سازمان هواشناسی کشور
I.R. OF IRAN
METEOROLOGICAL
ORGANIZATION

# AI-Based Operational Flood Warning System Using Multi-Model NWP Data

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## System Overview and Operational Framework

- This system has currently been developed for 380 hydrometric stations across the provinces of Semnan, Tehran, Alborz, Gilan, Mazandaran, Zanjan, Sanandaj, Ardabil, East Azerbaijan, and West Azerbaijan, with development ongoing for the remaining regions of the country.

- The flow simulation period is from 1990 to 2020.

- In this model, data from 200 synoptic and climatological stations, the geometric characteristics of the region, and dam operation information were utilized.

- To forecast flood warnings over a 10-day horizon, three models—GFS, GEM, and ICON—were employed in this system.

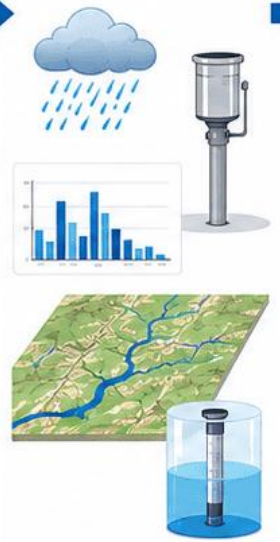
- By incorporating a management and crisis system (international internet disconnection), which is the primary challenge in system operation, along with the use of synoptic station data, pre-stored statistical data from forecast models for the next 15 days (received and stored every 5 days), as well as the behavior of precipitation events in preceding days through statistical analysis and artificial intelligence, this system remains operational.

# General Architecture of the Flood Warning System

## 1 Define the problem

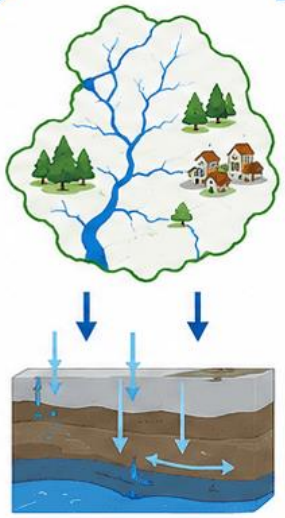
Clarify objectives, key questions, scope and constraints.

## 2 Collect data



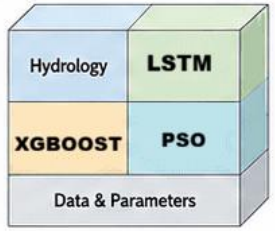
Gather relevant data (e.g., rainfall, streamflow, terrain, land use, soils, water use).

## 3 Build the conceptual model



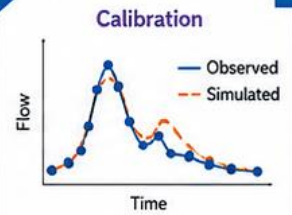
Represent how the watershed system works: processes, components and interactions.

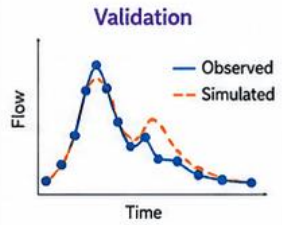
## 4 Set up the Hydrology model




**Employ an LSTM AI model with basin physiographic characteristics to prepare the hydrological simulation.**

## 5 Calibrate and validate




Adjust parameters and test the model to ensure it reproduces observed conditions reliably.

## 6 Interpret results and support decisions

Turn model insights into clear information and recommendations to support informed decisions.

## 7 forecast correction and diagnostics

**NWP**

GFS
ICON
GEM

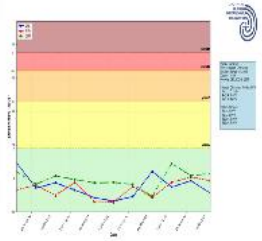
**LSTM**

- Early Stopping
- ReduceLROnPlateau
- Overfitting Control
- GPU/CPU (auto)

**XGBoost**

- Learning Rate
- Max Depth
- n_estimators
- Regularization
- Early Stopping

## 8 Flow rate prediction



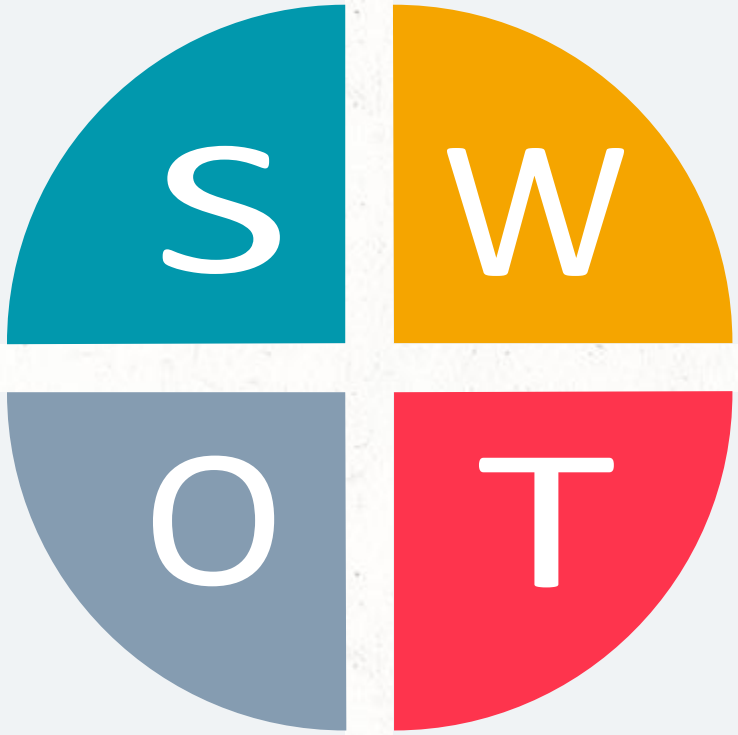
# SWOT Analysis

**STRENGTHS**

**Fast execution and offline model operation**

**WEAKNESSES**

Requires detailed watershed information




Use of AI and available watershed data

**OPPORTUNITIES**

**THREATS**

Internet disconnection and IP changes of NWP model servers

# Overall Architecture of Numerical Weather Model Ensemble System

**Observed Weather**
(Historical data)

**1 Stage 1**
GFS / GEM / ICON

GFS | GEM | ICON

**Evaluation Metrics**
(For each model and variable)

**Game Theory Ranking**
(Model weighting and ranking)

**Precipitation Metrics**

- MAE (Mean Absolute Error)
- RMSE (Root Mean Squared Error)
- Bias (Mean Bias)
- POD (Probability of Detection)
- FAR (False Alarm Rate)
- ETS (Equitable Threat Score)

**Temperature Metrics**

- MAE (Mean Absolute Error)
- RMSE (Root Mean Squared Error)
- Bias (Mean Bias)
- Correlation (Pearson Correlation)
- R2 (Coefficient of Determination)

**2 Stage 2:** LSTM+XGBoost

- 5 NWP models
- Game Theory coefficients
- Bias correction
- Seasonal lag
- Cyclic features

LSTM | XGBoost

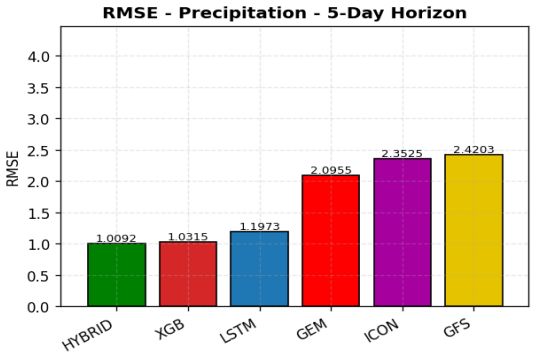
Weighted / Ridge Stacking

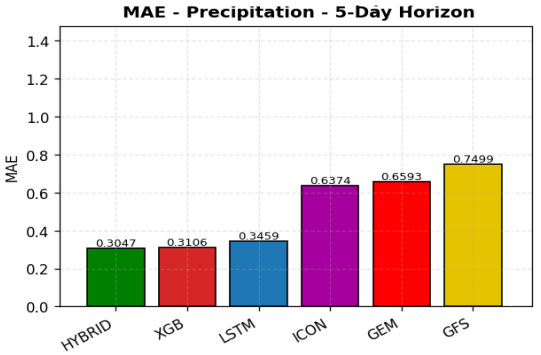
Corrected forecast

**3 Stage 3 / 5-Day Real Forecast**

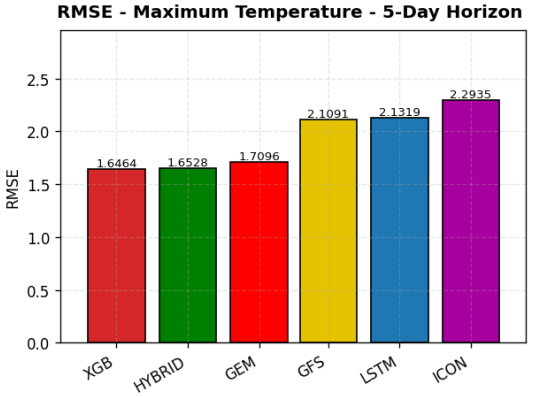
Today (h0 optional) → Tomorrow (h1) → +2 Days (h2) → +3 Days (h3) → +4 Days (h4) → +5 Days (h5)

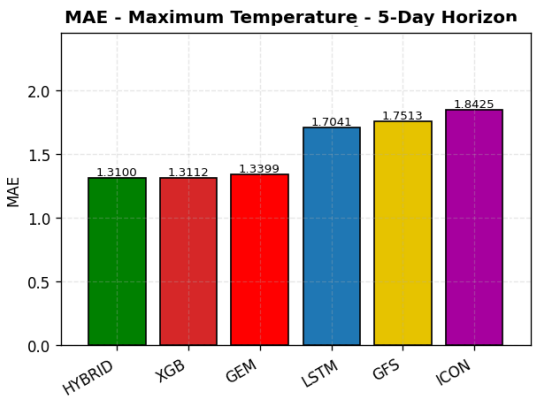
## Station 40702 - Model Ranking - Precipitation - 5-Day Horizon



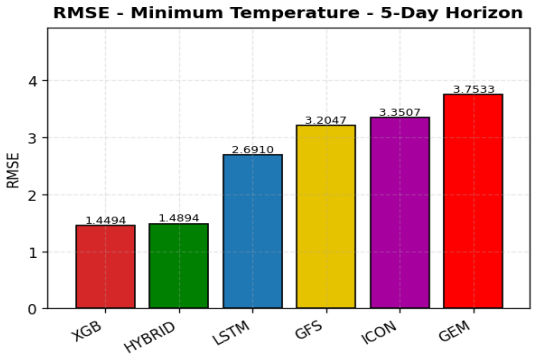



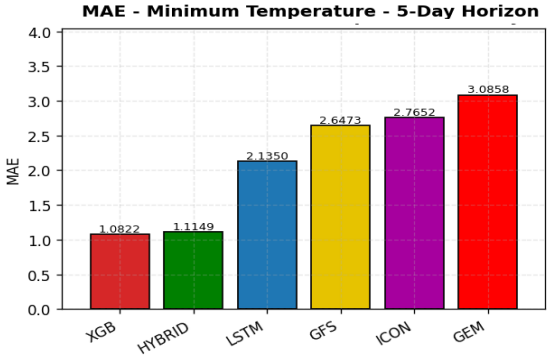

## Station 40702 - Model Ranking - Maximum Temperature - 5-Day Horizon



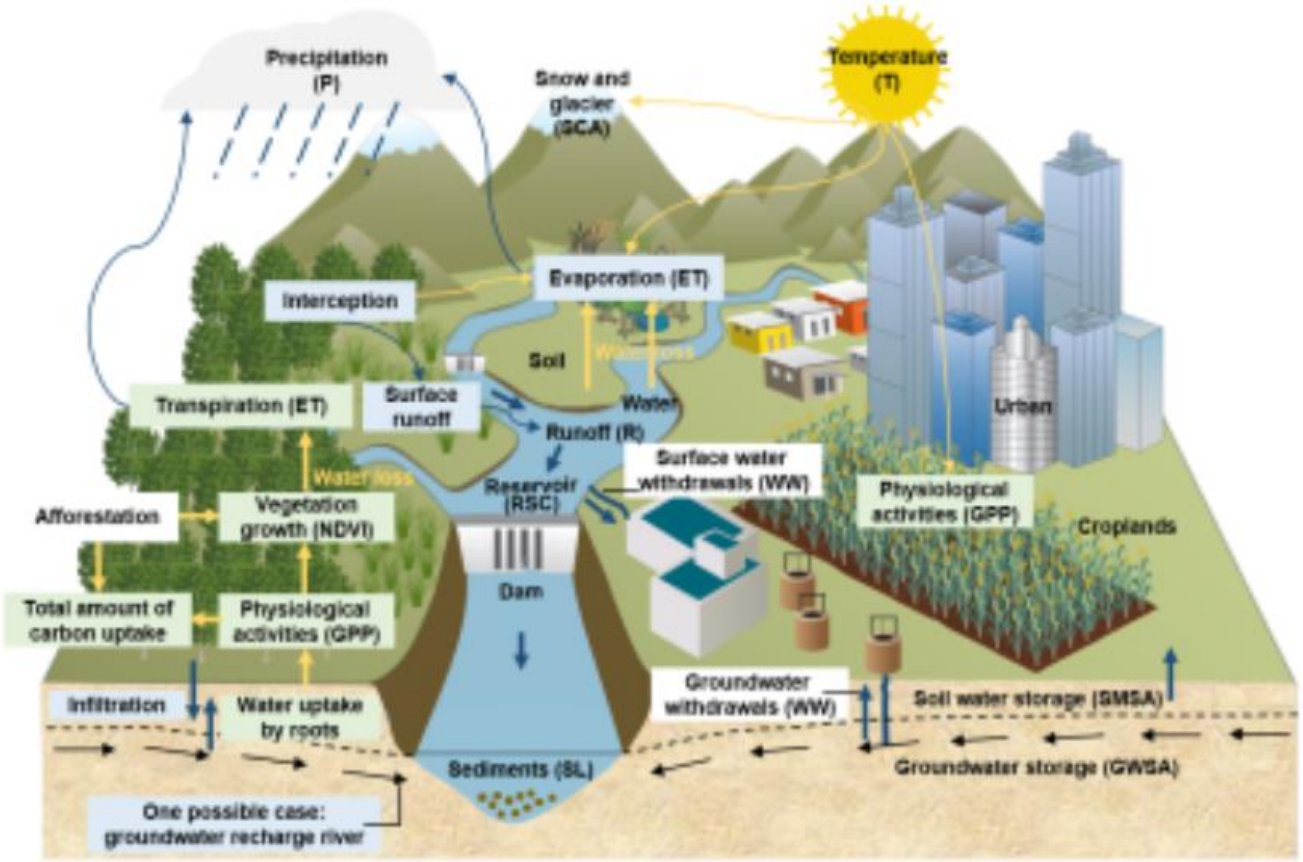




## Station 40702 - Model Ranking - Minimum Temperature - 5-Day Horizon



# Watershed Characteristics



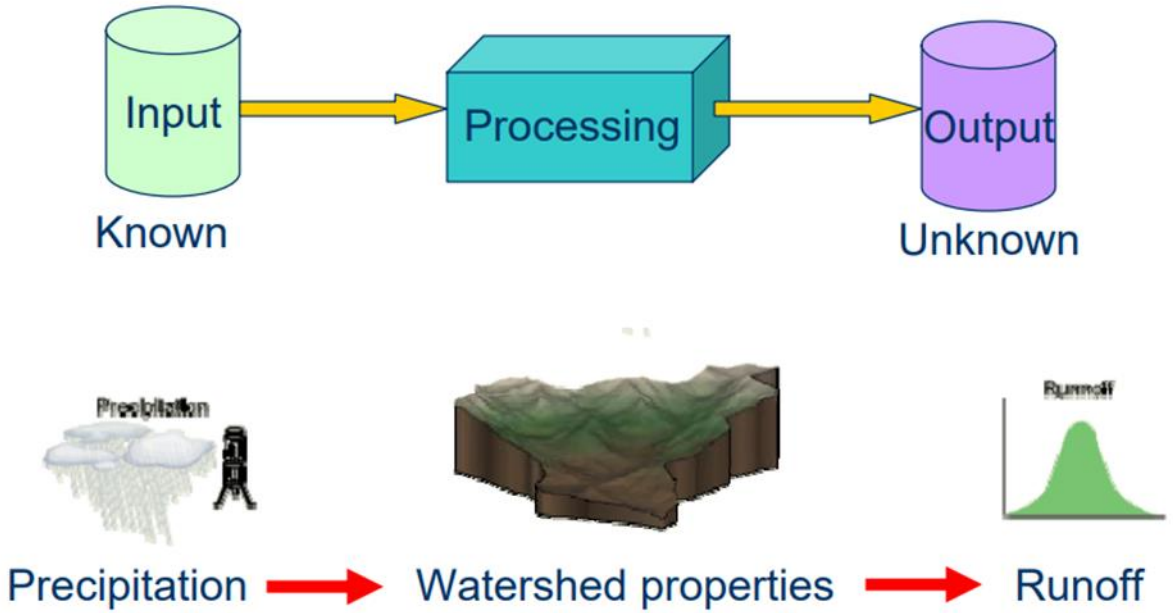

- Sub-basins ❑
- River Network ❑
- Vegetation Cover and Land Use ❑
- Soil Hydrologic Group ❑
- Dam Information and Location ❑
- Synoptic Station Information ❑
- Hydrometric Station Information ❑

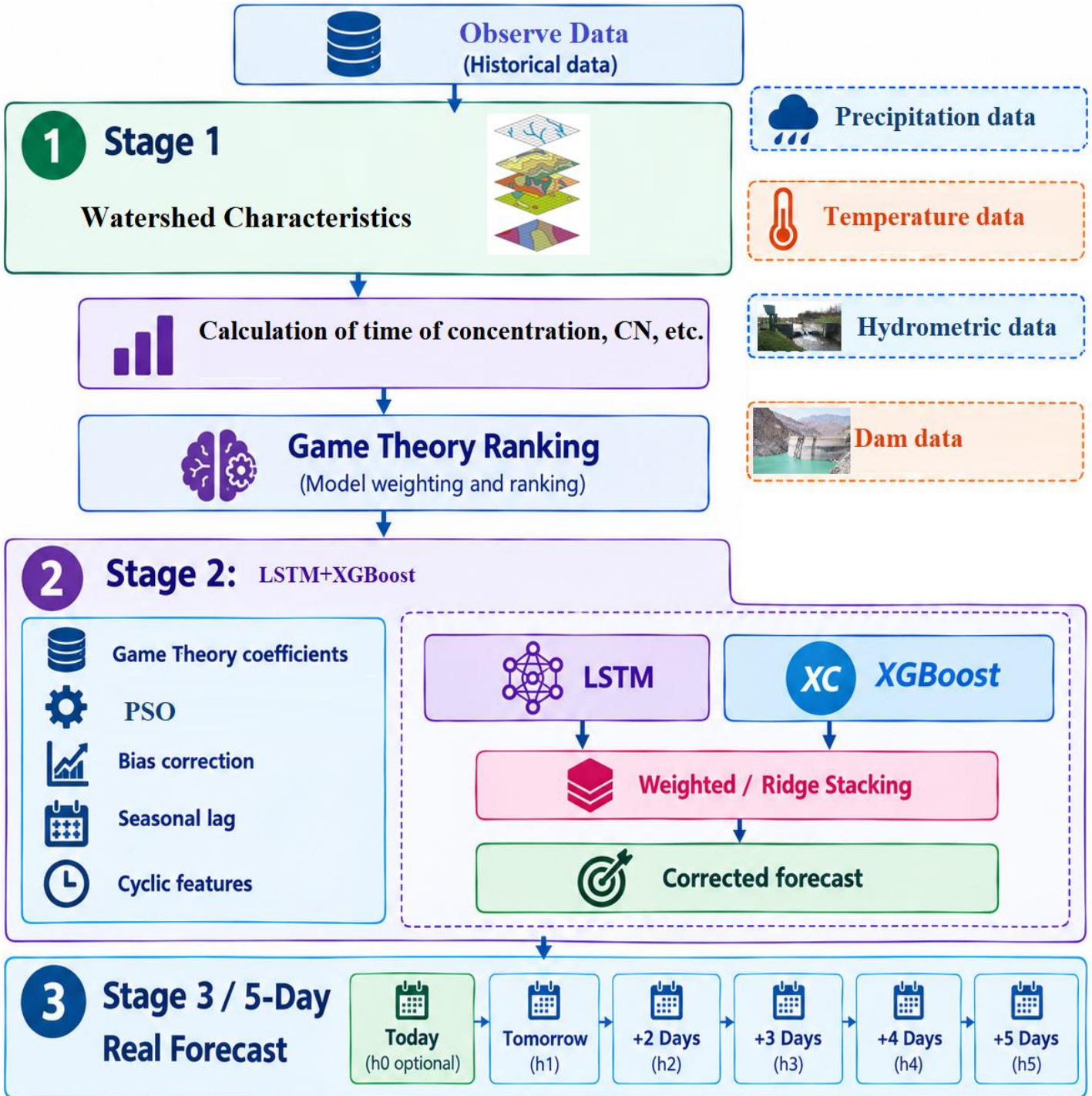
**Overview of Recorded Data Status at Meteorological Stations**

| Station Type | Data Recording Method | Recording Time | Recording Accuracy | Usability in Forecast Mode |
|---|---|---|---|---|
| Synoptic | Automatic | 6 UTC | Suitable | Available |
| | Automatic | 18 UTC | Degraded | |
| Rain Gauge | Traditional | 15 UTC | Unsuitable | Requires synchronization for daily recording |
| Climatology | Traditional | 15 UTC | Unsuitable | |
| | Automatic | 6 UTC | Suitable | |

# Hydrological Modeling Using LSTM

## LSTM-Based Streamflow Simulation Using Watershed






**Generating land use layers (1990–2025) using Google Earth Engine**

**Using the geometric and operation information of dams**

**Using data from 380 hydrometric stations and 200 synoptic and climatological stations**

Simulation Discharge (LSTM+XGBoost)

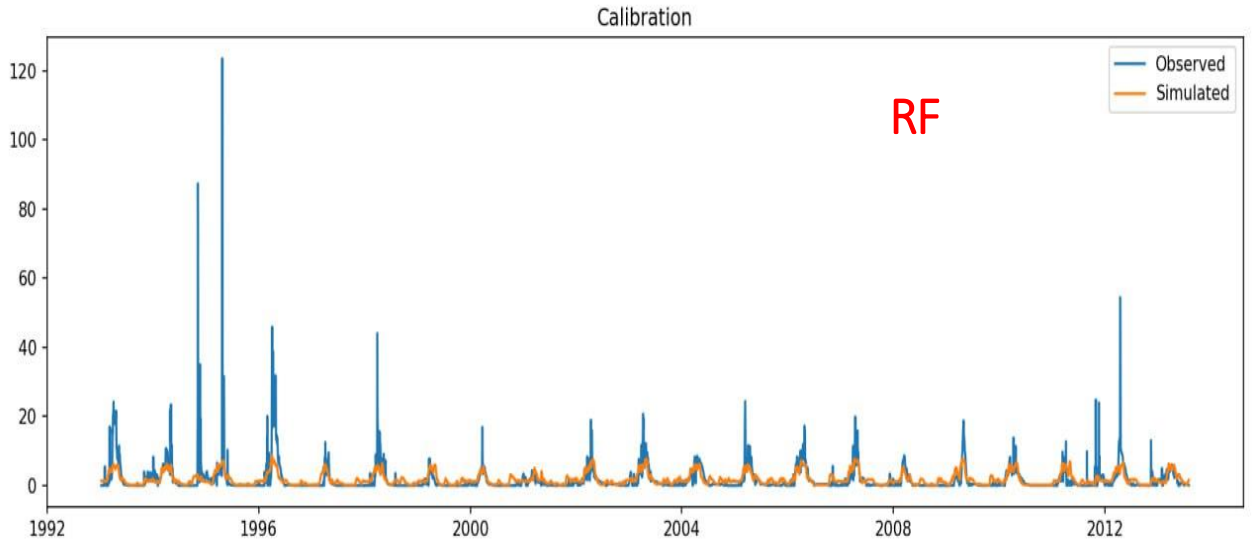
**Evaluation of ensemble/hybrid models and various datasets, running the system offline (without internet access) using information from radar, stations, and downloaded statistical forecast data for the next 15 days**

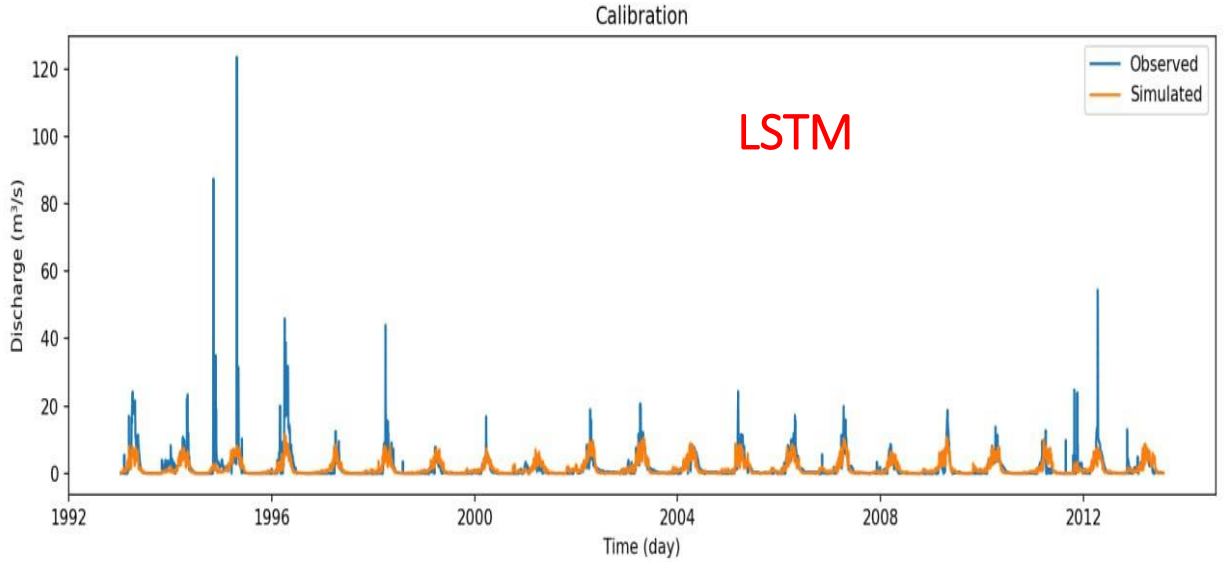
$$R^2 = \frac{\left[\sum_i^n (Q_{O_i} - \bar{Q}_O)(Q_{S_i} - \bar{Q}_S)\right]^2}{\sum_{i=1}^n (Q_{O_i} - \bar{Q}_O)^2 \sum_{i=1}^n (Q_{S_i} - \bar{Q}_S)^2}$$

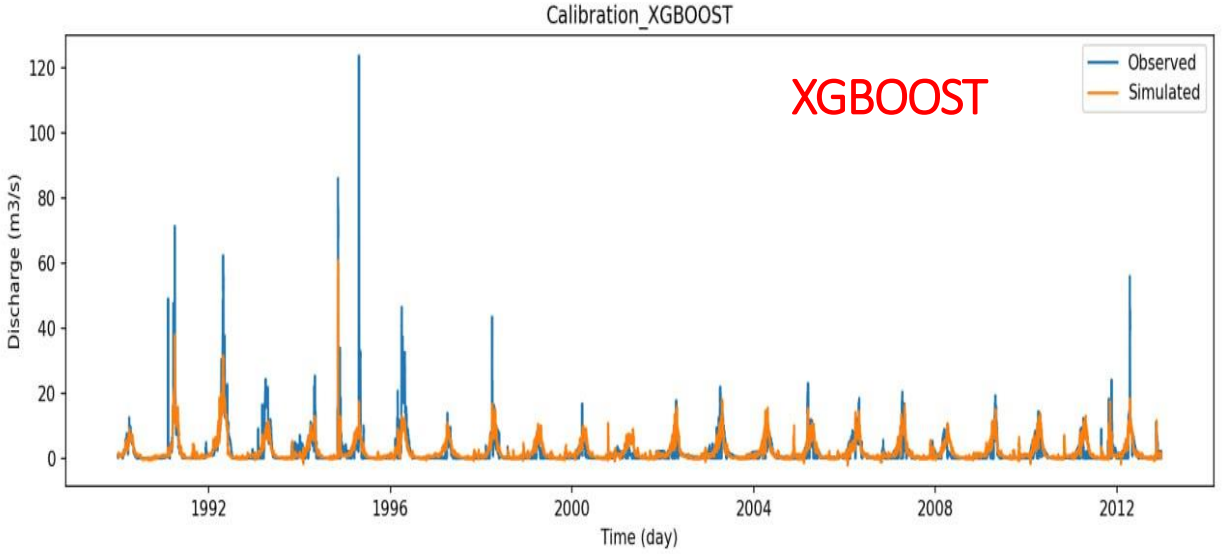
$$NSE = 1 - \frac{\sum_{t=1}^T (Q_o^t - Q_m^t)^2}{\sum_{t=1}^T (Q_o^t - \bar{Q}_o)^2}$$

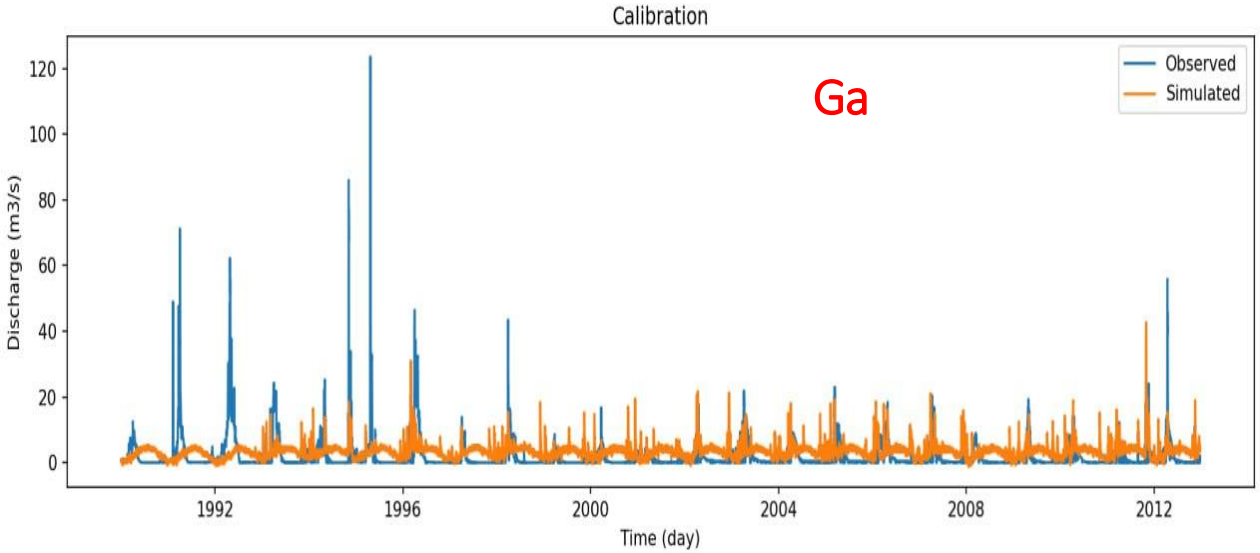
| Value | Model Performance |
|---|---|
| NSE=1, R2=1 | Perfect |
| 0.75≤NSE<1<br>0.75≤R2<1 | Excellent |
| 0.5≤NSE<0.75<br>0.5≤R2<0.75 | Good |
| 0≤NSE<0.5<br>0≤R2<0.5 | Acceptable |
| NSE<0<br>R2<0 | Poor |

# Results of Each Model Alone for Hydrograph Extraction at Solghan Hydrometric Station

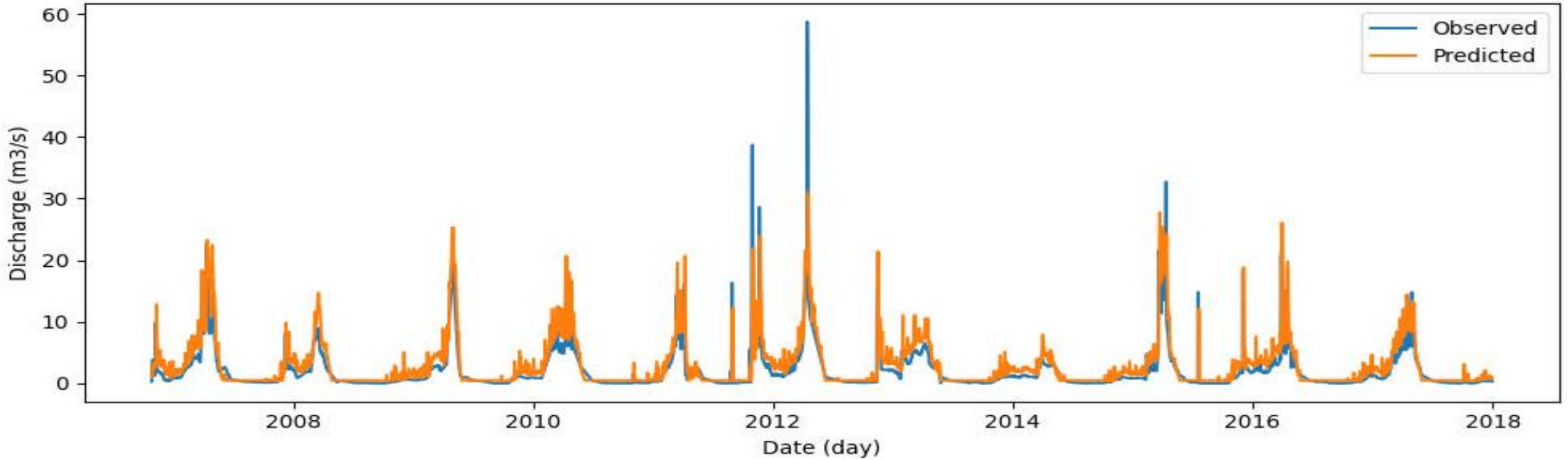


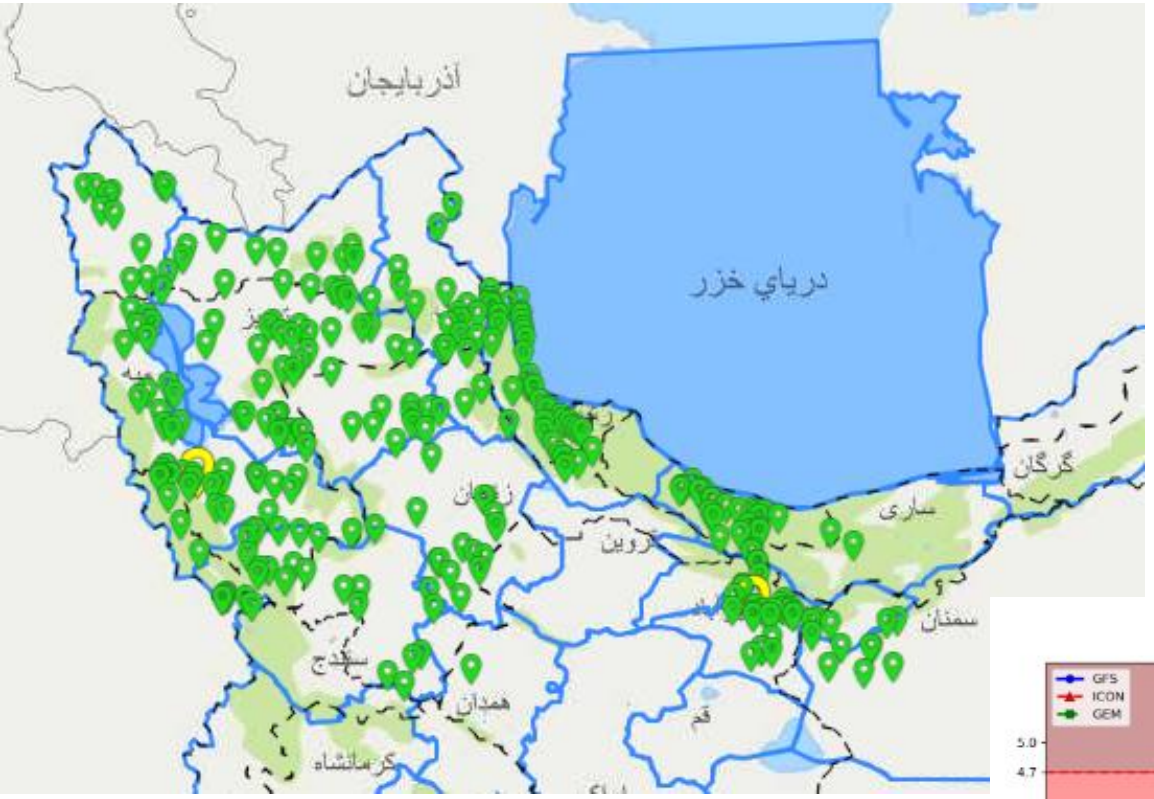



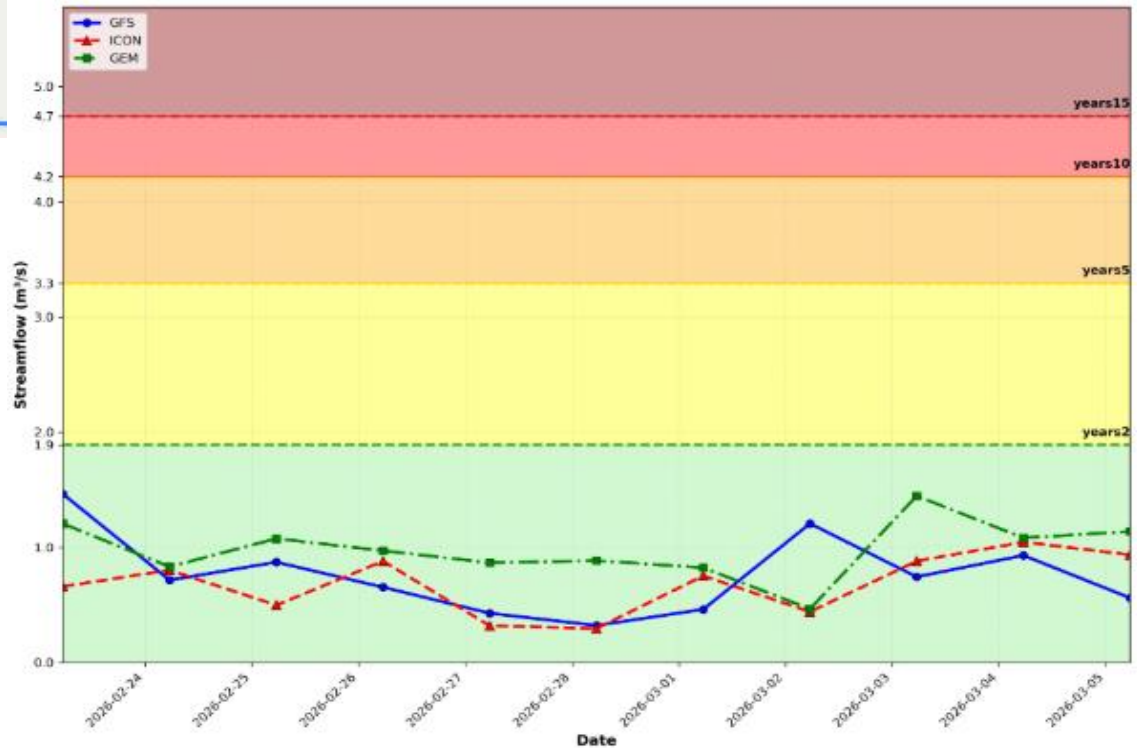



# Evaluation of the Hybrid LSTM + XGBOOST Model at Solghan Hydrometric Station




| Model | NSE | $R^2$ | RMSE |
|---|---|---|---|
| LSTM | 0.۴۰ | ۰/۵۵ | ۳/۴۹ |
| GA | ۰/۳۴ | ۰/۴۸ | ۳/۸۷ |
| RF | ۰/۴۱ | ۰/۵۹ | ۳/۴۲ |
| XBOOST | 0.۷۲ | ۰/۸۳ | ۱/۱۵ |
| LSTM + XBOOST | ۰/۸۳ | ۰/۹ | ۰/۷ |

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Basin: Garmsar
River: Darreh Chartagh
Station: Tange-e-Rameh
Code: 47942
Models: GFS, ICON, GEM

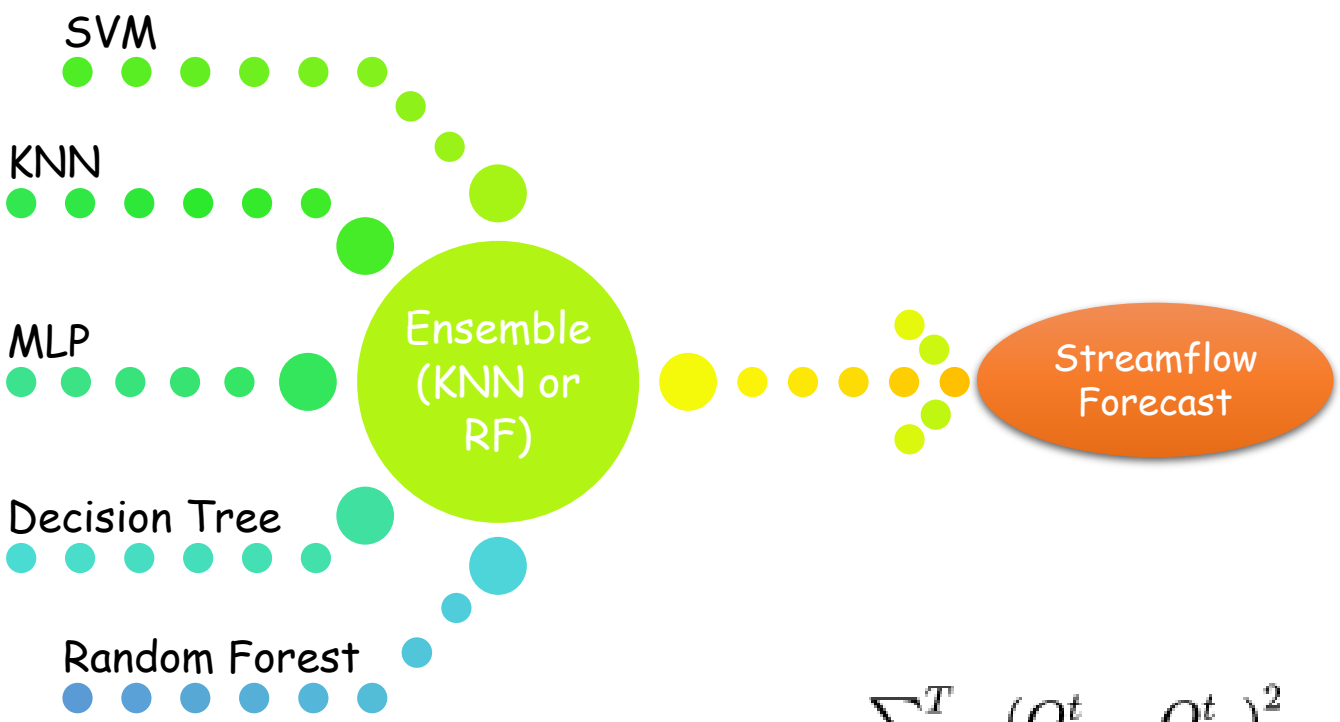
Highest Discharge Model: GFS
Max: 1.5 m³/s
Avg: 0.8 m³/s
Min: 0.3 m³/s

Return Periods:
T2: 1.9 m³/s
T5: 3.3 m³/s
T10: 4.2 m³/s
T15: 4.7 m³/s

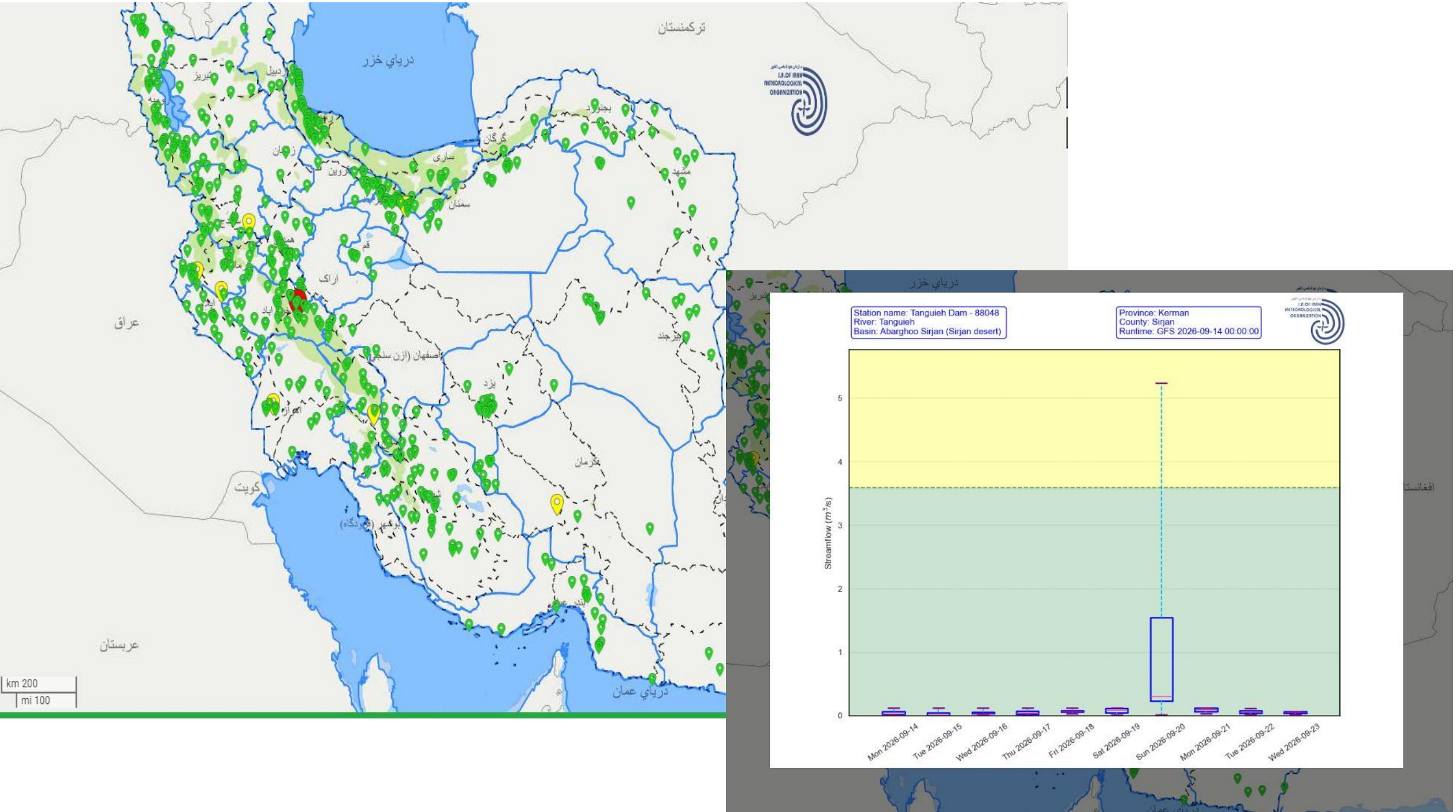
# توسعه مدل پیش بینی سیلاب با رویکرد یادگیری ماشین

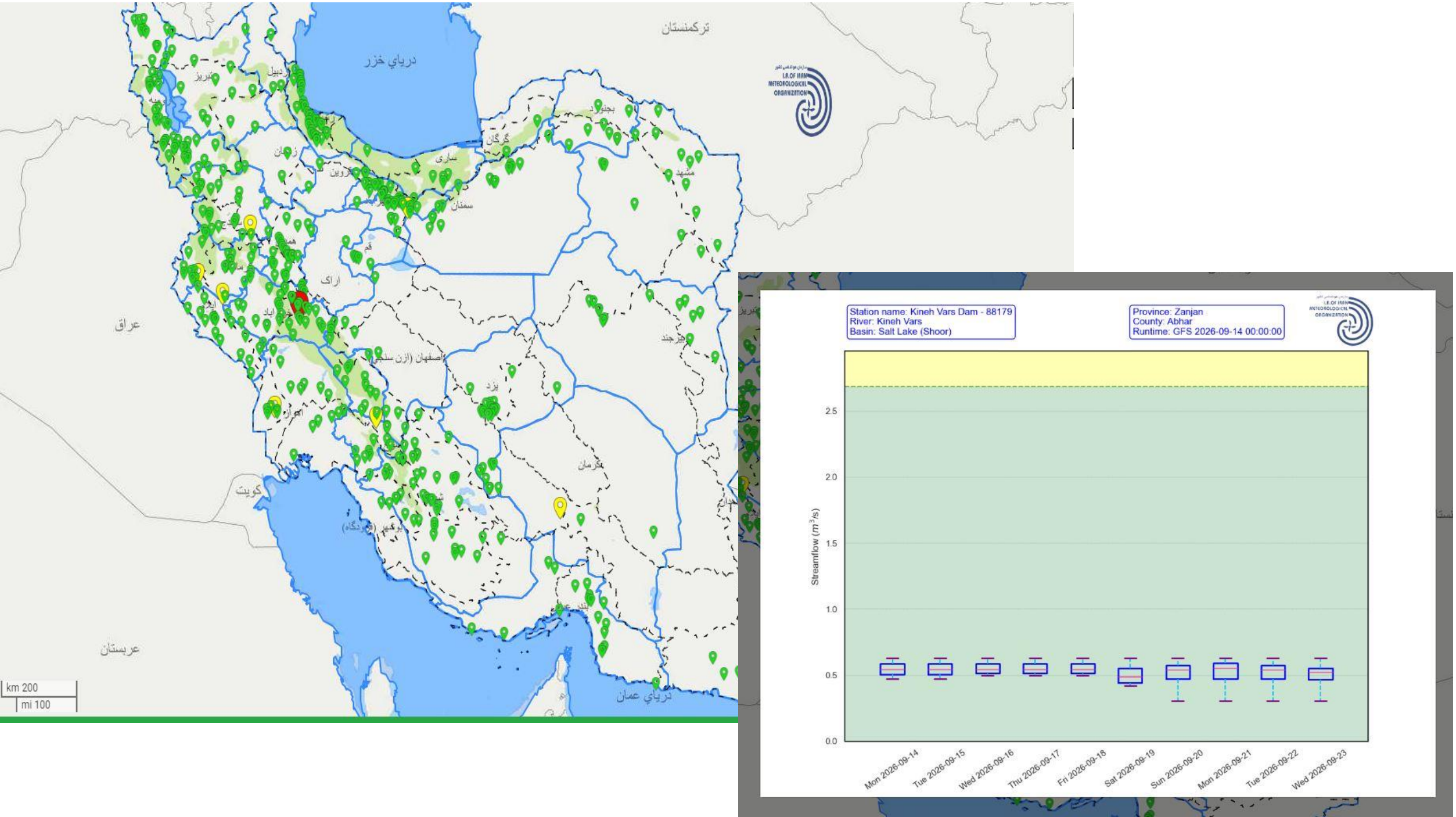
# روش

- ✓ جمع‌آوری داده‌های بارش از ایستگاه‌های هواشناسی و ماهواره
- ✓ جمع‌آوری داده‌های دبی روزانه ایستگاه‌های هیدرومتری
- ✓ تکمیل داده های هواشناسی (بارش) با استفاده از روش وزنی ضرایب همبستگی
- ✓ انتخاب بهترین مجموعه پارامتر برای مدلسازی شامل:
  - بارش پیشین تجمعی ۲، ۵، ۱۰ و ۳۰ روزه
  - ماه شمسی
  - شماره روز از ابتدای سال
  - جریان پایه




$$NSE = 1 - \frac{\sum_{t=1}^{T} \left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T} \left(Q_o^t - \overline{Q}_o\right)^2}$$


Station name: Tanguieh Dam - 88048
River: Tanguieh
Basin: Abarghoo Sirjan (Sirjan desert)
Province: Kerman
County: Sirjan
Runtime: GFS 2026-09-14 00:00:00
Streamflow ($m^3/s$)
0
1
2
3
4
5
Mon 2026-09-14
Tue 2026-09-15
Wed 2026-09-16
Thu 2026-09-17
Fri 2026-09-18
Sat 2026-09-19
Sun 2026-09-20
Mon 2026-09-21
Tue 2026-09-22
Wed 2026-09-23
دریای خزر
ترکمنستان
عراق
کویت
عربستان
دریای عمان
km 200
mi 100


ترکمنستان
دریای خزر
تبریز
اردبیل
بجنورد
گرگان
ساری
زنجان
قزوین
مشهد
سمنان
اراک
عراق
اصفهان (ازن سنجی)
یزد
بیرجند
کرمان
کویت
بوشهر (فرودگاه)
عربستان
دریای عمان
km 200
mi 100
Station name: Kineh Vars Dam - 88179
River: Kineh Vars
Basin: Salt Lake (Shoor)
Province: Zanjan
County: Abhar
Runtime: GFS 2026-09-14 00:00:00
Streamflow ($m^3/s$)
0.0
0.5
1.0
1.5
2.0
2.5
Mon 2026-09-14
Tue 2026-09-15
Wed 2026-09-16
Thu 2026-09-17
Fri 2026-09-18
Sat 2026-09-19
Sun 2026-09-20
Mon 2026-09-21
Tue 2026-09-22
Wed 2026-09-23