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RESEARCH ARTICLE

Analyzing Disease and Pest Dynamics in Steppe Crop Using Structured Data

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ABSTRACT In this study, an analysis of the spectral brightness coefficients (SBC) of agricultural crops in the steppe regions of Kazakhstan was carried out using remote field and space measurements during the growing season. The possibility of assessing structural changes in plants using near-infrared data was explored. An electronic database of corrected spectral data of SBC for the studied crops has been created. The results obtained confirm that the dynamics of SBC values reflect morphophysiological changes in crops during their growing season. Analysis of the seasonal dynamics of the spectral brightness of pests and diseases makes it possible to diagnose their species composition and the physiological state of plants. Spectrophotometric information obtained from satellite data of various crops can be used to build simulation models that provide scientifically based forecasts of the dynamics of the spatial distribution of the species composition of vegetation cover. The study highlights the potential of using subtle spectral differences to study the spatial distribution of different vegetation types and their ecological status. The results of the analysis of satellite information from Sentinel confirm the prospects of its use for assessing the morphophysiological state of agricultural crops using ground-based spectrometric calibration, as well as for predicting yields.

INDEX TERMS Structured data, crops, spectral brightness coefficients, diseases and pests, data verification.

I. INTRODUCTION

The study is significant due to several contextual factors and challenges facing agriculture [1] in Kazakhstan, especially in its steppe regions [2]. The steppe regions of Kazakhstan are crucial for the country's agriculture, mainly grain and livestock farming [3]. These areas are vast and often subject to a variety of biotic stresses, such as pests and diseases [4], which can significantly impact productivity and sustainability. The study is in line with Kazakhstan's strategic goals set in the state program for 2021-2025, which include improving public services and introducing digital technologies into agriculture. The study uses these technologies, particularly remote sensing and spectral data analysis, to better understand and solve agricultural problems.

The use of spectral brightness coefficients (SBCs) from remote field and space-based measurements allows the assessment of plant health and environmental stressors [5]. This method provides a non-invasive way to effectively monitor large agricultural areas, which is critical given the vastness of steppe regions. Understanding disease and pest dynamics is vital to developing effective management and control strategies. Structured data analysis helps identify patterns and trends in the prevalence of diseases and pests at different times and places, offering insight into their behavior and impact on crop health. The main objective of the study is to

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systematize data on the state of crops in Northern Kazakhstan and the Akmola region using spectral and remote sensing data. This involves the creation of an electronic database of adjusted spectral data for the crops under study, reflecting the morphophysiological changes of crops during the growing season. The ultimate goal is to develop predictive models that can predict disease and pest dynamics, thereby enabling timely and effective agricultural interventions. By providing a scientific basis for predicting and mitigating the impacts of pests and diseases, research contributes to the sustainability of agricultural practices. This is especially important for Kazakhstan, where agriculture plays a vital role in the economy and food security.

The purpose of this study is to analyze the dynamics of the spread of diseases and pests in agricultural crops in the steppe regions of Kazakhstan. Using modern remote sensing technologies and information systems, our task is to systematize data, identify patterns and trends in the spread of diseases and pests. This abstract model-based approach not only reveals the current state, but also provides a basis for developing effective control and prevention strategies. As part of our research, we used orthogonal transformation methods [6] to identify homogeneous areas on aerial photographs. Informative textural features were determined to search for grain crops and weed foci in agricultural land, and the Loves texture mask method was used to identify factors that negatively affect the environment and affect the growth of wheat [7], [8]. Based on the data obtained, a model [9] was developed for identifying pests and diseases of agricultural crops [10], using machine learning methods in the analysis of aerial photographs [11].

In light of the importance of gross grain yields for ensuring food security, agricultural development becomes a key factor. Therefore, forecasting the yield of grain crops and assessing their condition at the level of large administrative units are of particular relevance. Ground-based methods of route agrometeorological survey [12], despite their reliability, are limited in regularity and breadth of coverage. In this regard, the development of remote methods, including satellite monitoring, becomes a necessary element of effective information support for agriculture [13], [14], [15]. Satellite monitoring of the state of grain crops provides objective and regular monitoring of the development of crops, as well as assessment of crop productivity and the intended use of agricultural land [16], [17]. However, for the effective functioning of the monitoring system, it is necessary to improve the methods of processing satellite data [18] in order to more accurately assess the condition of crops and identify cultivated areas within the framework of regional monitoring. Such a task is not only of interest from a theoretical point of view, relating to digitalization and the introduction of digital technologies in agriculture [19], [20], but also becomes a practical issue for improving methods for monitoring the condition of crops. This is considered a key factor in the successful development of the agro-industrial complex of Kazakhstan [20], [21], [22], [23], [24], [25] in modern and future periods.

This research presents a significant advancement in the field of agricultural monitoring through its innovative use of spectral brightness coefficients (SBC) analysis derived from both ground-based and satellite measurements. Unlike traditional methods, this approach allows for the continuous and detailed monitoring of crop health and stress factors across vast areas without the need for physical sampling. By leveraging modern remote sensing technologies, the study introduces a method that can systematically detect and analyze the effects of environmental stressors such as disease, pests, and moisture variations on crop health. The creation of a comprehensive electronic database of these spectral signatures enables not only real-time monitoring but also facilitates the development of predictive models for crop health. These models, built on machine learning algorithms, harness the subtle spectral differences captured across various bands, offering a more nuanced understanding of crop physiology and its interaction with the environment. This methodology represents a substantial leap forward from existing practices by providing a scalable, efficient, and more precise tool for agricultural stakeholders to enhance productivity and sustainability in crop management.

II. METHODS

The study was conducted using structured data obtained from various sources. Remote field and space measurements of spectral brightness coefficients (SBC) of agricultural crops during the growing season were carried out using modern remote sensing technologies. The study, conducted in the steppe regions of Kazakhstan, involved the collection and analysis of structured data using modern remote sensing technologies to monitor crop health. Data collection was carried out using satellites and ground-based sensors, which allowed for objective and regular measurements of spectral brightness coefficients (SBC) throughout the growing season. These data have undergone extensive preprocessing, including calibration, normalization, and correction, to eliminate biases and ensure the accuracy of the analysis. The feature extraction stage used machine learning techniques to analyze textural characteristics and determine the influence of various factors on plant health. The developed machine learning model, trained on corrected data, made it possible to classify and predict the spread of diseases and pests, which is key to the development of effective control strategies. Extensive documentation of all stages of the study, including data processing methods and model parameters, ensures its reproducibility and contributes to further development in the field of agricultural technologies and environmental monitoring. During the study, information about the considered places in Northern Kazakhstan and the Akmola region was received from the National Space Tourism Company of Kazakhstan. The data covers the period 2021-2023. The data consists of the growing season, types of diseases and pests, and their growth phases in a real coordinate system. The analysis revealed that the database contains 23 types of diseases, pests and weeds. The database contains about 15,000 data. Reference values for

TABLE 1. Reference values of SBR of diseases and pests.

date	B01	B02	B03	B04	B05	B8A	Target
2021-06-01	683	920	1038	1250	1367	1641	Creeping bitterweed
2021-06-03	1450	1500	1700	1790	1961	2187	Creeping bitterweed
2021-06-03	1450	1500	1700	1790	1961	2187	Creeping bitterweed
2021-07-08	4746	4036	3912	3816	4302	4540	Creeping bitterweed
2021-07-08	4746	4036	3912	3816	4302	4540	Creeping bitterweed
2021-07-08	4746	4036	3912	3816	4302	4540	Creeping bitterweed
2021-07-08	4746	4036	3912	3816	4302	4540	Creeping bitterweed
2021-07-08	4746	4036	3912	3816	4302	4540	Creeping bitterweed
2021-07-08	4746	4036	3912	3816	4302	4540	Creeping bitterweed
2022-03-03	9273	9384	9440	9456	9471	8478	Golden potato nematode
2022-03-03	9273	9384	9440	9456	9471	8478	Golden potato nematode
2022-03-03	9273	9384	9440	9456	9471	8478	Golden potato nematode
2022-03-03	5286	3031	2976	2776	3612	3859	Golden potato nematode
2022-03-03	5286	3031	2976	2776	3612	3859	Golden potato nematode
2022-03-03	9534	10192	10177	10080	10070	8895	Golden potato nematode
2022-03-16	681	688	852	988	1081	1240	Pepino mosaic virus
2022-03-16	681	688	852	988	1081	1240	Pepino mosaic virus
2022-03-16	681	688	852	988	1081	1240	Pepino mosaic virus
2022-03-17	6408	5328	5444	5844	5859	6449	Creeping bitterweed
2022-04-01	11750	10680	10000	9592	9843	8387	Dodder
2022-04-01	11750	10680	10000	9592	9843	8387	Dodder
2022-04-04	2330	3349	3463	3903	3662	3372	Creeping bitterweed
2022-04-28	2457	2292	2178	2092	1783	1928	Creeping bitterweed
2023-04-12	628	792	962	1098	1327	1754	Italian Prussian
2023-04-12	628	792	962	1098	1327	1754	Italian Prussian

TABLE 1. ***(Continued.)*** **Reference values of SBR of diseases and pests.**

2023-04-12	628	792	962	1098	1327	1754	Italian Prussian
2023-04-12	628	792	962	1098	1327	1754	Italian Prussian
2023-04-12	735	878	1122	1348	1499	1967	Italian Prussian
2023-04-12	735	878	1122	1348	1499	1967	Italian Prussian
2023-04-12	735	878	1122	1348	1499	1967	Italian Prussian
2023-04-12	735	878	1122	1348	1499	1967	Italian Prussian
2023-04-14	8741	7880	7880	7992	8667	8837	Italian Prussian
2023-04-14	8741	7880	7880	7992	8667	8837	Italian Prussian
2023-04-14	8741	7880	7880	7992	8667	8837	Italian Prussian
2023-04-24	5690	5660	5428	5516	5782	5549	Gray Grain Fall Armyworm
2023-04-24	5690	5660	5428	5516	5782	5549	Gray Grain Fall Armyworm
2023-04-24	3947	3920	3812	4020	4295	4364	Gray Grain Fall Armyworm
2023-04-24	7765	7768	7656	7640	7964	7388	Gray Grain Fall Armyworm
2023-04-25	518	602	742	936	1004	1252	Gray Grain Fall Armyworm
2023-04-25	404	638	798	1066	1242	1663	Gray Grain Fall Armyworm
2023-04-25	404	638	798	1066	1242	1663	Gray Grain Fall Armyworm
2023-04-25	668	924	1150	1516	1661	1934	Gray Grain Fall Armyworm
2023-05-02	817	962	1218	1376	1643	2359	Italian Prussian
2023-05-02	666	882	1090	1420	1510	1818	Italian Prussian
2023-05-02	666	882	1090	1420	1510	1818	Italian Prussian
2023-05-02	542	644	767	938	888	1189	Italian Prussian
2023-05-02	542	644	767	938	888	1189	Italian Prussian

TABLE 1. ***(Continued.)*** **Reference values of SBR of diseases and pests.**

2023-05-02	446	626	803	958	1159	1697	Italian Prussian
2023-05-02	446	583	778	940	1171	1846	Italian Prussian
2023-05-02	485	615	759	874	1101	1715	Italian Prussian
2023-05-10	1599	1606	1712	1816	1925	2451	Septoria
2023-05-10	1599	1606	1712	1816	1925	2451	Septoria
2023-05-10	1599	1606	1712	1816	1925	2451	Septoria
2023-05-17	561	744	958	1226	1405	1725	Hessian fly
2023-05-17	578	762	965	1234	1388	1700	Hessian fly
2023-05-17	561	744	958	1226	1405	1725	Hessian fly
2023-05-29	247	266	160	124	97	71	Meadow moth
2023-05-29	662	794	1000	1348	1525	1888	Meadow moth
2023-05-29	587	713	900	1020	1323	2058	Meadow moth
2023-05-29	665	792	960	1220	1380	1659	Meadow moth
2023-05-29	255	264	179	111	87	74	Meadow moth
2023-05-29	364	566	808	998	1371	2579	Meadow moth
2023-05-30	591	720	988	1180	1447	2426	Asian locust
2023-05-30	495	624	830	1028	1308	2078	Asian locust
2023-05-30	650	920	1238	1760	1954	2246	Asian locust
2023-05-30	642	650	926	1011	1446	2277	Asian locust
2023-05-30	596	558	838	876	1378	2468	Asian locust
2023-05-30	241	167	226	231	279	369	Asian locust
2023-05-30	538	658	934	1058	1388	2252	Asian locust
2023-05-30	533	692	937	1098	1313	2218	Asian locust
2023-06-01	784	932	1090	1308	1447	1783	Meadow moth
2023-06-22	444	520	889	880	1385	2923	Hessian fly
2023-06-22	386	494	848	792	1397	3312	Hessian fly
2023-06-22	543	844	1248	1446	1833	2763	Hessian fly
2023-06-22	337	658	988	1824	2108	2436	Hessian fly
2023-06-22	1373	1476	1322	1160	1162	1104	Hessian fly
2023-06-23	6497	8096	7224	6756	6973	5611	Hessian fly
2023-06-23	1794	1780	1908	2142	2381	2690	Hessian fly
2023-06-23	485	560	833	932	1335	2387	Hessian fly
2023-06-23	590	798	936	1272	1426	1839	Hessian fly
2023-06-23	556	774	1118	1488	1685	2274	Hessian fly
2023-06-23	5523	8408	7456	7272	7424	6891	Hessian fly
2023-06-23	561	648	835	1100	1261	1638	Hessian fly
2023-06-23	1524	1284	1360	1678	1960	1917	Hessian fly
2023-06-23	4592	3744	4132	4112	4397	4081	Hessian fly
2023-06-23	992	1528	1434	1348	1386	1377	Hessian fly

TABLE 1. ***(Continued.)*** **Reference values of SBR of diseases and pests.**

2023-06-26	14607	13856	13040	12848	13717	12387	Septoria
2023-06-26	15113	15120	15040	15032	14958	14828	Septoria
2023-06-26	15112	15120	15040	15032	14958	14368	Septoria
2023-06-26	13565	11736	10400	9344	9889	8421	Septoria
2023-06-26	20408	16312	14192	12800	13916	11723	Septoria
2023-06-26	12904	12128	11424	11144	11866	10259	Septoria
2023-06-26	14601	14208	13688	13304	14063	12224	Septoria
2023-06-26	8315	7896	7744	7720	8179	7616	Septoria
2023-06-26	8158	8192	8120	8416	8695	8373	Septoria
2023-06-26	6177	6268	6076	6220	6269	6081	Septoria
2023-06-26	15113	15120	14248	13680	14585	12259	Septoria
2023-06-26	15113	15120	14432	13944	14839	12326	Septoria

the SBC of pests and diseases of agricultural crops have been created. Below is a part of the reference values of the SBC created for the growing season (Table 1).

The spectral bands from remote sensing are crucial for various applications in plant health assessment. Band 1 – B01 (Coastal aerosol, 443.9 - 479.1 nm) helps detect chlorophyll, indicating plant health and possible stress from disease or pests. Band 2 - B02 (Blue, 490.6 - 516.5 nm) and Band 3 - B03 (Green, 559.8 - 597.6 nm) also analyze chlorophyll levels and assess plant condition, with changes in these bands signaling potential stress. Band 4 - B04 (Red, 650.0 - 680.0 nm) is utilized for analyzing plant pigmentation and physiological states. Bands 5 - B05 (698.5 - 712.5 nm), Bands 6 - B06 (733.5 - 747.5 nm), and Bands 7 - B07 (773.1 - 793.1 nm), known as Vegetation Red Edge, are instrumental in analyzing plant conditions, identifying stress factors, and detecting diseases. Lastly, Band 8 – B08 (NIR, 793-842 nm) primarily focuses on vegetation health and the assessment of biophysical parameters, providing a comprehensive view of plant health and vitality.

To identify the dynamics of the spread of diseases and pests in agricultural crops in the steppe regions of Kazakhstan, an analysis of time series of spectral coefficients was carried out. This analysis included identifying key peaks and changes in spectral characteristics associated with disease phenomena and pest pressure. Based on the corrected spectral data, an electronic database was created, structured for subsequent analysis. This database enables efficient storage and retrieval of information on disease and pest dynamics.

In light of the conducted research, based on structured data, it was revealed that the integration of a broad information context is an integral component for a deeper understanding of the dynamics of the spread of diseases and pests in crops

FIGURE 1. Creeping bitterweed.

FIGURE 2. Original image.

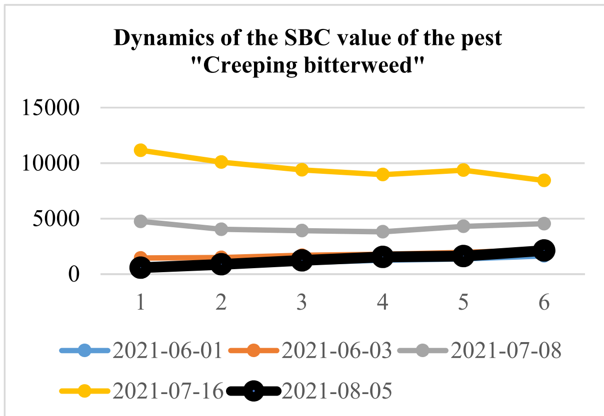

FIGURE 3. Dynamics of pest development.

in the steppe regions of Kazakhstan. The concepts of type, abstraction and abstract data type are of particular importance, acting as key elements that ensure the efficiency and controllability of information systems. The language abstraction tools and data type mechanisms emphasized in this study are not only tools for formalizing and structuring data, but also tools for improving the accuracy of analysis and effective management of crop health. This abstract model-based approach not only reveals the current state, but also provides a basis for developing effective disease and pest control and prevention strategies. Thus, the integration of abstract data types and abstraction principles in the analysis of disease and pest dynamics in crops strengthens the methodological approach and provides precise tools for understanding and monitoring agricultural processes in the steppe regions of Kazakhstan. These conclusions emphasize not only the relevance of the study, but also its practical significance in the development of the agro-industrial complex.

III. RESULTS AND DISCUSSIONS

In the presented study, a pest was selected to test the developed model - creeping bitterweed, taken from the database. Agronomist and academician A. Maltsev described creeping bitterweed as "the most dangerous and malicious weed of all our weed flora." This weed not only seriously impedes soil cultivation, but its roots also release toxic substances that suppress other crops, especially vegetables, even after the underground part of the weed dies. That is why creeping bitterweed (Fig. 1) was included in the list of quarantine objects of the Government of the Republic of Kazakhstan, and financing of measures for its localization and elimination is carried out from the state budget.

Creeping bitterweed, also known as pink or creeping cornflower, was originally distributed mainly in the southern regions of the country, but in recent years it has begun to actively move north, affecting crops in virgin farming areas. Currently, infection with it covers all regions, including Akmola. Its importance is confirmed by the Government's decision to control and manage the spread of this pest, which indicates the urgent need to combat it in order to maintain crop health and ensure food security. As shown in Figure 2 below, based on the established database, a land plot belonging to the Northern region of Kazakhstan was analyzed.

The dynamics of the spectral brightness of the pest during the growing season under consideration is presented in Figure 3. The analysis of the results showed that the dynamics of the spectral brightness curve of the pest has a similar shape. A characteristic feature can be identified in the presented graphs: in the period from early June to mid-July, an increase in spectral brightness values is observed in all channels. There is also a sharp increase in the values of the spectral brightness curve in the period from 2021-07-08 to 2021-07-16. This trend indicates favorable conditions for the reproduction of the pest, in this case creeping bitterweed. Consequently, the presented seasonal dynamics of spectral brightness can serve as an important indicator for diagnosing the physiological state of crops.

After carrying out agrotechnical measures in the period from 2021-07-16 to 2021-08-05, there was a decrease in the reproduction of pest foci, which is also reflected in Figure 3. Such measures led to a change in the dynamics of spectral

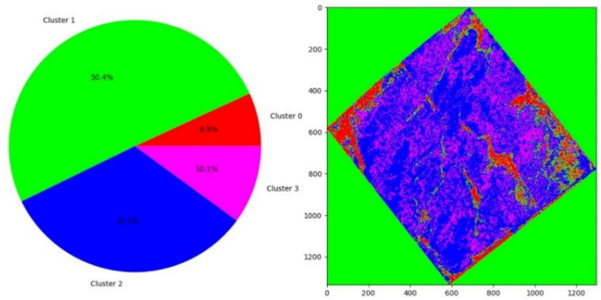

FIGURE 4. The result of clustering using k-means methods during the growing season 2021-07-16.

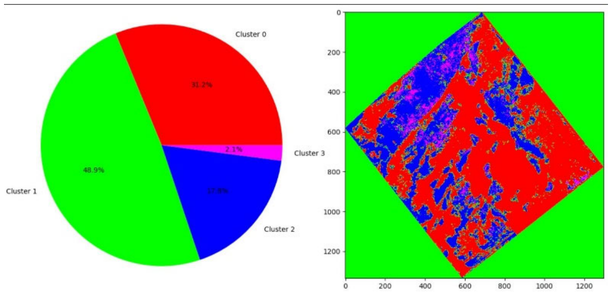

FIGURE 5. The result of clustering using k-means methods during the growing season 2021-08-05.

brightness, indicating the effectiveness of the actions taken. These results highlight the importance of monitoring and analyzing spectral data to quickly respond to changes in pest development and take necessary control measures. To visualize changes in the studied land plots during different growing seasons, the k-means method was used and clustering was carried out (Figure 4). Based on the obtained images, the correctness of the spectral brightness curve (SBC) values obtained during the study was assessed. A high percentage of the pest is observed as of 2021-07-16, and after carrying out agrotechnical measures as of 2021-08-05, a decrease in this percentage is noted, which confirms the effectiveness of the measures taken to control the pest. These results provide important data for further analysis and decision-making in agriculture and crop conservation.

As a result of the study, it was shown that the dynamics of reflectivity obtained using ground-based remote sensing methods and Sentinel-2 L2A satellite images makes it possible to identify fine structures characteristic of identifying pests and diseases, which can be used to identify the condition of plants. The model developed in work [9] became the basis for scientifically based forecasts of the dynamics of the spatial distribution of the species composition of vegetation cover. The results of the study thus highlight the possibility of using subtle spectral differences in certain regions of the reflectance spectrum to study the spatial distribution of different vegetation types and their ecological status. Spectrophotometric information derived from Sentinel-2 L2A satellite data shows potential for assessing the morphophysiological condition of agricultural crops using ground-based spectrometric calibration.

In our study, we expanded the analysis to integrate a wide range of agro-climatic conditions and a variety of crops, allowing us to deepen the assessment and predictive accuracy of the model under different climate and management conditions. Collaboration with local agricultural research stations in different regions has enriched our study with a comprehensive data set that includes a variety of environmental conditions and crop responses. This expansion of the database not only increased its diversity but also brought practical insights from experts, thereby significantly improving our analytical process. The results show that the enhanced model can perform reliably in a variety of agricultural conditions, making it a valuable tool for farmers and agronomists in making informed decisions that promote sustainable agricultural practices.

IV. CONCLUSION

In conclusion, the study notes that the analysis and processing of the electronic database of spectrophotometric information obtained both from space and field ground measurements of the dynamic spectral brightness of crop pests during their growing season led to a number of important conclusions. The significance of this research lies in its potential to transform agricultural practices in Kazakhstan's steppe regions through advanced technologies. By enhancing the understanding of crop health dynamics and environmental impacts, the study supports the development of more resilient agricultural systems that can withstand the challenges posed by diseases and pests. This not only aids in improving the yield and quality of agricultural products but also supports the strategic development goals of the country.

Firstly, the dynamics of the spectral brightness of crops turns out to be a significant indicator of morphophysiological changes in phytoelements of the studied crops. This allows not only to monitor the state of plants, but also makes it possible to predict their development based on spectral data. Secondly, the creation of an electronic data bank of the spectral characteristics of various pests and diseases of crops during their growing season represents an important step in the field of agroecological research. This resource can become the basis for further analytical work and the development of methods for monitoring the condition of agricultural land. The third finding comes from the use of Sentinel-2 L2A imagery, which demonstrates the ability to highlight small areas of agricultural plantations. This opens up new prospects for monitoring and managing agricultural crops using space technologies. Finally, analysis of the resulting spectral curves in the identified classes highlights the promise of using subtle spectral differences to study the spatial distribution of different vegetation types and their ecological status. These findings highlight the importance of modern methods for analyzing spectral data in agriculture and ecology.

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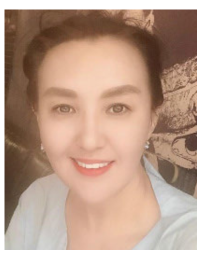

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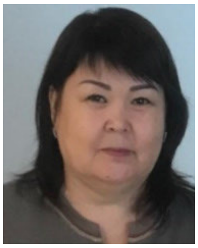

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