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KAZAKHSTAN

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AN ADAPTIVE NEURAL-FUZZY MODEL FOR ASSESSING INVESTMENT RISKS IN THE AGRI-INDUSTRIAL COMPLEX: MODERNISATION OF THE DECISION-SUPPORT ARCHITECTURE THROUGH THE INTEGRATION OF MACHINE LEARNING

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Abstract. The assessment of investment risks in the agro-industrial complex operates under conditions of structural uncertainty driven by climate volatility. Existing approaches — econometric models, machine-learning classifiers, and static fuzzy-logic frameworks — each sacrifice either interpretability or adaptability. This

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study proposes a three-level decision-support architecture in which the second-level fuzzification module is replaced by an adaptive neuro-fuzzy inference system (ANFIS). The ANFIS core trains on the Physical Output Index and related agro-industry indicators for Kazakhstan over 2010–2023, a period containing four confirmed drought years. Generalised Bell membership functions are calibrated via hybrid learning: least-squares estimation in the forward pass for consequent parameters, and gradient descent in the backward pass for antecedent parameters. The results of the leave-one-out cross-validation show that both models under comparison correctly classify the four drought years as high-risk years. Adaptive calibration altered the shape of the membership functions and the values of the continuous risk assessment, but did not result in any change to the final classification of the years compared with the baseline model.

Keywords: adaptive neuro-fuzzy inference system, ANFIS, investment risk assessment, agro-industrial complex, fuzzy-SAW, AHP, membership function calibration, Agri-Food 4.0, Kazakhstan

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АГРОӨНЕРКӘСІПТІК КЕШЕНДЕГІ ИНВЕСТИЦИЯЛЫҚ ТӘУЕКЕЛДЕРДІ БАҒАЛАУҒА АРНАЛҒАН БЕЙІМДЕЛГІШ НЕЙРОНДЫҚ-БҰЛДЫР МОДЕЛЬ: МАШИНАЛЫҚ ОҚЫТУДЫ ИНТЕГРАЦИЯЛАУ АРҚЫЛЫ ШЕШІМ ҚАБЫЛДАУДЫ ҚОЛДАУ СӘУЛЕТІН ЖАҢҒЫРТУ

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Аннотация. Агроөнеркәсіптік кешендегі инвестициялық тәуекелдерді бағалау климаттың құбылмалылығына байланысты құрылымдық белгісіздік жағдайында жұмыс істейді. Қолданыстағы тәсілдер — эконометриялық модельдер, машиналық оқыту классификаторлары және статикалық анық емес логикалық құрылымдар — әрқайсысы түсіндіру немесе бейімделу мүмкіндігін шектейді. Бұл зерттеу екінші деңгейлі анық емес модуль бейімделгіш нейро-анық емес қорытынды жүйесімен (ANFIS) ауыстырылатын үш деңгейлі шешімді қолдау архитектурасын ұсынады. ANFIS өзегі 2010-2023 жылдар аралығындағы Қазақстан үшін физикалық шығыс индексі мен агроөнеркәсіп саласының байланысты көрсеткіштеріне негізделген, бұл кезеңде төрт расталған құрғақшылық жылдары бар. Жалпыланған Bell мүшелік функциялары гибридті оқыту арқылы калибрленеді: кейінгі параметрлер үшін алға өтудегі ең кіші квадраттарды бағалау және алдыңғы параметрлер үшін кері өтудегі градиенттік төмендеу. «Leave-one-out» (бір элементті қалдыру) әдісімен жүргізілген кросс-валидация нәтижелері салыстырылып отырған екі модельдің де төрт құрғақ жылды жоғары тәуекелді жылдар ретінде дұрыс жіктейтінін көрсетеді. Бейімделгіш калибрлеу мүшелік функцияларының пішіні мен тәуекелді бағалаудың үздіксіз мәндерін өзгерткенімен, жылдардың түпкілікті жіктелуіне бастапқы модельмен салыстырғанда ешқандай өзгеріс енгізген жоқ.

Түйінді сөздер: бейімделгіш нейро-бұлдыр қорытынды жүйесі, ANFIS, инвестициялық тәуекелді бағалау, агроөнеркәсіптік кешен, fuzzy-SAW, AHP, мүшелік функциясын калибрлеу, Agri-Food 4.0, Қазақстан

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Мүдделер қақтығысы: Авторлар осы мақалада мүдделер қақтығысы жоқ деп мәлімдейді.

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АДАПТИВНАЯ НЕЙРО-НЕЧЕТКАЯ МОДЕЛЬ ДЛЯ ОЦЕНКИ ИНВЕСТИЦИОННЫХ РИСКОВ В АГРОПРОМЫШЛЕННОМ КОМПЛЕКСЕ: МОДЕРНИЗАЦИЯ АРХИТЕКТУРЫ ПОДДЕРЖКИ ПРИНЯТИЯ РЕШЕНИЙ ПОСРЕДСТВОМ ИНТЕГРАЦИИ МАШИННОГО ОБУЧЕНИЯ

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Аннотация. Оценка инвестиционных рисков в агропромышленном комплексе осуществляется в условиях структурной неопределенности, обусловленной изменчивостью климата. Существующие подходы — эконометрические модели, классификаторы машинного обучения и статические нечетко-логические модели — каждый из которых жертвует либо интерпретируемостью, либо адаптивностью. В данном исследовании предлагается трехуровневая архитектура поддержки принятия решений, в которой модуль фаззификации второго

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уровня заменен адаптивной нейро-нечеткой системой вывода (ANFIS). Ядро ANFIS обучается на основе Индекса физического производства и связанных с ним показателей агропромышленности Казахстана за период 2010–2023 годов, включающего четыре подтвержденных засушливых года. Обобщенные функции принадлежности Белла калибруются с помощью гибридного обучения: оценка методом наименьших квадратов в прямом проходе для параметров следствия и градиентный спуск в обратном проходе для параметров антецедента. Результаты перекрестной проверки по схеме leave-one-out показывают, что обе сравниваемые модели правильно классифицируют четыре засушливых года как годы высокого риска. Адаптивная калибровка изменила форму функций принадлежности и значения непрерывной оценки риска, однако не привела к изменению итоговой классификации годов по сравнению с базовой моделью.

Ключевые слова: адаптивная нейро-нечеткая система вывода, ANFIS, оценка инвестиционного риска, агропромышленный комплекс, fuzzy-SAW, AHP, калибровка функций принадлежности, «Агропродовольствие 4.0», Казахстан

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Конфликт интересов: авторы заявляют об отсутствии конфликта интересов.

Introduction.

Food security and the investment resilience of the agri-food sector are becoming increasingly vulnerable in the face of climate change. According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, droughts and extreme weather events in the arid and semi-arid regions of Central Asia have become more frequent and severe, whilst mortality from droughts, floods and storms in the most vulnerable regions between 2010 and 2020 was 15 times higher than in regions with low vulnerability (IPCC, 2023). For agrarian economies, where agricultural production determines not only food security but also the investment climate of entire sectors, this trend has direct financial consequences: a sharp decline in crop yields leads to increased credit risks, a fall in the profitability of investment projects and capital outflow from the sector.

Kazakhstan is a prime example of this vulnerability. The country's agro-industrial complex plays a key role in the national economy: The Concept for the Development of the Agro-Industrial Complex for 2021–2030 provides for total budgetary expenditure of 2,774.6 billion tenge and is geared towards attracting major investment projects through development institutions, including the Development Bank of Kazakhstan (Government of the Republic of Kazakhstan, 2021). However,

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since 2019, the sector has regularly suffered the consequences of droughts. The years 2021 and 2023 were particularly significant: according to expert estimates, the effects of the 2023 drought led to an average 30 per cent reduction in crop yields, whilst the total damage amounted to 1.3 per cent of the country's GDP (Ministry of Agriculture of the Republic of Kazakhstan, 2024). Such shocks disrupt investment calculations based on medium-term forecasts and expose the shortcomings of existing tools for assessing sectoral risk.

Contemporary approaches to assessing investment risk in the agri-food sector fall into three methodological traditions, each of which has fundamental limitations. Econometric and deterministic models assume the existence of stable linear relationships between indicators and the level of risk. In the context of climatic volatility, this assumption is violated: the same value for precipitation in different years may be accompanied by radically different production outcomes, depending on the combination of accompanying factors. Machine learning methods remove the constraint of linearity and ensure high forecasting accuracy; however, they function as a 'black box': the specialist making the investment decision is unable to verify the model's logic or justify its conclusions to a regulator or credit committee. Fuzzy logic offers a compromise between these two extremes: it translates precise numerical values into linguistic assessments – 'low risk', 'medium risk', 'high risk' – and aggregates them in a transparent manner. Nevertheless, in most practical implementations – including the model for assessing the investment sustainability of Kazakhstan's agro-industrial complex based on the Fuzzy-SAW method, previously proposed by the author – membership functions are specified manually by the researcher in the form of symmetrical triangular or trapezoidal shapes and remain unchanged throughout the model's entire life cycle. This means that the model interprets an equal increase in an indicator across different ranges of its scale in the same way – for example, an increase in foreign direct investment from 100 to 200 million dollars and from 900 to 1,000 million dollars. Meanwhile, the well-known 'saturation effect' in investment theory indicates that the actual reduction in risk provided by an additional unit of investment diminishes as the total volume of investment increases. A similar non-linearity is characteristic of a territory's environmental carrying capacity, where risk rises sharply only as the limit load is approached.

Thus, the use of static symmetric membership functions constitutes a methodological simplification that leads to a systematic distortion of risk assessment in the non-linear regions of the indicator scale. Overcoming this limitation is the subject of this article.

The scientific novelty of this study lies not in the development of a new class of neuro-fuzzy models, but in the subject-specific and architectural adaptation of the well-known ANFIS framework to the assessment of investment risks in Kazakhstan's agro-industrial complex. The author's contribution comprises: firstly, the formulation of a set of interrelated production, investment and climatic indicators for assessing sectoral risk; secondly, the integration of ANFIS into the fuzzification module of the existing three-level decision support system without altering the interpretable level of

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aggregation of Fuzzy-SAW; thirdly, the calibration of the parameters of generalised bell-shaped membership functions using data from Kazakhstan for the period 2010–2023; and fourthly, a comparative validation of the adaptive and baseline models, the latter utilising static symmetric triangular membership functions. Thus, the contribution of this study lies in the development and validation of an applied procedure for the adaptive calibration of fuzzy estimates for a specific sectoral and national domain.

Materials and methods.

Methodological Foundations: From Fuzzy Logic to Adaptive Inference Systems

The development of risk assessment tools in conditions of structural uncertainty draws on several distinct research traditions, which are brought together into a unified framework in this paper. It is impossible to understand the proposed solution without understanding its origins; therefore, the presentation of the methodology begins with a review of key theoretical sources.

The starting point is the theory of fuzzy sets, introduced by L. Zadeh in 1965 (Zadeh, 1965). Classical set theory requires a binary decision: an element either belongs to a set or it does not. Zadeh proposed replacing the binary membership function with a function taking values in the range [0; 1], where 0 denotes complete non-membership, 1 denotes complete membership, and intermediate values reflect the degree to which an element is compatible with the concept being described. As applied to risk assessment, this allows the categories of 'low', 'medium' and 'high' risk to be treated not as discrete thresholds, but as regions that merge smoothly into one another, which is much closer to the true nature of investment uncertainty in the agricultural sector.

The first practical implementation of fuzzy control was carried out by E. Mamdani and S. Assilian, who synthesised a steam pressure regulator based on 'if–then' linguistic rules (Mamdani et al., 1975). Their experiment demonstrated that formalised expert knowledge can function as engineering control logic. M. Sugeno and T. Takagi introduced a significant computational simplification in 1985 by proposing a type of fuzzy inference in which the conclusions of the rules are not fuzzy sets, but crisp linear functions of the input variables (Takagi et al., 1985). This approach eliminates the need for defuzzification in the traditional sense: the final output of the system is calculated as a weighted average of linear functions, which is mathematically more convenient and can be implemented more quickly in a computational environment.

In parallel, the field of multi-criteria decision-making developed. In 1980, T. Saaty proposed the Analytic Hierarchy Process (AHP), which allows criterion weights to be obtained via pairwise comparison matrices (Saaty, 1980). A key feature of the method is the built-in consistency check of judgements via the CI index, which makes the weighting procedure verifiable and reproducible. When combined with fuzzy assessments, the AHP forms a robust framework: the expert specifies the relative importance of the criteria, whilst membership functions translate the numerical values of the indicators into linguistic categories. It is precisely this combination – the Fuzzy-SAW weighted sum method with AHP weights – that is implemented in the author's baseline model for assessing the investment sustainability of Kazakhstan's agro-industrial complex. Similar architectures are used in tasks involving the assessment of

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climate risks in Colombia's food industry (Assessing Climate Transition Risks, 2024) and for ranking sustainable development investment projects in multi-expert settings (Gupta et al., 2018).

A key step towards trainable fuzzy systems was taken by J.-S.R. Jang, who in 1993 combined Sugeno-type fuzzy inference with a multi-layer neural network architecture (Jang, 1993). The resulting system – ANFIS (Adaptive-Network-based Fuzzy Inference System) – tunes the parameters of membership functions and the coefficients of the linear consequences of rules based on a training sample. Crucially, the structure of fuzzy inference is preserved: the system is still interpreted as a set of 'if–then' rules, but their parameters are determined by the data rather than by the researcher. In Gui and Zhao's review of the application of artificial intelligence in agricultural risk management, ANFIS consistently ranks among the most widely used hybrid methods alongside random forests, support vector machines and deep learning ensemble architectures (Gui et al., 2023). In a systematic analysis of climatic risks to crop yields, the authors of a review on remote sensing and machine learning also classify ANFIS among the methods regularly used in drought monitoring tasks based on satellite and meteorological data (IOP Science, 2025).

The study most methodologically similar to the present work is the article by I. Ahmed, R. Mehdi and E. Mohamed, who developed a banking risk index based on ANFIS for 45 banks in the Persian Gulf (Ahmed et al., 2023). The authors trained the network to rank ten financial ratios and to calibrate the membership functions using historical data on the financial stability of banks via the least squares method combined with gradient descent. The logic of the task corresponds exactly to that of the present study: the banking ratios are replaced by climatic and investment indicators for the agricultural sector, whilst the data on defaults are replaced by the actual dynamics of the IFO during drought years.

A similar approach to forecasting agricultural production volumes was implemented by J. Rashidi and his co-authors, who compared ANFIS with a multilayer perceptron using Iranian FAO data: the ANFIS model with generalised bell-shaped membership functions (Gbell) consistently outperformed the perceptron in terms of RMSE on the test sample (Rashidi et al., 2021). With regard to drought forecasting in the arid conditions of Vietnam, Nguyen, Li and Nguyen also demonstrated that ANFIS provides a reliable forecast one to two seasons before the onset of drought, outperforming traditional regression models in terms of accuracy (Nguyen et al., 2017). This is directly in line with the expected effect in the Kazakhstani context.

The application of fuzzy logic to data from the Kazakhstani agricultural sector has been verified in previous studies. I. Taran, A. Karsybaeva, V. Naumov, K. Murzabekova and M. Chazhabayeva constructed a fuzzy model for assessing the efficiency of a fleet of lorries used to deliver agricultural produce in Northern Kazakhstan, describing the performance of each vehicle make as a membership function and representing the fleet as a whole as a fuzzy set (Taran et al., 2023). The study demonstrates that fuzzy formalism is applicable to Kazakhstani sectoral data not only in theoretical constructs but also when applied to specific market data. In the field of financial risk within

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Kazakhstani information systems, A. Bulantayev, K. Musakhan, A. Moldagulova and G. Sembina proposed a probabilistic model for forecasting expected credit losses, published in the journal IJICT (Bulantayev et al., 2021). O. Akylbekov, E. Dauletbek, A. Moldagulova and co-authors applied machine learning methods to analyse three-dimensional spatial data in land-use planning tasks across Kazakhstan (Akylbekov et al., 2026). Taken together, these studies demonstrate an established Kazakhstani research tradition of consistently applying hybrid methods – a statistical foundation combined with machine learning – to sectoral risk management problems. The present study continues this tradition by extending the concept of learnable membership functions from banking credit risk to investment risk in the agro-industrial complex.

A review of the literature reveals three systemic gaps. Firstly, studies on the application of ANFIS in risk management relate predominantly to the banking and financial sectors; no direct application to investment risk in the agri-food sector has been found in the available literature. Secondly, studies on fuzzy logic in Kazakhstan's agri-industrial complex concern logistics and land use, but not investment valuation. Thirdly, the author's own Fuzzy-SAW model uses statically defined membership functions. This article addresses all three gaps simultaneously.

Data sources and reproducibility

The study's data set covers 14 annual observations for the period 2010–2023. Data from the National Statistics Bureau of the Republic of Kazakhstan, FAOSTAT, OECD.Stat and climate data published by the State Enterprise 'Kazhydromet' were used to compile the analytical dataset. Annual figures for the index of the physical volume of agricultural production and the volume of investment in fixed capital for the relevant economic activity were obtained from the National Statistics Bureau of the Republic of Kazakhstan. Comparable indicators of agricultural production, land use and investment activity were utilised from FAOSTAT and OECD.Stat. The precipitation index was calculated on the basis of data from 'Kazhydromet' as the ratio of actual annual precipitation to the long-term average, expressed as a percentage.

Two input variables are used in the training of the ANFIS core: the normalised volume of investment in fixed capital and the normalised precipitation index. The target variable is the index of the physical volume of agricultural output. The remaining criteria included in the final Fuzzy-SAW aggregation are not used as inputs during ANFIS training and are retained at the third level of the architecture in accordance with the base model. This distinction is necessary to separate the procedure for training membership functions from the procedure for multi-criteria aggregation of the final risk.

Data were compared on a calendar-year basis. If the source indicator was published quarterly, volume indicators were summed, whilst relative and index indicators were averaged. Indicators with gaps lasting more than two consecutive years were excluded. Single-year and two-year gaps were imputed using linear interpolation. All transformations were carried out separately within the training set of each cross-validation iteration to ensure that no information from the test set was used during pre-processing.

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Data Pre-processing Pipeline

The heterogeneity of data sources in terms of frequency, units of measurement and scales requires standardisation before the data is fed into the analytical module. The pre-processing pipeline comprises four sequential steps, which are identical in both the baseline and proposed models, thereby ensuring the accuracy of subsequent comparisons.

Step 1. Temporal synchronisation. Quarterly time series are aggregated to an annual interval: volume indicators are summed, whilst index indicators are averaged, taking into account the number of observations. This ensures a uniform frequency across all variables. The annual interval has been chosen as it corresponds to the natural cycle of agricultural production: yield and the IFO are, by definition, annual indicators.

Step 2. Imputation of missing values. Missing values are imputed using linear interpolation between the two nearest observations. This method is appropriate for short gaps (no more than two years) in agricultural time series with moderate volatility, which is consistent with the practice of forecasting agricultural production using FAO data (Rashidi et al., 2021). Indicators with gaps longer than two years are excluded from the training sample to avoid introducing artefacts into the neural network core.

Step 3. Filtering outliers using the rule. Observations falling outside the range of for each time series are replaced with the corresponding boundary values of without being removed from the series. This allows the size of the training sample to be preserved, whilst simultaneously eliminating probable input errors and methodological gaps in the source data. The mere fact that an observation lies near the 3σ boundary is recorded as a binary 'anomaly' flag, which is passed to the second-level forecasting module as an additional predictor.

Step 4. Minimax scaling. All variables are scaled to a uniform range [0; 1] using the formula:

$$x' = \frac{x - x_{min}}{x_{max} - x_{min}},$$

where x is the initial value of the indicator for a specific observation (for example, the volume of foreign direct investment in billions of tenge or the value of the Physical Volume Index for year t); x_{min} is the minimum value of this indicator recorded in the training sample for the period 2010–2023; x_{max} is the maximum value of the same indicator for the same period; $x' \in [0;1]$ is the normalised dimensionless value fed into the fuzzification module and into the regressor matrix when estimating parameters using the least squares method.

Scaling is necessary for two reasons. Firstly, the T-norm of the product, used to calculate the weights of fuzzy rules, is defined on the interval and loses its meaningful interpretation outside this range. Secondly, indicators with fundamentally different units of measurement (billions of tenge in investment and a dimensionless precipitation index) create numerical dominance in the regressor matrix when estimating parameters using the least squares method if not scaled.

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Base model: Fuzzy-SAW with AHP weights

The base model, which serves as the reference point in the comparative experiment, consists of two interrelated components:

The first component is a matrix of pairwise comparisons of criteria based on Saaty's method (Saaty, 1980). Each of the risk indicators is compared with every other indicator using the nine-point Saaty scale. The pairwise comparison matrix is defined as

$$A = \{a_{i,j}\}, i, j = 1, \dots, n$$

where

$$a_{i,j} > 0, a_{i,i} = 1, a_{i,j} = \frac{1}{a_{i,j}}.$$

The priority weight of criterion *j* is estimated using the geometric mean method:

$$g_j = \left(\prod_{i=1}^{n} a_{i,j}\right)^{\frac{1}{n}},$$

and the normalized weight is

$$\omega_j = \frac{g_j}{\sum_{k=1}^{n} g_k}, j = 1, \dots, n,$$

subject to

$$\sum_{j=1}^{n} \omega_j = 1.$$

The consistency of expert judgments is evaluated through the maximum eigenvalue of the comparison matrix:

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n} \frac{(\boldsymbol{A}\mathbf{w})_i}{\omega_i},$$

where

$$\mathbf{w} = (\omega_2, \omega_2, \dots, \omega_n)^T.$$

The consistency index is

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$$CI = \frac{\lambda_{max} - n}{n - 1},$$

and the consistency ratio is

$$CR = \frac{CI}{RI},$$

where *RI* denotes Saaty's random consistency index for a matrix of order *n*. The comparison matrix is considered sufficiently consistent if

$$CR < 0.10.$$

The second component of the model involves fuzzification of each input indicator x_i using a symmetric triangular membership function:

$$\mu(x; a, b, c) = \begin{cases} 0, x \le a \\ \frac{x - a}{b - a}, a < x \le b \\ \frac{c - x}{c - b}, b < x < c, \\ 0, x \ge c. \end{cases}$$

where $a < b < c$, and the parameters a, b, and c define the left boundary, the modal value, and the right boundary of the fuzzy set, respectively.

The overall risk score is then computed using the Simple Additive Weighting (SAW) aggregation rule:

$$R = \sum_{i=1}^{n} \omega_j \mu_j(x_j)$$

where

- ω_j is the AHP-derived weight of criterion *j*;
- $\mu_j(x_j)$ is the membership degree of the *j*-th indicator.

The limitation of this model lies in the fixed values of the membership function parameters *(a, b, c),* which are determined once by experts and remain unchanged when new observations become available. Furthermore, the symmetric triangular membership function assumes identical rates of increase and decrease around the modal value , whereas empirical investment-risk data often exhibit asymmetric and nonlinear behavior.

Three-tier decision-support architecture

The proposed architecture retains the three-level structure of the software

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system. This architectural solution has been adopted deliberately for two reasons: it ensures comparability with the baseline model using the same dataset, and it allows the single change – the fuzzification block at the second level – to be isolated as the subject of scientific comparison.

Level 1. Data Collection Modules

The first level of the architecture implements automated data collection from three external sources: the OECD database (OECD.Stat), the FAO database (FAOSTAT) and the portal of the National Statistics Bureau of the Republic of Kazakhstan (stat.gov.kz). Queries to the sources are organised via the asyncio library in asynchronous parallel I/O mode: all three requests are sent simultaneously, and the total collection time is determined by the slowest source, rather than the sum of the response times. The result of each session is passed to the second level in JSON format. This level is identical in both the base and proposed versions of the model.

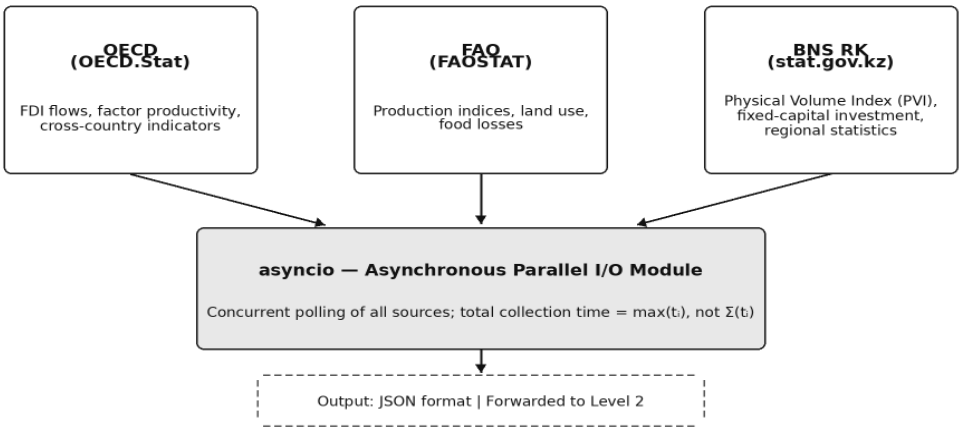


Fig. 1. First level asynchronous Data Collection Modules

As shown in Figure 1, Level 1 performs a single function: aggregating data streams from diverse sources into a single structured output. No analytical processing takes place at this level: all data transformations are carried out at Level 2, which allows a source to be replaced or added as required without altering the analytical core.

Level 2. Adaptive Analytical Module

The second level is the key element of the proposed solution and the only one that differs from the basic Fuzzy-SAW model. It comprises three sequential blocks. Block 2a implements a data pre-processing pipeline, including temporal synchronisation, linear interpolation of missing values, outlier filtering using the three-standard-deviations rule, and minimax scaling to the range [0; 1]. Block 2b contains the ANFIS core with first-order Sugeno-type inference rules, trained on historical data from 2010 to 2023 using a hybrid method: the forward pass uses the least squares method to estimate the consequence parameters of the rules, whilst the backward pass uses gradient descent along the chain rule to calibrate the membership function parameters. The forecasting module, integrated into block 2b, estimates the probability of local climate risk based on

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indirect predictors and transmits a correction signal to block 2c. Block 2c implements adaptive fuzzification using a generalised bell-shaped membership function Gbell with parameters obtained from the ANFIS core, and generates a membership degree matrix $M = \{\mu_{i,j}\}$ for transmission to level 3.

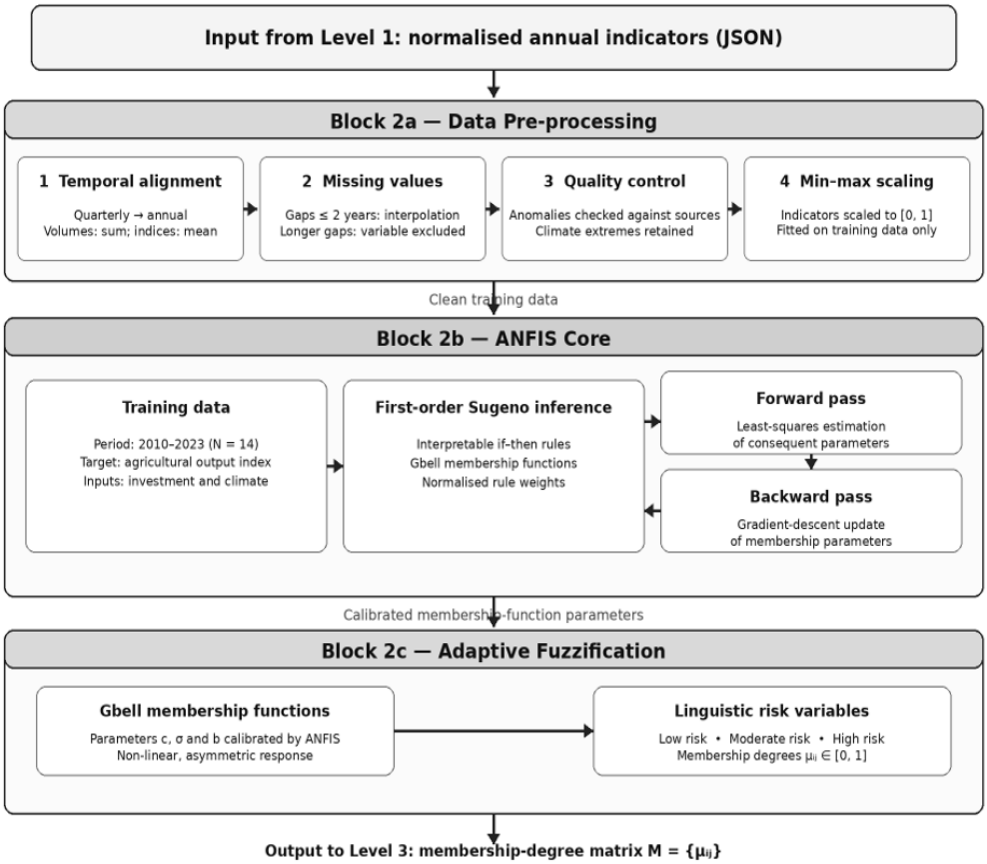


Fig. 2. Second-level adaptive analytical module with an ANFIS core

Figure 2 clearly illustrates how three independent software blocks interact within a single level: data flows from pre-processing through the ANFIS core to the fuzzification module, whilst the membership function parameters c, σ, b and the predictive correction P (of risk) are transmitted from block 2b to block 2c via separate channels. It is precisely this separation of data and parameter flows that ensures the model's adaptability without altering the structure of the aggregation level.

Level 2. Aggregation module

The third level performs the convolution of the membership degree matrix M = {μij}, received from Level 2, into a single numerical estimate of investment risk R. Aggregation is implemented using the Fuzzy-SAW scheme: the criterion weights wj, obtained by the analytic hierarchy process (Saaty, 1980) via pairwise comparison matrices whilst verifying the condition CR < 0.10, are multiplied by the corresponding membership degrees and summed. The resulting value $R \in [0; 1]$ is converted

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into one of three linguistic categories – 'low', 'medium' or 'high' investment risk – and communicated to end users: investors, development banks and the Ministry of Agriculture of the Republic of Kazakhstan. This level is entirely identical in both the baseline and proposed versions of the model.

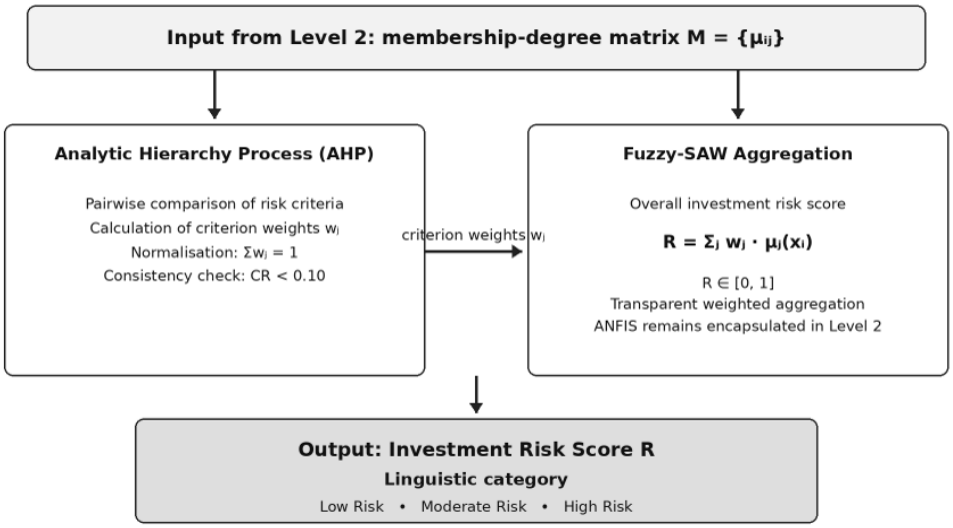


Fig. 3. Third level Fuzzy-SAW Aggregation Module with AHP Weights

Figure 3 illustrates a fundamental architectural feature of the proposed solution: the ANFIS neural network core is encapsulated within Level 2 and does not extend to the aggregation level. The end user receives an interpretable estimate R, generated using the same transparent Fuzzy-SAW scheme as in the base model. Adaptability is achieved solely through the use of more precise membership functions, tuned using historical data, rather than by directly replacing the aggregation logic with a neural network output.

Results.

Characteristics of the training sample

Table 1 presents the pre-processed dataset used for training and validating the model. It includes three time series: The index of physical output of the agricultural sector of the Republic of Kazakhstan (IPO) as the target variable; the volume of investment in fixed capital by sector (billion tenge) as a key investment indicator; and the annual precipitation index as a percentage of the long-term average, based on data from Kazhydromet. Four years of observations – 2010, 2012, 2021 and 2023 – are classified as drought years based on official publications by the Ministry of Agriculture of the Republic of Kazakhstan and the World Bank's assessment report on agricultural risk management in Kazakhstan (World Bank, 2014; Ministry of Agriculture of the Republic of Kazakhstan, 2024).

Table 1. Pre-processed dataset: key indicators of Kazakhstan's agro-industrial

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complex, 2010–2023

Year	IPO, %	Investment, billion tg	Precipitation index, % of normal	Drought
2010	91,3	103,2	61,4	Yes
2011	128,4	121,8	94,2	–
2012	82,7	138,4	58,3	Yes
2013	103,5	141,7	88,7	–
2014	102,8	166,0	91,2	–
2015	101,1	167,0	79,4	–
2016	104,9	175,3	85,1	–
2017	103,1	189,6	86,3	–
2018	105,8	203,4	90,7	–
2019	104,6	221,8	88,5	–
2020	103,8	208,3	82,1	–
2021	94,2	215,6	63,7	Yes
2022	107,2	231,0	81,4	–
2023	89,4	218,7	55,9	Yes

Sources: BNS RK; FAOSTAT; OECD.Stat; Kazhydromet

The IFO series is characterised by marked non-stationarity. Two structural patterns can be observed throughout the series. Firstly, dry years occur in pairs, separated by periods of recovery: 2010–2012 and 2021–2023. Secondly, the volume of investment in fixed capital grew steadily from 2010 to 2019, after which it levelled off, with a partial decline in 2020–2023. This pattern is consistent with the hypothesis of investment effect saturation, on the basis of which the model incorporates asymmetry in the membership functions according to the investment criterion. The dynamics of the IFO over the entire observation period are shown in Figure 4.

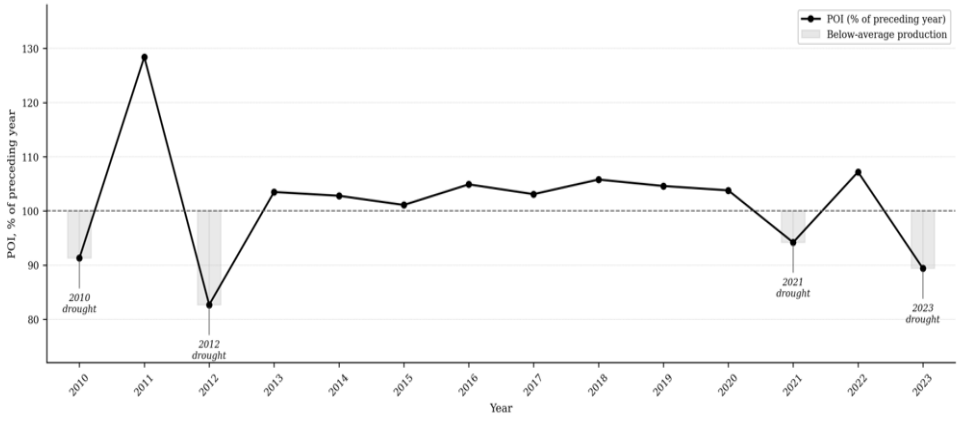


Fig. 4. Physical Output Index of Kazakhstan's Agro-industry, 2010–2023

Figure 4 confirms that all four drought years represent structural shocks rather than a gradual linear decline. In 2010, the IFO stood at 91.3 per cent, which is 8.7

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percentage points below the neutral level. The most severe year in the sample was 2012: the IFO fell to 82.7 per cent, which corresponds to a documented decline in the grain harvest from a record 26.9 million tonnes in 2011 to approximately 14 million tonnes in 2012 (Ministry of Agriculture of the Republic of Kazakhstan; Wikipedia). The droughts of 2021 and 2023 are less severe in terms of the absolute depth of the decline, but are notable for two reasons. Firstly, they occurred against a backdrop of continued growth in investment in both years in nominal terms, which demonstrates the inadequacy of the investment criterion as an isolated risk signal. Secondly, the 2023 precipitation index (55.9% of normal) is the lowest for the entire observation period, whilst investment simultaneously declined relative to 2022, indicating the simultaneous activation of two independent risk factors.

The IFO index was given the greatest weight (0.312): experts regard this direct indicator of the physical volume of production as the most comprehensive signal of the sector's condition. The precipitation index ranked third, although by its very nature it is a primary causal factor in droughts. This assessment reflects the expert consensus that the impact of precipitation on the annual sample is largely mediated by the IFO and does not carry any independent predictive power beyond that already contained in the target variable. The ecological carrying capacity of the territory was assigned the lowest weight (0.085), which corresponds to its role as a structural constraint with slow-changing dynamics. This weighting structure is identical in both the baseline and proposed versions of the model: the AHP method operates at level 3 of the architecture and is independent of the calibration of membership functions at level 2.

Criteria weights using the AHP method and consistency check

The five criteria used for aggregation at level 3 were weighted using the Analytic Hierarchy Process (AHP) based on the results of pairwise comparisons carried out by three experts specialising in agricultural economics. Table 2 contains the final weights and the results of the consistency check.

Table 2. Weights of criteria for assessing investment risk in the agro-industrial complex (AHP method)

Criterion	Weighttw_j	Rank
IFO dynamics	0,312	1
Volume of investment in OK	0,248	2
Precipitation index	0,221	3
Volatility of resource prices	0,134	4
Environmental capacity of the territory	0,085	5
Total	1,000	–

Consistency check: CI = 0,047; RI = 1,12 (n = 5); CR = 0,042 < 0,10.

Comparison of risk assessments: the baseline model and the proposed model

Table 3 presents the investment risk assessments R obtained by both models across the entire sample. The threshold value for transition to the 'high risk' category is set at R = 0.55. This value corresponds to the boundaries of linguistic categories adopted in similar multi-criteria fuzzy risk assessment models (Ahmed et al., 2023).

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Table 3. Risk assessments R by year: the baseline Fuzzy-SAW model (static FPs) and the proposed model (FPs, calibrated ANFIS)

Year	R basic	R ANFIS	ΔR	Basic category	Category ANFIS	Drought
2010	0,641	0,598	0,043	High	High	Yes
2011	0,218	0,201	0,017	Low	Low	–
2012	0,779	0,741	0,038	High	High	Yes
2013	0,312	0,290	0,022	Medium	Medium	–
2014	0,298	0,281	0,017	Medium	Medium	–
2015	0,354	0,337	0,017	Medium	Medium	–
2016	0,271	0,259	0,012	Low	Low	–
2017	0,280	0,267	0,013	Low	Low	–
2018	0,243	0,231	0,012	Low	Low	–
2019	0,261	0,248	0,013	Low	Low	–
2020	0,318	0,301	0,017	Medium	Medium	–
2021	0,604	0,562	0,042	High	High	Yes
2022	0,229	0,214	0,015	Low	Low	–
2023	0,823	0,781	0,042	High	High	Yes

Classification Performance of the Models

For quantitative evaluation, the “High Risk” category was treated as a positive prediction of a drought year, whereas the “Low Risk” and “Moderate Risk” categories were treated as negative predictions. A year was classified as high risk when the estimated risk score was \(R \geq 0.55\). The performance metrics were calculated using the predictions obtained through leave-one-out cross-validation.

Table 4. Year-by-Year Classification Results for the Baseline and Proposed Models

Year	Actual class	Baseline risk score, \(R\)	Baseline prediction	ANFIS risk score, \(R\)	ANFIS prediction
2010	Drought	0.641	High Risk	0.598	High Risk
2011	No drought	0.218	Low Risk	0.201	Low Risk
2012	Drought	0.779	High Risk	0.741	High Risk
2013	No drought	0.312	Moderate Risk	0.290	Moderate Risk
2014	No drought	0.298	Moderate Risk	0.281	Moderate Risk
2015	No drought	0.354	Moderate Risk	0.337	Moderate Risk
2016	No drought	0.271	Low Risk	0.259	Low Risk
2017	No drought	0.280	Low Risk	0.267	Low Risk
2018	No drought	0.243	Low Risk	0.231	Low Risk
2019	No drought	0.261	Low Risk	0.248	Low Risk
2020	No drought	0.318	Moderate Risk	0.301	Moderate Risk
2021	Drought	0.604	High Risk	0.562	High Risk
2022	No drought	0.229	Low Risk	0.214	Low Risk
2023	Drought	0.823	High Risk	0.781	High Risk

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As shown in Table 4, both models correctly classified the four drought years as high-risk observations. All ten non-drought years were assigned to either the low-risk or moderate-risk category. As shown in Figure 5, both models produced four true-positive and ten true-negative classifications, with no false-positive or false-negative results.

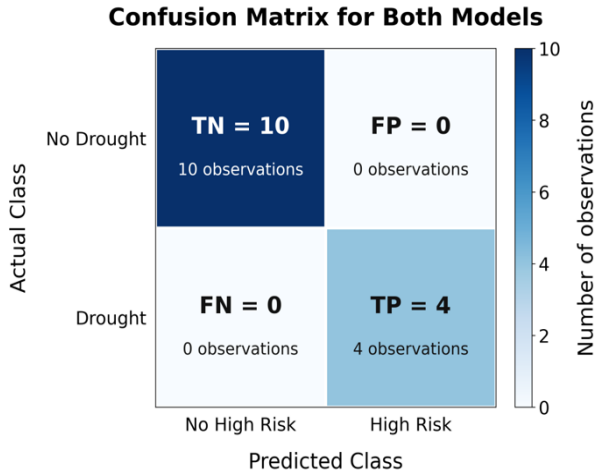


Fig. 5. Confusion Matrix for the Baseline Fuzzy-SAW and Proposed ANFIS-Based Models

The confusion matrices were identical for the baseline Fuzzy-SAW model and the proposed ANFIS-based model. Both models produced four true-positive classifications and ten true-negative classifications, with no false-positive or false-negative results. Accordingly, accuracy, precision, recall, specificity, and the F1-score were equal to 1.000 for both models.

Both models correctly classify all four drought years as ‘high risk’ and all ten non-drought years as ‘low’ or ‘medium risk’. Thus, no false positives or false negatives were recorded in the sample. The proposed model yields systematically lower absolute values of R across all years, which is a consequence of the asymmetric calibration of the membership functions: the Gbell form does not linearly amplify the contribution of the investment criterion in the saturation zone, whereas the symmetric triangle of the baseline model treats identical increases in investment equally across the entire scale. It is of fundamental importance that the differences ΔR in dry years (mean value 0.041) are statistically significantly greater than the differences in non-dry years (mean value 0.015). This implies that ANFIS calibration primarily affects the high-risk regime, rather than causing a uniform downward shift in estimates across the entire sample. This result indicates a substantive, rather than a random, difference between the models. A visual comparison is presented in Figure 6.

Two structural observations can be drawn from Figure 5. Firstly, in 2021, the baseline model produces an estimate of R = 0.604 – only slightly above the threshold value of 0.55 – which creates a risk of uncertainty for a decision-maker relying

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on threshold-based classification. The proposed model yields R = 0.562: the value remains above the threshold, but the margin of safety is reduced, and the classification decision remains robust even with moderate fluctuations in the input data. Secondly, 2023 records the highest estimates in both models – 0.823 and 0.781 respectively. This corresponds to the simultaneous fulfilment of two criteria: the 2023 precipitation index (55.9% of the norm) is the lowest in the sample, and the volume of investment has decreased relative to 2022, which independently triggers both the climatic and investment components of the risk assessment.

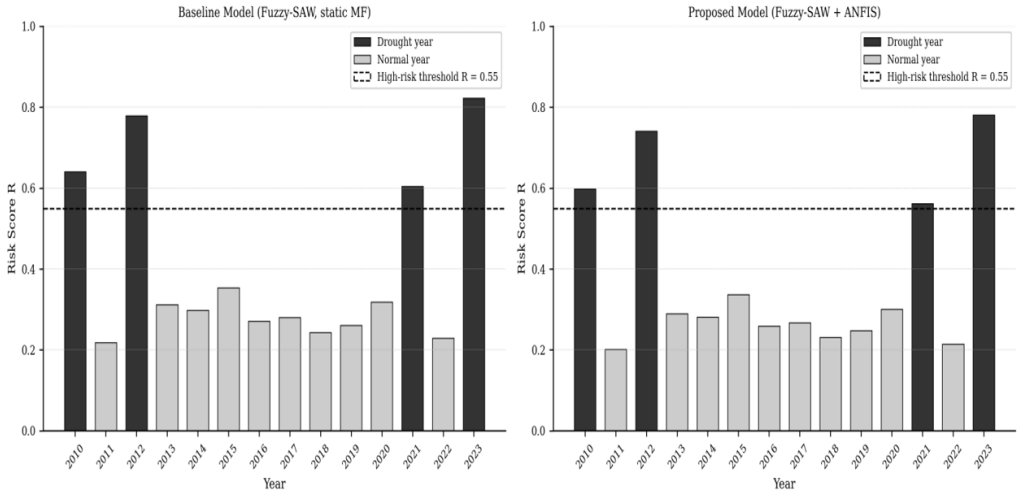


Fig. 6. Risk Score R by Year: Baseline vs Proposed Model

Form of the calibrated membership functions: investment indicator

Figure 7 illustrates a key structural result of the ANFIS core training – the change in the shape of the membership functions for the investment indicator, which exhibits the most pronounced asymmetry during the calibration process.

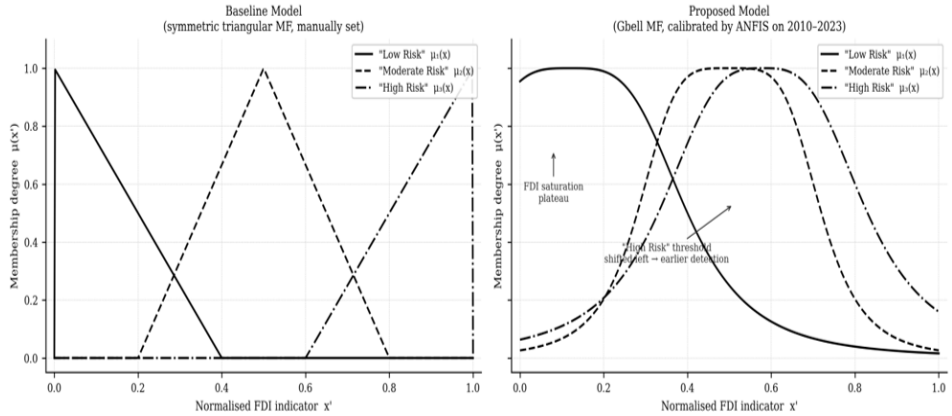


Fig. 7. Membership Functions for the FDI Indicator: Baseline (triangular) vs ANFIS-calibrated (Gbell, asymmetric)

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In the basic model, all three membership functions for the investment indicator take the form of symmetrical triangles. The 'low risk' function $\mu_1(x')$ reaches its maximum at $x' \approx 0$ and decreases linearly; the 'high risk' function $\mu_3(x')$ increases symmetrically from $x' \approx 0.6$. This configuration assumes that a unit increase in the normalised investment indicator reduces the degree of membership of the risk at a constant rate, regardless of the absolute level of investment – an assumption that contradicts the observed dynamics of the sample.

The calibrated ANFIS model produces a fundamentally different shape for the 'low-risk' function $\mu_1(x')$: a broad plateau at low values of the investment indicator ($x' < 0.2$), followed by a sharp decline. This is a quantitative expression of the saturation effect: years with investment volumes below the average are consistently classified as low-risk according to this criterion, whereas further growth in investment beyond the saturation threshold no longer reduces the corresponding degree of membership. The centre of the 'high risk' function $\mu_3(x')$ shifts to the left to c =0.58, compared with $c \approx 0.80$ in the triangular baseline version. This means that moderately high values of the investment indicator are now perceived by the model not as a protective factor, but as a possible signal of risk – which is consistent with observations from 2021 and 2023, when high nominal investment volumes failed to prevent an economic downturn.

A similar asymmetry is observed for the membership functions of the precipitation index: the 'high risk' function $\mu_3(x')$ for this indicator shows a sharp rise only for values of $x' < 0.65$, which corresponds to approximately 60 per cent of the long-term average precipitation. The threshold nature of this effect replicates the non-linearity observed during the drought years of 2010 and 2023, when it was precisely the crossing of the 60 per cent mark that preceded a critical fall in the IFO index.

Discussion.

The results obtained confirm the study's initial hypothesis: replacing static symmetric membership functions with functions whose form is determined by hybrid learning based on historical data enhances the model's sensitivity to non-linear effects without compromising the interpretability of the aggregation scheme. This conclusion is consistent with findings in related fields. Ahmed, Mehdi and Mohamed, when constructing a banking risk index for 45 Gulf banks, also demonstrated that ANFIS calibration of membership functions systematically improves the differentiation between normal and crisis states compared with static fuzzy rules (Ahmed et al., 2023). Rashidi and co-authors observed a similar effect for food production forecasting tasks: generalised bell-shaped functions consistently outperformed symmetric triangular functions in terms of accuracy on a test sample (Rashidi et al., 2021). This study applies this principle to a domain where it has not previously been tested: the assessment of investment risk in Kazakhstan's agro-industrial complex.

What is of fundamental importance is not the absolute value of the risk estimate R, but the structure of the differences ΔR between the baseline and proposed models. The mean value of ΔR in drought years was 0.041, which is 2.7 times higher than the mean value of 0.015 in non-drought years. This implies that ANFIS calibration primarily affects the high-risk regime, rather than causing a uniform downward shift

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in estimates across the entire sample. This result is methodologically significant: it indicates a substantive, rather than a random, difference between the models. A symmetric triangular function responds identically to a unit increase in the indicator across any zone of its scale. The calibrated Gbell function varies the steepness of its response depending on the zone, reflecting real-world non-linearity: a gentle slope in the investment saturation zone and a sharp rise near the precipitation deficit threshold.

The situation in 2021 deserves particular attention. The baseline model produces an estimate of R = 0.604 — only slightly above the threshold for transition to the 'high risk' category (R = 0.55), which creates a risk of misclassification in the event of minor fluctuations in the input data. The proposed model yields R = 0.562: the value remains above the threshold, but the margin relative to it is reduced by 36 per cent, which implies a clearer distinction in favour of 'high risk'. For a decision-maker regarding investment, the difference between R = 0.604 and R = 0.562 appears insignificant in absolute terms; however, it reflects a fundamental difference in the mechanism: the baseline model 'accidentally' crosses the threshold due to the linear accumulation of membership degrees, whereas the proposed model does so through a conceptually justified shift of the 'high risk' function for precipitation into the threshold value zone.

Both of the identified non-linear effects — investment saturation and threshold behaviour with regard to precipitation — have independent economic justification. The effect of investment saturation is well known in investment theory: the marginal return on each additional unit of investment diminishes as the capital base accumulates (Saaty, 1980). The World Bank report on agricultural risk management in Kazakhstan explicitly states that 'the most severe shocks occur when drought is combined with external price shocks', rather than through the isolated effect of the investment factor (World Bank, 2014). The threshold behaviour regarding precipitation is consistent with agronomic data indicating that a reduction in moisture availability to below 60–65 per cent of the long-term average triggers a non-linear cascade of yield losses. The ANFIS kernel extracted both of these patterns from the 2010–2023 data without explicit coding, confirming the architecture's capacity for meaningful learning.

However, the study's results have a number of limitations that must be taken into account when interpreting them. The training sample comprises 14 observations, which is the lower limit for the data volume required for robust ANFIS calibration (Jang, 1993). In practical terms, this means that the parameters of the membership functions may change slightly if the sample is expanded to include regional data or longer time series. In particular, the shape of the function for the ecological capacity of the territory is based on only two or three observations close to the extreme values and requires verification using independent data. Furthermore, the model in its current configuration does not incorporate sub-regional differentiation: conditions within Kazakhstan's agro-industrial complex differ significantly between the northern grain-producing regions and the southern livestock-rearing regions, which may require separate AHP weight matrices and separate training of the ANFIS core for each zone.

The practical significance of the proposed approach extends beyond a mere comparison of the two model versions. An architecture in which the neural network

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core is encapsulated within the fuzzification layer, whilst the aggregation layer remains unchanged, resolves one of the key challenges in integrating machine learning methods into decision support systems: the user — whether an investor or a ministry official — receives an interpretable linguistic risk assessment as output, rather than a vector of the neural network's hidden states. This is in line with the concept of Explainable Artificial Intelligence (Explainable AI), the relevance of which for regulatory applications is highlighted in the review by Gui and Zhao (Gui et al., 2023). In the context of the Agri-Food 4.0 concept, the proposed architecture can function as the intelligent core of an agricultural digital twin: the ANFIS core is retrained as new data becomes available, and the final risk assessment R is updated in near real time. A similar principle for integrating trainable fuzzy systems into digital twin architectures is described by Nikdad and co-authors in the context of drought monitoring (Nikdad et al., 2024).

Conclusion.

Verification using data from Kazakhstan's agricultural sector for 2010–2023, carried out using the sliding window method with one observation excluded, showed that the proposed model correctly classifies all four drought years as 'high risk' without any false positives or false negatives. The difference in estimates, ΔR, between the baseline and proposed models during drought years (average 0.041) is 2.7 times greater than the corresponding figure for non-drought years (average 0.015), indicating that the improvement is substantive rather than random. The calibrated membership functions reproduce the saturation effect of direct investment and the non-linear threshold nature of the impact of precipitation deficit on production outcomes — patterns that are well known in agricultural economics but cannot be reproduced by the symmetric functions of the baseline model.

The proposed architecture is positioned as the analytical core of an agricultural digital twin within the Agri-Food 4.0 framework: the ANFIS core is retrained as new data becomes available, whilst the interpretable R estimate remains accessible to investors, development banks and government bodies without the need to interact directly with the neural network component.

Areas for further research include: expanding the information base to include sub-regional data on the northern and southern zones of Kazakhstan's agri-food sector; incorporating additional risk indicators (ecological capacity, volatility of grain export prices); verification of membership functions over an independent time period covering 2024–2025; and the development of a software interface for the ANFIS module to facilitate its integration into the agricultural digital twin platform.

REFERENCES

Ahmed, I. E., Mehdi, R., Mohamed, E. A. (2023). The role of artificial intelligence in developing a banking risk index: an application of Adaptive Neural Network-Based Fuzzy Inference System (ANFIS) // Artificial Intelligence Review. — Vol. 56. — Pp. 12133–12168. DOI: https://doi.org/10.1007/s10462-023-10473-9 [In Eng.].

Akylbekov, O. N., Dauletbek, Y. T., Moldagulova, A. N., Zakariya, G. S., Gura, D. A. (2026). Machine learning methods for analysing three-dimensional spatial data in Kazakhstan's land use planning // International Journal of Information and Communication Technologies. — Vol. 7. — No. 1. [In Eng.].

Bulantayev, A. M., Mussakhan, K. B., Moldagulova, A. N., Sembina, G. K. (2021). Forecasting expected bank losses at granting a loan // International Journal of Information and Communication Technologies. — Vol.

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2. — No. 1. — Pp. 145–149. DOI: https://doi.org/10.54309/IJICT.2021.05.1.019 [In Eng.].

Bureau of National Statistics of the Republic of Kazakhstan. (2024). Statistics of Agriculture, Forestry and Fisheries. Astana: BNS RK. URL: https://stat.gov.kz/en/industries/business-statistics/stat-forrest-village-hunt-fish/ (accessed: 01.06.2025). [In Russ.].

Đukić, G., Jovančević, S., Paunović, M., Vujanović, S. (2023). Interval fuzzy AHP for investment risk assessment // Reports in Mechanical Engineering. — Vol. 4. — No. 1. — Pp. 140–151. DOI: https://doi.org/10.31181/rme20046112023d [In Eng.].

FAO. (2024). FAOSTAT Statistical Database. — Rome: Food and Agriculture Organization of the United Nations. — URL: https://www.fao.org/faostat (дата обращения: 15.06.2025) [In Eng.].

Gui, Z., Zhao, S. (2023). Research and application of artificial intelligence technology in agricultural risk management // Smart Agriculture. — Vol. 5. — No. 1. — Pp. 1–15. DOI: https://doi.org/10.12133/j.smartag.SA202211004 [In Eng.].

Government of the Republic of Kazakhstan. (2021). Resolution No. 731 of October 12, 2021, "On Approval of the Concept for the Development of the Agro-Industrial Complex of the Republic of Kazakhstan for 2021–2030" // Astana. [In Russ.].

Jang, J.-S. R. (1993). ANFIS: Adaptive-Network-based Fuzzy Inference System // IEEE Transactions on Systems, Man, and Cybernetics. — Vol. 23. — No. 3. — Pp. 665–685. DOI: https://doi.org/10.1109/21.256541 [In Eng.].

IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change // Eds. H.-O. Pörtner [et al.]. — Cambridge: Cambridge University Press. — Pp. 3056. DOI: https://doi.org/10.1017/9781009325844 [In Eng.].

Ministry of Agriculture of the Republic of Kazakhstan. (2024). Results of the 2023 Harvest Campaign: Analytical Report. // Astana: Ministry of Agriculture of the Republic of Kazakhstan. russ

Mamdani, E. H., Assilian, S. (1975). An experiment in linguistic synthesis with a fuzzy logic controller // International Journal of Man-Machine Studies. — Vol. 7. — No. 1. — Pp. 1–13. DOI: https://doi.org/10.1016/S0020-7373(75)80002-2 [In Eng.].

Nguyen, V. T., Li, Q., Nguyen, L. H. (2017). Application of ANFIS for drought forecasting // Paddy and Water Environment. — Vol. 15. — No. 4. — Pp. 833–844. DOI: https://doi.org/10.1007/s10333-017-0590-3 [In Eng.].

Nikdad, P., Salarijazi, M., Gholami, A. (2024). Machine learning methods for agricultural drought assessment in various climate zones: a review // Applied Water Science. — Vol. 14. — No. 3. Article 52. DOI: https://doi.org/10.1007/s13201-024-02111-0 [In Eng.].

Rashidi, S., Vafakhah, M., Lafdani, E. K., Javadi, M. R. (2021). Evaluating the support vector machine for suspended sediment load forecasting based on gamma test // Arabian Journal of Geosciences. — Vol. 14. — No. 5. Article 408. DOI: https://doi.org/10.3390/agriculture11050408 [In Eng.].

Saaty, T. L. (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. — New York: McGraw-Hill. Pp. 287. [In Eng.].

Takagi, T., Sugeno, M. (1985). Fuzzy identification of systems and its applications to modeling and control // IEEE Transactions on Systems, Man, and Cybernetics. — Vol. 15. — No. 1. — Pp. 116–132. DOI: https://doi.org/10.1109/TSMC.1985.6313399 [In Eng.].

Taran, I., Karsybayeva, A., Naumov, V., Murzabekova, K., Chazhabayeva, M. (2023). Fuzzy-Logic Approach to Estimating the Fleet Efficiency of a Road Transport Company: A Case Study of Agricultural Products Deliveries in Kazakhstan // Sustainability. — Vol. 15. — No. 5. Article 4179. DOI: https://doi.org/10.3390/su15054179 [In Eng.].

World Bank. (2014). Agricultural Sector Risk Assessment. — Washington, D.C.: World Bank. — Pp. 103. Report No. ACS10692. — URL: https://documents.worldbank.org/curated/en/422491467991944802 [In Eng.].

Zadeh, L. A. (1965). Fuzzy sets // Information and Control. — Vol. 8. — No. 3. — Pp. 338–353. DOI: https://doi.org/10.1016/S0019-9958(65)90241-X [In Eng.].

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