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ORIGINAL PAPER

Evaluation of the performance of satellite products and microphysical schemes with the aim of forecasting early flood warnings in arid and semi-arid regions (a case study of northeastern Iran)

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Abstract

Flood early warning requires rainfall data with a high temporal and spatial resolution for flood risk analysis to simulate flood dynamics in all small and large basins. However, such high-quality data are still very scarce in many developing countries. In this research, in order to identify the best and most up-to-date rainfall estimation tools for early flood forecasting in arid and semi-arid regions, the northeastern region of Iran with 17 meteorological stations and four rainfall events was investigated. The rainfall products of satellites (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Climate Data Record, Global Satellite Mapping of Precipitation, Climate Hazards Group InfraRed Precipitation with Station, European Reanalysis (ERA5), Global Precipitation Measurement) along with the most widely used microphysical schemes of Weather Research and Forecasting (WRF) model (Purdue-Lin (Lin), WRF Single-Moment class 3, 6, and WRF Double-Moment class 6. were used for rainfall modeling. The efficiency of each of these models to forecasting the amount of rainfall was verified by four methods: Threat Scores (TS), False Alarm Ratio, Hit Rate (H), and False Alarm (F). Analysis of research findings showed that the WRF meteorological model has better accuracy in rainfall modeling for the next 24 h. In this model, Lin's microphysical scheme has the highest accuracy, and its threat score (TS) quantity is up to 98% efficient in some stations. The best accuracy of satellite products for estimating the amount of rainfall is up to 50%. This accuracy value is related to the satellite product (ERA5). In this method, an 18 km distance from the ground station is the best distance for setting up the space station, which is used for input to hydrological/hydraulic models. Based on the results of this research, by using the connection of the WRF model with hydrology/hydraulic models, it is possible to predict and simulate rainfall-runoff up to 72 h before its occurrence. Also, by using these space stations, the amount of rainfall is estimated for the entire area of the basin and an early flood warning is issued.

Keywords Precipitation · Satellite products · Flood · WRF · Warning forecast

Extended author information available on the last page of the article

1 Introduction

Damages caused by sudden floods due to severe climatic events in the world are increasing rapidly (Chao et al. 2021). Flash floods cause loss of life and severe financial losses worldwide (Hu et al. 2020) and threaten the development of human societies (Li et al. 2016). In Iran, there was an increase in flood losses from 17.19 to 133 million USD between 1950 and 2000 (ESCAP 2019). In 2019 alone, flooding accounted for the death of 78 people around the country and caused over 1.1 billion USD in damage in Iran (Boroujeni 2019). Studies show that the number of floods in recent years is increasing in arid and semi-arid areas of Iran. Because climate change worsens the intensity and frequency of extreme weather conditions in arid and semi-arid regions, and leads to heavy rainfall, high temperatures and longer periods of drought (Council 2009; Nabinejad and Schüttrumpf 2023). Therefore, communities should manage and implement strategies to reduce the damages of these floods in arid and semi-arid areas. One of the solutions is to use flood forecasting and early warning systems (Hong et al. 2010; Jang et al. 2021). Early warning and emergency response to destructive floods depend on accurate and timely rainfall forecasts (Belabid et al. 2019; Cloke and Pappenberger 2009; Massari et al. 2018; Pan et al. 2021). Which are introduced as input to hydrological/hydraulic models (Sättele et al. 2015; Worqlul et al. 2017) Precipitation is considered the most important variable for early warnings (Falck et al. 2021; Liu et al. 2012; Moradkhani et al. 2012). One of these forecasting methods is the use of remote sensing data sets and meteorological models that can fill this gap (Wanzala et al. 2022; Worqlul et al. 2017). Advances in remote sensing and space science have facilitated the availability of real-time data and high spatial and temporal resolution of rainfall products (Guntu et al. 2020; Yeditha et al. 2020). These advantages have led many flood warnings to use satellite precipitation products as input to hydrological models (Agarwal et al. 2020; Gao et al. 2018; Liu et al. 2018; Sulugodu and Deka 2019). In addition to precipitation products, Numerical Weather Prediction (NWP) has become a tool in operational meteorological research and forecasting in recent years (Lu et al. 2020; Mayer and Yang 2022). With the increasing accuracy of NWPs and the availability of cheap computing power, these models have been used in many studies to predict precipitation (Cossu and Hocke 2014; Kostarev and Vetrov 2018; Spiridonov et al. 2020). Uncertainty in precipitation forecasting is one of the main limitations in hydrologic/hydraulic modeling, causing errors in rainfall/runoff simulation (Mane and Chandrasekar 2022). Due to this, it is necessary to use timely forecasting with high certainty. Among the types of atmospheric models, the Weather Research and Forecasting (WRF) Model is widely used to study global, regional and local scale atmospheric systems that are responsible for heavy rainfall (Hasan and Islam 2018). This model is used for short-scale rainfall forecasting. A study (Cao et al. 2015) in the study area of the west coast of America showed that among the products and models of The GPM, The Tropical Rainfall Measuring Mission (TRMM) and WRF, the WRF model had the least error in the estimation of precipitation, which in the study of Roy et al. (2018) also compared WRF, TRMM Multi-satellite Precipitation Analysis (TMPA), CHIRPS, GPM and ERA models and products were confirmed. Furthermore through continued evaluations, it was found that the WRF model has a more reliable accuracy for mountainous areas (Zhang et al. 2021b). In most recent studies around the world (China, South Korea, India, Thailand, Spain, Germany, Poland, Greece and Iran), Remote sensing products are used to estimate rainfall and input to hydrological models (Adhikary et al. 2015; Ayanwale and Alabi 2017; Hong et al. 2007; Hou 2018; Jung et al. 2014; Kreklow et al. 2019; Putthividhya and Tanaka 2012; Tian et al. 2018; Tiwari et al. 2020; Usowicz et al. 2021; Xu et al. 2017). Nowadays, due to the role of climate change and heavy rains in dry areas, including the eastern regions of Iran, there is a need for models that simulate floods with high accuracy. However, the accuracy of (hydrological) simulation models depends on accurate precipitation forecasts. In various research (Table 1), satellite products and meteorological models are used to predict rainfall in basins. But in this research, it has not yet been determined precisely which of these models has a higher accuracy in predicting precipitation for input to hydrological models. And how can they be used at different intervals for input to hydrological models? For this purpose, this research has been tried: A: by using the latest satellite products (Google Earth Engine) along with the most powerful meteorological model to compare rainfall forecasts in a dry and semi-arid basin in northeastern Iran. (b). by comparing the schematics of the meteorological model with the rainfall products, the best forecasting model in the study area is identified. (c). Due to the limitation of hydrometric and rain gauge stations in arid and semi-arid regions, the network of stations is prepared for input to the hydrological model. By identifying the best forecasting model, and preparing rain gauge stations for all parts of the basin, researchers and managers in the flood basin use these models as input to hydrological and hydraulic models.

The approach is applied to a case study in the northeastern region of Iran, which is subject to severe flood damage every year. With the implementation of this method, it is possible to get an early flood warning in the northeastern regions of Iran or in different regions of the world. It is also possible to detect floods and heavy rains in different parts of the world before their occurrence (up to the next 72 h).

2 Study area

The catchment area is Kashf-Roud, which is considered as a part of the Qaraqom basin. Which is located in the northeast of the country and in the northern areas of Razavi Khorasan province and starts from the east of Qochan city and extends towards the eastern heights, almost to the southeast of Mashhad. In other words, this basin extends from the north to the ridge of Hazar Masjid Heights -Kope Dagh, from the south to the ridge of Binaloud Heights. It is limited from the north-west to the Atrak watershed, from the southeast to the Jam-Rood basin, from the east to the Harir-Rood River, and from the west to the mountains of Khajah Ali, Pashte Par and Shah Jahan. The Kashf-Roud basin is located at the coordinates of 57°, 22′ and 61°, 9′ east longitude and 35°, 38′–37° north latitude. The study area in North-Eastern Iran is equal to 117 769 square kilometers (Fig. 1). Of the entire region, 49.2% of its surface is mountainous and 50.8% is plains (Azamirad and Esmaili 2018). This region, which is located on the border between Turkmenistan and Afghanistan, is very diverse in terms of natural conditions due to its large size and each of its different areas has special characteristics (Shorabeh et al. 2019). Qochan station with 296 mm and Gonabad station with 71 mm have the highest and lowest annual rainfall, respectively (Chezgi and Soheili 2021; Zabihi et al. 2022). The average annual rainfall for the entire region is 193 mm, while the maximum monthly rainfall occurs in March (Sharafati and Pezeshki 2020).

In this research, the Digital Elevation Model (DEM) is one of the main elements in creating hydrological models using topographic maps. In the following, after preparing the DEM according to Fig. 2 and by controlling the topographic maps on a scale of 1:25000, the boundaries of the basin and physiographic characteristics such as area, environment, height, slope, concentration time and waterway network were calculated (Azamirad and

Table 1 Study background of the research

Authors	Model	Case study	Description
Rahman et al. (2012)	ECMWF and TRMM	Bangladesh	Both models perform well in estimating rainfall in the study area
Cao et al. (2015)	GPM, TRMM and WRF	U.S. West Coast	WRF meteorological model has less error in rainfall estimation
Roy et al. (2018)	WRF, TMPA, CHIRPS,GPM and ERA	North Western Himalaya in India	The WRF meteorological model has better accuracy in simulating rainfall in the study area
Aminyavari et al. (2019)	ECMWF, NCEP[a], UKMO and IMERG	Iran	The NCEP model has better accuracy in predicting precipitation for high-threshold precipitation
Zhang et al. (2021a)	WRF, TRMM	Northwest China	WRF model has more reliable accuracy for mountainous areas
Zhang et al. (2021c)	TRMM, CMORPH and PERSIANN	China	PERSIANN precipitation satellite has higher accuracy in five-day rainfall estimation
Moishin et al. (2021)	ConvLSTM[b], CNN[c] and LSTM[d]	Fiji	ConvLSTM model has more accurate prediction for flood assessment than other methods
Benkirane et al. (2022)	TRMM and GPM	Morocco	Both satellite products have poor accuracy in estimating rainfall in the Mediterranean region
Le Mire et al. (2023)	ANS[e], WRF	French	Optimization of the parameterization of the WRF Model is carried out using measurements collected from a propagation experiment
(Maggioni et al. 2023)	WRF	**Italy**	Relevance of assimilating mesoscale observations and lightning data in the WRF model, to simulate a strong convective

[a]National centers for environmental prediction

[b]Convolutional long short-term memory

[c]Convolutional neural network

[d]Long short-term memory

[e]Atmospheric numerical simulator

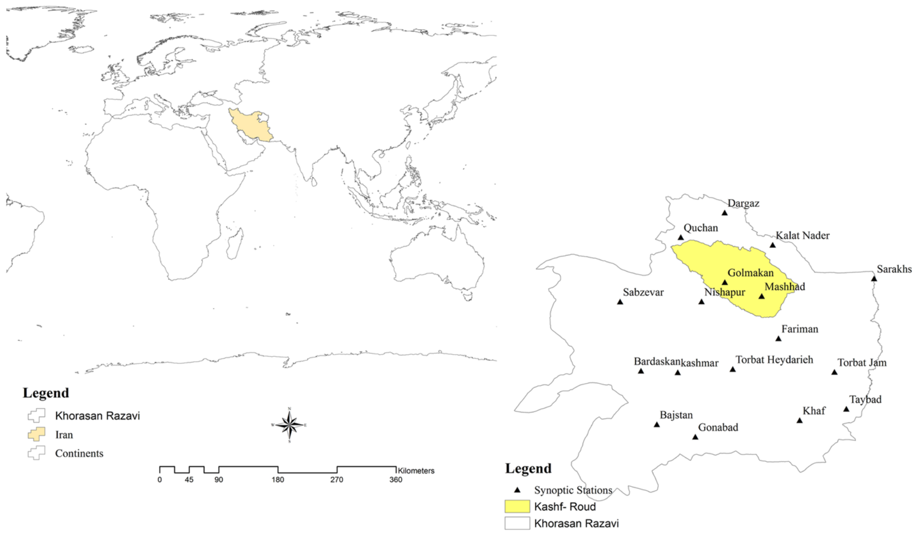


Fig. 1 Geographical location of the study area

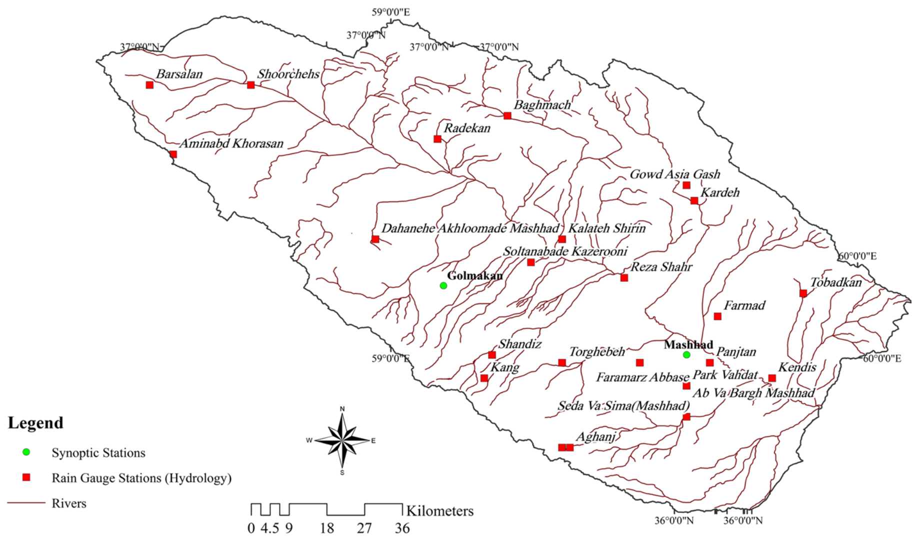


Fig. 2 Map hydrographic network of Kashf-Roud watershed

Esmaili 2018). Table 2 presents some important physical characteristics of the basin. Next, the map of the waterways and the DEM are presented in Fig. 3.

the study area due to its location in the arid and semi-arid region experiences a high level of uncertainty in rainfall, leading to unpredictable periods of drought or heavy rainfall (Toosi et al. 2020). These rainfall events, especially in spring, have the potential to cause severe floods, soil erosion, damage to the agricultural sector, and damage to infrastructure, especially in urban areas.

Table 2 Physical parameters Kashf-Roud watershed (Azamirad and Esmaili 2018)

Area (A)	Environment (P)	Length waterway(L)	Drainage density(Dd)	Time of concentration (TC)	
Km^2	Km	Km	Km/Km^2	Williams	Kerpich
8996	498	166.9	2.90	37.86	17.50
Gravelius (C)	Elongation ratio (Re)	Elevation (m)		Slope medium	
		Max	Min	%	
1.47	0.7	3287	891	14.50	

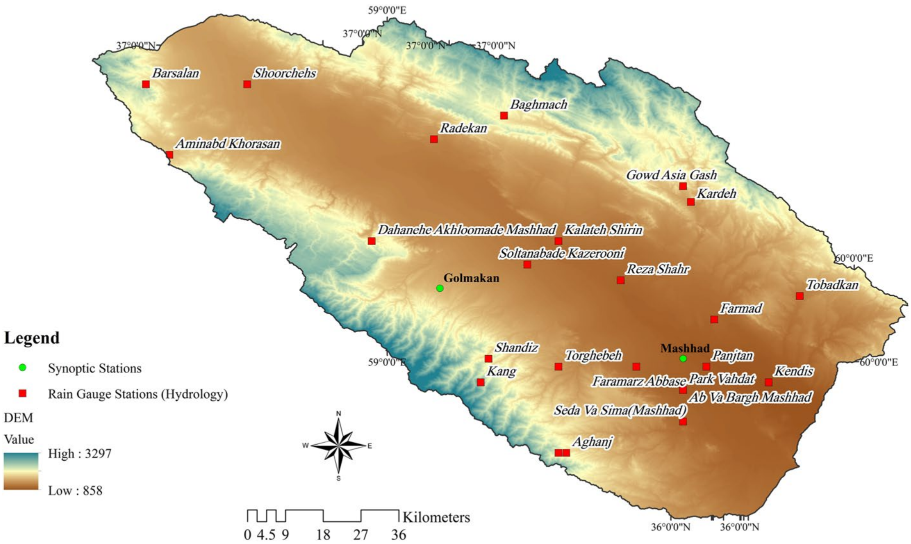


Fig. 3 Maps of digital elevation model (DEM) the watershed

In the current research, the use of satellite products and meteorological models as a tool in predicting rainfall is considered to be an effective step in flood management in the study area.

3 Data and research method

For this research, 17 meteorological stations in the province and 21 rain gauge stations of the Ministry of Energy have been used in the basin. Hourly rainfall data of synoptic stations and rain gauge station were prepared from Meteorological Organization and Regional Water Company of Razavi Khorasan province, respectively. It is possible to use precipitation satellite products and the output of the WRF meteorological model in hydrological/hydraulic models to provide a flood early warning system, so this research has entered into this issue in two parts. In the first part, five satellite precipitation products are evaluated in the Google Earth Engine (GEE) portal, and in the second part, rainfall prediction is done using four microphysical schemas of the WRF weather model.

3.1 Google earth engine (GEE)

Earth Engine consists of a multi-petabyte ready-to-analyze data catalog with a high-performance parallel computing service. It is accessible and controllable through an Internet-accessible Application Programming Interface (API) and a web-based Interactive Development Environment (IDE) that enables rapid prototyping and visualization of results (Gorelick et al. 2017).

This web portal engine provides global satellite imagery and vector data, precipitation-based calculations, and access to software and algorithms for processing such data (Kumar and Mutanga 2018). The data repository is a collection of more than 40 years of satellite imagery for the entire world, this web portal has an impressive collection of annual, monthly, weekly, daily, hourly, and minute data. Data are available from multiple satellites, such as the complete Landsat series.

That includes Moderate Resolution Imaging Spectrometer (MODIS), National Oceanic and Atmospheric Administration (NOAA), Advanced Very High Resolution Radiometer (AVHRR), Advanced Earth Observation Satellite (ALOS) etc. (Gorelick et al. 2017). To evaluate the performance of satellite products in rapid flood warning forecasting, five rainfall satellite products were used, whose specifications are listed in Tables 3 and 4.

The selection of these products has been done according to time and space separation (data availability in terms of time and place for flood warning) suitable for them. After selecting rainfall products by coding them (Fig. 4) in the Google Earth (GEE) web environment at https://code.earthengine.google.com, the amount of rainfall was calculated for four events that represent different rainfalls in the region. These events are used because they cover all the rainfall in the study area, and on the other hand, because of the accuracy of the models in forecasting rainfall, these events are used.

The performance of each of the satellite products and metrological model schemes calculate using verification methods (Table 6), And finally, the best rainfall satellite products or the appropriate schema for rainfall forecasting will be determined.

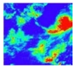
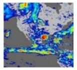
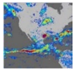
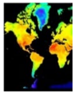
3.2 WRF meteorological/dynamic model

The WRF model is a medium-scale numerical/dynamic weather forecasting model developed by the United States in collaboration with National Centers for Environmental Prediction (NCEP), and the National Center for Atmospheric Research (NCAR) for weather simulation and forecasting. It uses scale analysis to solve fluid dynamics and thermodynamic equations that describe atmospheric motion in predicting future atmospheric and air circulation (Xu et al. 2021). The WRF model uses the advanced dynamic kernel of the Advanced Research version of the Weather Research and Forecasting (WRF) Model (WRF-ARW). This dynamic kernel is used in wide ranges of spatial scale from a few meters to thousands of kilometers. The WRF model is fully compressible, non-stationary, and uses a grid that is more accurate in resolution and simulation than Arakawa's horizontal C grid (Archer et al. 2020; Li et al. 2019).

3.3 The data of WRF model

The data used in this research come in two main categories, namely observational data and Global Forecast System (GFS) data. Rainfall data for the selected period of

Table 3 Specifications of rainfall satellite products

Insignia	Product	Resolution (m)	Temporal coverage	Description	Website details
	PERSIANN-CDR[a]	27830	Daily	Estimated daily precipitation	https://developers.google.com/earth-engine/datasets/catalog/NOAA_PERSIANN-CDR#bands
	GSMaP[b]	11132	Hourly	Snapshot of hourly precipitation rate	https://developers.google.com/earth-engine/datasets/catalog/JAXA_GPM_L3_GSMaP_v6_operational#description
	GPM	11132	30-min	IR precipitation	https://developers.google.com/earth-engine/datasets/catalog/NASA_GPM_L3_IMERG_V06#description
	ERA5[c]	11132	Hourly	It is the sum of large-scale precipitation and convective precipitation	https://developers.google.com/earth-engine/datasets/catalog/ECMWF_ERA5_LAND_HOURLY#image-properties
	CHIRPS	5566	Daily	Precipitation	https://developers.google.com/earth-engine/datasets/catalog/UCSB-CHG_CHIRPS_PENTAD

[a]Precipitation estimation from remotely sensed information using artificial neural networks-climate data record

[b]Global satellite mapping of precipitation microwave-IR combined product

[c]European atmospheric reanalysis five

Table 4 Band specifications of rainfall satellite products

Product	Band	ImageCollection	Value		Units	Dataset availability
			Min	Max		
PERSIANN-CDR	Precipitation	NOAA/PERSIANN-CDR	0*	718.62*	mm	1983-01-01T00:00:00Z-NPT
GSMaP	HourlyPrecipRate	JAXA/GPM_L3/GSMaP/v6/operational	0*	204.88*	mm/hr	2014-03-01T00:00:00Z-NPT
GPM	IRprecipitation	NASA/GPM_L3/IMERG_V06	0*	79.5*	mm/hr	2000-06-01T00:00:00Z-NPT-
ERA5	Total_precipitation	ECMWF/ERA5_LAND/HOURLY	0	∞	mm	1981-01-01T01:00:00Z-NPT
CHIRPS	Precipitation	UCSB-CHG/CHIRPS/PENTAD	0*	1072.43*	mm/pentad	1981-01-01T00:00:00Z-NPT

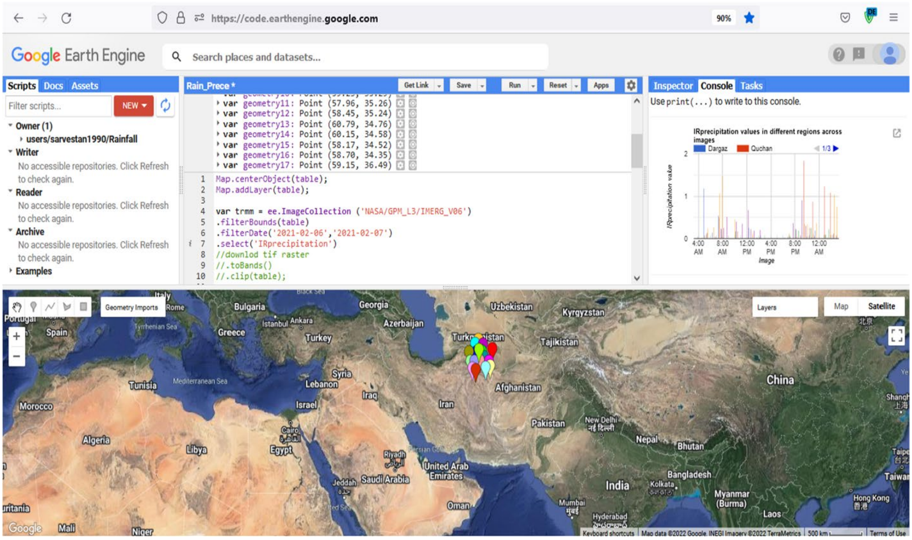


Fig. 4 Google earth engine development environment

4 months (The year 2021) were received from the Iran Meteorological Organization. Out of the entire dataset, four recent events (Jan, Feb, Mar, and May 2021) representing extreme rainfall, wet seasons, and all rainfall levels from low to moderate and high were selected. Developed at National Centers for Environmental Prediction (NCEP), GFS is a weather prediction model that provides data for several meteorological and land variables, including temperature, wind, precipitation, soil moisture, ozone concentration, etc. This system adjoins four independent models (i.e., atmosphere, ocean model, earth/soil model, and sea ice model) which work together to draw an accurate image of weather conditions. Specifications of the data used in this research are given in Table 5.

The four rainfall events whose precipitation values were estimated using satellite products in the previous stage. At this stage of the research, they are implemented using the capabilities of the WRF model with the application of four of the most widely used microphysics schemes: Lin, WSM5, WSM3, and WDM6 (Table 6).

Then extracting the amount of rainfall by means of satellite products and meteorological models, in order to evaluate their efficiency and performance in rainfall modeling, the four verification methods of Table 7 have been used (Fig. 5 shows the stages of this part of the research).

After determining the best forecasting tool in order to use forecasted rainfall for points that do not have ground stations (to use them for hydrological/hydraulic models in basins), four interpolation methods, Empirical Bayesian Kriging (EBK), Cokriging

Table 5 Global forecast system (GFS) data feature

Scale/network	Registration period	Model cycle (UTC)	Parameters	Output time (hours)
0.5	After 30 days	00	pgrb2 pgrb2b pgrb2full	0–24

Table 6 The statistical coefficients applied in the verification method of fence quantities (Mohammadiha et al. 2012)

Type	Verification coefficient	Formula	Range	Perfect value
Positives	Threat score (TS)	$TS = \frac{a}{a+b+c}$	0–1	1
	Hit rate (H)	$H = POD = \frac{a}{a+c}$	0–1	1
Negatives	False ALARM Ratio (FAR)	$FAR = \frac{b}{a+b}$	0–1	0
	False alarm (F)	$F = \frac{b}{b+d}$	0–∞	0

a: The number of times of rainfall has occurred and its occurrence is forecasted. b: The number of times that of rainfall did not happen, but its occurrence was forecasted. c: The number of times of rainfall has occurred but its occurrence was not forecasted. d: the number of times that of rainfall did not happen, but its occurrence was not forecasted

Table 7 The verification indices and the relevant equations for evaluating the accuracy of interpolation methods

Verification index	Verification equation	Range	Perfect fit
R-squared (R^2)	$R^2 = 1 - \frac{First\ Sum\ of\ Errors}{Second\ Sum\ of\ Errors}$	0–1	1
Mean absolute percent error (MAPE)	$MAPE = \frac{100\sum_{i=1}^{n}\left\lvert\frac{Y_i-\hat{Y}_i}{Y_i}\right\rvert}{n}$	0–∞	0
Mean absolute deviation (MAD)	$MAD = \sum_{i=1}^{n}\left\lvert\frac{Y_i-\hat{Y}_i}{n}\right\rvert$	0–∞	0
Root mean square error (RMSE)	$RMSE = \sqrt{MSE}$	0–∞	0

n is the number of observational data and the total output values of the WRF model. Y_i is the *ith* observational value of rainfall and $\hat{Y}_i$ is the *ith* simulated value of rainfall determined by the geostatistical methods

(COK), Global Polynomial Interpolator (GPI) and Radial Basis Function (RBF), have been used.

For the accuracy of the interpolation methods for the points that do not have a ground station, the error criteria methods in Table 7 are used. Finally, the best interpolation method is determined to identify the appropriate distance for creating a rain gauge station (Fig. 6 shows the stages of this part of the research).

4 Results

The amount of rainfall modeled by WRF meteorological model and five rainfall products are given in Figs. 4, 5, 6, 7. The amount of rainfall modeled for the event of 01/31/2021 by WRF meteorological model schemes shows that in this event, WSM3 and Lin microphysical schemes have more acceptable accuracy than other schemes, so that in these schemas, respectively, 11 and 8 station estimated the amount of rainfall with a difference of less than 2 mm for the next 24 h (Fig. 7a). Examining the estimated amount of precipitation in five satellite products indicates that the ERA5 product has better accuracy in estimating precipitation in the northeastern region of the country. In this satellite, nearly 8 stations have estimates less than 2 mm (Fig. 4b). The investigation of the 2021/07/02 event shows that the ERA5 satellite and the Lin scheme have higher accuracy in rainfall modeling than other

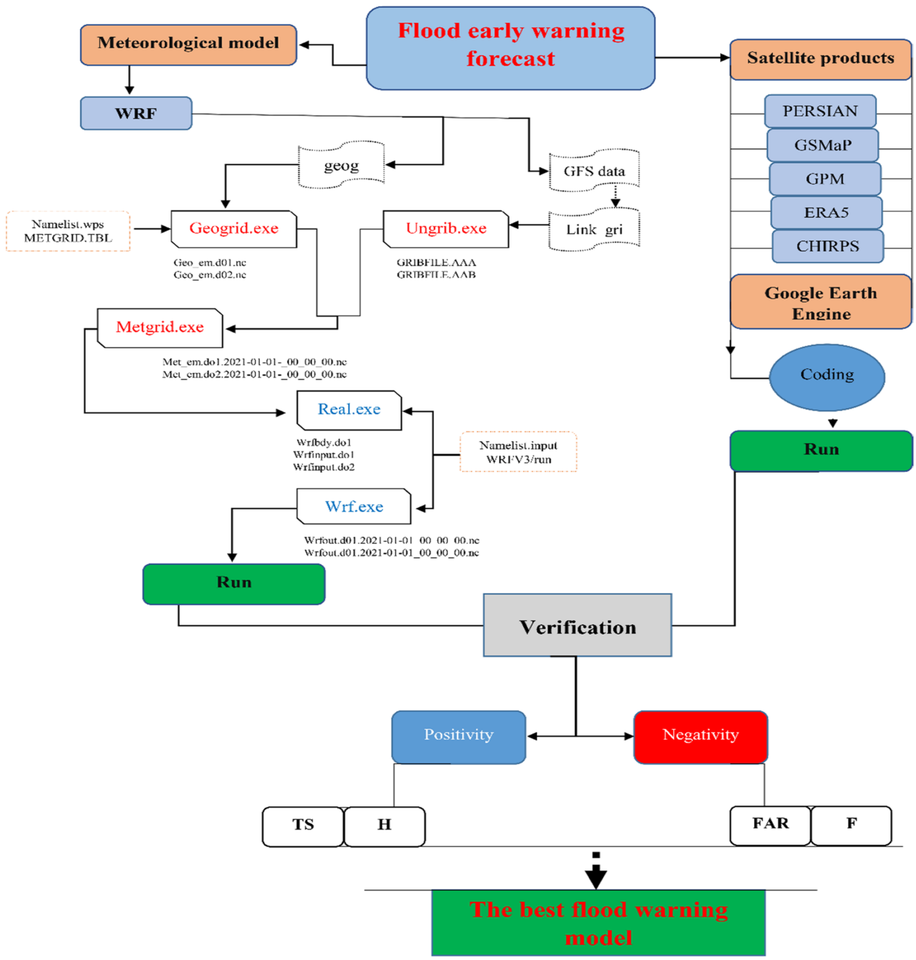


Fig. 5 Steps of the research method

methods. The difference between the microfiche schemes and the satellite products shows that the satellite products are less accurate for higher amounts of rainfall, but the meteorological model schemes can better model high rainfall amounts (Fig. 8a and b).

The results of the modeling of the 2021/12/03 event indicate that the microphysical schemes of the WRF meteorological model have better accuracy in modeling rainfall in the study area, so that in this area, among the satellite products and the microphysical schemes of the Lin scheme in 13 synoptic stations, the amount It estimated the rainfall with an error of less than one millimeter. Meanwhile, in the best satellite product (ERA5), while, in the best satellite product (ERA5), 7 rainfall stations were simulated with acceptable accuracy (Fig. 9a and b). Rainfall modeling of the 2021/03/05 event indicates that the satellite products have a poor estimate of rainfall in each of the satellites, for example, in its best product, ARE5, the amount of rainfall in only 6 stations has a low difference with the observed amount. Examining the amount of observed and modeled rainfall in microphysical schemes showed that the Lin scheme is still more accurate in rainfall modeling, so that this scheme,

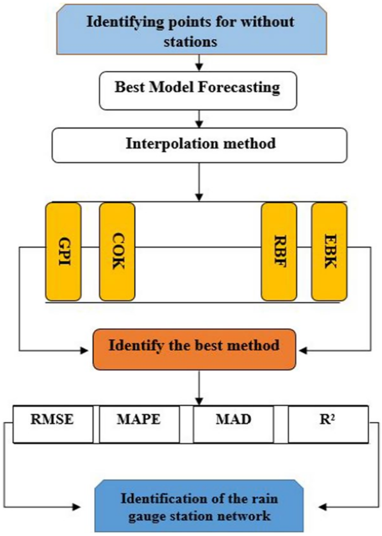


Fig. 6 Steps of the research method

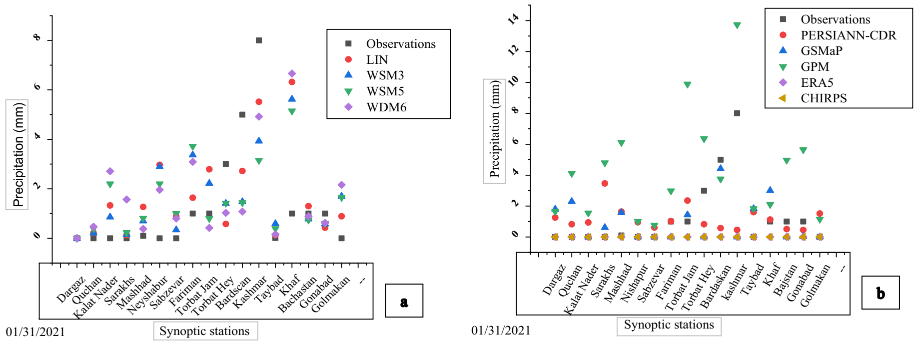


Fig. 7 The amount of rainfall simulated by the WRF meteorological model (**a**), the amount of rainfall estimated by precipitation satellite products (**b**)

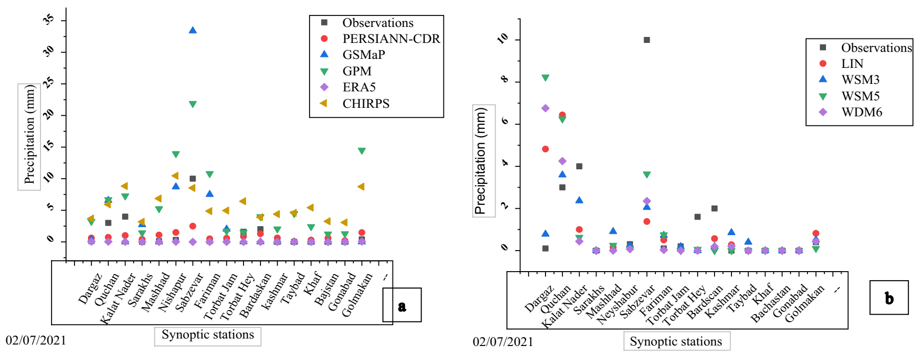


Fig. 8 The amount of rainfall simulated by the WRF meteorological model (**a**), the amount of rainfall estimated by precipitation satellite products (**b**)

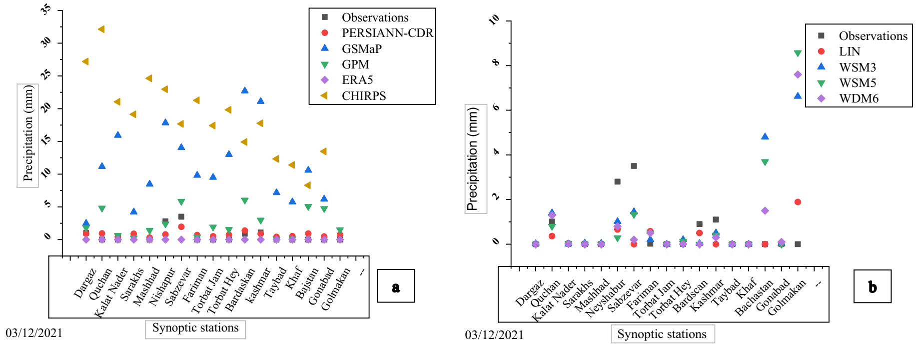


Fig. 9 Rainfall amount simulated by WRF meteorological model (**a**), rainfall amount estimated by rainfall satellite products (**b**)

among 17 synoptic stations, for 14 stations, the amount of rainfall with a difference of less than 1.5 mm fashioned (Fig. 10a and b).

4.1 Verification

Verification in this research is divided into two quantities: negativity and positivity. In quantitative positivism, the closer the quantity values are to one, the better the model can estimate rainfall. This mode has the opposite mode for negative quantification; That is, as the negativity quantities get closer to one, they actually show the weakness of the model in rainfall modeling. The examination of the verification findings of the precipitation satellite products show that the ERA5 satellite has a higher accuracy in rainfall modeling than other products, so that in this satellite, due to the stronger verification quantities, the Threat Score (TS) and the false alarm ratio (FAR) are 5. The station models the amount of rainfall with 50%. These stations include Gonabad, Taybad, Khaf, Bejestan and Mashhad respectively (Fig. 11).

The verification of WRF meteorological model schemas indicates that in the strongest quantity of positivity of TS verification, 10 stations model the amount of rainfall above 70%. This accuracy value corresponds to Lin's microphysical scheme. In this scheme, the

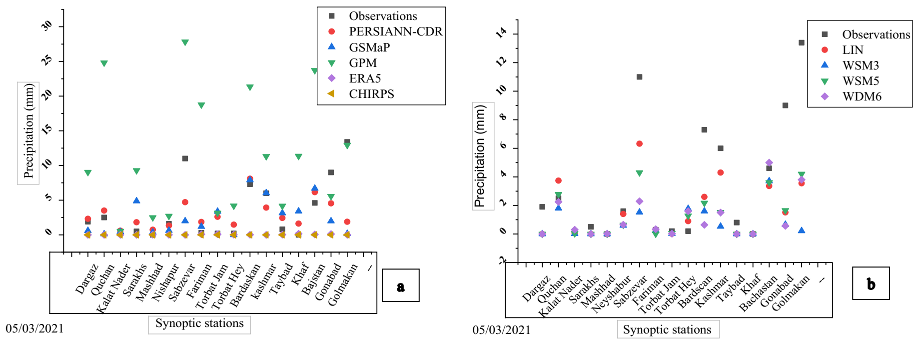


Fig. 10 Rainfall amount simulated by WRF meteorological model (**a**), rainfall amount estimated by precipitation satellite products (**b**)

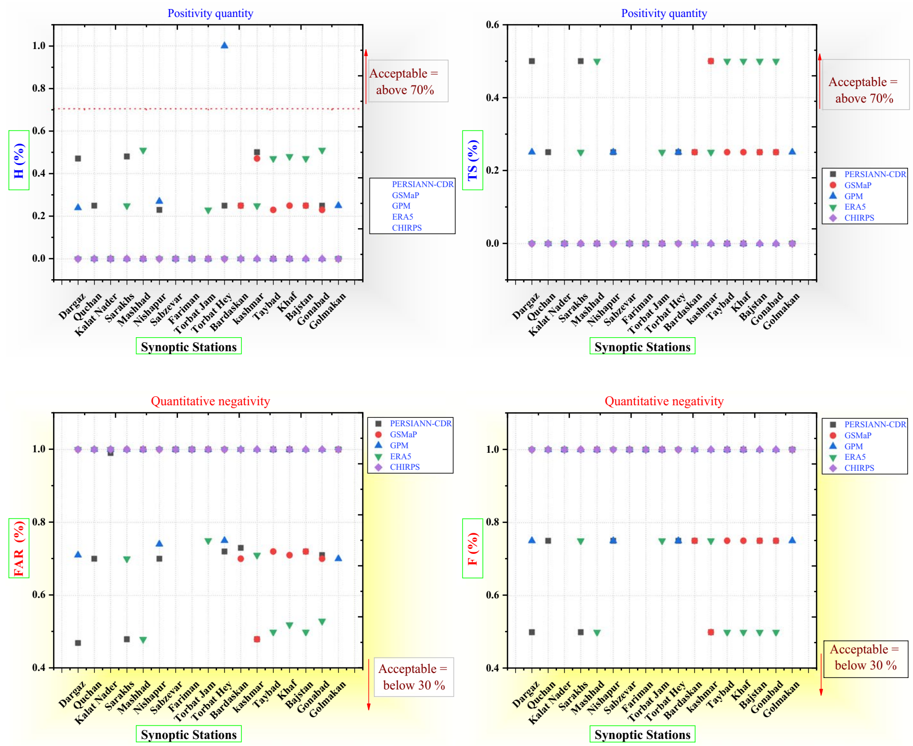


Fig. 11 The amount of verification of precipitation products

two stations of Fern and Freeman are modeled with 98% of rainfall. The False Alarm Rate (FAR) as the best verification of negativity shows that the Lin scheme still has the highest acceptable accuracy in rainfall modeling in the study area. So that the number of 10 stations modeled the amount of rainfall with a false alarm of less than 25% (Fig. 12).

4.2 Identify the acceptable stations

The output of hydrological and hydraulic models are faced with a level of error. For this reason, to solve these issues, the output of the WRF weather model should be used as input to these models. One of the applications of the WRF model is to use a network of stations for places that do not have a rain gauge station.

With the aim of knowing the efficiency and performance of the WRF meteorological model in the Kashf-Roud basin, using its best selected scheme (Lin), three heavy rainfall events were predicted in the Kashf-Roud catchment for 72 h. Figure 13 shows the output of the meteorological model in the form of rain gauge stations. In this form, the study area is created at a grid distance of 9 × 9 km from each other rain gauge station. After forecasting and designing the network of space stations (The output of the meteorological model), in order to identify the best stations for the points that do not have a ground station. Four interpolation methods LPI, RBF, EBK, and COK between meteorological model output stations have been used. For interpolation, the amount of

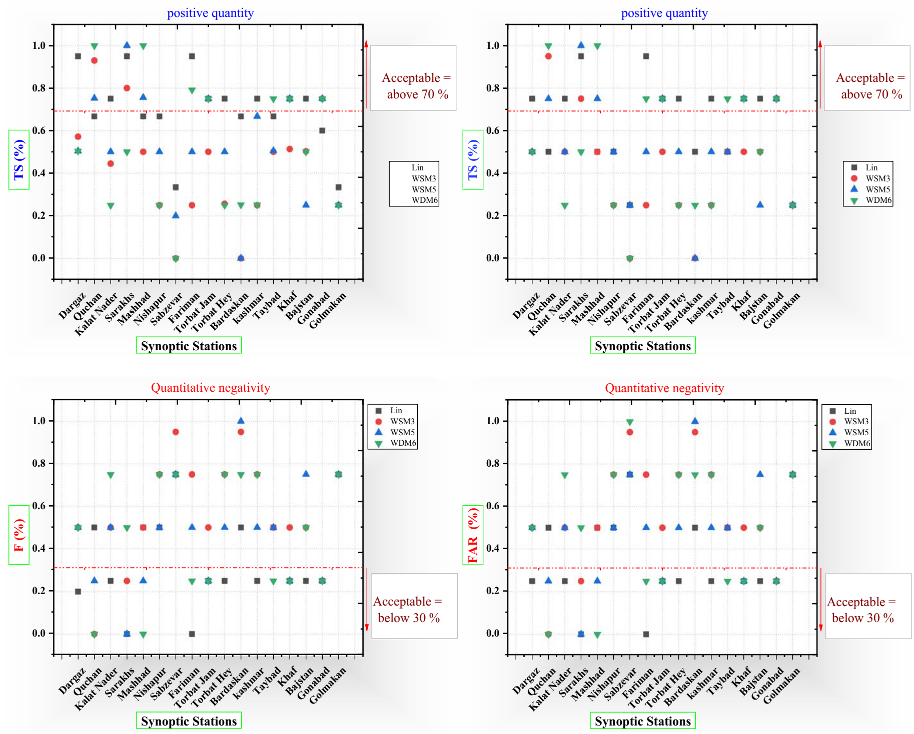


Fig. 12 Verification value of WRF model microphysical schemes

rainfall at the ground station was evaluated with each of the output stations of the WRF dynamic model up to a distance of 50 km. the results show that among the interpolation methods, the RBF method has a higher accuracy in estimating rainfall for points without stations. In this method, the value of R2 reaches 0.95, while the value of R^2 for other interpolation methods reaches less than 0.9 (Fig. 14 and Table 8).

To select space stations (points without stations) and then introduce these stations to hydrological and hydraulic models, it is necessary to examine the number of points around ground stations (hydrology/rain gauges) up to different distances from the station (ground stations/rain gauges). For this purpose, the amount of observed rainfall (at the rain gauge station) is compared and estimated with the amount of rainfall at each of the output points of the meteorological model using the RBF method (Fig. 15).

In these figures, the blue bar chart shows different distances from the ground station, and the black and red curves each show the amount of observed and predicted rainfall in each space station. The Result show in the events of 09/04/2020, 10/27/2020, and 2020/02/2020 indicates that up to a distance of 18 km from the ground (rain gauge) station, 17, 19, and 13 stations have measured the amount of rainfall with They estimate acceptable accuracy.

This acceptable value is actually the difference between the observed and forecasted rainfall at each of the output stations of the dynamic model with the ground stations of the basin, which cumulatively estimates the rainfall with a difference of less than 2 mm in 72 h. By determining the appropriate distance of the rain gauge station (output of the

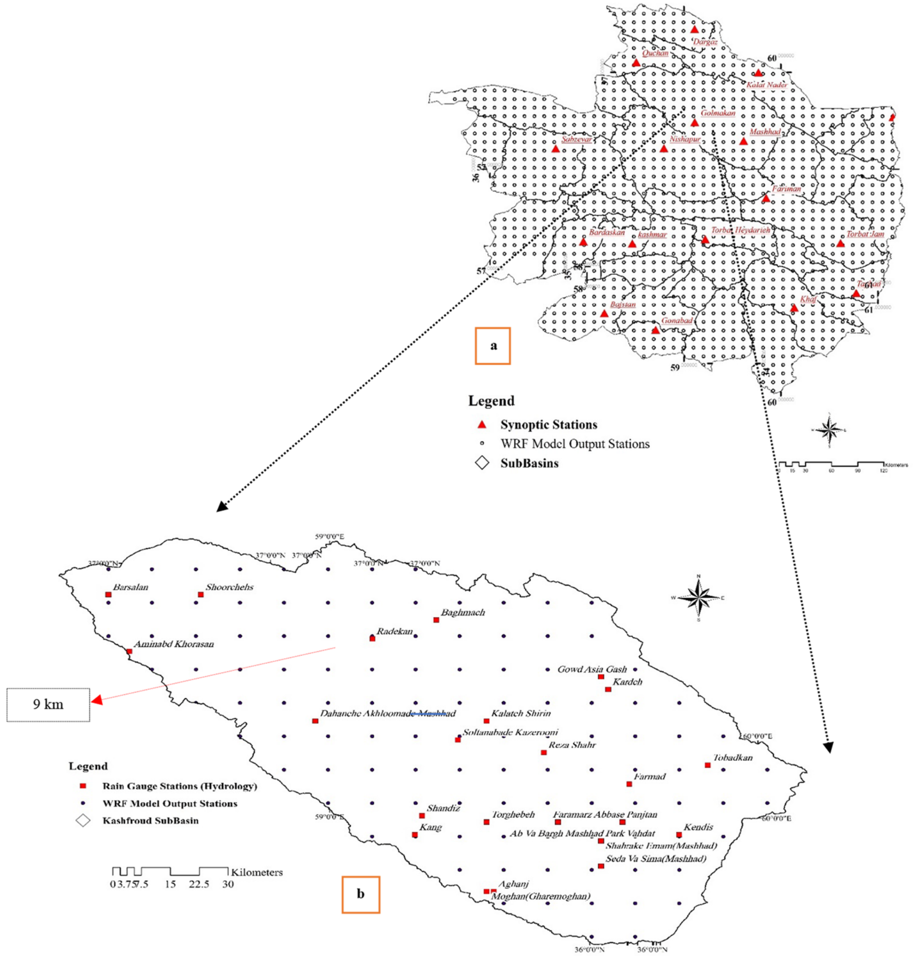


Fig. 13 Output stations of the meteorological model at the level of the province (**a**) and Kashf-Roud watershed (**b**)

WRF model), these stations can now be introduced for input to the hydrological/hydraulic models.

The introduction of these points helps hydrology/hydraulic models to forecast and simulate floods and different types of rainfall in different parts of the basin before their occurrence (three days). The network of suitable stations is shown in Fig. 16. In this figure, the appropriate distance for selecting the stations to the models desired by the experts is specified.

The appropriate distance for estimating the acceptable rainfall of each station (ground/rain gauge station) is a circle with a radius of 18 km centered on the rain gauge station. The same distance (radius of the circle) is considered for each station (earth station). For example, in the desired circle, 11 rain gauge stations (output of WRF model) are introduced to hydrology and hydraulic models to simulate rainfall/runoff/floods.

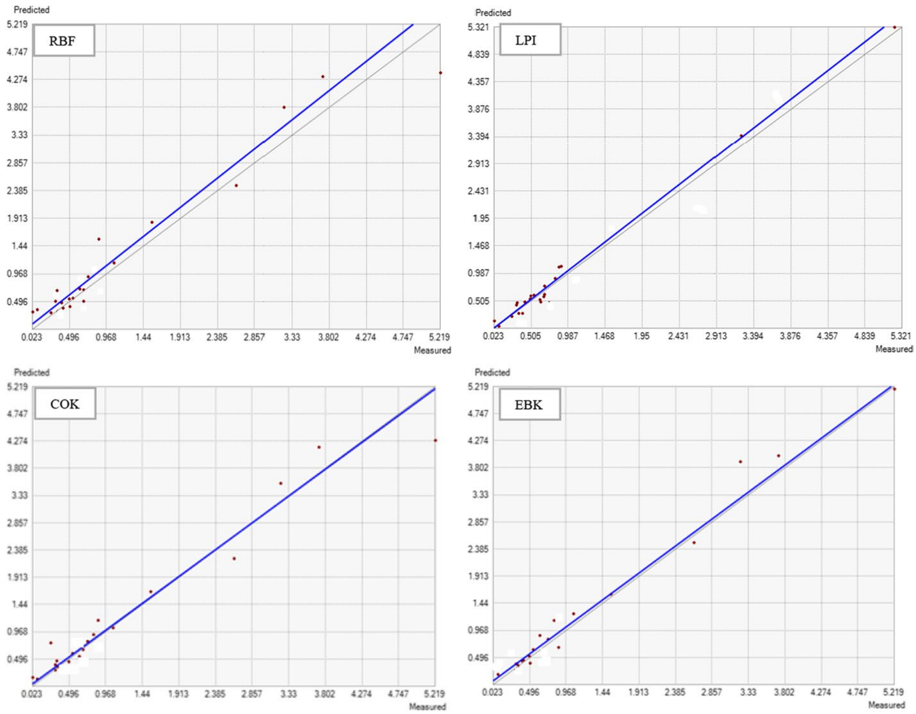


Fig. 14 Evaluation of error criteria with interpolation methods at the level of the Kashf-Roud River watershed

Table 8 Error criteria in each of the interpolation methods

Row	Error	EBK	KO	LPI	RBF
1	MAD	0.97	1.41	0.76	0.72
2	RMSE	1.42	1.88	1.11	1.31
3	MAPE	2.35	3.41	1.90	1.77
4	R^2	0.87	0.89	0.90	0.95

5 Discussion

The increase in the occurrence of sudden floods has necessitated the need for a reliable flood forecasting system to minimize human and financial losses. The most important challenge for flood early warning is the lack of spatial and temporal resolution of rainfall data for different areas, especially in developing countries. In the current research, an attempt has been made to evaluate the performance of the most powerful and available dynamic meteorological model and satellite products in the direction of rainfall forecasting and early flood warning in an arid and semi-arid climate. The results of this research showed that the WRF meteorological model has good accuracy in estimating 72-h rainfall in the northeastern region of Iran. So that in this model, its best scheme, the Lin microphysical scheme, simulates rainfall with a false alarm of less than 25%. These results in agreement with the research of Skamarock et al. (2008) and Lowrey and Yang (2008). The WRF

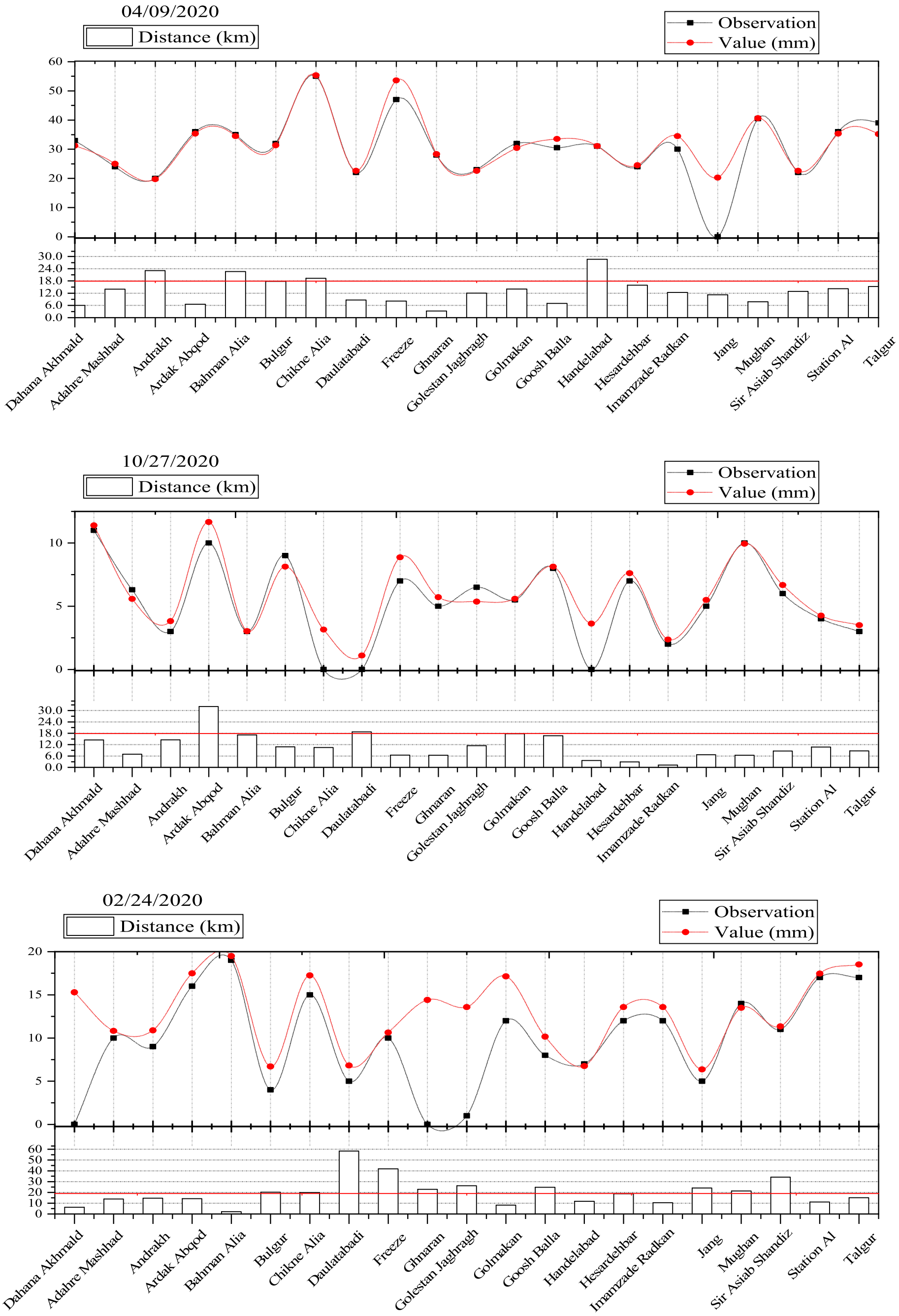


Fig. 15 The Rainfall amount by distance from different stations in each forecasted event

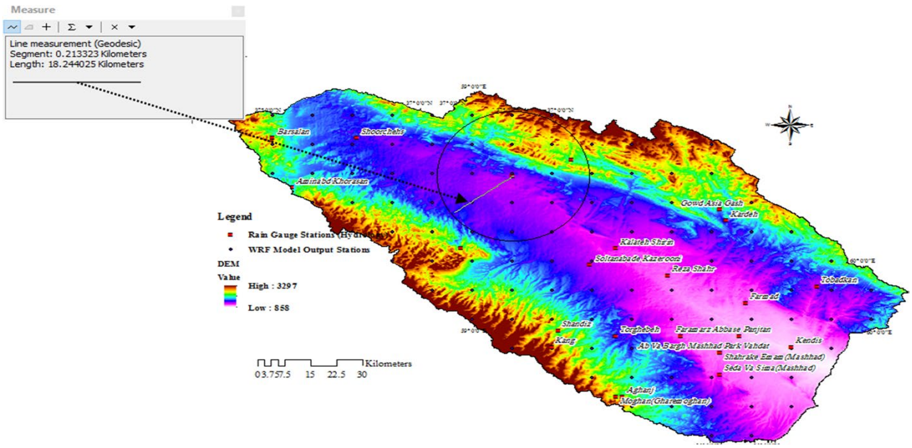


Fig. 16 Appropriate radius of each station to the distance from the main station in the direction of entry to hydrological and hydraulic models

meteorological model also has higher accuracy than the rainfall satellite products, and this is due to the abnormal and excessive beam emission of the satellite products, which causes non-uniformity in the particle beam reflection, which in this respect is in agreement with the results of the studies of (Guo et al. 2021); Krajewski and Smith (2002) have been aligned. Also, the climate conditions of the studied area can cause the weakness of satellite product beams in underestimating or overestimating rainfall, and this is in agreement with the results of (Nasrollahi et al. 2012; Nikolopoulos 2010; Ramadhan et al. 2022). Due to convection and mixing with particles, ice, water, and snow, Lin's microphysical scheme is more accurate than other schemes for evaluating rainfall in arid and semi-arid regions. This scheme is able to meet heavy rainfall values as well as weak rainfall values unlike the CHIRPS precipitation product (Figs. 4, 5, 6, 7a). These results are in agreement with the results of (Dinku et al. 2018). In their results, the CHIRPS satellite product has a poor performance in estimating rainfall in arid and semi-arid areas, but its performance has been far better for plains and mountainous areas. By comparing the satellite products and WRF weather model schemes, it was also found that the ERA5 satellite product has a better estimate among the satellite products and its false alarm rate is 50%. Which is in agreement with the results of El Khalki et al. (2020) (Fig. 11). In their research, the use of this satellite product in the time of data shortage along with the WRF model is suggested and they discovered this blend useful for developing lands such as Morocco and other North African nations.

In previous works, the performance of each of the satellite products has been evaluated with a smaller number of rainfall products and the monthly and annual performance of satellite products, but in this research, in order to better estimate rainfall from a larger number of more powerful and faster satellite products in the Google Earth Engine (GEE) engine. It was used together with the microphysical scheme. For example, in the research DeVries et al. (2020), Tripathy and Malladi (2022) to prepare rapid flood mapping and rapid flood monitoring, only Google Earth Engine (GEE) was used for the flood event. Meanwhile, in this research, hourly/daily satellite products along with the most powerful WRF dynamic model have been used for the better efficiency and performance of rainfall in Northeast Iran for early flood warning. By examining the results of this research, it was also found that although the satellite products have a weaker performance and efficiency than the dynamic model schemas, they are able to be implemented with less time (with coding less than 1 min). These advantages of satellite products in Google Earth Engine can be used before running the dynamic model in order to have an overview of rainfall warnings in different regions.

In developing countries, rainfall estimation still faces errors due to the lack of ground stations. The design and building of these stations are not possible due to their inaccessibility or economic limitations (Figs. 13 and 15). Therefore, one of the important challenges of this research has been to eliminate this error and design the space station network. The design of the network of stations (WRF model output) showed that up to a distance of 18 km from the ground station, around 11 stations are suitable in different directions (Fig. 15). Achieving these station rainfall values will help hydrologists and hydraulics to simulate and forecast floods before they occur by connecting them (by entering rainfall) to crisis management models. With this model, in fact, an early flood warning is issued in different areas. The difference between this part of the research and the previous research is that in this research, the purpose of this research was to prepare the network of the output stations of the dynamic model (spatially or to prepare points without stations) for the purpose of input to the hydrological and hydraulic models. But in past research, they use the ground station forecast data for flood simulation, example in the research (Wagner et al. 2016; Yuan et al. 2018; Zhang et al. 2019).

6 Conclusion

This research has proposed several methods to predict and compare data to prepare for input to hydrological models. This method was confirmed in Northeast Iran and four different events were carried out. The performance of various events has been evaluated with the most up-to-date satellite precipitation products and meteorological model schemes. The results showed that the meteorological model schemes have higher and more acceptable accuracy than the selected satellite products. These microphysical schemes perform better even in their weakest approximation. Satellite products can be used when the goal is only to estimate rainfall in a wide area. The use of the most powerful meteorological model scheme along with interpolation methods makes it possible to estimate the amount of rainfall for other different parts of the basin in addition to the rainfall forecast for the ground station. Also, the rainfall forecast of other parts of the basin makes it possible to use these points (as stations) for input to other models. So having this accurate and high-certainty forecast available will help officials, and various planners in other water, crisis, and flood management sectors to use the outputs for flood early warning in other models.

This research only emphasizes the prediction, evaluation and preparation of precipitation data for hydrological models. And the hydrological model has not been used along with the meteorological model and satellite products. For future studies, we suggest that the output of meteorological models and satellite products be used as input to the hydrological and hydraulic model to determine the amount of simulated runoff for each of these data. It is recommended that the effect of increasing or decreasing the distance between stations is investigated and introduced to the model.

This allows us to introduce appropriate stations and intervals to hydrological models and evaluate. The method of rainfall inputs to hydrologic and hydrologic models is a simple way to predict and simulate floods in different environments. The use of data from meteorological models has the potential to improve flood forecasting and simulation for locations that require rapid responses. The presented approach is a promising tool to increase the accuracy of meteorological and hydrological forecasting and simulation, which, therefore, helps to make it more resistant to floods. By implementing this method, the amount of rainfall and flood volume in different parts of the basin will be estimated for at least the next three days.

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Declarations

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