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Evaluating optimized digital elevation precipitation model using IDW method (Case study: Jam & Riz Watershed of Assaloyeh, Iran)

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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 IDW3 with the best conditions and lowest mean standard error provides the most accurate estimates of precipitation.

Keywords: Optimized exponent, Standard ellipse, Standard deviation ellipse, IDW; Interpolation

1. Introduction

Spatial interpolation methods are widely used in creating 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; Javris and Stuart, 2001a, b; Kurtzman and Kadmon, 1999; Mitas and Mitasova, 1988; 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; Hofierk *et al*., 2002), also several more recent geostatistical textbook are available (Issaks 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:

$$K_{xy} = \frac{\sum_{i=1}^{N} k_i w_i}{\sum_{i=1} w_i} \tag{1}$$

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Where, k_i is the control value for Ith 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 interpolation 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:

$$w_i = d_{xy}^{-m} \tag{2}$$

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:

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

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 once (Sullivani and Unwin, 2003).

$$w_i = \frac{w}{\sum_{i=1}^{N} w_i} = \frac{d_{xyi}^{-m}}{\sum_{i=1}^{-m} d_{xyi}^{-m}} \tag{4}$$

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:

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

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:

$$K_{xy} = \frac{\sum_{i=1}^{N} k_i w_i (v_i,\ldots,v_x)}{\sum_{i=1}^{N} w_i (v_i,\ldots,v_x)} \tag{6}$$

Where, the weights w_i are determined by the variables $v_i \ldots v_x$. A multivariate version based on Eq. 3 can be redefined as Eq. 7:

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

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).

2. 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 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 GIS9. The highest point of the study area shows

1414 m and its lowest point is 57.8 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 erratic rainfall in the region. Seasonal distribution of rainfall in the region, clears that rainfall regime is based on Mediterranean regime. It means, more than 60% of annual precipitation occurs in winter and summer with only 1% annual precipitation is the driest season. Monthly precipitation regime represents that maximum rainfall happens in January and December. 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.
● Topographic maps at 1:25000 scale of 2001 from the National Cartographic Center of Iran.
● Climatic statistics and data, prepared by researchers' organization of water resources.

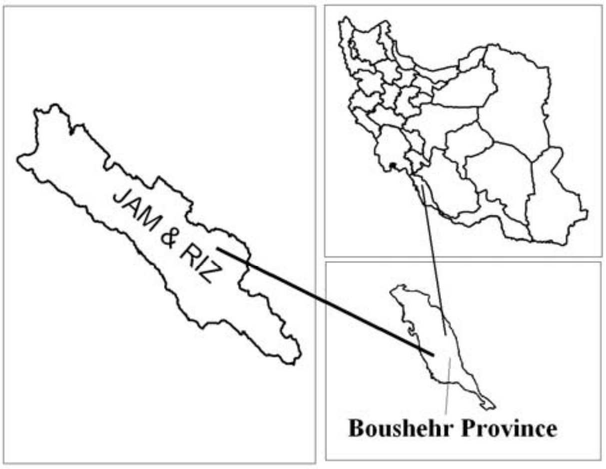

Fig. 1. Geographical location of Jam & Riz watershed in Iran

Determining the optimized digital elevation model using interpolation method of IDW

First, they have scanned as topographic maps and then georeferenced in Erdas Imagin9.1 software. The border of basin which was already limited on the mentioned maps traced in Arc View and then border vector Layer was prepared. In next stage between 15156 elevations points of the base map 10637 points were selected to consider 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. Table 1 shows some of the statistical features of these points.

Table 1. Statistical features of the elevation points in Jam and Riz basin

Statistical features	Values
No. of point	10637.00
Average of elevation	606.97
Maximum elevation	1414.00
Minimum elevation	57.76
Range	1356.24
Variance	74237.00
Standard deviation	272.460
Skewness	0..31
Kurtosis	2.71
Median	606.00

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 by the following expressions 8 and 9 (Ebdon, 1998).

$$SD = \sqrt{\frac{\sum_{i=1}^{n} fi(xi - xmc)^2 + \sum_{i=1}^{n} fi(yi - ymc)^2}{\sum_{i=1}^{n} fi}} \quad (8)$$

$$(xmc, ymc) = \frac{\sum_{i=1}^{n} xi}{n}, \frac{\sum_{i=1}^{n} yi}{n} \qquad (9)$$

Where: xmc and ymc = represent coordinates of average center, yi and xi = coordinates of I points, fi = frequency of point I and n is the number of points

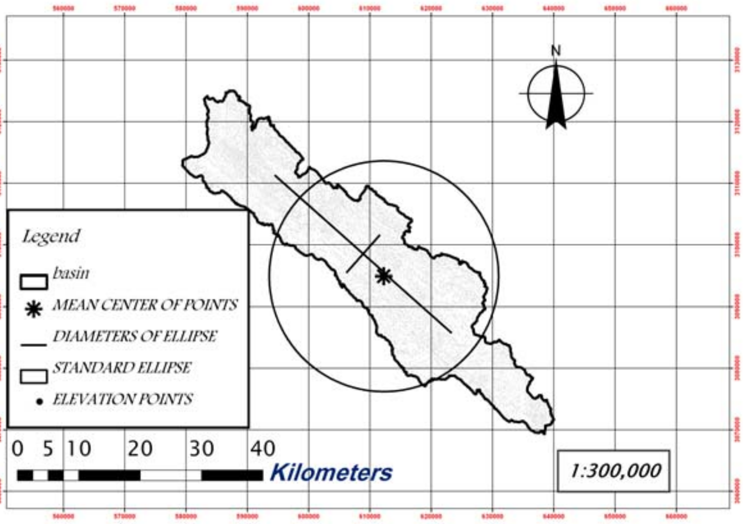

Fig. 2. Standard ellipse and standard deviation ellipse for elevation point group

During the past three decades, models that solve the catchments and or solute transport equations in conjunction with n optimization technique have been increasingly used as watershed management tools (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 point's indifferent directions to each other can represent several geomorphologic features of spatial area. The standard deviation ellipse was identified as follows:

● Coordinates of average center (Xmc, Ymc) were calculated on map which is starting points for transmission them. For every points of pi in distribution, coordinates transmission was done as follows:

$$Xi = xi - xmc$$
$$Yi = yi - ymc \qquad (10)$$

After transmission, all points were concentrated on average center.

● Rotation angle was calculated using Wong relation (Wong, 2000):

$$\tan\theta = \frac{(\sum_{i=1}^{n} xi^2 - \sum_{i=1}^{n} yi^2) + \sqrt{(\sum_{i=1}^{n} xi^2 - \sum_{i=1}^{n} yi^2)^2} + 4(\sum_{i=1}^{n} xi - \sum_{i=1}^{n} yi)}{2(\sum xi \sum yi)} \qquad (11)$$

● Deviation in length of X and Y axes have derived according to the relations of Eq. 12 and 13 (Levine *et al*., 1995).

$$\delta X = \sqrt{\frac{\sum_{i=1}^{n} (xi\cos\theta - yi\sin\theta)^2}{n}} \qquad (12)$$

$$\delta X = \sqrt{\frac{\sum_{i=1}^{n} (xi\sin\theta - yi\cos\theta)^2}{n}} \qquad (13)$$

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. According to this value and the represented factors, the best digital elevation models were prepared for the study area (Fig.3).

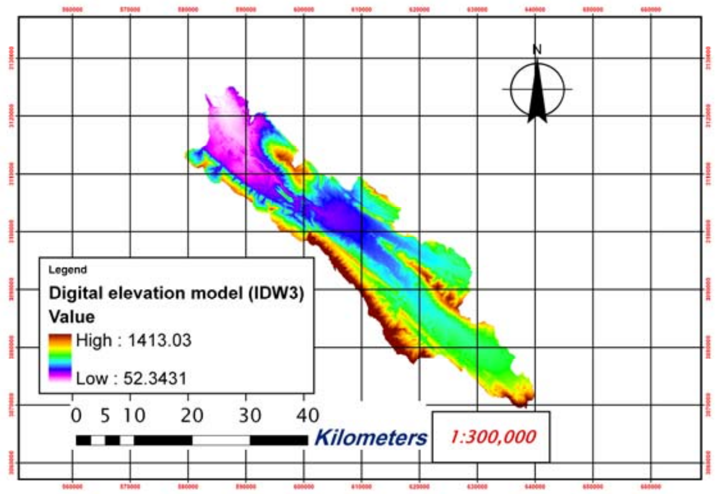

Fig. 3. Optimized digital elevation model (IDW3)

Identifying the average gradient of annual precipitation using available data base

In first stage the total available stations in Jam and Riz basin, which is about 103 stations, were prepared. Because of long distance and in accordance with climatic conditions, many of the stations omitted. Then 22 stations were selected. Some of general specification related to these stations is given in Table 2. 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 between data average during statistical period. In order to reconstruct the precipitation statistic, the normal ratio technique was used (Mahdavi, 2007):

$$p_x = \frac{1}{n}\left[\left(\frac{\overline{p}_x}{\overline{p}_A} * p_A\right) + \left(\frac{\overline{p}_x}{\overline{p}_B} * p_B\right) + \ldots\right] \qquad (14)$$

Where, p_x is precipitation of deficient station in a regarded year, n is number of reference stations, $\overline{p}_x$ is average precipitation in a deficient station which existent statistic, $\overline{p}_A, \overline{p}_B$ 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.

Table 2. General specifications of selected stations in the study area

Sr. No.	Station Name	Station Type	Lat/Lon (Deg, Min)		Elevation(m)
1	Farashband	Evaporimeter	28, 52	52, 06	790
2	Tangab	Evaporimeter	28, 55	52, 03	1310
3	Ghantareh	Evaporimeter	28, 15	51, 52	75
4	Baghan	Rain Gauage	28, 12	51, 53	110
5	Jahrom	Evaporimeter	28, 32	52, 34	1110
6	Jam	Rain Gauage	27, 50	52, 19	650
7	Khourab	Rain Gauage	28, 36	52, 19	580
8	Dahrom	Rain Gauage	28, 27	52, 20	380
9	Dezhgah	Evaporimeter	28, 11	52, 21	200
10	Hangam	Rain Gauage	28, 22	52, 35	560
11	Dehroud	Rain Gauage	28, 37	52, 34	880
12	Kangan	Rain Gauage	27, 50	52, 04	2
13	Glashgerd	Evaporimeter	28,00	51, 13	560
14	Boushehr	Synoptic	28, 59	50, 50	20
15	Boushehr Daryaee	Synoptic	28, 57	50, 51	8
16	Firouzabad	Climatology	28, 52	52, 36	1340
17	Ahrom	Rain Gauage	28, 53	51, 18	90
18	Kangan e Jam	Synoptic	27, 49	52, 22	655
19	Dayer	Synoptic	27, 50	51,56	4
20	Shahr e Khas	Rain Gauage	27, 57	52, 12	513
21	Anarestan	Rain Gauage	28, 03	52, 04	330
22	Kordalan	Rain Gauage	28, 14	51, 51	113.5

It should be mentioned that between 22 stations the stations had short term observation, did not include in analysis and obviously they applied to conform achieved results and used as ancillary points in drawing the map. Therefore, according to expert studies just 11 stations were selected and whole calculations and analyses about precipitation subject was done on 11 selected stations (Table 3). The annual rainfall values of concerned stations have given in Table 4. After studying the concerned stations, average annual precipitation gradient equation of Jam and Riz basin achieved (Fig.4).

Table 3. The name of reconstructed and base stations with their coefficient of correlation

Reconstructed Station	Base Station	Coefficient of Correlation
Hangam	Khourab	0.90
Dahrom	Baghan	0.82
Khourab	Baghan	0.81
Ghantareh	Baghan	0.94
Ahrom	Boushehr	0.88
Kangan	Baghan	0.59
Boushehr	Boushehr Daryaee	0.99
Kangan e jam	Baghan	0.83
Firouzabad	Baghan	0.76

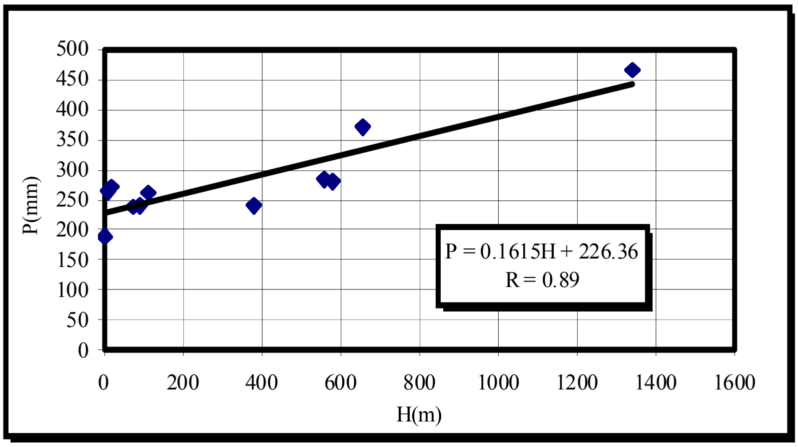

Fig. 4. Average annual precipitation gradient of Jam & Riz basin
P: annual precipitation (mm)
H: elevation (m)

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 GIS9.2.

3. Result 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 neighboring stations or from relationships with other variables (Marquines *et al.*, 2003). This techniques (IDW), can obtain satisfactory results from limited data, based mainly on the geographical 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 into geostatistical approaches (Martinez-Cob, 1996). Others have developed relationships between precipitation and various topographic variables such as altitude, 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.2). the extracted results of this study are presented in Table 5. 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 6). According to this value and the represented factors, digital elevation models were prepared for the study area (Fig.3).

Table 4. The values of annual precipitations of stations (mm)

water year/ station	Hangam	Dahrom	Khourab	Baghan	Ghantareh	Ahrom	Kangan	Boushehr	Boushehr Daryaee	Kangan e jam	Firouzabad
1986-87	345.4	312.2	364.1	336	253	293	85	328.7	336.7	502.3	630
1987/88	343	239.7	279.5	258	260	249	92	253.8	260	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	160.9	148.5	131.5	127	55	172.8	177	222	444.9
1990-91	181	155	242	180318	213.5	182	84.5	239.5	224.9	475.4	317
1991-92	364	299	327	269	248.5	304	259	325	310.2	402.2	318.5
1992-93	340.5	237.5	297	259.5	217	351	216	351.2	308.9	388	441
1993-94	104	114	181	103.5	109.5	182	144	135.6	136	241.2	358
1994-95	238.5	254	263	195	218	308	259.5	256.4	268.6	344.4	500.5
1995-96	245	179.5	143	182	132.5	213	187.5	198.1	171.1	392	345
1996-97	378	204.5	303	247	350.5	191	369.5	190.3	195.3	608.5	619
1997-98	683	462	556.5	416.5	394	292.5	308.5	265.1	229	668.1	316
1998-99	103.7	132	100	94.5	103.5	58	72.8	83	81.8	108.3	456.3
1999-2000	305	379.1	442.1	408	332.5	295	156	308.3	292.5	315.4	571.6
2000-1	505	450	477	729.5	639	519	412	588.5	622.8	822.9	804.2
2001-2	212	208.5	195	219	230	182	204.5	281.9	251.2	248.1	219.8
2002-3	390	411	504	437	454.5	447	381.5	746.5	747.1	508.1	645
2003-4	231	272.5	2995	172.5	184	234	142.5	196.8	189.7	241.7	401
2004-5	150	113	145.5	171	127.5	173	123	223.6	190.3	228.6	187.5
2005-6	144	153	222	166	82	131	149	191.5	197.7	157.9	290.5
Average	284.6	240.4	280	261.6	238.8	240.6	189	271.2	264	370.5	465.9
Maximum	683	462	556.5	729.5	639	519	412	746.5	747.1	822.9	816
Minimum	103.7	93.1	100	94.5	82	58	55	83	81.8	108.3	187.5
SD	141.5	114.3	133.2	151.1	140.1	115	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

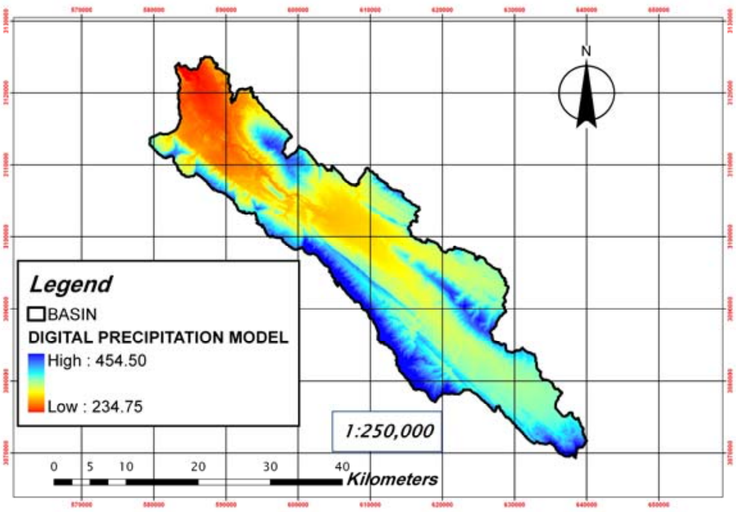

Fig. 5. Optimized digital precipitation model

Table 5. Characteristics of the test samples in IDW model

Characteristics	IDW1	IDW2	IDW3	IDW4	IDW5	IDW6	IDW7	IDW8
No. of neighbor points	3	5	7	15	3	5	7	15
Radius of standard ellipse (m)	18705.1	18705.1	18705.1	18705.1	*	*	*	*
Major axis value (m)	*	*	*	*				
Minor axis value (m)	*	*	*	*				
Rotation angle	*	*	*	*				
Center of standard ellipse (UTM)	612278 3094928	612278 3094928	612278 3094928	612278, 3094928	*	*	*	*
Cross center of diameters (UTM)	*	*	*	*	608884 3098526	608884 3098526	608884, 3098526	608884 3098526

Table 6. The value of optimized power in digital elevation models

Digital Elevation Model	IDW1	IDW2	IDW3	IDW4	IDW5	IDW6	IDW7	IDW8
Optimized Power	2.4624	2.9533	3.299	3.9389	2.8811	3.2819	3.476	3.7787

With comparing the 10637 extracted points of 8 digital elevation models by SPSS14 which due to geographical 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 7.

Table 7. Test of compare means (paired t-test) for observation elevation value and elevation values of IDW model

Observation Values						
IDW model	Mean	SD	MSE	t	df	Significant (5%)
IDW1	0.2598	28.37946	0.27517	0.944	10636	0.345
IDW2	0.347	27.84728	0.27001	1.285	10636	0.199
IDW3	0.3131	27.6836	0.26842	1.166	10636	0.243
IDW4	0.2396	27.82845	0.26982	0.888	10636	0.375
IDW5	0.6295	30.41523	0.2949	2.134	10636	0.033
IDW6	0.6377	30.72485	0.29791	2.141	10636	0.032
IDW7	0.6534	30.85.84	0.29913	2.184	10636	0.029
IDW8	0.6521	31.04604	0.30102	2.166	10636	0.03

4. Conclusion

In fact, from the gained digital models the accurate one is a model which it's resulted elevation points. However it is logical that the data which do not have main differences to land observation in 5% level of significance 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 among 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, the optimized digital elevation precipitation model in Jam and Riz basin, by putting the digital elevation model (IDW3), would achieved

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