Dataset Development of Non-Ice-Strengthened Vessel Operational Risks in the Navigable Waters of the Northern Liaodong Bay (2021–2022)

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Abstract: To quantitatively assess the navigation risks for no-ice-class vessels in the northern Liaodong Bay during winter, this research developed a spatiotemporal Risk Index Outcome (RIO) dataset based on the Polar Operational Limit Assessment Risk Indexing System (POLARIS). The data sources include: GF-4 satellite visible and near-infrared remote sensing imagery acquired during the 2021–2022 winter season under clear-sky conditions over Liaodong Bay (used for sea ice thickness inversion), along with polygon vector data for 12 navigable waters soured from the China Pilot A101. The dataset comprises 2 components: (1) Boundaries of the 12 navigable waters defining the statistical scope (.shp format); (2) Daily average RIO tables for these waters across 44 clear-sky days (.xlsx format), totaling 528 data points. The total compressed size is 36.2 KB. This dataset provides quantitative baseline data to ensure vessel operational safety, plan winter navigation routes, and support maritime regulatory decision-making.

Keywords: POLARIS; navigable waters; no-ice class vessels; operational risks; northern Liaodong Bay

DOI: https://doi.org/10.3974/geodp.2026.01.13

Dataset Availability Statement:

The dataset supporting this paper was published and is accessible through the *Digital Journal of Global Change Data Repository* at: https://doi.org/10.3974/geodb.2025.04.04.V1.

Received: 31-10-2025; **Accepted:** 26-01-2026; **Published:** 25-02-2026

Foundations: Guangdong Ocean University (060302132106, 080508132401, 202421); Natural Science Foundation of Guangdong Province (2022A1515011603, 2023A1515011212, 2025A1515010886); Department of Education of Guangdong Province (2022ZDZX3005); Natural Science Foundation of Shenzhen (JCYJ20220530162200001)

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Data Citation: [1] Guo, Z. K., Qian, S. H., Fan, J. M. Dataset development of non-ice-strengthened vessel operational risks in the navigable waters of the northern Liaodong Bay (2021–2022) [J]. *Journal of Global Change Data & Discovery*, 2026, 10(1): 102–109. https://doi.org/10.3974/geodp.2026.01.13.

[2] Ma, L., Fan, J. M., Qian, S. H., *et al*. Dataset of non-ice-strengthened vessel operational risks in the navigable waters of the northern Liaodong Bay during the winter based on POLARIS methodology (2021–2022) [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2025. https://doi.org/10.3974/geodb.2025.04.04.V1.

1 Introduction

Sea ice disasters, one of the five major marine hazards, primarily occur in polar and high-latitude regions, but also impact mid-latitudes seasonal sea ice regions[1]. The Bohai Sea is a typical seasonal ice region, where winter sea ice is primarily influenced by cold waves[2]. Among the various waters of the Bohai Sea, Liaodong Bay experiences the most severe sea ice conditions, with extreme ice regime years seeing the entire bay covered in ice[3]. Located in the northern hinterland of Liaodong Bay, YingKou Port serves as the closest seaports to the three northeastern provinces and the four eastern leagues of Inner Mongolia. It consistently ranks among the top northern ports in grain transshipment volume, with an annual average throughput exceeding 30 million tons[4]. The freezing season in Liaodong Bay coincides with the peak period for transporting grain from north to south. Severe ice conditions significantly restrict vessel operations, becoming a critical environmental factor that affects maritime traffic safety and operational efficiency. Different levels of ice formation pose significant threats to vessel navigation safety, especially for conventional vessels without ice-strengthened vessels[5]. Therefore, systematically assessing the operational risks of no-ice-class vessels in the ice regions waters of Liaodong Bay is essential for ensuring vessel safety, planning winter navigation route, and supporting maritime regulatory decision-making.

Currently, the International Maritime Organization (IMO) recommends the Polar Operational Limit Assessment Risk Indexing System (POLARIS) for assessing navigation risks in polar waters[6]. This method comprehensively consider sea ice conditions and ice class of vessel, effectively quantifying navigation risks and supporting vessel operations and decision-making by owners. The POLARIS methodology is primarily applied in polar waters and utilizes sea ice conditions data provided by the National Snow and Ice Data Center (NSIDC). It conducts weekly analyses of polar sea ice conditions using Synthetic Aperture Radar (SAR) and generates corresponding GIS shapefile data.

In non-polar ice regions, the application of risk quantification using the POLARIS methodology remains insufficient. Currently, China has not yet established a continuous remote sensing observation dataset for sea ice, and the generation and analysis of relevant sea ice data also lag behind. While remote sensing data (such as SAR) offers distinct advantages in terms of broad coverage and ice condition acquisition, its application in non-polar waters is still limited. Notably, mature datasets for converting remote sensing data into GIS shapefiles and spatially join them with navigable waters for risk assessment are lacking.

In recent years, China's Gaofen series satellites, particularly the Gaofen-4 (GF-4) satellite, with its high temporal resolution and visible-near infrared observation capabilities, has provided crucial data for the dynamic monitoring of coastal sea ice. At the same time, the 2016 edition of the China Sailing Directions Bohai Sea and Yellow Sea clearly delineates the spatial scope of the primary navigable waters in northern Liaodong Bay, providing a foundation for dividing navigational spatial units. This study addresses data scarcity by integrating remote sensing observations with GIS data of navigable water areas. It establishes a standardized, reproducible dataset for non-polar vessel operational risks in ice-covered waters, offering more precise support for risk assessments in non-polar ice zones. This enhancement broadens the applicability of the POLARIS methodology, allowing for a more comprehensive evaluation of navigation risks in ice-covered waters and offering robust data support for vessel operational decisions.

The core contributions of this dataset include: (1) Data fusion. Spatially linking GF-4 satellite-derived sea ice thickness products with official shipping lane vector data ensures high alignment between risk assessment units and actual shipping operations; (2) Method standardization. Strictly adhering to the IMO recommended POLARIS methodology framework for calculations, quantifying navigation risks through Risk Index Outcomes (RIO) to advance the development and refinement of the POLARIS methodology; (3) Product serialization. Establishing daily scale risk index time series for the 2021–2022 winter season, covering 44 clear-sky days and 12 critical navigable waters. This systematically characterizes the spatiotemporal evolution of operational risks for no-ice-class vessels in the northern Liaodong Bay.

This paper serves as the data paper for the dataset, systematically detailing its composition, development methodology, and results. The release of this dataset aims to fill the gap in quantitative data on navigation risks of no-ice-class vessels in the ice-covered waters of Liaodong Bay. It provides foundational data support for maritime regulation and decision-making in ice regions, vessel auxiliary decision-making, and research on vessel navigability in ice regions under climate change conditions.

2 Metadata of the Dataset

The metadata of the Dataset of non-ice-strengthened vessel operational risks in the navigable waters of the northern Liaodong Bay during the winter based on POLARIS methodology (2021–2022)[7] is summarized in Table 1. It includes the dataset full name, short name, authors, year of the dataset, temporal resolution, spatial resolution, data format, data size, data files, data publisher, and data sharing policy, etc.

3 Methods

The development of this dataset strictly adheres to the IMO recommended POLARIS methodology, yielding daily scale RIO for no-ice-class vessels navigating the northern Liaodong Bay. During development, a standardized risk assessment framework was established by integrating sea ice thickness data derived GF-4 satellite remote sensing, official spatial vector data of navigation channels, and meteorological observations data. This ensures the scientific rigor, consistency, and reproducibility of the data products. The sources, descriptions, and key parameters of all input data required for dataset construction are detailed in Table 2. All raw data underwent quality control and preprocessing to meet the computational requirements of the POLARIS methodology.

3.1 Algorithm

The POLARIS methodology is based on the integrated consideration of sea ice concentration, ice type, ice thickness, and ice-class vessel. It quantifies the operational risk imposed by various ice conditions using Risk Index Values (RIVs) and subsequently evaluates vessel operational limits in ice-covered waters through the RIO[12].

(1) RIO calculation

For independently operating vessels, the RIO is calculated as the weighted sum of the RIVs for each sea ice types with the waters, multiplied by their corresponding sea ice concentration. Using the high-resolution of the GF-4 imagery, pixel classified as sea ice are assumed to represent complete sea ice covered, ie., a sea ice concentration of 10/10. Based on this assumption, the RIO calculation only requires to multiplying the RIVs by 10. The Equation is as follows[13]:

$$RIO = \sum_{i=1}^{n} \left(10 \times RIV_i\right) \tag{1}$$

Where RIV_i denotes the risk index value corresponding to sea ice type *i*, with a range of –8 to 3.

Table 1 Metadata summary of the Dataset of non-ice-strengthened vessel operational risks in the navigable waters of the northern Liaodong Bay during the winter based on POLARIS methodology (2021–2022)

Items	Description
Dataset full name	Dataset of non-ice-strengthened vessel operational risks in the navigable waters of the northern Liaodong Bay during the winter based on POLARIS methodology (2021–2022)
Dataset short name	NIS_Vessel_RIO_LiaodongBay2021-2022
Authors	Ma, L., Naval Architecture and Shipping College, Guangdong Ocean University, malong@gdou.edu.cn Fan, J. M., Naval Architecture and Shipping College, Guangdong Ocean University, fanjiemin@stu.gdou.edu.cn Qian, S. H., Naval Architecture and Shipping College, Guangdong Ocean University, qiansihan@stu.gdou.edu.cn Xu, J., Naval Architecture and Shipping College, Guangdong Ocean University, jinxu@gdou.edu.cn Cao, L., Naval Architecture and Shipping College, Guangdong Ocean University, caoliang@gdou.edu.cn Xu, S., Naval Architecture and Shipping College, Guangdong Ocean University, xs20221053@163.com Li, X. W., Key Laboratory of Philosophy and Social Science in Hainan Province of Hainan Vocational University of Science and Technology, xiaowenli_capt@126.com
Geographical region	Northern Liaodong Bay
Year	2021–2022
Temporal resolution	Day
Spatial resolution	50 m
Data format	.xlsx, .shp
Data size	78.7 KB
Data files	Polygonal vector data for 12 navigable water areas in northern Liaodong Bay; RIO values for 12 navigable water areas in northern Liaodong Bay during 44 clear days in the 2021–2022 winter season
Foundations	Guangdong Ocean University (060302132106, 080508132401, 202421); Natural Science Foundation of Guangdong Province (2022A1515011603, 2023A1515011212, 2025A1515010886); Department of Education of Guangdong Province (2022ZDZX3005); Natural Science Foundation of Shenzhen (JCYJ20220530162200001)
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	(1) *Data* are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use *Data* subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute *Data* subject to written permission from the GCdataPR Editorial Office and the issuance of a *Data* redistribution license; and (4) If *Data* are used to compile new datasets, the "ten percent principal" should be followed such that *Data* records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[8]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS, GEOSS, PubScholar, CKRSC

Table 2 Data sources and parameter descriptions for the dataset

Data categories	Data description	Source	Key parameter specifications
Satellite remote sensing imagery	GF-4 Satellite Visible and Near-Infrared Band Imagery	Natural Resources Satellite Remote Sensing Cloud Service Platform[9]	Spatial resolution: 50 m; Band: 0.45–0.90 μm used for sea ice thickness inversion. Covers 44 clear-sky days within the ice season from December 17, 2021 to March 4, 2022, in the northern Liaodong Bay region
Navigation channel vector data	Polygonal boundaries of 12 navigable water (passages and anchorages) in northern Liaodong Bay	China Sailing Directions Bohai Sea and Yellow Sea (China Navigation Books Publishing House, 2016)[10]	Data format: vector polygons; Geographic coordinate system: WGS 84. Defined spatial statistical units for risk assessment, including key waters of ports such as Huludao, Jinzhou, Panjin, and Yingkou
Supplementary meteorological data	Daily average temperature	Yingkou Meteorological Station (National Meteorological Science Data Center)[11]	Time period: December 17, 2021 to March 4, 2022, used to analyze the relationship between sea ice growth and decay processes and RIO variations

(2) Determination of Risk Index Values

The RIVs are defined by both the ice-class vessel and the prevailing sea ice type[14]. As this dataset focuses on no-ice-class vessels, the corresponding RIVs for different sea ice types are presented in Table 3[6].

Table 3 Mapping of stage of development to RIVs for no-ice-class vessels

Stage of development	Ice thickness (cm)	RIVs
Ice free	/	3
New ice	<10	1
Gray ice	10–15	0
Gray-white ice	15–30	−1
Thin first year ice (stage 1)	30–50	−2
Thin first year ice (stage 2)	50–70	−3
Medium first year ice	70–100	−5
Thick first year ice	>100	−6

3.2 Technical Route

From raw data to the generation of the final dataset, several processing steps are required (Figure 1). First, GF-4 satellite imagery undergoes radiometric calibration and geometric correction. The pixel reflectance is then converted into continuous sea ice thickness raster data using an optical remote sensing empirical model. Subsequently, the sea ice thickness raster data is discretized into sea ice types in compliance with the POLARIS standard, based on sea ice thickness thresholds. Given the high spatial resolution (50 m) of the GF-4 imagery, all pixels identified as sea ice are uniformly assigned a sea ice concentration of 10/10 (full coverage). Next, corresponding RIVs for each pixel are determined based on its sea ice type, and RIO values are calculated as RIO=RIV×10 on a pixel-by-pixel basis. This generates daily RIO spatial distribution maps, covering the entire study area (44 maps in total). Finally, the vector polygon boundaries of the 12 navigable waters are spatially joined with the daily RIO grids. The average RIO value across all pixels within each polygon is then calculated to represent the RIO values for that navigable waters on the corresponding day. By integrating vector boundary information with daily-scale time-series statistics, a structured and comprehensive dataset is ultimately created.

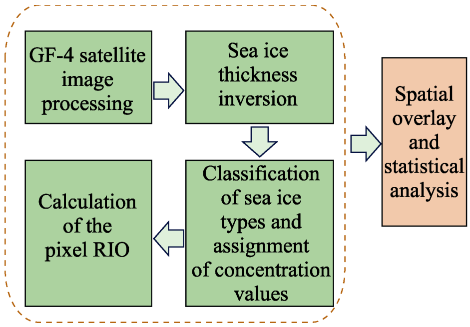

Figure 1 Flowchart of the dataset development

4 Data Results

4.1 Dataset Composition

The Dataset of non-ice-strengthened vessel operational risks in the navigable waters of the northern Liaodong Bay during the winter based on POLARIS methodology (2021–2022) comprises the following 2 components, collectively forming a comprehensive spatiotemporal risk assessment product:

(1) Spatial boundary data. This includes vector boundary files for 12 critical navigable waters (designated 1–12) in the northern Liaodong Bay, formatted as .shp. These files define the fundamental spatial units for risk assessment and statistical analysis.

(2) RIO data. The core dataset file is a .xlsx spreadsheets containing the daily average RIO values for the 12 critical navigable waters during 44 clear-sky days in the 2021–2022 winter season. The spreadsheet organizes data by date in rows and navigable waters in columns, resulting in a total of 44 days×12 regions=528 valid RIO data points.

4.2 Data Products

Figure 2 depicts the geographic distribution of 12 critical navigable waters (including channels and anchorages) in the northern Liaodong Bay, while Table 4 details the geographic boundaries of these areas. Figure 3 shows the spatial distribution of RIO values calculated using the POLARIS methodology, exemplified by data from January 21, 2022. Integrating Figures 2 and 3 reveals that more than half of the RIO values for navigation waters are below 0, indicating elevated navigation risk in the northern Liaodong Bay during late January.

To quantify the winter navigation risk in the northern Liaodong Bay, data from the 44 clear-sky days were integrated to further analyze the time-series characteristics of RIO for each water (Table 5). This includes the advantage RIO for each navigable waters across the 44 observation days, the percentage of days corresponding to different RIO levels, and the start and end dates of high-risk periods (RIO< −10). The advantage RIO characterizes the relative risk level of each navigable waters throughout the study period. When RIO ≥ 0, vessels can operate normally; when RIO< 0, vessels cannot navigate, with lower values indicating higher risk. The percentages of days corresponding to different RIO levels reflect the frequency and duration characteristics of risk occurrence.

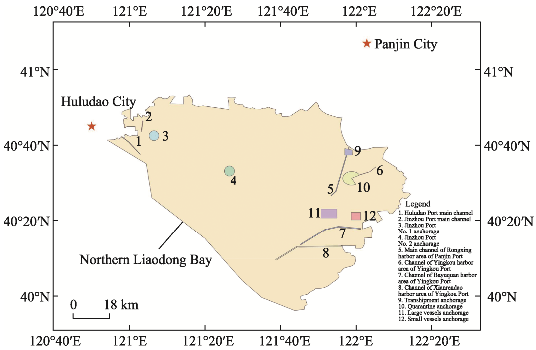

Figure 2 Map of the navigable waters in northern Liaodong Bay

Table 4 Geographic boundaries of navigable waters in Northern Liaodong Bay

No.	Navigable waters	Geographic boundaries
1	Huludao main channel	From Huludao No. 1 light buoy (40°37′30″N, 121°02′55″E) to No. 16 light buoy
2	Jinzhou Port main channel	From Jinzhou Port No. 1 light buoy (40°43′29″N, 121°03′12″E) to No. 7 light buoy
3	Jinzhou Port No. 1 anchorage	Centered at 40°42′24″N, 121°06′30″E, radius 1 NM
4	Jinzhou Port No. 2 anchorage	Centered at 40°33′00″N, 121°26′30″E, radius 1 NM
5	Main channel of Rongxing harbor area of Panjin Port	From Panjin Port No. 1 light buoy (40°26′26″N, 121°53′35″E) to No. 35 light buoy
6	Channel of Yingkou harbor area of Yingkou Port	From Yingkou harbor area No. 1 light buoy (40°31′54″N, 122°01′00″E) to No. 11 light buoy
7	Channel of Bayuquan harbor area of Yingkou Port	From Bayuquan harbor area No. 1 light buoy (40°13′22″N, 121°45′30″E) to No. 36 light buoy
8	Channel of Xianrendao harbor area of Yingkou Port	From Xianrendao harbor area No. 1 light buoy (40°09′19″N, 121°38′59″E) to No. 40 light buoy
9	Transhipment anchorage	Anchorage connected by the following 4 points: 40°37′17″N 121°57′09″E, 40°37′17″N 121°59′08″E, 40°38′34″N 121°59′08″E, 40°39′01″N 121°57′09″E
10	Quarantine anchorage	Centered at Yingkou light buoy (40°31′06″N, 121°58′58″E), radius 1.8 NM. A 3/4 circle formed by rotating 270° anticlockwise from Yingkou light buoy to No. 1 light buoy as the starting edge
11	Large vessels anchorage	Anchorage connected by the following 4 points: 40°22′55″N 121°55′03″E, 40°22′55″N 122°50′51″E, 40°20′31″N 121°50′51″E, 40°20′31″N 122°55′03″E
12	Small vessels anchorage	Anchorage connected by the following 4 points: 40°20′01″N 121°58′51″E, 40°20′01″N 122°01′21″E, 40°22′01″N 122°01′21″E, 40°22′01″N 121°58′51″E

The operational risks for no-ice-class vessels in the northern Liaodong Bay exhibit distinct spatiotemporal distribution patterns based on the Table 5. Spatially, the navigable waters show significant regional risk disparities, with higher risks in the west and lower risk in the east. High-risk waters (3, 4, 5, 7, 9, 10, 11) feature lower or even negative average

RIO values, and the proportion of days with RIO < 0 remains above 55%, indicating that these water face continuous and elevated navigation risks throughout the winter. Among these, high-risk Water 5 (main channel of Rongxing harbor area of Yingkou Port) and Water 10 (quarantine anchorage) exhibit the most pronounced risk, with negative average RIO values. In contrast, Water 1 (Huludao main channel) and Water 2 (Jinzhou Port main channel) show the highest average RIO values and experience the earliest conclusion of high-risk periods, indicating relatively favorable navigation conditions. Water 4 (Jinzhou Port No. 2 anchorage) presents a special case, with its high-risk period spanning almost the entire observation period. This aligns with the area's environmental characteristics—its proximity to the estuary and lower salinity, which favor sustained sea ice formation. Temporally, navigation risks in these waters dynamically shifted with the progression of winter. The heavy ice period (RIO<−10) for all waters primarily occurred between January and February, aligning with local sea ice formation and decay patterns. However, the onset and conclusion of high-risk periods varied across different waters, reflecting localized process peculiarities. Water 8 of southern experienced a later start to its risk period, while navigational risks generally began earlier in northern nearshore waters.

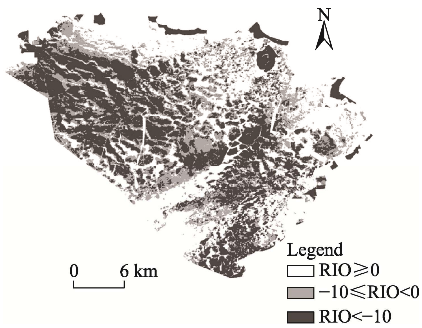

Figure 3 Spatial distribution map of RIO (January 21, 2022)

5 Discussion and Conclusion

The dataset integrates sea ice thickness information derived from GF-4 satellite inversions with official channel vector data, strictly adhering to the POLARIS methodology framework. It generates daily-scale RIO of no-ice-class vessel indices for 12 critical navigable waters in the northern Liaodong Bay across 44 clear-sky days. Its development and release not only provide a refined quantitative tool for maritime safety management in northern Liaodong Bay but also offer a significant case study for validating the application of the POLARIS methodology in non-polar waters, thereby advancing the development of the POLARIS methodology. Analysis indicates that the operational risks for no-ice-class vessels in the northern Liaodong Bay winter exhibit significant spatiotemporal heterogeneity. High-risk waters are primarily concentrated in the main navigation channels of the main channel of Rongxing harbor area of Yingkou Port and quarantine anchorage (Water 5 and 10), while eastern waters present relatively lower risks. High-risk periods predominantly occur from January to February. This dataset is publicly available in a standardized, machine-readable format and enables direct application in winter maritime safety management, vessel route optimization, ice navigation risk assessment model validation, and ice-region vessel navigability studies under climate change. It provides critical data support for safe operations and long-term research in related fields.

Table 5 Summary of RIO statistics for navigable waters in northern Liaodong Bay (winter 2021–2022)

Navigable waters	Mean RIO	RIO ≥0	−10≤ RIO<0	RIO <−10	High-risk period RIO<−10) start and end dates
1	9.68	77	14	9	Dec. 31–Feb. 2
2	7.02	70	12	18	Dec. 31–Feb. 1
3	2.42	41	36	23	Dec. 30–Feb. 4
4	3.43	41	36	23	Dec. 26–Feb. 16
5	−1.09	32	50	18	Jan. 11–Feb. 17
6	3.93	57	36	7	Dec. 29–Feb. 19
7	2.88	41	32	27	Jan. 20–Feb. 24
8	5.37	54	23	23	Jan. 19–Feb. 24
9	0.53	40	50	10	Dec. 28–Feb. 2
10	−1.43	36	41	23	Jan. 16–Feb. 24
11	1.72	43	34	23	Jan. 20–Feb. 24
12	5.05	52	21	27	Dec. 26–Feb. 21

This dataset retains certain limitations from its development process. Its construction was constrained by clear-sky observation conditions, resulting in only 44 valid observation days, which makes continuous monitoring throughout the entire ice period challenging. Sea ice thickness inversion primarily relies on empirical optical remote sensing models, which lack sufficient validation through field measurements. The delineation of navigable waters is based on the 2016 edition of the China Sailing Directions Bohai Sea and Yellow Sea and does not reflect recent dynamic changes in navigation channels. Additionally, the assessment model does not account for vessel dynamic parameters or human operational factors. Future research will aim to monitoring continuity by integrating multi-source remote sensing data such as SAR and passive microwave. It will also optimize inversion algorithms through field measurements, introduce AIS data and ship logs to develop a human-vessel-ice coupled risk assessment model, and update spatial assessment units based on the latest fairway information. These improvements aim to achieve higher precision and real-time capability in ice navigation risk assessment.

Author Contributions

Qian, S. H. was responsible for the overall design of the dataset and research plan guidance, and participated in revising and guiding the data paper. Guo, Z. K. contributed to the data collection, data processing, and model and algorithm design, and also drafted the paper manuscript. Fan, J. M. contributed to the data validation and wrote the paper.

Conflicts of Interest

The authors declare no conflicts of interest.

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