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THE INFLUENCE OF VARIATIONS BETWEEN TIDE GAUGE AND RTK TIDE DATA ON DREDGING CALCULATIONS IN HYDROGRAPHIC SURVEYS0

Ahmed Ghareeb [(1)i], Eman Hamdan [(2)] and Ahmed Khedr [(3)]

(1) College of Maritime Transport and Technology, Arab Academy for Science, Technology and Maritime Transport, P.O. Box: 21937, Abu-Qir, Alexandria, Egypt, Ahmed.ghareeb14@gmail.com

(2) Marine Engineering Technology Department, Arab Academy for Science, Technology and Maritime Transport, P.O. Box: 21937, Abu-Qir, Alexandria, Egypt, eman_youssef@aast.edu

(3) College of Maritime Transport and Technology, Arab Academy for Science, Technology and Maritime Transport, P.O. Box: 21937, Abu-Qir, Alexandria, Egypt, akhedr@aast.edu

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ABSTRACT: This paper explores the impact of discrepancies between Tide Gauge and RTK (Real-Time Kinematic) Tide information on dredging computations in hydrographic surveys. The research focuses on cases where an average discrepancy of 10 cm exists between the two tide measurement sources. There are differences of 0.037 cm between them at a distance of 1 km from the base station, and these differences quickly increase as we sail further away from the base station, exceeding our expectations by about 0.139 cm at a distance of 10 km. The study aims to highlight how an average of 10 cm difference between Tide Gauge and RTK Tide measurements affects the accuracy of dredging computations. The results shed light on how such discrepancies can impact the accuracy and reliability of dredging computations, influencing navigational safety and operational efficiency in maritime settings. The research underscores the necessity of minimizing these discrepancies and proposes potential strategies to mitigate their influence on dredging computations. The study contributes significant insights for improving the accuracy of dredging calculations and enhancing navigational safety and operational efficiency in maritime settings.

1. INTRODUCTION

The global surge in maritime trade, spurred by advancements in transportation technology, globalization, and international trade growth, has prompted significant investments in maritime infrastructure worldwide. Dredging, a crucial activity for maintaining and enhancing maritime infrastructure, involves the removal of sediment to create deeper channels, accommodating larger vessels amidst rising shipping demands. Hydrographic surveying, essential for harbors' planning, relies on accurate pre- and post-bathymetric data to quantify dredged material. Tide, influenced by gravitational forces from celestial bodies, plays a pivotal role, with the Lowest Astronomical Tide (LAT) serving as a benchmark for mariners and surveyors. Over the past two decades, Global positioning system (GPS) technology, particularly Real-Time kinematics (RTK), has revolutionized hydrography. RTK's precise X, Y, and Z coordinates, with less than 2 cm precision, offer advantages in vertical positioning. This paper explores the applicability of GPS in RTK mode for tide measurements, following International Hydrographic Organization (IHO) standards, as an alternative to Auto Tide Gauge (ATG). An experiment in the Suez Canal duplication project compares RTK and ATG methods, evaluating their accuracy in measuring tide during dredging activities. Two experiments in the study area location, one at 1 km and another at 10 km from the base station as shown in Figure 1, utilizing Multibeam echo systems and tide gauges, aim to assess RTK's potential as an accredited method for tidal measurements. Mathematical analysis will be employed to gauge the accuracy of the collected tidal data, providing insights into the effectiveness of RTK tide measurement in maritime applications. Hydrographic surveys serve as a fundamental tool in estimating dredging requirements, evaluating compensation for dredging contractors, overseeing offshore disposal zones, and verifying a project's clearance to its designated navigable depth. The conventional method for acquiring depth data involves employing a single-beam echo sounder (SBES) in conjunction with Global Positioning System (GPS) positioning, particularly in DGPS (Differential Global Positioning System) and RTK modes. The RTK mode, as highlighted by M. Rabah (2009), facilitates precise height determination during soundings, ensuring survey accuracy without relying on the water surface as a reference.

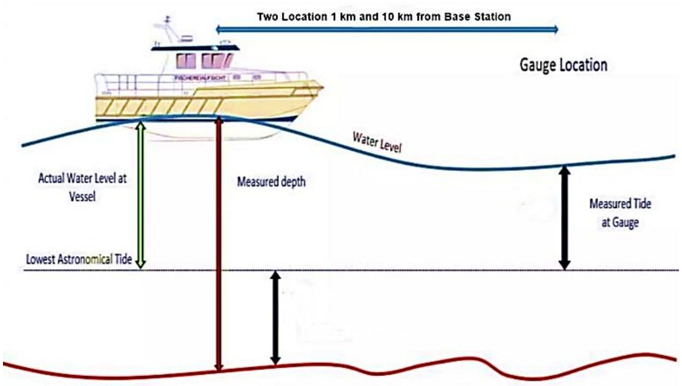

Figure 1 : Two experiments in the study area location as shown one at 1 km and another at 10 km from the base station.

The repercussions of uncertainties in hydrographic surveys are especially notable in stone placement operations, where inaccuracies may occur. Misjudgments in dredged quantities can impact the overall cost of dredging operations. To address the need for enhanced precision, motion sensor equipment has become a standard practice in an expanding array of port and harbor surveys, as noted in FIG Publication No. 56 (2010). Port surveys play a critical role in ensuring unobstructed waterways and maintaining adequate depth for safe navigation. The potential risks posed by insufficiently surveyed water bodies underscore the importance of comprehensive hydrographic data and regularly updated charts for shipping safety. Dredging and underwater excavation are key components in designing and constructing essential harbor infrastructure. Accurate assessments of dredging projects are crucial for determining excavation volumes and evaluating material characteristics, influencing decisions regarding equipment, production schedules, timelines, and overall project expenses, as emphasized by A. El-Hattab (2014).

Hydrographic surveying, employing various methodologies and tools, remains the primary means for creating detailed underwater topography maps across oceans, lakes, rivers, ports, and other aquatic bodies. Its systematic mapping of water areas is integral to maritime endeavors throughout project stages, including planning, data acquisition, design, construction, operational phases, and maintenance. The principal goal of hydrographic surveys is to collect essential data for nautical charts, emphasizing elements crucial for safe navigation, while also serving diverse purposes such as supporting marine navigation tools, coastal management initiatives, engineering projects, and scientific investigations, according to FIG Publication No. 56 (2010).

2. DATA AND METHODS OF ANALYSIS

2.1. Location and Data Collection

The study was conducted within the region designated for the Suez Canal Duplication project, spanning from kilometer 122.000 to kilometer 132.000 in 2022, depicted in Figure 2. Regular Multibeam surveys were carried out daily to oversee the progress of dredging activities. Specifically, two specific surveyed zones were chosen to compare the differences in tide values obtained from RTK and tide gauge measurements.

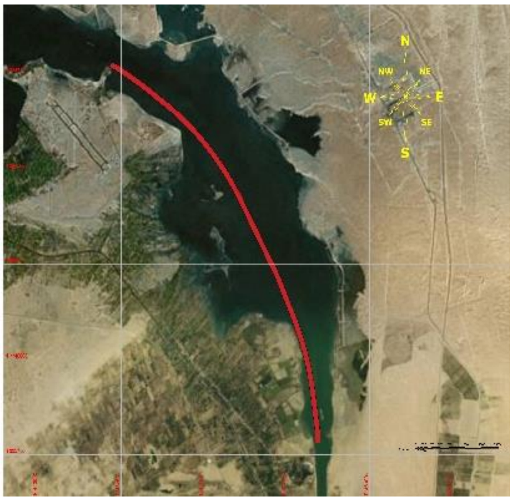

Figure 2 : Displays exactly where the study is located in Suez Canal from KP 122 to KP 132, Egypt, Google Earth.

2.2. Survey Boat Equipment and Calibration.

2.2.1 Multibeam installation and Calibration

The depth data for the study were acquired using a Multibeam Teledyne T20 echo sounder situated on a moon pole. Utilizing a Multibeam echo sounder offers a significant advantage by providing comprehensive coverage of the entire water bottom, enhancing the accuracy of seafloor knowledge, and facilitating the detection of all submerged objects, including areas designated for dredging. The MBES model 'T20' was specifically employed in this case, and position information, along with vessel motion calibration, was carried out through Applanix's POS MV system. Furthermore, the position information (x, y, z) was received at a rate of 4Hz using a LAN (Local Area Network) cable using the Real-Time Kinematic (RTK) principle. The collected data were classified and analyzed for consistency along each surveying line. The Patch Test was conducted once the survey boat was fully mobilized and configured. It was carried out in the field by the survey crew onboard the vessel immediately after completion. The outcomes of the Patch Test were compared to previous results to identify any potential issues with the survey system. These results were then recalculated during data processing and incorporated into the survey data. Following the delineation of three profile boxes in the Multibeam Area Editing – Standard view, the Multibeam Calibration appeared as described in Figure 3.

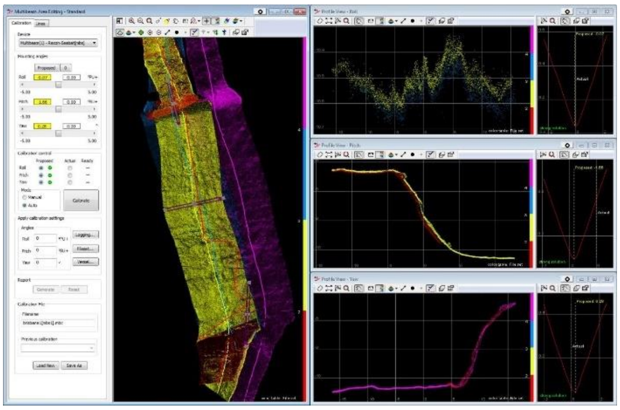

Figure 3 : Displays patch test Calibration and results, PDS 2000.

2.2.2 Base Station Positioning System

Establishing a GPS base station involves the installation of a reference point equipped with a GPS receiver. This station serves as a stable and well-known location linked to an external radio, transmitting corrections over a Radio Antenna at a baud rate of 9600. It functions as a point of reference for other GPS receivers or rovers to determine their positions accurately. The procedure includes placing the GPS receiver at a specific geographic location with known Easting, Northing, and Elevation, often using pre-known coordinates, and allowing it to collect satellite data for precise position determination. Following this, the base station transmits correction signals to nearby GPS rovers, thereby improving the accuracy of their location calculations.

2.2.2.1 Vertical offset calibration

Validating measurements is crucial, regardless of the method employed to determine vertical offsets, whether it involves using a tape measure or other means. The calibration of vertical offsets for a survey boat's Global Navigation Satellite System (GNSS) can be accomplished by positioning the vessel close to an Auto Tide Gauge (ATG). The Real-Time Kinematics (RTK) tide values in the acquisition software should align with the tide values obtained from the ATG. This calibration process enables the assessment of the positioning technique and the fine-tuning of the vertical offset of the antenna. Any discrepancies between the GNSS water level and the gauge water level, considering the latter as the "truth," may be attributed to various factors, including:

1. Error in base station height,
2. Error in vessel antenna Z-offset,
3. Error in draft,
4. Error in the separation model (Olsson, 2009).

2.2.3 Tide Gauge Measurements

A self-contained VALEPORT740 tide-gauge is proposed because it is often easily installed at a suitable jetty location and tied into the Jetty (vertical) Datum (JD). The tide gauge was adjusted to record, at 10-minute intervals, the relative site Benchmark. The tide gauge was installed in a safe location Figure 4 so that the data were not compromised by third-party interference. The system comprises a logging and control housing connected via an influence and data cable, to the pressure transducer. The transducer was fixed and mounted on the jetty face and leveling was surveyed to be connected with one of the control points by Trimble SPS985.

Figure 4 : Displays Tide Gauge Location, Google Earth.

2.2.4 Software

a) The Multibeam data obtained were collected and processed using the PDS software.

b) MATLAB and Microsoft Excel were used for statistical analysis and correlation

c) AutoCAD and Google Earth software were used for drawings.

2.3. Data Processing

Through PDS2000, the Multibeam data can be subjected to various processing steps, including cleaning, and filtering as shown in Figure 5. The software allows to correction of factors such as sensor offsets, motion-induced errors, and sound velocity variations in the water column, ensuring the accuracy of the final bathymetric dataset. After each day of acquisition, Tide gauge data and GPS RTK tide data were downloaded from ATG and PDS logging files, respectively. After all of the fieldwork had been finished, the MATLAB and Microsoft Excel program were used to compare the tide gauge and RTK data to find Correlation data collection.

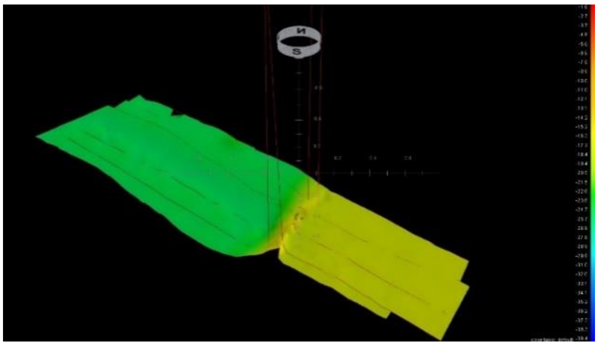

Figure 5: The processing of Hydrographic survey data, PDS 2000.

2.4. Data Analysis

Data analysis aims to show the difference between observed RTK tide values and observed Tide Gauge values and their effect on the dredging quantity. Based on RTK Tide values that were calculated by RTK GPS the data was exported from bathymetric software every 10 min, also tide gauge data was downloaded from the installed tide gauge nearshore every 10 min. The tide values are measured by both the tide gauge and RTK for two locations the first one is 1km and the second one is 10 km away from the base station. To properly define the relationship between each of the tide reduction techniques, the two data sets were utilized throughout the analysis process. The survey was completed for DTM (Digital Terrain Model) production with an additional QA (Quality Assurance) survey completed as per the mentioned Methodology. The datasets utilized for the analysis can be found below:

- Initial DTM Dataset.
- GPS RTK Tide Dataset.
- Tide Gauge Dataset.

Comparisons between each of the DTM models will be completed by directly comparing the elevations produced at each position by each of the tidal techniques' methods with DTM elevations of the model at the 0.5m spacing x 0.5m. Finally, volume calculations will be evaluated over the four DTMs for each method for additional analysis of accuracy and position.

3. RESULTS

The tides experiment is summarized in Figure 6&7 below. The same graph displays RTK and tide gauge data as per the first experiment 1km distance from the reference base station.

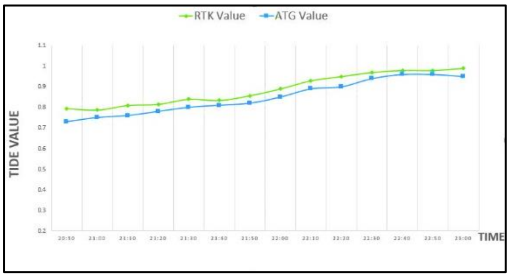

Figure 6 : Comparaison between RTK and tide gauge data distance about 1 km from the base station

Figure 7 : Comparison between RTK and tide gauge data distance about 10 km from the base station

As seen in Figure 6, RTK tide value measurements are proportionally compared to tide gauge measurements. There are differences of 0.037 centimeters between them at a distance of 1 km from the base station, and these differences quickly increase as we sail further away from the base station, exceeding our expectations by about 0.139 centimeters at a distance of 10 km in Figure 7.

3.1. *Statistical Analysis Between RTK Tide and Tide Gauge Values*

1. The mean and standard deviation for RTK with tide gauge data have been compared as shown in Table 1.

Table 1 Compares RTK with tide gauge data for the first experiment 1km

Tide	*N total*	*Mean*	*Minimum value (m)*	*Maximum value (m)*	*Standard deviation*
RTK Tide	14	0.89	0.79	0.99	0.077
Tide gauge	14	0.85	0.73	0.96	0.083

2. The conclusive outcomes and statistical data from the tide experiment, which compares RTK data with tide gauge information for the second 10 km experiment, are presented in Table 2.

Table 2 Compares RTK with tide gauge data for the second experiment 10 km

Tide	*N total*	*Mean*	*Minimum value (m)*	*Maximum value (m)*	*Standard deviation*
RTK Tide	9	0.57	0.52	0.64	0.037
Tide gauge	9	0.43	0.37	0.48	0.035

3.2. *Accuracy in the Reduced Depth.*

The accuracy in the reduced depth measurements plays a crucial role in achieving the primary goal of the hydrographic survey. This goal is to provide consultants with comprehensive information for the creation of bid documents. These documents, in turn, include essential quantity details that aid construction companies in preparing bids for required dredging work. The quantities of dredged works are determined based on the seabed reaching the approved design level. Two key premises were employed in calculating these quantities. Firstly, the impact of tide correction on depth was compared using both RTK tide and tide gauge data when the survey area was near the reference station (1 km). Table 3 presents samples of the height (depth) data from the first surveyed area near the reference station, revealing a marginal 0.05 m difference between the datasets processed using RTK tide and those processed using ATG values. A cross-correlation of 86% was observed between each set of data. Table 4, on the other hand, showcases samples of the height (depth) data from the second surveyed area, located approximately 10 km away from the reference station. This information is vital for evaluating the accuracy of reduced depth measurements under different conditions and distances from the reference point.

Table 3 Compares depths for the first experiment to 1km

East	North	RTK TIDE(m)	ATG(m)	Diff(m)
452802.50	3347642.50	22.99	22.94	-0.05
452803.50	3347642.50	23.00	22.94	-0.06
452804.50	3347642.50	22.98	22.93	-0.05
452800.50	3347643.50	23.00	22.97	-0.03
452801.50	3347643.50	23.02	22.98	-0.04
452802.50	3347643.50	23.02	22.98	-0.04

The Second experiment is made based on using RTK tide and ATG data for depth reduction, while the survey is far from the reference station about 10 km.

Table 4: Compares the depths of the survey are far from the reference station about 10 km

East	North	RTK TIDE (m)	ATG(m)	Diff(m)
457984.5	3341632.5	24.22	24.32	-0.10
457985.5	3341632.5	24.30	24.40	-0.10
457986.5	3341632.5	24.46	24.56	-0.10
457987.5	3341632.5	24.62	24.73	-0.11
457988.5	3341632.5	24.81	24.91	-0.10
457989.5	3341632.5	24.93	25.03	-0.10

The data shows there is about a 0.11 m difference between the data processed using RTK tide and the data processed by ATG values. A cross-correlation was 99 % between every set of data.

3.3. Quantity Computation in the Area of Study

The effectiveness of tide reduction in volume calculation relies on two presumptions:

- The first experiment is done based on using RTK tide and ATG data for depth reduction, while the study area was near to reference station. DTM of data processed by ATG will be a reference surface for volume calculation as it's more suitable than RTK data. The data in Figure 8 shows that there are about 1,473 m³, as the green color in the legend shows the differences between the two data sets from zero to 0.10 cm.

Figure 8: Differential chart illustrating the disparities between RTK tide data and tide gauge data for the first experiment 1 km,PDS2000.

- The second trial involved employing RTK tide and ATG data for depth reduction, with the study area positioned approximately 10 km away from the reference station. The computation of dredged quantities was carried out based on the existing tide correction. The Digital Terrain Model (DTM) derived from data processed by ATG serves as a more suitable reference surface for volume calculation compared to RTK data. Figure 9 illustrates the color-coded disparities ranging between 0.10 cm and 0.20 cm, revealing a substantial difference of approximately 36,991 m³ between the dataset processed using RTK tide values and the one processed using ATG tide values.

Figure 9 : Differential chart illustrating the disparities between RTK tide data and tide gauge data for the second experimental 10 km,PDS 2000.

4. DISCUSSION

- The objective of this study was to assess the appropriateness of employing the RTK tide method in hydrographic surveys for dredging operations. Based on our experimental tests and results, it can be concluded that the primary limitation of RTK technology lies in its range.
- The restriction of ineffective radio-link range and the impact of atmospheric, orbital, and clock errors' effective decorrelation constitute two distinct elements contributing to range limitations. The reference station, constrained by the radio-link range and the experiment of uniform atmospheric effects between the reference and rover, must be positioned at a specific location with precisely known coordinates near the survey area.
- The RTK method depends on transmitting unprocessed measurements from the reference station to the rover through a communication link, typically utilizing a radio operating in the VHF or UHF frequency range, with an effective range limited to line-of-sight (approximately 10 km). The radio link may be lost as the signal traverses the atmosphere, encountering obstacles such as hills and mountains. In such cases, the ambiguities may vanish, causing the solution to shift from fixed to floating. This change in GPS mode, from RTK Fixed to RTK Float, can significantly impact the accuracy of the RTK tide value if not promptly recognized by the hydrographer.
- GPS surveying involves the measurement of disparities in ellipsoidal heights (represented as "h"). To derive heights with practical significance, such as orthometric heights (denoted as "H"), a precise model capturing the separation between the geoid and the ellipsoid—known as the geoid height (N)—is essential. Additionally, GPS surveying efficiently captures ellipsoidal height differences over extensive distances. These aspects can underscore potential issues within the current geoid model or vertical datum, or both.
- Regardless of whether the geoid model incorporates a distortion process, it is advisable for the GPS survey to confirm the alignment between the geoid model and the vertical datum within a specific project area. This verification can be achieved by occupying a minimum of three established stations with known vertical datum height values as part of the GPS survey. If any residual local distortion is identified, it can be addressed during the survey adjustment process.
- It's important to assess how RTK errors escalate with the length of the baseline, taking into account the specific equipment setup. While RTK may be well-suited for initial surveys or those involving contour and detail accuracy within several centimeters, it may not meet the heightened precision demands often necessary for engineering surveys at the one-centimeter level. In such cases, RTK usage should be confined to baselines shorter than a kilometer. Projects spanning over a kilometer may necessitate the deployment of multiple RTK base stations.
- When dealing with projects spanning multiple kilometers, it is crucial to carefully address issues related to geoid and local vertical datum distortion. This consideration holds whether the range is extended through the use of additional base stations or by prolonging the observation period.
- After identifying the variances between Chart Datum and WGS84, this disparity can be extrapolated to offshore areas. However, modeling becomes essential as the separation is not consistent and varies. The only instance where this rule does not apply is when a small area and a near-shore hydrographic survey are both conducted. In such cases, the separation can be considered uniform across the entire survey area.

- Validate side-by-side at a known water level gauge at the start and finish of each project. Comparisons ought to period a full tide cycle or at least three hours.
- It is recommended to use an automated tide gauge to carry out hydrographic survey operations for the purpose of dredging activities rather than RTK tide values generated by RTK GPS which will increase the uncertainty in volume calculations.

5. CONCLUSION

Employing real-time Kinematic (RTK) technology for monitoring tides in dredging projects offers several notable advantages and considerations. RTK demonstrates its efficacy in providing real-time tide data, particularly when immediate and up-to-date information is crucial for project requirements. The integration of motion unit sensors enhances the accuracy and reliability of RTK tide measurements, especially in areas prone to varying meteorological conditions affecting tide collection.

However, to comprehensively assess and understand the behavior of RTK across complete tide cycles, extensive data collection spanning at least 12 hours or a full tide cycle is recommended. This prolonged observation period ensures a more thorough analysis of RTK performance within dredging areas.

Furthermore, while RTK proves beneficial for real-time tide monitoring, it is essential to note that the use of tide gauges remains valuable, especially for validation purposes and as a benchmark for accuracy. Tide gauges should continue to be maintained and utilized alongside RTK technology to verify measurements and confirm the reliability of separation models.

Ultimately, the utilization of RTK in dredging projects offers a valuable tool for obtaining immediate tide data, but it should be complemented by careful considerations of data collection duration, the inclusion of additional sensors for improved accuracy, and the continued use of tide gauges for validation and benchmarking purposes.

6. RECOMMENDATIONS

- To achieve more conclusive results, it is recommended to perform this experiment close to a permanent tide gauge. This close distance enables a more reliable comparison between RTK tide data and data obtained from a permanent tide gauge. Additionally, it provides an opportunity to compare the tidal measurements recorded by the temporary campaign tide gauge with those from the permanent tide gauge, aiding in the assessment of the accuracy of the campaign tide gauge.
- Future survey endeavors could benefit from expanding the survey area to multiple locations where tidal data can be observed. By comparing RTK tide data from different locations, a deeper understanding of how the distance from the tide gauge influences RTK tide data can be gained.
- To improve the definitiveness of variations in the ultimate output, such as depth charts, it is advised to attain complete coverage of the seafloor. This can be achieved by conducting multibeam surveys and subsequently comparing the obtained results.
- For upcoming surveys that demand real-time tide data, it is suggested to employ the RTK technique. Conversely, when real-time tide information is not crucial, the ATG data technique is recommended. Combining both approaches leads to a more authentic end product, especially concerning the representation of tide patterns in the surveyed area.

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