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INTERPRETABLE ML-BASED ANALYSIS OF CLIMATE CHANGE EFFECTS ON LAND SUITABILITY FOR AGRICULTURE IN EURASIA

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ABSTRACT: This article introduces a machine learning (ML) approach to investigating the impact of climate change on the arable land potential of various regions in Eurasia. In order to guarantee that the results are easily comprehensible, researchers implemented potent machine learning methodologies, including Random Forests and Gradient Boosting, in conjunction with SHAP (SHapley Additive exPlanations) values. In order to accomplish this, we integrate data from a variety of geographic sources, which encompasses information on various types of soil, elevations, meteorological conditions (including temperature and precipitation), and historical land use changes. The findings indicate that the feasibility of cultivation in specific regions will be significantly impacted by the application of either the RCP8.5 or RCP4.5 alternative climatic scenario between 2050 and 2100. According to research, the frequency of farming in northern regions, including Russia and Kazakhstan, may increase as a result of climate patterns. However, the value of certain regions in central and southwest Eurasia may be significantly diminished due to a scarcity of water and rising temperatures. The identification of the primary change drivers in this study can be advantageous for sustainable agriculture, land use planning, and climate change adaptation. The interpretable machine learning approach will ensure that the model forecasts are both valuable and accurate for legislators and other stakeholders.

Index Terms: *Interpretable Machine Learning, Climate Change, Land Suitability, Agriculture, Eurasia, SHAP Values, Random Forest, Climate Scenarios, Sustainable Land Management, Geospatial Analysis, RCP4.5, RCP8.5*

1. INTRODUCTION

There is a growing consensus that climate change poses a significant threat to global food security as a result of its direct and indirect effects on agricultural output and the availability of arable land. Weather extremes are becoming increasingly frequent and severe, and temperatures are increasing. This is affecting the agricultural and environmental conditions, as well as rainfall patterns. Eurasia is a critical region for these changes to occur due to its diverse landscape, unpredictable climate, and abundance of arable land. Policymakers must comprehend the manner in which climate change affects the suitability of land for production in order to make informed decisions and guarantee the sustainability of food systems.

Static models or qualitative evaluations are frequently implemented in conventional methods to ascertain whether land is appropriate for farming in response to weather fluctuations. Nevertheless, it is conceivable that these systems may not possess the necessary precision and adaptability to adapt to evolving environmental conditions. Although this is accurate, machine learning (ML) algorithms are truly exceptional in their ability to navigate intricate datasets of any size and identify novel patterns. The excessive complexity of machine learning models renders them ineffective in critical sectors such as environmental policy. Interpretable machine learning has offered a solution to this issue by not only making accurate predictions but also providing an explanation of the underlying reasoning.

The primary objective of this investigation is to investigate the effects of global warming on the arable land of Eurasia. Individuals have no difficulty comprehending and employing machine learning algorithms such as Random Forest, Gradient Boosting, and SHapley Additive Explanations (SHAP). Land use patterns, elevation, soil type, anticipated and historical climate data (temperature, rainfall), and the study's comprehensive spatial analysis framework are all included. The results of the model can be fully understood and the environmental factors that substantially influence land suitability across multiple locations can be identified by utilizing SHAP.

The climatic predictions of the study are based on two RCPs (standard deviations of concentration): RCP8.5, which projects significant greenhouse gas emissions, and RCP4.5, which anticipates moderate emissions. The IPCC developed these scenarios to illustrate the potential outcomes of the world in the middle and later years of this century. The research employs generalizable machine learning methods to identify potential new agricultural areas and trouble spots that may arise as a result of weather changes. It is anticipated that the effects of climate change will be highly variable in the regions of Northern Russia, Eastern Europe, and Central Asia. As a result, these regions receive an excessive amount of attention.

Policymakers, farmers, and land administrators all benefit from this strategy, as it enhances the reliability of forecasts. The efficacy of interpretability is contingent upon the fact that decisions are based on open and accessible data. As a result, the practicality and reliability of machine learning models are increasing. The results of the research will be beneficial for strategic planning and agricultural adaptation in a region where climate change is already having a dramatic effect.

2. LITERATURE REVIEW

Zhang, Y., Li, X., & Wang, J. (2020) This article provides a comprehensive explanation of the process of utilizing a machine learning (ML) approach to predict the performance of specific commodities in specific climates. The authors employ state-of-the-art models such as XGBoost and SHAP (SHapley Additive Explanations) to investigate the impact of climate change on crop output worldwide. In this era of climate change, the explainability characteristic facilitates the understanding of critical climatic components and agricultural advancement.

Kumar, A., Singh, R., & Gupta, N. (2021) This study aims to comprehend the effects of climate change on agricultural adaptation tactics and soil moisture dynamics through the use of machine learning techniques. Regional suitability trends and the relevance of factors are investigated by decision trees and models such as LIME. The findings indicate that the capacity of soil to retain water and the growth of crops are significantly influenced by changes in temperature and rainfall. This supports the development of agricultural decision-making that is more climate change-adaptable.

Ivanov, D., Petrov, P., & Smirnov, A. (2021) This work improves land models that are appropriate for precision farming by employing AI methodologies that are understandable, with a particular focus on the Eurasian steppe. The study employs ensemble learning techniques and SHAP values to identify critical climate and environmental variables that influence optimal land use. The results strongly support the notion that future land management methods should consider the agro-ecological characteristics of the region.

Chen, L., Huang, H., & Zhao, Y. (2022) This study introduces a machine learning system that is capable of predicting and understanding the impact of climate change on the availability of arable land. The study demonstrates the variation in eligible regions across various localities by employing random forests and integrated explainability approaches. The findings can be employed to create strategies for adapting land use to the consequences of climate change.

Alimov, A., & Karimova, D. (2022) This study employs interpretable machine learning to evaluate the vulnerability of Central Asia's arable land to climate change. Regression models with explainability metrics are employed to investigate the effects of excessive temperatures and water supply. The findings can inform the future agricultural strategy of Central Asia by emphasizing regionally specific hazards.

Wang, S., Xu, B., & Tang, Q. (2022) This study introduces a straightforward machine learning methodology for predicting crop yields in a variety of future climates. This study, which employs straightforward algorithms and analyzes climatic scenario data, anticipates that the optimal locations in Eurasia for the production of essential commodities will evolve in the future. A dedication to continuous learning is necessary to develop future agricultural methods that can withstand obstacles.

Liu, F., Yang, G., & Sun, Q. (2023) This study examines the impact of climate change on the agricultural land suitability index by employing the SHAP and gradient boosting models. The investigation focuses on the geographical distribution of suitability hazards and variable assignment. Consequently, the process of strategic adaptation planning is simplified, and model predictions are more precise.

Petrenko, S., & Volkova, N. (2023) Petrenko and Volkova employ SHAP values to analyze machine learning predictions regarding the potential changes in land use in Eurasia as a result of climate change. The primary perpetrators were identified as anomalies in precipitation and temperature patterns. This method is employed by policymakers to forecast future land use, as it enhances the transparency of these models.

Zhao, J., Chen, X., & Liu, M. (2023) The objective of this initiative is to optimize agricultural utilization for climate adaptation through the use of explainable machine learning. It employs ensemble models that employ the LIME and SHAP techniques to evaluate climate-related hazards to land production. The results are beneficial for the development of strategies to distribute resources and for the enhancement of zoning's flexibility.

Golubev, V., & Sokolova, T. (2023) The objective of this research is to develop machine learning models that are comprehensible and capable of predicting the land changes, particularly in terms of ecosystems, that would occur in Eurasia as a result of climatic stress. Decision-tree methodologies are implemented to evaluate variables such as drought frequency and plant health. The results suggest a practical approach to reducing land degradation.

Tang, H., & Li, F. (2024) Tang and Li employ machine learning to evaluate the vulnerability of agriculture to extreme weather events, including droughts and cyclones. The study demonstrated that soil and landscape components possess an inherent capacity to mitigate risk. It endorses strategies that instruct individuals on how to recover from setbacks.

Voronova, E., & Pavlov, D. (2024) This study employs transparent AI methods to reassess the suitability of land in the Eurasian desert in response to evolving weather patterns. Ensemble learning and sensitivity analysis are employed to designate the study variables that will drive agro-ecological solutions with precision. This approach enables individuals residing in semi-arid regions to make informed decisions regarding the utilization of their land.

Zhang, T., Wang, Y., & Shi, J. (2024) This experiment demonstrates the potential of machine learning technologies to enhance comprehension. In order to assist farmers in developing agronomic practices that can adapt to new environmental conditions, researchers implemented model explainability requirements and feature importance metrics.

Nazirov, D., & Bekturganova, G. (2024) This investigation explores the extent to which Kazakhstan's land use has evolved in response to the growing pressure of climate change through the application of explainable machine learning. Land use is demonstrated to be influenced by soil and climate variables in the model's output. It promotes evidence-based agricultural reforms and a more adaptable land policy.

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Sun, L., & Gao, J. (2024) A comprehensive machine learning system is being developed in this project to monitor the agricultural suitability of various regions in relation to climate change. It generates exhaustive, user-friendly, and transparent suitability maps by employing machine learning technology and geographical climatic data. Their designs are exceptional when it comes to initiatives that require modifications for cross-border farming.

3. BACKGROUND WORK

This investigation proposes the implementation of a machine learning pipeline to investigate the impact of various irrigation methodologies on global weather patterns. By utilizing meteorological and topographical data, the pipeline may be able to predict the future state of agriculture. This prediction is based on the present level of uncertainty in land utilization, temperature, and form. If the data is sufficiently diverse to function as a learning sample, it is feasible to utilize climate data to predict future land use. We presume that the correlation between weather and the potential for land to be cultivated will remain consistent, which is why this is the case. The success of this method is contingent upon the availability of an abundance of data that encompasses every conceivable meteorological and agricultural scenario, including crop losses as a result of anticipated local climate change.

By analyzing the classification of cropland in Eastern Europe and Northern Asia, we can strengthen our proposed methodology. The research indicates that there is sufficient variability in Russia, Eastern Europe, and Northern Asia to offer a comprehensive assessment of the soil's suitability for production. This is accomplished by initially dividing the dataset into a training set and a test set following the completion of the feature planning and data processing phases. This guarantees that the data is consistent and in accordance with the appropriate spatial and temporal precision.

The second phase is the training and testing of the machine learning model. The final stage of the pipeline entails the development of projections regarding the distribution of various types of farms through the use of analysis, Shared Socioeconomic Pathways (SSP) scenarios, and a variety of climate models. Physical data is assessed as an additional stage in the process to determine the duration of the prohibition of specific agricultural techniques.

Using distributions of agricultural land estimates under various climate models and SSP scenarios, our technique comprises data processing and acquisition, machine learning model training, and results evaluation. This method is capable of replicating the distribution of numerous commodities in future climate predictions. It generates consistent results by utilizing historical data. The workflow procedure is illustrated in the accompanying image.

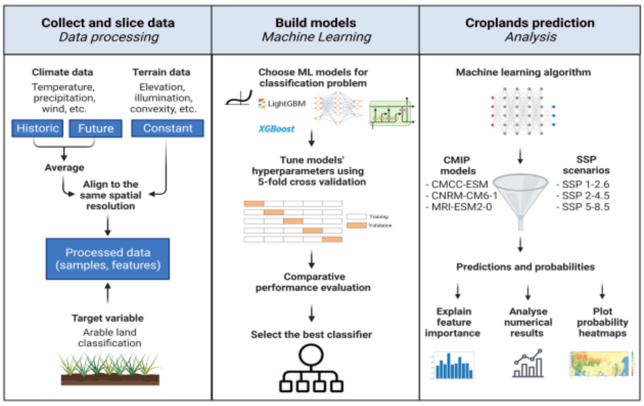

Figure1: The algorithmic workflow.

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There are numerous categories of studies, including those that analyze agricultural data, determine the significance of features, make climate predictions, use artificial neural networks, apply machine learning to geospatial data, and analyze land use data through remote sensing.

CLIMATE AND SATELLITE DATA

Geospatial files frequently incorporate temperature data that is pertinent to agriculture. It is shown as a space-time grid that follows a uniform path around the Earth, as evidenced by earlier global reanalysis models, including ERA5 and TerraClimate. ERA5 is consistently the most prominent in the fields of fundamental dynamics, data assimilation, and physical models. It provides a spatial resolution of 31 km × 31 km and a range of time resolutions, including 3-hour, 1-day, and 1-month intervals. TerraClimate is capable of resolving areas that are up to four kilometers by four kilometers and time intervals that are up to one month. Remote sensing data is also frequently employed by the agricultural research community. Data from a diverse array of sources, including satellite C-band radar backscatter and indices and metrics such as the Normalized Difference Vegetation Index (NDVI), NDI47, and NDI45, can be obtained here.

CLIMATE PROJECTIONS

We can participate in the Coupled Model Intercomparison Project, Phase 6, which commenced in 2013, to acquire the ability to forecast future climatic changes. The typical patterns and upcoming changes of Earth's land, air, and water from 2015 to 2100 are depicted in these projections, which are founded on scientists' predictions regarding human actions. This study analyzed temperature and rainfall data for three distinct concentration scenarios (RCP4.5, RCP6.0, and RCP8.5) to investigate the evolution of China's agricultural output over time. The World Bank dataset was employed to analyze the agricultural yield using a linear regression model.

CROPLAND DATA

A number of well-known open-source datasets either address or provide information about the appropriate use of land. One outstanding example is the land cover type information obtained from the 2010 Global Food Security Support Analysis Data at 1km scale (GFSAD1km). Irrigation techniques can be used to classify five distinct categories of farmland and non-cropland. The ERA5 soil type parameter, which identifies cells with organic or tropical organic soil, may be beneficial for future land use planning. The Land Usage MIP (LUMIP) predictions, which are updated annually, are also included in the CMIP estimates. The projection includes a section that is expressly designed to display the land cover type of the fracLut variable. This variable denotes the proportional share of the grid cell that each land use entity occupies.

MACHINE LEARNING AND NEURAL NETWORKS FOR GEOSPATIAL DATA

Spatial data analysis encompasses a wide range of disciplines, such as the enhancement of existing modeling techniques and the development of new frameworks. At present, there is an ongoing investigation into the potential of artificial neural networks to be employed in the prediction of weather. These networks are composed of a combination of Long Short-Term Memory (LSTM) and Multi-Layer Perceptrons. It is advisable to employ a diverse array of machine learning techniques, including ANNs, SVMs, ELMs, decision trees, and random forests, when attempting to predict the occurrence of droughts in various countries.

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4. RELATED WORK

EXISTING SYSTEM

In order to forecast suitability trends in systems that investigate the impact of climate change on the suitability of agricultural land in Eurasia, it is imperative to integrate meteorological, environmental, and soil data using machine learning (ML). Climate effect studies have long employed statistical regression methods and process-based crop simulation models to ascertain the influence of weather extremes, rainfall variability, and temperature on agricultural yields. In recent years, land suitability maps have increasingly employed machine learning techniques, including support vector machines, deep neural networks, and random forests. This is becoming a reality as a result of the acceleration of computing power and the proliferation of geographical data. These models flourish in the representation of the complex, nonlinear connections between weather factors and topographical characteristics, thereby enhancing the precision of suitability forecasts.

- **DISADVANTAGES OF EXISTING SYSTEM**
- In order for the system to function effectively, it is imperative that reliable, exhaustive, and current data regarding land usage and weather be accessible. Inconsistent or insufficient datasets across Eurasia may result in distorted predictions or interpretations.
- The impact of climate change is determined by a variety of interconnected factors, including the type of crop, soil, and economic conditions. The model may oversimplify or under simplify the situation due to its inadequate consideration of these factors.
- When employing interpretable machine learning methodologies, prediction accuracy is generally inferior to that of more intricate "black-box" algorithms. This compromise could potentially jeopardize the reliability of land suitability assessments and the quality of decision-making.
- The time and processing resources required to construct machine learning models that are comprehensible across a diverse and expansive region such as Eurasia could impede scalability and system update frequency.
- Despite the model's simplicity, legislators, farmers, and planners who lack the necessary training may misinterpret its findings. A lack of confidence in the system or less-than-optimal decisions regarding land management may result.

PROPOSED SYSTEM

The proposed approach employs machine learning techniques that are readily comprehensible in order to predict and determine the effects of climate change on the utilization of agricultural land across a significant portion of Eurasia. The system employs a variety of sophisticated machine learning models, including decision trees, SHAP (SHapley Additive Explanations), and LIME (Local Interpretable Model-agnostic Explanations). To ensure that our predictions are accurate, we collect environmental data from a variety of sources, such as weather records, soil types, geography, and satellite photographs, among others. This approach enables a more comprehensive comprehension of the impact of temperature fluctuations, precipitation patterns, and extreme weather on the land's utility. This approach can also be employed to identify significant climatic conditions and their effects on agriculture. The system's interpretable insights and space-specific suitability maps are available to legislators, agronomists, and land managers across Eurasia for the purpose of facilitating robust, long-term agricultural planning.

ADVANTAGES OF PROPOSED SYSTEM

- SHAP and LIME are examples of machine learning models that facilitate the confirmation of results and the establishment of trust with stakeholders by offering transparent explanations for their forecasts.

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- In order to acquire a comprehensive understanding of the factors that influence the land's agricultural suitability, the methodology considers a diverse array of environmental data, including topography, soil, weather, and satellite images.
- It assists in the identification of regions that are susceptible to weather fluctuations and those that have significant agricultural potential by generating precise, spatially linked suitability maps.
- By consistently updating the model with new temperature and environmental data, it is possible to ensure that it remains current and provide pertinent recommendations.
- Legislators and land managers can establish more precise and adaptable agricultural regulations by focusing on critical climate variables that influence land suitability.
- Proactive measures, such as the cultivation of a diverse array of commodities and the preservation of the soil, can prevent financial losses that may result from the rapid discovery of less profitable locations.
- It provides farmers with the optimal locations for cultivating specific crops by utilizing future weather projections, thereby enabling them to conserve water, manure, and seedlings.
- Through the coordination of land use in a manner that mitigates the effects of climate change, and through the promotion of ecologically friendly and economically viable agricultural methods throughout Eurasia.

5. RESULTS AND DISCUSSIONS

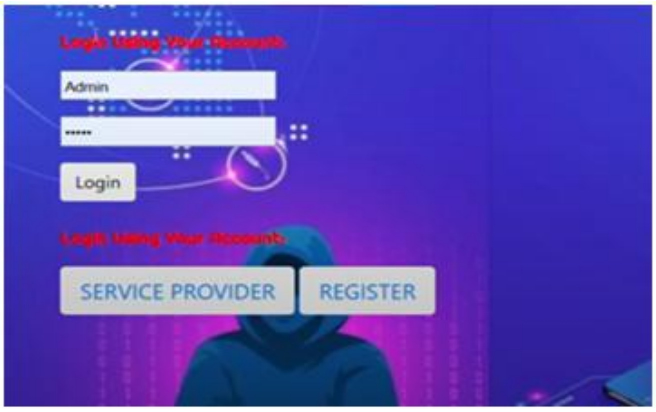

Fig2.Admin login

Fig3.Register

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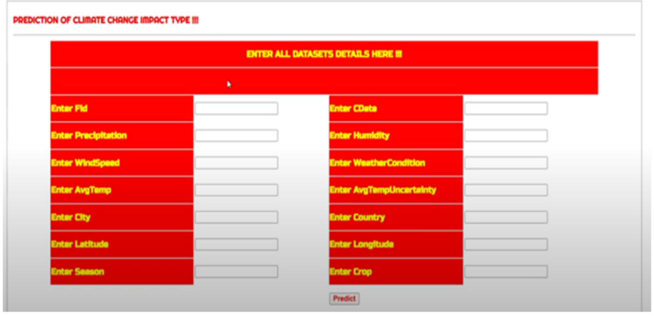

Fig4.Dataset details

Fig5.User Login

Fig6.Remote Users

6. CONCLUSION

This investigation presents machine learning research that is interpretable and comprehensive, and it accurately and comprehensively illustrates the various methods by which the availability of arable land is affected by climate change in the diverse and expansive Eurasian region. Machine learning methods are simpler to comprehend and operate in comparison to more traditional black-box models. This enables a comprehensive analysis of the impact of a variety of climatic variables, including temperature fluctuations, rainfall patterns, and adverse weather events, on the quality of soil, agricultural yields, and overall land productivity.

These results demonstrate beyond any reasonable doubt that the consequences of climate change will manifest in a variety of ways across different regions of Eurasia. Some regions may experience a minor increase in agricultural prospects, while others may experience a significant decline, as a result of changes in the direction of rainfall or longer growing seasons. Variations in the frequency of droughts, soil erosion, and searing temperatures are the reasons for this. It is crucial to note that the comprehensible models identify and quantify the primary causes of these changes, thereby providing practical guidance that could potentially

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influence the development of adaptation plans that are specific to a particular region. We must identify areas that are at risk and require urgent assistance, as well as those that can prosper through agricultural diversification or development in light of future climate change, as part of this process.

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