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Applying Digital Elevation Model to Interpolate Precipitation

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Abstract: A watershed management program is usually based on the results of watershed modeling. Accurate modeling results are decided by the appropriate parameters and input data. Precipitation is the most important input for watershed modeling. Precipitation characteristics usually exhibit significant spatial variation, even within small watersheds. Therefore, properly describing the spatial variation of precipitation is essential for predicting the water movement in a watershed. This study is concerned with mapping annual precipitation in Jam and Riz watershed of Iran, from sparse point data using Inverse Distance Weighting (IDW) method. The objective in the optimization process is to minimize the estimated error of precipitation. Thus the performance of each interpolation was assessed through examination of mapped estimates of elevation. The results show that the estimated error is usually reduced by this method. Particularly, when optimized exponent in IDW method was selected for digital elevation model which, is secondary variable for the annual average precipitation gradient equation. It was conclude that IDW-3 with the best conditions and lowest mean standard error provides the most accurate estimates of precipitation.

Key words: DEM, IDW, optimized exponent, precipitation, Jam and Riz watershed, Iran

INTRODUCTION

Spatial interpolation methods are widely used in creating continuous environmental data sets from network of sparsely sample points (Cooper and Jarvis, 2004). In particular, they have been employed to build continuous representations of terrain, soil composition, terrestrial, atmospheric pollution and climate variables (Heuvelink and Webster, 2001; Hutchinson and Gallant, 1999; Jarvis and Stuart, 2001 a, b; Kurtzman and Kadmon, 1999; Mitas and Mitasova, 1988; Oliver and Khayrat, 2000; Oliver and Webster, 1990; Philip and Watson, 1982). Maps of precipitation have a wide range of applications and many different interpolation procedures have been used to drive maps from collected as part of monitoring networks (Hutchinson, 1995). There has been a range of studies which compared different algorithms for deriving estimates of precipitation from point data (Bastin *et al.*, 1984; Tabios and Salas, 1985; Hevesi *et al.*, 1992a, b; Hutchinson, 1998a, b; Hay *et al.*, 1998; Pudhomme and Reed, 1999; Goovaerts, 2000; Gomez-Hernandez *et al.*, 2001; Hofierka *et al.*, 2002), also several more recent geostatistical textbook are available (Isaaks and Srivastava, 1989; Cressie, 1991; Goovearts, 1997;

Armstrong, 1998; Chiles and Delfiner, 1999; Webster and Oliver, 2000; Wackernagel, 2003) that describe in more detail these algorithms. The inverse distance method, which is also called the Inverse Distance Weighted (IDW) interpolation, is a general technique for interpolating (Ware *et al.*, 1991). The basic equation, Eq. 1 for the inverse distance method is:

$$K_{xy} = \frac{\sum_{i=1}^N k_i w_i}{\sum_{i=1}^N w_i} \quad (1)$$

where, k_i is the control value for i^{th} sample point, w_i represents a weight determining the relative importance of individual control point k_i in the interpolation process, K_{xy} is the point to be estimated and N is the number of sample points (Bartier and Keller, 1996). This concept is also commonly applied to estimate average precipitation and interpolate unknown rainfall. In the case, when each control point has the same relative importance, the inverse distance method is identical to the arithmetic average method for estimating precipitation (Ashraf *et al.*, 1997). Using this approach, w_i is equal to 1 for the several control points nearest to the point to be interpolated, or for the set of control points within some radius of the

point being interpolated and w_i is given by 0 otherwise (Meyers, 1994). An alternative weighting strategy near points more influence than distance points is based on a formula using the inverse of distance to a power, such as Eq. 2:

$$w_i = d_{xy}^{-m} \quad (2)$$

where, d_{xy} is the distance between K_{xy} and k_i and m is an exponent given by the users and also named the order of distances (Deraisme *et al.*, 2001). As the exponent becomes larger distances from the location becomes smaller. In other word, as the value of the exponent is increased, the estimate at a given location becomes more similar to the closest observations (Burrough and McDonnell, 1998). The inverse distance method is flexible due to the adjustable nature of the order of distances (Ghohroudi, 2006) Eq. 1 can be rewritten as:

$$K_{xy} = \frac{\sum_{i=1}^N k_i d_{xyi}^{-m}}{\sum_{i=1}^N d_{xyi}^{-m}} \quad (3)$$

Also, the weighting factors, w_i , which represents the relative influence, can be defined as Eq. 4. The sum of the weighting factors of each rainfall gauging station in the neighborhood is equal to one (Sullivan and Unwin, 2003).

$$W_i = \frac{w_i}{\sum_{i=1}^N w_i} = \frac{d_{xyi}^{-m}}{\sum_{i=1}^N d_{xyi}^{-m}} \quad (4)$$

After determining the weighting factors, the average precipitation can be estimated. The basic calculation of the IDW interpolation for estimating precipitation is expressed as Eq. 5:

$$P_p = \sum_{i=1}^N (W_i P_i) = \frac{\sum_{i=1}^N P_i d_{pi}^{-m}}{\sum_{i=1}^N d_{pi}^{-m}} \quad (5)$$

where, P_p is the interpolated precipitation in the area p ; P_i is the precipitation of rainfall gauge i ; w_i is the weighting factor that represents the relative influence of gauging station i and d_{pi} is the distance between the area p and the rainfall gauge i (Chang *et al.*, 2003). The IDW interpolation is univariate with a single influence factor, namely horizontal distance. This technique assumes that the interpolation area is uniform rather than variable (Hodgson, 1989). Therefore, it cannot be applied in an area with abrupt changes in elevation, which would create a major obstacle to estimating unknown information (Lloyd, 2005). Subsequently, precipitation multivariate

IDW interpolation, a modified version for considering additional independent variables, was developed to improve upon the previous method. The modified equation can be given by Eq. 6:

$$K_{xy} = \frac{\sum_{i=1}^N k_i w_i(v_1, \dots, v_x)}{\sum_{i=1}^N w_i(v_1, \dots, v_x)} \quad (6)$$

where, the weights w_i are determined by the variables v_1, \dots, v_x . A multivariate version based on Eq. 3 can be redefined as Eq. 7:

$$K_{xy} = \frac{\sum_{i=1}^N k_i d_{xyi}^{-m} w_i(v_1, \dots, v_x)}{\sum_{i=1}^N d_{xyi}^{-m} w_i(v_1, \dots, v_x)} \quad (7)$$

The data value independency and the pure linearity of IDW enabled isolating the effects of missing data on the variation in mapping accuracy from the effects of the nonlinearity and data value dependency (Yuval *et al.*, 2005). In this equation, it is assumed that there are two independent weights (horizontal distance and elevation difference), represents the influence of all other factors (Chang *et al.*, 2005).

MATERIALS AND METHODS

Jam and Riz basin is located in 25 km toward North Kangan and Jam town and 220 km from Southern part of Boushehr Port. The geographical location of the study area is indicated 51°, 48', 31.7"E. to 52°, 25', 14"E. and 27°, 44', 28"N to 28°, 14', 55"N (Fig. 1).

The area of the basin was estimated as 90919.2 ha using Arc GIS 9.2 software. The highest point of the study area shows 1414 m and its lowest point is 57.764 m from the sea level (Modallaldoust, 2007). Annual precipitation investigation shows that maximum precipitation in Baghan station have been 724.5 mm and minimum value in Ghantareh station have been 82 mm. The study of coefficient of variation represents disorderly rainfall in the region. Seasonal distribution of rainfall in the region, clears that rainfall regime is base on Mediterranean regime. It means, more than 60% of annual precipitation is in winter and summer with only 1% annual precipitation is driest season. Monthly precipitation regime represent that maximum rainfall happens in January and December, respectively. June and July are month with lowest rainfall.

Following materials and methods have been used in this research:

- Topographic maps at 1:250000 scale of 1999 from the Iranian Geographical Organization.

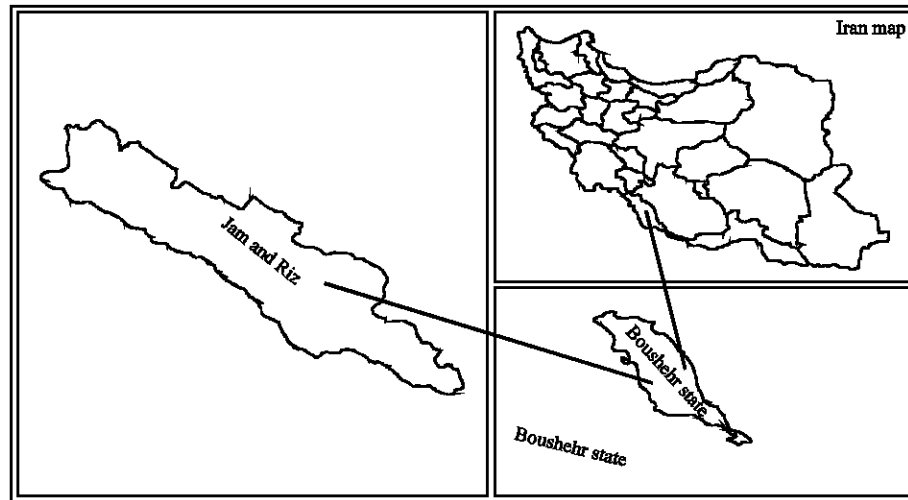


Fig. 1: Geographic location of Jam and Riz watershed

- Topographic maps at 1:25000 scale of 2001 from the National Cartographic Centre of Iran.
- Climatic statistics and data, prepared by researches organization of water resources.

Determining the optimized digital elevation model using interpolation method of IDW: First, they have scanned as topographic maps and then georeferenced in Erdas Imagin 9.1 software. The border of basin which was already limited on the mentioned maps traced in ArcView3.2a environment and then border vector layer was prepared. In next stage between 15156 elevations points of the base map 10637 points were selected to consider the basin border in the form of digital which was occurred during the process. These points were gained from ground control using Global Positioning System (GPS) during 2003 to 2004 period in the study area. These numbers of elevation points were selected to cover out of the study area. The reason is related to the accurate results from the used model of DEM. In this method, two factors such as neighbor points and point searching radius assumed as model variables. Weight standard distance which is searching radius of standard ellipse (Fig. 2) calculated in ArcView3.2a by Spatial Analysis Extension automatically. During the past three decades, models that solve the catchments and or solute transport equations in conjunction with an optimization technique have been increasingly used as watershed management tools (e.g., Rizzo and Dougherty, 1996; Minsker and Shoemaker, 1998; Zheng and Wang, 2002; Mayer *et al.*, 2001). Simulation-optimization models have been developed for a variety of applications. Standard ellipse

is an appropriate way to show the spatial protection of points group (Greene, 1991) but in geographic view the points group may have directional deviation. This problem is very important specially in preparing the numerical models by use of elevation points. In fact, elevation points in different directions to each other can represent several geomorphologic features of special area. The standard deviation ellipse was identified as follows (Fig. 3).

According to the mentioned methods, the model was tested with 4 categories of 3, 5, 7 and 15 dotted of neighbors points in two radius domains of standard searching circle and standard deviation ellipse. Therefore 8 digital elevation models were extracted. Then 10637 points equal to 10637 land dots evidence were driven for each model. Finally, the extracted points from each model using SPSS14 and by use of means difference test were compared with the land evidence point.

Identifying the means gradient of annual precipitation by use of existent database: In first stage the total existent stations in Jam and Riz basin, which is about 103 stations, were prepared. Because of long distance and in according with climatic conditions, many of the stations omitted. Then 22 stations were selected. In second stage, reconstruction procedure for whole rain gauge stations was done by normal ratio method. The reason of selecting this method was it's applicability in mountainous region, lower limitation and instability between data average during statistical period. In order to reconstruct the precipitation statistic, the normal ratio technique was used (Mahdavi, 2007a, b):

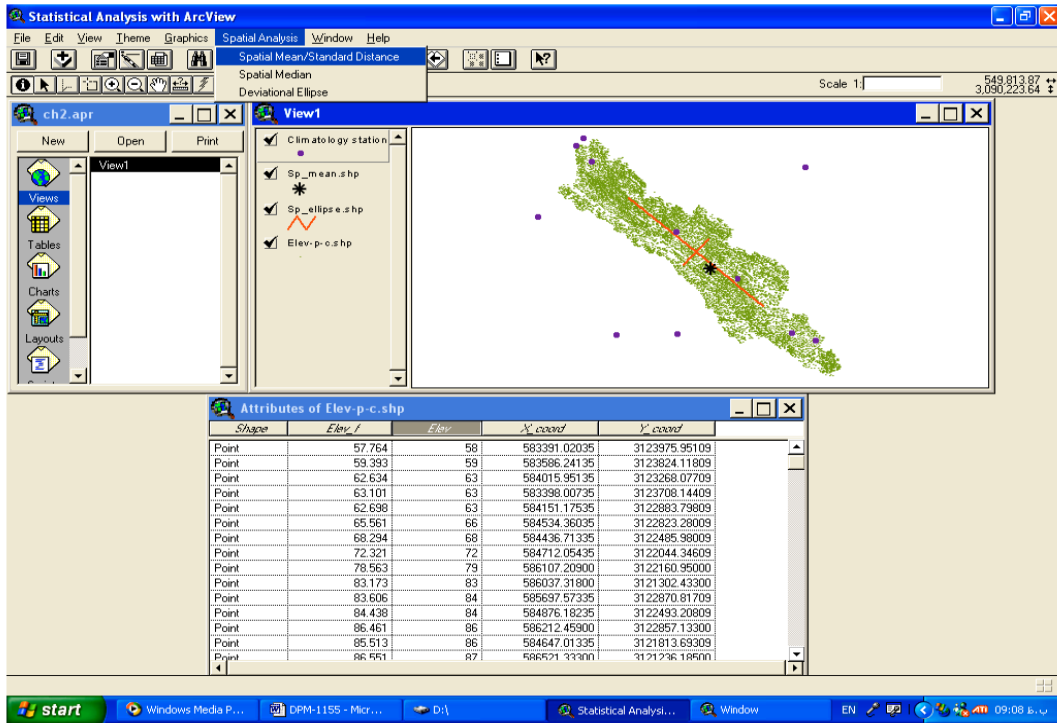


Fig. 2: Using spatial analysis menu for production of weight standard distance

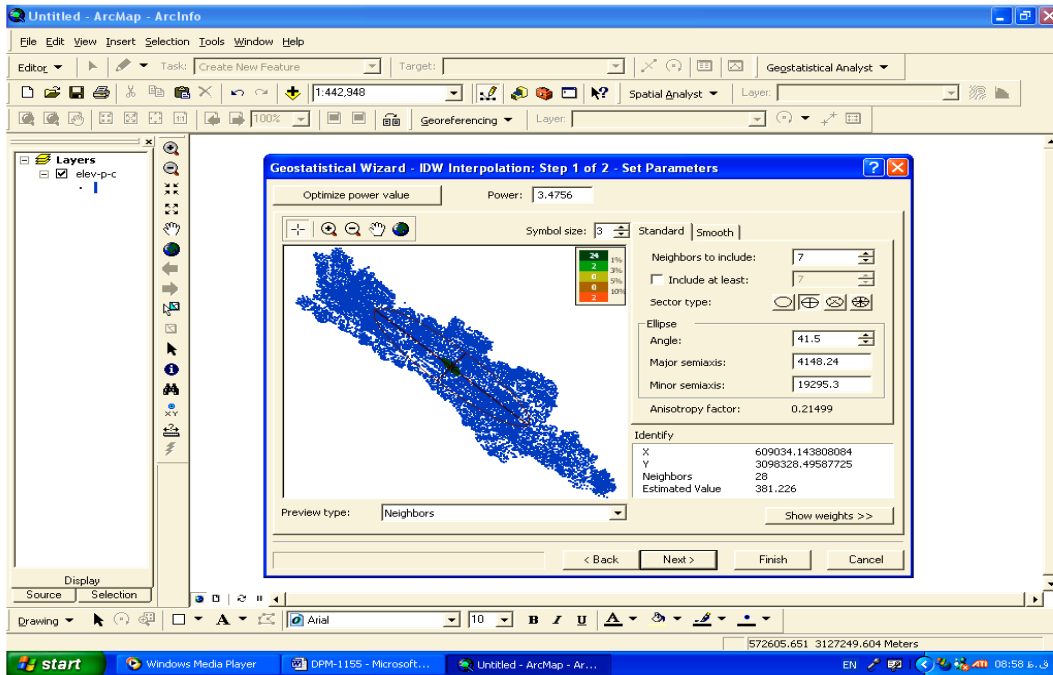


Fig. 3: Standard ellipse and standard deviation ellipse for elevation point group

Table 1: The values of annual precipitation of stations

Water year	Hangam	Dahrom	Khourab	Baghan	Ghantareh	Ahrom	Kangan	Boushehr	Boshehr daryace	Kangane Jam	Firouzabad
1986-87	345.4	312.2	364.1	336.0	253.0	293.0	85.0	328.7	336.7	502.3	630.0
1987-88	343.0	239.7	279.5	258.0	260.0	249.0	92.0	253.8	260.0	385.7	670.8
1988-89	194.6	93.1	108.6	100.2	94.4	80.6	77.2	87.5	89.6	149.8	281.6
1989-90	234.6	138.0	160.9	148.5	131.5	127.0	55.0	172.8	177.0	222.0	444.9
1990-91	181.0	155.0	242.0	318.0	213.5	182.0	84.5	239.5	224.9	475.4	317.0
1991-92	364.0	299.0	327.0	269.0	248.5	304.0	259.0	325.0	310.2	402.2	318.5
1992-93	340.5	237.5	297.0	259.5	217.0	351.0	216.0	351.2	308.9	388.0	441.0
1993-94	104.0	114.0	181.0	103.5	109.5	182.0	144.0	135.6	136.0	241.2	358.0
1994-95	238.5	254.0	263.0	195.0	218.0	308.0	259.5	256.4	268.6	344.4	500.5
1995-96	245.0	179.5	143.0	182.0	132.5	213.0	187.5	198.1	171.1	392.0	345.0
1996-97	378.0	204.5	303.0	247.0	350.5	191.0	369.5	190.3	195.3	608.5	619.0
1997-98	683.0	462.0	556.5	416.5	394.0	292.5	308.5	265.1	229.0	668.1	316.0
1998-99	103.7	132.0	100.0	94.5	103.5	58.0	72.8	83.0	81.8	108.3	456.3
1999-2000	305.0	379.1	442.1	408.0	332.5	295.0	156.0	308.3	292.5	315.4	571.6
2000-1	505.0	450.0	477.0	729.5	639.0	519.0	412.0	588.5	622.8	822.9	804.2
2001-2	212.0	208.5	195.0	219.0	230.0	182.0	204.5	281.9	251.2	248.1	219.8
2002-3	390.0	411.0	504.0	437.5	454.5	447.0	381.5	746.5	747.1	508.1	645.0
2003-4	231.0	272.5	295.0	172.5	184.0	234.0	142.5	196.8	189.7	241.7	401.0
2004-5	150.0	113.0	145.5	171.0	127.5	173.0	123.0	223.6	190.3	228.6	187.5
2005-6	144.0	153.0	222.0	166.0	82.0	131.0	149.0	191.5	197.7	157.9	290.5
Average	284.6	240.4	280.3	261.6	238.8	240.6	189.0	271.2	264.0	370.5	465.9
Maximum	683.0	462.0	556.5	729.5	639.0	519.0	412.0	746.5	747.1	822.9	816.0
Minimum	103.7	93.1	100.0	94.5	82.0	58.0	55.0	83.0	81.8	108.3	187.5
SD	141.5	114.3	133.2	151.1	140.1	115.0	110.2	156.5	160.9	185.8	185.3
CV	49.7	47.6	47.5	57.8	58.7	47.8	58.3	57.7	60.9	50.2	39.8

The No. of gray cells was reconstructed, SD: Standard deviation, CV: Coefficient of Variation

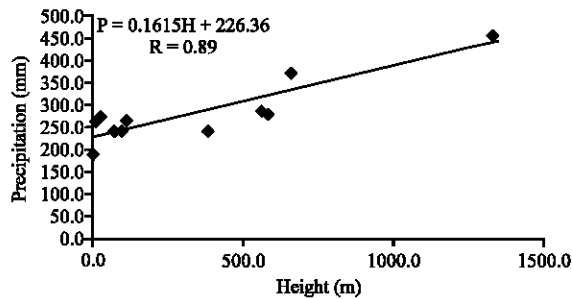


Fig. 4: The annual precipitation gradient of Jam and Riz basin

$$P_x = \frac{1}{n} \left[\left(\frac{\bar{P}_x}{\bar{P}_A} * P_A \right) + \left(\frac{\bar{P}_x}{\bar{P}_B} * P_B \right) + \dots \right] \quad (8)$$

where, P_x is precipitation of deficient station in a regarded year, n is number of reference stations, \bar{P}_x is average precipitation in a deficient station with existent statistic, \bar{P}_A, \bar{P}_B are average precipitations in reference station and are contemporary with statistic of deficient station, P_A, P_B are precipitations in reference stations of A and B in concerned year to complete the statistic of deficient station. It should be mentioned that between 22 stations the stations had short term statistic, did not contain in analysis and obviously they applied to conform achieved results and used as aid points in drawing the map. So, according to expert studies just 11 stations were selected and whole calculations and analyses about

precipitation subject was done on 11 selected stations. The annual rainfall values of concerned stations have given in Table 1. After studying the concerned stations, means annual precipitation gradient equation of Jam and Riz basin achieved (Fig. 4).

P and H: Are annual precipitation and height value base on millimeter and meter respectively. Finally, optimized digital elevation model put in place of elevation factor (H) in equation. So, for all Jam and Riz basin according to applied cells size net, the amount of rainfall in millimeter was calculated as digital precipitation model in Arc GIS 9.2 software.

RESULTS AND DISCUSSION

Spatial modeling of climate variables is of interest because many other environmental variables depend on climate. Accurate climate data only exist for point locations, the meteorological stations, as a result of which values at any other point in the terrain must be inferred from neighboring stations or from relationships with other variables (Marquinez *et al.*, 2003). This technique (IDW), can obtain satisfactory results from limited data, based mainly on the geographic situation of the sampling points, on the topological relationships between these points and on the value of variable to be measured. Precipitation generally increases with elevation (Spreen, 1947; Smith, 1979) and so many authors have incorporated elevation

Table 2: The value of optimized power in digital elevation models

	IDW1	IDW2	IDW3	IDW4	IDW5	IDW6	IDW7	IDW8
Digital elevation model optimized power	2.4624	2.9533	3.300	3.9389	2.8811	3.2819	3.476	3.7787

Table 3: Test of compare means (paired t-test) for observation elevation value and elevation values of inverse distance weighting model

	Mean	SD	Mean of standard error	t-values	df	Significant (5%)
IDW1 Observation values	0.2598	28.37946	0.27517	0.944	10,636	0.345
IDW2 Observation values	0.3470	27.84728	0.27001	1.285	10,636	0.199
IDW3 Observation values	0.3131	27.68360	0.26842	1.166	10,636	0.243
IDW4 Observation values	0.2396	27.82845	0.26982	0.888	10,636	0.375
IDW5 Observation values	0.6295	30.41523	0.29490	2.134	10,636	0.033
IDW6 Observation values	0.6377	30.72485	0.29791	2.141	10,636	0.032
IDW7 Observation values	0.6534	30.85084	0.29913	2.184	10,636	0.029
IDW8 Observation values	0.6521	31.04604	0.30102	2.166	10,636	0.030

into geostatistical approaches (Martinez-Cob, 1996; Goovaerts, 2000). Others have developed relationships between precipitation and various topographic variables such as altitude, latitude, continentally, slope, orientation or exposure, using regression (Basist *et al.*, 1994; Goodale *et al.*, 1998; Ninyerola *et al.*, 2000; Wolting *et al.*, 2000; Weisse and Bois, 2001). In this research the described expansion of elevation points set based procedure by two hypothesized of spatial dispersion and point's directional deviation was investigated using standard and standard deviation ellipses (Fig. 3). With an assessment of the necessary factors such as cell size in network (value 3), number of neighbor points (3, 5, 7, 15), standard radius (for standard ellipse) and ellipse rotation angle (in standard deviation ellipse), the optimized power was calculated for each one of 8 digital models automatically (Table 2).

According to this value and the represented factors, digital elevation models was prepared for the study area. With comparing the 10637 extracted points of 8 digital elevation models by SPSS14 which due to geographic coordinates is equal to 10637 land evidence points and using of means differences test, the best digital elevation model was obtained. The related results to this analysis are shown in Table 3. In fact, from the gained digital models the accurate one is a model which it's resulted elevation points has the lowest difference with land elevation points. However it is logical that the data which do not have main differences to land observation in significant 5% is with most accurate. According to the Table 3, four elementary digital models, from IDW1 to IDW4, can not show the main differences with the land observations. To identifying that between 4 digital models which one is with high accuracy, it can be determined with the average of fault value in Table 3. It seems that this data are extremely similar but between them the IDW3 digital elevation model has the lowest RMSE of 27.68. On the other hand these conclusions show that digital earth data with standard ellipse had sensible response rather than standard deviation ellipse. He described data have

spatial dispersion and the points contain lower directional deviation. However, it can concluded that, IDW3 digital elevation model with optimized power of 3.3 using IDW interpolation is the best digital elevation model for the study area of Jam and Riz basin in Iran which is recommended to used for the same catchments. Therefore, by putting the digital elevation model (IDW3), would achieved the optimized digital precipitation model in Jam and Riz basin.

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