GIS-BASED REAL-TIME GAS LEAK DETECTION SYSTEM AT BASKENT NATURAL GAS DISTRIBUTION COMPANY

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ABSTRACT:

Natural gas has been used for heating and production purposes in Turkey since 1987, and every passing year, the natural gas pipeline network continues to expand with investments. The distribution of natural gas within urban areas is achieved through a complex network structure formed by the joining of Polyethylene (PE) and Steel (ST) pipes using various connection elements. This complex structure is susceptible to deformation over time due to various reasons such as corrosion in steel lines, manufacturing errors in connection elements in PE lines, and other factors. As a result, natural gas leaks occasionally occur in these pipelines. The leakage control process in natural gas pipelines is carried out using specially designed equipment and vehicles equipped for this purpose. However, while these systems may be sufficient for collecting the necessary data for leak detection, the complex structure of the distribution network and the necessary data for leak detection, the complex structure of the distribution network and the necessity of performing this process with multiple teams bring about many challenges in terms of tracking, management, and reliability of the operation. At this point, the advancement of GIS (Geographic Information System), mobile, and communication technologies has made it possible to overcome these challenges. In this study, a real-time GIS-supported leak detection system developed using these technologies for Başkent Natural Gas Distrubition Inc. (Başkentgaz), which provides natural gas distribution services in Ankara, has been described. The study discusses the benefits brought by this system to the natural gas leak detection process.

1. INTRODUCTION

As of the 2020 data, the length of the pipeline within the natural gas distribution system reached 169.000 kilometers, and the natural gas consumption amounted to 47.7 billion m^3 (Uçar, 2021). In 1988i Ankara transitioned to the use of natural gas to address air pollution concerns due to its geographical location and weather conditions. Today, with a natural gas distribution network covering nearly 16.000 kilometers, Ankara is the second-largest city in Turkey in terms of the natural gas distribution network. As of the year 2023, natural gas is used for heating and production purposes in over 2 million households, with an annual consumption of approximately 4 billion m^3. At Başkentgaz, where a significant portion of daily operations is comprised of field operation, by Article 60 of the Natural Gas Market Distribution and Customer Services Regulation, leak detection for potential safety hazards and the necessary precautions are taken by conducting leak checks on natural gas distribution lines at intervals of less than six months. This process is carried out using specially equipped vehicles with equipment specifically designed for this purpose, in compliance with relevant regulations and standards (EPDK, 2022).

With the advancement of information technologies, geospatial technologies supported by GIS have begun to play a more effective role in the real-time management of field applications (Ozdilek and Seker, 2004). Especially during projects conducted with multiple teams in different locations, the real-time collection of location-based data, management of teams, quick analysis of collected data, and utilization of this information in decision support stages can be carried out much more efficiently and effectively through GIS-supported technologies. The main elements crucial in applications developed to ensure the real-time management of field applications using GIS-supported technologies are outlined below;

1. Mobile Wireless Network Performance
2. Mobile Devices Performance
3. Mobile Operating System
4. GPS/GNSS Accuracy
5. Open Map Data
6. Open Source Map Libraries

The widespread coverage and increase of mobile internet have enabled the rapid and uninterrupted transmission of large-scale data to central servers. GIS-based applications require efficient rendering of map data; therefore, the device on which the application runs should have the speed and capacity to perform this task, ensuring the healthy operation of the system. The operating system on the mobile device being used should provide a suitable environment for application development and be widely accepted by a broad developer community, as this is essential for application continuity and diversity. GIS-based field applications require location information about the working area and teams. Therefore, the developed applications and hardware must integrate with GPS/GNSS systems. Field operations require data to function effectively. The updating of map-based data for cities involves challenges in terms of both cost and time. In this context, openly available map-based data serves to overcome these challenges. To ensure the seamless and healthy operation of all these systems together, application developers require developer libraries and software with these capabilities. These libraries and software, developed with open-source GIS capabilities (such as PostGIS, OpenLayers, Leaflet, uDig, GeoExt, etc.) are frequently used today and meet needs arising during the development of GIS-supported field applications (Ajwaliya et al., 2017.). In addition to technological elements, system integration, device management, maintenance, and support are crucial factors for the effective utilization of mobile solutions (Wang et al., 2006).

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In the process of leak detection in natural gas pipelines, especially in cities with complex natural gas distribution networks like Ankara, leveraging information technologies becomes inevitable. At the same time, the comprehensive coverage of the leak detection process across the entire city, its execution with multiple teams, and the evaluation of actions taken at points where leaks are detected directly make the study a subject of GIS. The leak detection process can be carried out in various ways based on the need, using tools specifically developed for this purpose. When researching the methods used for leak detection, it is observed that they are classified under three main categories, comprising a total of 12 different methods. (Murvay and Silea, 2012).

1. Externally based methods
   a. Acoustic sensors
   b. Fibre optic sensing cable
   c. Vapor sensing tube
   d. Liquid sensing tube
   e. Optical
2. Visual/Inspection methods
   a. Human/trained dog
   b. UAVs/Drones/Robots
3. Internally/Computational-based methods
   a. Balancing systems
   b. Real-time fani modeling
   c. Pressure/flow monitoring
   d. Negative pressure wave
   e. Statistical analysis

At Başkentgaz, the PMD (Portable Methane Detector) device is used which is produced by Sensit Company and classified by the "Optical Method" category. The PMD device detects gas using Infrared (IR) Absorption Spectroscopy combined with an electronic narrowband filter. This technology utilizes an infrared light source that changes when certain gases absorb light. The filter allows only specific light wavelengths to be monitored and measured. The concentration of the gas is proportional to the amount of specific IR light absorbed and is displayed as PPM (Part Per Billion), %LEL (Lower Explosion Limit), and/or %Vol (Gas Volume Percentage) ("SENSIT® PMD," n.d.). The scanning process occurs by mounting the device on a vehicle, which travels at approximately 20 km/h through streets where natural gas pipelines pass. During this movement, the device measures the instant methane concentration in the air. The device measures the methane gas concentration in the air in real time using the Filtered Infrared Spectroscopy technique, reporting it in PPM. If the PPM value in the air exceeds a threshold, the device alerts the operator with an audible warning. At the same time, the device can share the obtained values with other devices using Bluetooth technology.

This study focuses on real-time detection of leaks during the leak detection process, tracking of data, and team management stages through Geographic Information System-based field management systems, as well as the benefits of this system.

The purpose of the study;

- Accessing the data from the leak detection device in real time via mobile devices
- Creating a Mobile GIS system
- Creating of Web GIS system
- Tracking of vehicle movements with high-precision GPS/GNSS location data
- Real-time analysis of vehicle movements and instant sharing of scanned/to-be scanned locations with the entire working team

Benefits of the study;

- Increased efficiency in team management
- More accurate detection of leaks
- Improved analysis of leak results
- Reduction in scanning costs
- Increased speed of decision-making with real-time data

2. METHODOLOGY

2.1 Study Area

The study area covers 13 districts within the boundaries of Ankara city. The information regarding the lines to be scanned for the years 2020-2023 is specified in the table below.

Network Info	2020	2021	2022
Study Area (km^2)	5.077	5.238	5.412
Pipeline Length (km)	12.991,80	13.840.09	14.902.41
ST Pipeline Lentgh (km)	1.879,70	1.909,98	2.002
PE Pipeline Length (km)	6.947,78	7.609,82	8.374
Service Pipeline (km)	4.164,32	4.320,29	4.526

Table 1. Pipeline length to be scanned by year

2.2 Installation of Sensit PMD Device

The process occurs while the vehicle is in motion, where air is sent to the device through pumps mounted in front of the vehicle at a height of 5-10 cm above the ground. The device analyzes the air, calculates the methane gas information in PPM, and communicates it to the operator.

Figure 1. Leak detection vehicle

Since the system operates on the principle of air pumping, it does not work in rainy weather and areas with water accumulation. In the study, the leak threshold value is set at 5 PPM, and the vehicle speed limit is determined to be 20 km/h. A scanning team consists of two individuals: the vehicle driver and the monitoring operator.

In areas where the vehicle cannot enter but the operator deems scanning necessary, the operator exits the vehicle and manually

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conducts the scan using devices developed for this purpose. Such applications are often needed during the scanning of service lines.

2.3 Integration of Mobile Device

Inside the vehicle, there is also a tablet with an Android operating system to guide the operator. We aim these with this tablet,

- Collecting PPM values (Bluetooth)
- Gathering vehicle location information (GPS/GNSS)
- Showing the operator, the natural gas lines to be scanned and the ones already scanned

Figure 2. Interior view of the vehicle

In the study, a tablet (Hi-Target QPad X5) supported by the NTRIP (Networked Transport of RTCM via Internet Protocol) protocol was used to ensure high accuracy and reliability in GNSS-based precise positioning system applications. The tablet transmits GNSS signals to the NTRIP server, receiving real-time differential corrections to enhance location accuracy. It particularly demonstrates high performance in geographic data collection processes.

There are four basic criteria for GNSS performance, Accuracy, integrity, continuity ve availability (Zhu et al., 2018). The vehicle continuously collects high-precision location information while moving at low speed through GNSS receivers. During this process, although GNSS receivers attempt to correct errors caused by atmospheric effects and signal path, in some cases, precision may be compromised. During low-speed navigation, a program operating in a network-connected office environment examines the collected location data to identify points where precision is compromised. At these points, errors arising from factors such as weakening of GNSS signals or reflections are detected.

2.4 Data Collection and Communication Processes

To determine the geographical locations of detected leaks, a dataset is created by synchronizing the PPM values sent via bluetooth from the detector device with high-precision GNSS coordinate data. This dataset is transmitted in real-time to central servers through web services.

Inside of dataset;

- Coordinates (X, Y)
- Speed
- PPM Value
- Accuracy

The data transmission is managed through APN (Access Point Name) configurations over a 3G/4G connection. In this context, data transmission occurring through the tablet is ensured depending on the proper configuration of APN protocols, allowing for secure and fast data transmission.

2.5 Development of Mobile and Web-Based GIS Applications

In this study, a mobile-based GIS application has been developed using the Leaflet library to effectively manage field operations. "Leaflet is an open-source map library developed with the well-known JavaScript language, known for its lightweight structure and user-friendly design. It is preferred, especially for mobile devices, due to its high performance (Leaflet Development Team, n.d.). The mobile application includes features such as positioning field teams, data collection, and real-time updates to optimize field operations.

Simultaneously, a web-based GIS application has been developed using the OpenLayers library for managing teams in the office environment and effectively reporting the obtained data. OpenLayers is an open-source map library developed with the well-known JavaScript language, known for its rich map features and flexibility (OpenLayers Development Team, n.d.). This web application has been customized and integrated using open-source software development libraries. Open-source libraries have accelerated the application development process and increased the sustainability of the project by reducing costs.

Additionally, Geoserver has been used to provide geographic data services. Geoserver is an open-source geographic data service server developed in the Java programming language, supporting standard geographic data formats (Geoserver Development Team, n.d.). This service has enabled mobile and web applications to access geographic data quickly and reliably. Thus, data management in both field operations and office environments has been integrated seamlessly.

The contribution of geographic data within internet resources continues to increase, thanks to map data providers like OpenStreetMap and Google Maps (Król, 2020). In this study, the use of OpenStreetMap (OSM) as a basemap emerges as a significant component in GIS applications. OpenStreetMap is an open-source map service created, edited, and continuously updated by volunteer contributors worldwide. In our research, the detailed and up-to-date geographic data provided by OpenStreetMap enabled us to manage field operations more effectively (OpenStreetMap Development Team, n.d.).

As web-based GIS technology advances, this two-way approach aims to maximize the power of Geographic Information Systems by combining real-time management of field operations with strategic decision-making in the office environment.

2.6 Database Selection and Design

The need for a spatial database has arisen to store and analyze the geographic data collected in the study. The planned database is expected to be capable of storing point, line, and polygon geometry data, have robust spatial analysis capabilities (such as buffer, intersect, touch, etc.), and efficiently query large-sized vector data. In this context, it has been observed that there are multiple databases with both open-source and commercial spatial data processing features. (Li and Zhou, 2009).

Some of these databases include;

- IBM DB2 (Commercial)
- Oracle Spatial (Commercial)
- PostgreSQL (Open Source)
- MySQL Spatial (Open Source)

The study examined the performance of the mentioned databases in operations under functions such as 'St_touches', 'St_Within', 'St_Overlaps', 'ST_Distance', 'St_Intersection', 'St_Buffer', 'St_Centroid', 'St_Area'. It was observed that open-source databases, especially in 'ST_Touches', 'St_Within', and 'St_Area' functions, outperformed, while the Oracle Spatial database, a commercial software, was found to achieve a comparable performance level.

Due to the current GIS system running on Oracle and its sufficient performance for the desired analyses, the Oracle 11g version has been used as the central database for storing, analyzing, and serving the data collected in the field. Spatial data is stored in the 'SDO_GEOMETRY' data type in point, line, and polygon formats (Oracle Development Team, n.d.).

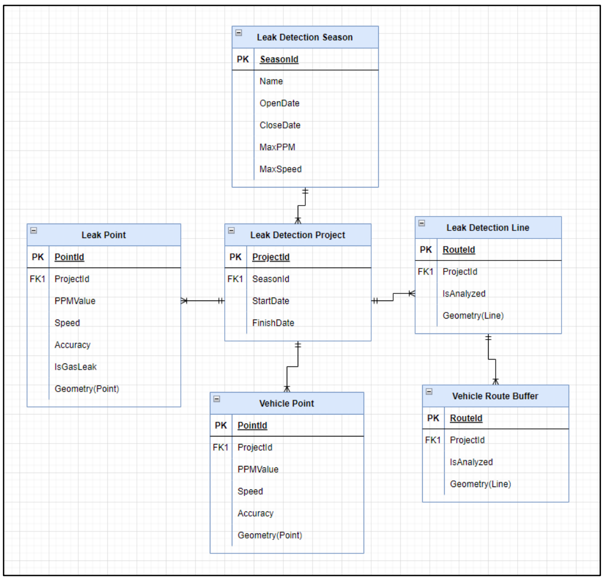

Figure 3. Database diagram

The data collected during the leak detection process has been stored in the following tables;

Leak Detection Season is used to keep track of which period the conducted scanning processes belong to.

The leak Detection Project is used to track when the operator started and finished a scanning process.

Vehicle Point is used to store the location and speed information of the vehicle along with PPM values during a leak detection project.

Leak Point is used to store information about points where detections above the specified PPM value are made during a leak detection project.

Leak Detection Line is used to store the route data generated from the collected coordinate information within the scope of the project when a leak detection project is closed.

Leak Detection Buffer is the table where the vehicle route information with buffer analysis applied to identify scanned and non-scanned lines is stored.

2.7 Analysis of Scanned Lines

The goal of the study is to track the streets where scanning is performed by teams and individuals working both in the office and in the field simultaneously. Therefore, the aim is to extract the vehicle movement trace from the coordinate data collected during the scanning process. The accurate extraction of the vehicle trace depends on collecting GPS data with high accuracy and precision. Especially in large cities and due to the way, this study is conducted, several factors affect the accuracy of GPS coordinate data, and consequently, the accuracy of vehicle speed;

- GPS antenna location
- Number and position of visible satellites
- Height of structures in the area
- Vehicle speed
- Weather conditions
- Signal jammers in the working area

The process of extracting the vehicle trace is calculated in real time by the mobile GIS software. Once the operator initiates the leak detection process, the mobile GIS software starts collecting vehicle coordinate information. The received coordinate information is examined in real-time, and erroneous data caused by the factors mentioned above is identified. Erroneous coordinate information is subtracted from the calculation to obtain a more accurate tracking.

Upon completion of the operator's scanning process, the vehicle trace containing corrected and verified coordinate information is recorded in the central database through web services. This process enables real-time monitoring and data recording functionality. Furthermore, the information stored in the central database can be utilized for subsequent analyses, reporting, or monitoring requirements.

When extracting the vehicle track from the collected vehicle coordinate information, the more coordinate data used, the more detailed the vehicle track becomes. However, the number of points used also affects the size of the stored data and the performance during queries. Therefore, to achieve the desired level of detail without sacrificing performance, Oracle's 'SIMPLIFY' method was used when creating the vehicle track from coordinate information (Oracle Development Team, n.d.). This method simplifies coordinate data by eliminating unnecessary details, reducing data size, and providing faster and more efficient performance in query operations.

The aim is to visualize scanned and unsupervised pipelines on the Web GIS system using the scan trace of vehicles and to effectively manage team operations. This process is facilitated through software that operates with a task logic via the server. The software completes scanning processes at intervals determined by the administrator (e.g., every 5 minutes) and applies buffer analysis for recorded vehicle traces that have completed scanning, storing the generated buffer objects to record the vehicle's domain on the web GIS. After this process, the buffer objects created are examined using the spatial intersection method to detect existing and non-existing natural gas pipelines.

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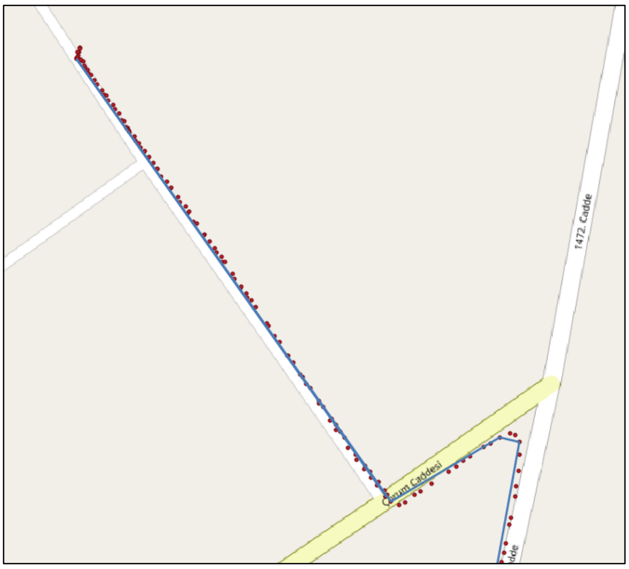

Figure 4. Line created with simple method

Figure 5. Buffer analysis results

2.8 Detection of Leaks

Before initiating the leak detection process, the relevant administrative system in the Web GIS software creates a period record to associate leak scans with a specific time frame. During this period record, the following information, to be used during the leak detection process, is entered into the system:

Season Name is the field where a specific name is assigned to define the period of the leak detection process. This name is used to identify and distinguish the relevant period.

The Threshold PPM Value is the upper limit value set for the system to issue a warning in case of leak detection.

The Maximum Vehicle Speed is the information specifying the maximum speed limit for the vehicles to be used in the leak detection process. This information enables operators to conduct field operations within a specified speed range and contributes to obtaining accurate coordinate and PPM (parts per million) data.

When the operator initiates the leak detection process, the system calculates the vehicle speed in real-time from GPS data and simultaneously monitors the amount of methane gas in the air in parts per million (PPM) through a bluetooth connection from the detector device. If the operator exceeds the speed limit set by the administrator, the system sends a warning to the operator. Additionally, if the PPM value exceeds a specified threshold, the system displays a pop-up screen to the operator and issues an audible warning. At this stage, the operator investigates the area where the PPM value was detected, and if necessary, performs manual inspections using handheld scanning devices in the scanning area. In cases where the operator concludes that the detected PPM value indicates a leak, the system records the message as a leak. This record is stored in the central database via web services and is communicated as a message to the maintenance and repair teams' ERP systems.

The detector device measures the amount of methane gas in the air in parts per million (PPM), and the methane gas in the air can originate not only from natural gas but also from biological sources such as sewage, garbage, etc. Therefore, each alert message is not automatically considered as a leak. The sources of generated alert messages are examined, and messages arising from biological causes are manually closed under the operator's control.

3. RESULTS

With the integrated system in place, natural gas distribution lines passing through the streets within the Ankara province have been scanned a total of 9 times between the years 2020 and 2023. In 2020, there were 2 scanning periods, while in 2021 and 2022, there were 3 periods each, and in 2023, there was 1 period. During each scan, more than 70% of the distribution lines were successfully scanned using this system. The lines that could not be scanned were mostly in areas where vehicle passage was not possible (such as fields, pedestrian paths, etc.).

Season	Scanned (km)	Not Scanned (km)	Percentage (%)
2020 Season – 1	6.824,30	4.185,50	62%
2020 Season – 2	6.806,73	766,19	90%
2021 Season – 1	7.400,88	1.724,95	81%
2021 Season – 2	7.267,63	1.844,39	80%
2021 Season – 3	7.235,78	3.453,42	68%
2022 Season – 1	7.680,73	3.026,76	72%
2022 Season – 2	7.868,58	2.856,00	73%
2022 Season – 3	8.210,49	2.817,12	74%
2023 Season – 1	2.683,93	8.337,03	76%

Table 2. Periodic scanned results

In each scan, locations where the PPM Alert value exceeded during the respective period were identified, and it was observed that a certain portion of these was related to natural gas leaks.

Season	Leak Count (All)	Leak Count (Ch4)	Leak Count Other (Bio)
2020 Season – 1	2907	46	2861
2020 Season – 2	4842	105	4737
2021 Season – 1	12609	505	12104
2021 Season – 2	5185	96	5089
2021 Season – 3	3861	106	3755
2022 Season – 1	4985	204	4781
2022 Season – 2	8836	163	8673
2022 Season – 3	7339	153	7186
2023 Season – 1	10594	107	10487

Table 3. Periodic leak detection results

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A distribution chart of leaks found during each scanning period has been generated based on districts. Upon examination of this chart, it is observed that there is varying intensity of leaks in different districts during different scanning periods.

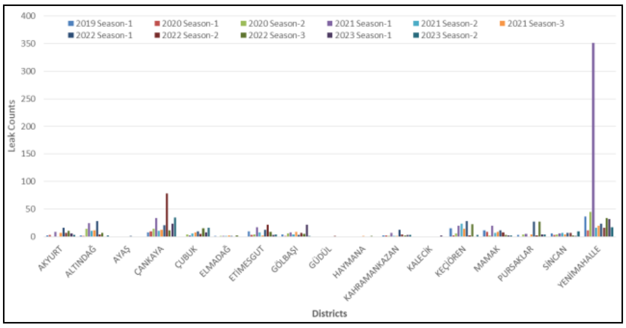

Figure 6. Leak counts distribution by districts

Especially in the 2021 1st Season scan, it was observed that the leaks in the Yenimahalle district were above the average. As a result of the neighborhood-based analysis conducted for the relevant season, the conclusion indicated in the graph below was reached, showing that leaks were predominantly detected in the Uğur Mumcu, Turgut Özal, Kardelen, and İlkyerleşim neighborhoods.

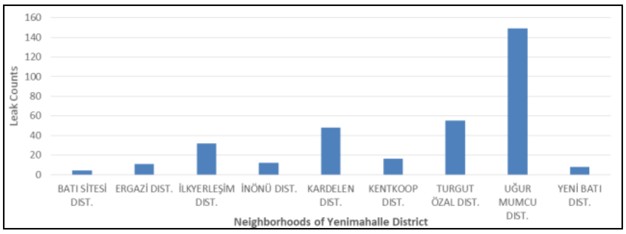

Figure 7. 2021 Sezon – 1 scanning leakage table for Yenimahalle district

The ages of the pipelines at the points where leaks were detected were investigated using the Nearest Geographic Analysis method. During the investigation, the main pipelines closest to the points where leaks were detected were identified. The identified pipelines were categorized based on their age and examined accordingly.

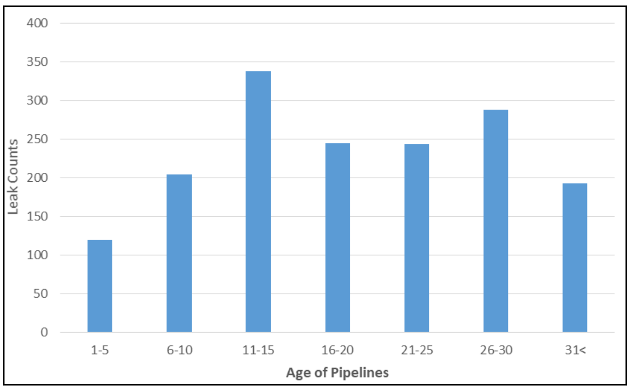

Figure 8. Number of leaks based on age range

As a result of the study, a linear relationship was observed between the age progression of the pipelines and the number of detected leakage points. The study was also conducted on the connection between the density of gas-consuming units at locations with leaks. In this context, a density heat map was created based on the number of units in the city's buildings. The detected leakage points were then combined with the created heat map to generate the thematic map below.

The points turning red on the created map indicate areas with high population density. As seen on the map, it has been observed that there is no linear relationship between the points with high leakage density and population density.

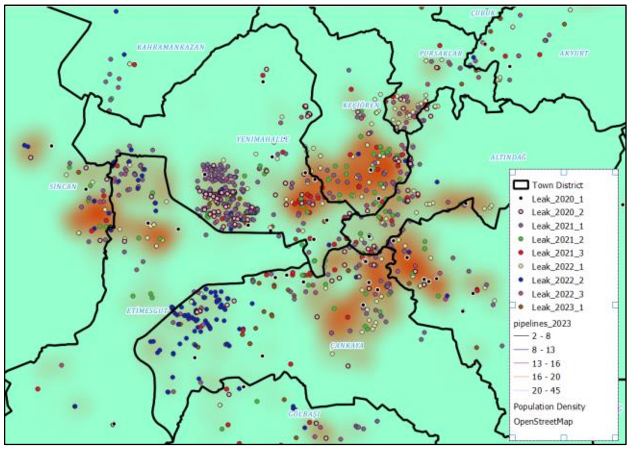

Figure 9. Leak density heat map

The distances from 886 points where leakage was detected with the vehicle to the nearest natural gas pipelines were calculated using the 'Nearest' geographic analysis method. The average distance from the leakage points to the natural gas pipelines was determined to be 4.6 meters.

The GPS accuracies of the detected leakage points were separately examined for manual scanning and vehicle-based scanning processes, and the following graphical table was created.

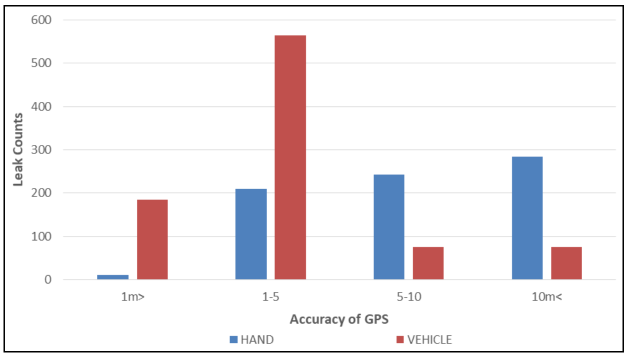

Figure 10. GPS accuracy for leakage point

When examining the table, it is observed that GPS data in vehicle-based scanning operations achieved a precision of 5 meters and below. However, for manual scanning operations, high-precision values could not be obtained. Manual scanning operations were mainly used for leakage scans in service lines in the study, and it was found that the accuracy was compromised due to the proximity of the working areas to buildings.

As can be seen in the example information in the above image, using high-precision GPS for street scans in leak detection processes, despite being adversely affected by reflection effects, weather conditions, GPS placement inside the vehicle, and signal jammers, provided sufficient accuracy in the study. When examining manual leak detection operations, it was observed that the location accuracy was significantly affected by the reflection effects caused by buildings, and sufficient benefit could not be achieved.

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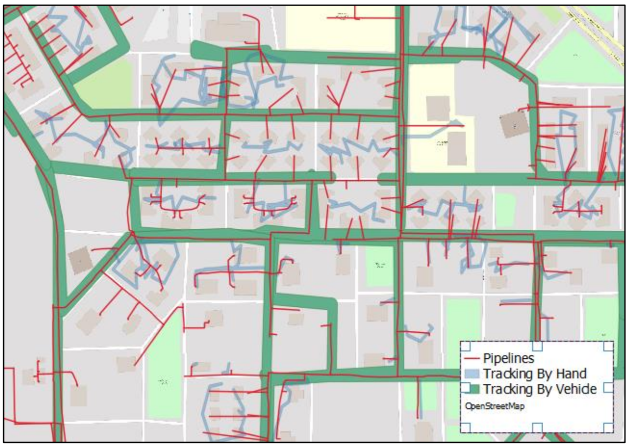

Figure 2. Comparison of manual and vehicle scanning

4. DISCUSSIONS AND CONCLUSIONS

In this study, the real-time leak detection system developed for Başkentgaz, supported by GIS, was examined. Various geographic analysis techniques were applied to the data collected between 2020 and 2023, and the results were evaluated regarding the advantages and challenges of the system. The study examined the following aspects:

- Number of detected leaks
- Amount of scanned pipelines
- Comprasion of leakage points based on districts and neighborhoods
- Population density around leakage points
- Ages of the pipelines where leaks were detected
- GPS accuracy during vehicle and manual scanning operations

When the results were examined in terms of the number of detected leaks and the number of scanned pipelines, it was observed that despite an increase in the number of scanned pipelines from the year 2021 onwards, there was a decrease in the number of detected leaks. It is believed that the system has an impact on reducing the number of leaks.

When the numbers of leakage points were compared based on districts and neighborhoods, it was observed that leaks were more densely detected in the Yenimahalle District, Uğur Mumcu neighborhood, compared to other areas. The reasons for this were found to be related to most leaks in this area being at service valve connections, the age of the pipelines being 20 years and older, and the intense individual house construction in the region, allowing residents to intervene in service lines. When evaluated in terms of GPS accuracy in the study, especially for scanning operations conducted on the streets:

- Movement of the vehicle
- Placement of the GPS device inside the vehicle
- Factors affecting the quality of GPS signal in the working area

Despite factors that could negatively affect the GPS accuracy, a precision of 5 meters and below was achieved, and it was found that this accuracy is sufficient for the results of the study. In this study, the integrated structure of the tablet and GPS antenna necessitated the use of the GPS device inside the vehicle. It is considered that a hardware setup with the GPS antenna outside could achieve higher accuracy.

However, in manual scanning operations, due to the proximity to buildings, the desired level of accuracy could not be achieved. Therefore, accurate results could not be obtained from GIS analyses conducted with these data. Research in this area has indicated that multi-story structures play a more significant role in GPS data accuracy compared to other factors. (Merry and Bettinger, 2019).

When examining articles on the subject, it was observed that in a sample study, the focus was on the real-time GIS leak detection system architecture and the gas distribution model at the leakage points (Li et al., 2015). In a study conducted in Boston, it was indicated that leaks occur more frequently in iron pipes that have been in use for over a century (Phillips et al., 2013). In another study conducted in Boston, MA, Staten Island, and NY, the natural gas leak detection process was carried out by attaching high-precision methane analysis equipment to Google Street View vehicles. In this study, it was determined that leaks were more frequently detected, especially in lines prone to corrosion, such as steel pipelines (von Fischer et al., 2017).

When examining the results of the GIS-supported leak detection application study, it was observed that the study particularly facilitated the detection of leakage points, increased efficiency in team management, revealed that leaks predominantly occurred in lines reaching a certain age, and demonstrated successful results, especially in street scanning operations, with the use of high-precision GPS.

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