic	Metal
Explosive material	TNT RDX	TNT RDX	TNT RDX	TNT
Warhead	Blast	Blast	Blast	Blast
Diameter	222 mm	333 mm	450 mm	265 mm

Height	92 mm	150 mm	94 mm	110 mm
Weight	3 kg	14.3 kg	9.5 kg	7 KG
Operating pressure	1800-220 kg	160-340 kg	120-226kg	100-180 kg
manufacture	Italy	US	US	Yugoslavia

2.2.2.2 AP Landmines

Tiny explosives known as AP landmines explode when someone steps on or tampers with them. Their main military goal is to maim opposing soldiers rather than kill them. AP landmine parameters are listed in Table 3, and multiple examples of them are shown in Fig 3 (Kasban, 2008).



(a) VS 5.0. **(b)** PMA 3. **(c)** PMD 6. **(d)** VAL 69.

Figure 3. Examples of Anti-Personnel (AP) Landmines.

Table 3. Technical Specifications of Anti-Personnel (AP) Landmines.

Type	VS 5.0	PMA 3	PMD 6	VAL 69
Case	Plastic	Metal	Wood	Plastic
Explosive material	RDX	Tetry	TNT	RDX+TNT
Warhead	Blast	Blast	Blast	Fragmentation
Diameter	90 mm	110 mm	220 mm	170 mm
Height	45 mm	40 mm	65 mm	50 mm
Weight	430 g	180 g	500 g	420 g
Operating pressure	10 kg	35 kg	10 kg	10 kg
Manufacture	Italy	Yugoslavia	USSR	Italy

2.3 Data Collection and Mapping

The investigation's data collection process involved acquiring information from the Kurdistan Region Government's Mine Action Agency (MAA) (KRG). The coordinates go from January 2025 to more than 20 years ago. For ten years, the KRG's MAA and a number of landmine organisations, including GDMA, UNOPS, SMAC, MAG, GMAC, ASA, PDO, and NPA, worked in the vicinity of the research area. They have located and measured (landmine fields, landmine area, and risks area) using Global Navigation Satellite Systems (GNSS).

Organisations engaged in landmine action have employed a variety of GNSS receivers during their operations, including the Trimble Da2 and GARMIN GPS, which are real-time kinematics (RTK)-capable devices that connect to Android and iOS devices via a straightforward Bluetooth connection. Additionally, mapping and polygon conversion were done using ArcGIS Pro. Field-focused methods that are accurate, scalable, easy to use, and, most importantly, cost-effective have been implemented.

3. Results and Discussion

3.1 Mine Areas and Fields Measurement

The region's mined areas, especially the study area, are near the Iranian border because of the ongoing hostilities between the two nations. According to Fig. 4, the majority of the mined areas are found in Maidan sub-district's north and east.

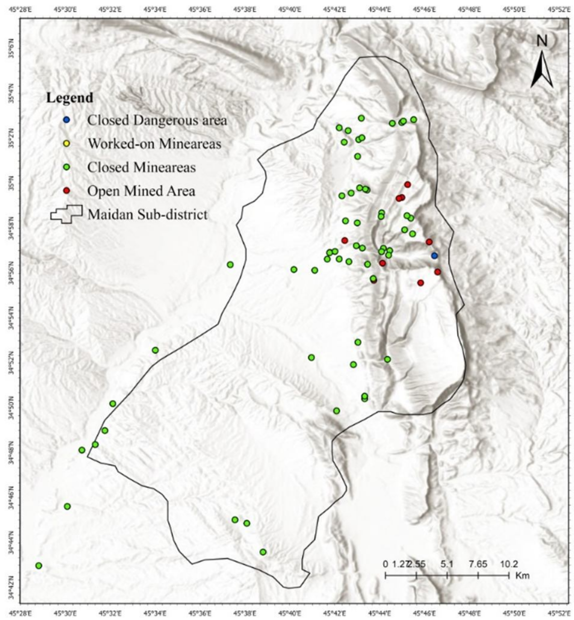


Figure 4. Distribution of Landmine Areas around Maidan Sub-District.

Moreover, the minefields are also close to the boarder of Iran. Most of the minefields are located in the north and southeast of Maidan sub-district, as shown in Fig. 5.

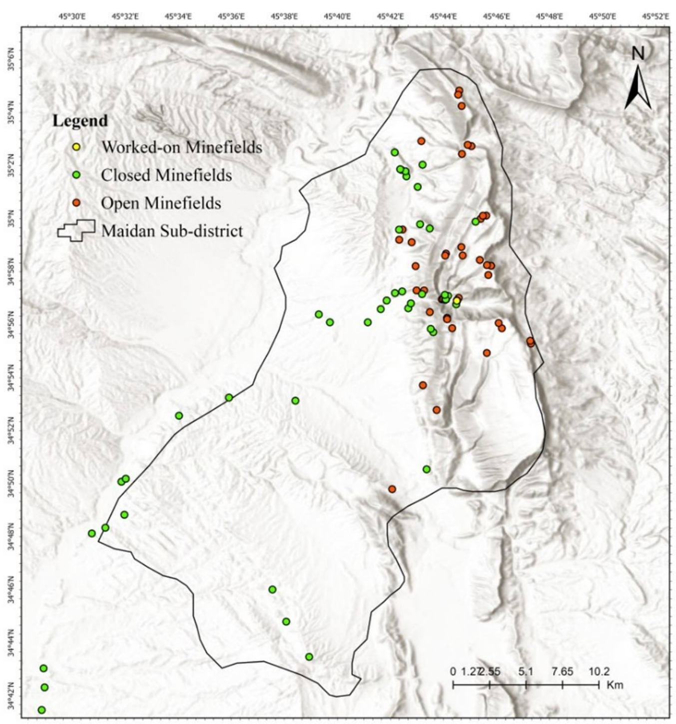


Figure 5. Distribution of Landmine Fields around Maidan Sub-District.

Data coordinates were gathered using Garmin GPS and Trimble DA2 receiver GNSS by the MAA of KRG of Iraq, obtaining in January 2025. The authorities did not specify the precise types of landmines, although the majority of the landmines found in the research region were anti-personnel (AP) and anti-tank (AT) landmines, which were meant to maim or kill anyone who came into direct contact with them. These mines pose a dual threat: AP mines directly endanger civilians and wildlife, while AT mines hinder safe use of agricultural lands and infrastructure development (Kasban et al., 2010; Abujarad, 2007). The MAA named the areas into four categories: worked on, open, closed, and dangerous. Table 4 presents the four categories of landmine fields, including the number of fields and their total area in square meters. In the mined areas, no areas have been identified as 'worked-on land' and 'dangerous land'. There are 10 areas of 'open land' covering 2,481,500, and 64 areas of 'closed land' spanning 12,515.

On the other hand, in the minefield, there is only one area classified as 'worked-on land' with a total area of 18,686. There are 36 areas of 'open land' covering 1,885,503, and 44 areas of 'closed land' spanning 1,589,427. Additionally, there is one area that has been identified as 'dangerous land' with a total area of 1,500. Across the area, there is only one section classified as 'worked-on land,' covering a total of 18,686. Additionally, 46 areas are designated as 'open land,' spanning 4,367,003, while 108 areas fall under 'closed land,' covering 1,601,942. There is also one 'dangerous land' area, measuring 1,500.

Table 4. Area Measurements of Landmine area and landmine fields.

	Worked on		Open		Closed		Dangerous	
	N. Fields	Area Field/m^2	N. Fields	Area Field/m^2	N. Fields	Area Field/m^2	N. Fields	Area Field/m^2
Mined areas	0	0	10	2,481,500	64	12,515	0	0
Minefields	1	18,686	36	1,885,503	44	1,589,427	1	1,500
Total	1	18,686	46	4,367003	108	1,601,942	1	1,500

The results of this study highlight how landmine contamination in the Maidan sub-district, especially in regions close to the Iranian border, has serious negative effects on the ecosystem. According to GIS-based mapping, the sub-district's northern and eastern regions have a disproportionately high concentration of mined zones, with larger areas of land still being categorised as ‘closed’ or ‘open.’ These places continue to be dangerous not only for human safety but also for the sustainability of local land use and the ecosystem.

The entire area that is designated as ‘closed land’—roughly 15,012,846 m²—reflects the degree of environmental inaccessibility and ecosystem disturbance. There are indications of vegetation loss, soil deterioration, and stalled natural succession in these areas, which are frequently abandoned or left in a degraded state. Particularly in formerly farmed or semi-wild areas, the ongoing contamination has hindered natural regeneration, decreased biodiversity, and fragmented ecosystems.

Moreover, the discovery of ‘worked-on land’ (about 4,317,096 m2) and its negligible percentage of the entire polluted region indicate the extent of recovery that is still to be accomplished. Large areas of the sub-district are still ecologically stagnant or unfit for grazing, agriculture, or forest regrowth, despite modest progress in removal. Even though it is just 1,500 m² in size, one ‘dangerous land’ zone serves as an example of the erratic dangers provided by unexploded ordnance, which further delays the regeneration of the surrounding ecosystem.

The ramifications from the standpoint of environmental management are significant. According to research by Kiernan (2007) and Oppong and Kalipeni (2005), landmine contamination has severely harmed local ecosystems by limiting the regrowth of vegetation (Hamad et al., 2018), causing habitat fragmentation (New Spotlight Magazine, 2025; Military Dispatches, n.d.), and making it unsafe to use land for grazing, agriculture, and other human activities (NCT CBNW, n.d.). Persistent contamination has rendered certain formerly profitable agricultural zones useless (Hamad et al., 2018). Additionally, in impacted areas, landmine explosions have resulted in soil and water contamination, the loss of flora and fauna, and impeded ecosystem restoration, resulting in decreased biodiversity and limited natural land recovery (Human Rights Watch, 2000; Military Missions, n.d.). These effects exacerbate rural livelihood instability and fuel long-term land degradation.

Quantifying these effects and offering a spatially explicit knowledge of the contamination required the integration of GNSS and GIS technology. Environmental planning is supported and humanitarian demining situational awareness is improved by the capacity to precisely map and classify mined areas. Future studies can predict habitat fragmentation, track landscape changes over time, and evaluate vegetation recovery by superimposing ecological or land use data across contaminated zones.

These findings highlight the necessity of consistent funding for environmental restoration as well as demining. To expedite post-conflict land rehabilitation, ecologically vulnerable or agriculturally valuable zones should be given priority in strategic clearance activities. To further improve knowledge of the long-term environmental impact of landmines, GIS-based environmental evaluations should be expanded to incorporate indicators generated from remote sensing (such as NDVI and LULC change). In post-conflict areas like Maidan, the study demonstrated how GIS-based mapping can highlight the complex environmental effects of landmine exposure and provide a basis for more comprehensive recovery plans.

4. Conclusion

This study shows how well GIS and GNSS technology can be combined to map and analyze the Maidan sub-district's landmine contamination. The geospatial technique made it possible to accurately calculate the amount of contaminated land, visualize mined areas in detail, and classify the land into useful categories like ‘closed,’ ‘open,’ ‘worked-on,’ and ‘dangerous.’ These divisions provide important information about the state of demining activities now and indicate areas of priority for upcoming clearing operations.

Beyond the technical mapping, the study shows that landmine exposure has serious negative effects on the environment. Critical implications include fragmentation of habitat, limited vegetation recovery, and agricultural land abandonment. These results highlight the fact that landmine contamination is a serious environmental problem that disturbs local ecosystems and impedes land recovery in areas that have experienced conflict, in addition to being a humanitarian and safety concern.

The spatial data and maps that are produced are crucial decision-support resources for politicians, environmental planners, and mining action authorities. To achieve humanitarian demining requirements, such those specified in the International Mine Action requirements (IMAS), they need be complemented with ground verification and cutting-edge detection technology, even though they improve operating efficiency and help prioritise clearance.

In the future, it is advised to incorporate remote sensing methods like vegetation indices (such the NDVI) and land cover change detection to enhance environmental analysis. Informed recovery plans, sustainable land use planning, and ecological restoration will all benefit from this. Ultimately, in areas like Maidan, where the effects of conflict continue to influence environmental and human security, GIS-based environmental assessment offers a strong foundation for addressing the long-term effects of landmine contamination.

Author Contributions

The study was conceived by the corresponding author, who also developed all of the figures and acquired data from the Kurdistan Regional Government (KRG) of Iraq's Mine Action Agency (MAA). The second author helped by making the tables and offering recommended sources. The third author was in charge of translating the Kurdish references and proofreading the work.

Acknowledgements

The data for the Maidan sub-districts were gained from the Directorate General of Garmian Mines Affairs. Their support and contribution are greatly appreciated.

Declarations

The authors declare that no funding was received for the conduct of this study.

Competing Interests

The authors declare no competing interests.

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JSH p-ISSN: 1813-0852, e-ISSN: 2617-3034