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Assessment of CAR and GIDS Methods to Interpolate Rain Values in Mexico City in Flood Event

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Abstract

Previous works regarding interpolated values in Mexico City has been carried out so far using Kringing in its different forms: OK, KED, UK, etc. The interpolation was used to estimate monthly average or to map the rain or temperature in Mexico to help agriculture. In this work an assessment is presented to observe the performance of two relatively new methods: CAR and GIDS. Furthermore, the assessment is made to observe the performance of rain values in Flood event in Mexico City. The values of September 29th 1976 were used and accuracy of the interpolators was measure through cross validation. The results are tabulated and analyzed.

Index terms: interpolation, CAR, GIDS, rainfall values.

Resumen (Evaluación de los métodos CAR y GIDS para interpolar valores de lluvia en la Ciudad de México en eventos de inundación)

Trabajos previos relacionados con valores de lluvia interpolados en Ciudad de México se han llevado a cabo hasta ahora usando Kringing en sus diferentes formas: OK, KED, UK, etc. La interpolación se usó para estimar un promedio mensual o para mapear lluvia o temperatura para ayudar a la agricultura. En este trabajo se presenta una evaluación para observar el desempeño de dos métodos relativamente nuevos: CAR y GIDS. Además, la evaluación se hace para observar el rendimiento de los valores de lluvia en eventos de inundación en la Ciudad. Los valores del 29 de septiembre de 1976 fueron usados y la precisión de los interpoladores fue medida a través de validación cruzada. Los resultados son tabulados y analizados.

Palabras clave: interpolación, CAR, GIDS, valores de lluvia.

1. Introduction

According to Prevention Web [1], in a period of twenty-eight years, from 1980 to 2008, there have been 2887 events, 195,843 people killed, 6753 people killed per years, causing an economic damage of 397,333,885 thousand dollars and an economic damage per year of 13,701,168 thousand dollars.

It is to take into account the kind of disaster, economical and humanitarian, depicted in this statistic. Several authors have made work evaluating the interpolation methods in many conditions.

Tabios and Salas [2] did an evaluation of the methods. Their conclusion was that Kriging throws the best results and the polynomial interpolation gives the poorest. Daly *et al.* [3] made a program called "Precipitation-elevation Regressions on Independent Slopes Model (PRISM) for the mapping of the average precipitation in which orography is an important parameter. In this paper it must be highlighted the analysis in mountainous terrain, such terrain is similar to Mexico City´s. For the cases with elevation, several papers proposed the use of the Digital Elevation

Model (DEM) [4] ,[5], and a special case is the proposed of Gradient Plus Inverse Distance Squared (GIDS) [6]. This proposal integrates the elevation as a parameter for the estimation of the rain value; the study took place in northern Canada. Schuurmans and Bierkens [7] established in their study how sensitive is the catchment response to rainfall variability and how this situation can lead to errors; in fact, they established that the ground features should be taken into account for the runoff estimation. Furthermore, this paper establishes that when a few meteorological stations are in used, the error can rise; the opposite could take place when more stations are considered and this can be compensated with the use of meteorological radar.

Vilchis Mata *et al*. [8] calculated the daily precipitation aided by a GIS from radar located nearby Mexico City Downtown. This information, they concluded, could be used for efficient management of the water resources in order to prevent future flooding.

The merge of the meteorological radar and daily station network appears in Haberlandt [9], his conclusion was that the use of the Kriging with External Drift is the optimal interpolator.

The integration of variables such a humidity and wind velocity improves the interpolation according to Kyriakids *et al*. [10], whose paper establishes that the best interpolation methods are the Simple Kringing with local mean and the Kriging with external drift, above the ordinary Kriging.

Faurés *et al*. [11] assess the impact of variables such as inclination and wind velocity in the behavior of the runoff and how these can affect the response of the catchment. Arnaud *et al*. [12] establishes the variability as one of the issues affecting the calculation of the runoff. In their paper made assumptions and simplifications for the models to improve. Shah *et al*. [13], [14] published a study which they divided in two parts, the first one is about the formulation and calibration of the model of the response of the catchment in conditions of spatial variability in rainfall, the second one makes experiments with lumped and distributed models. An interesting paper was written by Demyanov *et al*. [15] with the innovation of the use of Neural Networks with them. González-Hidalgo *et al*. [16] found some rain variabilities related to forest dynamics; in fact, describes an alteration in rainfall due to reduction of the forest area. For a real-time rainfall interpolation, the best interpolator will be the Kringing with external drift [17]. The hourly rainfall could hardly raise its accuracy with the use of an external drift in Kriging interpolation [18], nevertheless, the use of a radar is one option to improve interpolation. In cases where no access to this type of tool could happen, the next option is the use of the meteorological station. The incorporation of elevation as a second variable improves the interpolation [19]. The method with the best results was the Kringing with external drift, which appears in this study realized in Mexico City. In this paper it was interpolated the rainfall and the temperature for two dates. A study made by Segond *et al*. [20] establishes that urban basins are more sensitive to a rainfall spatial variability than the rural terrain. In this study the Thiessen polygon method [21] was used. Díaz Padilla *et al*. [22] conclude in their study that the best interpolator method for the zone of Veracruz, México is the Thin Plate Smoothing Spline with higher performance than the Kriging and the Inverse Distance Weighting. It could be observed an error regarding the stochastic or deterministic models, which can be accumulative in different steps within flood [23].

This author used a numerical weather prediction, a 2D hydrodynamic and a rainfall-runoff model to assess the propagation of the error. Cisneros *et al*. [24] conclude that the kriging method has a better performance than the splines method. A Cluster-Assisted Regression (CAR) [25] method was proposed as another option to the GIDS method. This method uses a multiple regression with clustering to improve interpolation, especially in mountainous zones, such as the territory of China. Finally, Lorenz [26] who studied the instability of the equations in a rain event establishes that the weather prediction is too variable to be accurately calculated. The objective of this work is to assess the GIDS and CAR interpolation methods for the climatological and topographical conditions in Mexico City. This City is subject to regular flooding, which has an impact in the population, mostly in the economic issue. So, measures must be taken in order to reduce the impact of such weather phenomena. So, aware of this, an interpolation method is needed in order to calculate, evaluate and, in some cases, predict flood events.

2. Description of CAR and GIDS methods

It was reviewed that in cases of interpolation the method exhibiting a better performance is the Kriging method with external drift and a spherical semivariogram. The proposal is to evaluate the GIDS [6] and the CAR [25] because of the features presented which fit into the Mexico City Orography.

The equation used for the GIDS is:

$$Z = \frac{\left[\sum_{i=n}^{n} \frac{Z_i + (X - X_i)\, xC_x + (Y - Y_i)\, xC_y + (E - E_i)\, xC_e}{d_i^2} \right]}{\left[\sum_{i=1}^{n} \frac{1}{d_i^2} \right]}$$

Where: Z are the interpolated rain valued, Z_i are the values of the meteorological stations; X,Y are the planar coordinates of the spot to be determined and E its height; X_i,Y_i are the coordinates of the stations and E_i its height; di is the distance from the spot to the stations and C_x, C_y and C_e are the regression coefficients. By means of the linear regression, the Coefficients are determined.

For the CAR method, the mathematical model is the following:

$$V_p = C_0 + X(C_x) + Y(C_y) + E(C_e)$$

Where V_p are the values to be determined, X,Y are the planar coordinates and E its height; C_0,C_x,C_y and C_e are the regression coefficients. The coefficients are determined in the same way as the GIDS method.

In both methods the coefficients are determined using regression method.

3. Methodology

The aim of this work is to assess the interpolation methods GIDS [6] and the CAR [25], then the methods will be validated by the mean square error (MSE) and the cross validation [27]. This has the objective to assess the methods in flood situations to obtain values of rainfall to input in runoff models afterwards, improving the calculation of the quantity of water to have a better management in order to prevent flood. Mexico City has a long rainy period in which flooding took place. The Statistics shows that in the year 2015, the rainiest season runs from May to September. The Table 1 shows the values of precipitation millimeters per month.

It is quite notorious the period when takes place the rain with most intensity. In specific, the rain average does not have an utility, as it isolated events can happen one day and the rest of the month could had a moderated rain. That is why the variability is the reason for this assessment is to be made for a specific day in which the rain caused the flooding.

Mexico City is a basin with a mountainous terrain [28]. In the description of the methods used in this work, the authors stated that China and Canada have also an irregular and mountainous orography.

Table 1. Mexico City´s Monthly Precipitation 2015.

January	February	March	April	May	June
0.3	2.9	19.5	8.3	69.6	74.1
July	**August**	**September**	**October**	**November**	**December**
94.1	79.2	114.3	20.2	5.4	4.1

The values depicted in the Table 2, were published by The National Meteorological System (SMN, by its initials in Spanish).

The map in Fig. 1 shows the distribution of the stations by its polar coordinates.

The Table 3 shows the values of the precipitation taken from the table 1, column 3; the fourth column shows the values obtained by the GIDS method and the fifth column shows the values obtained by the CAR method.

The MSE for both CAR and GIDS are depicted in the Table 4.

The figure 2 shows a graphic of the MSE for different stations.

Fig. 1. Distribution of the Meteorological Stations.

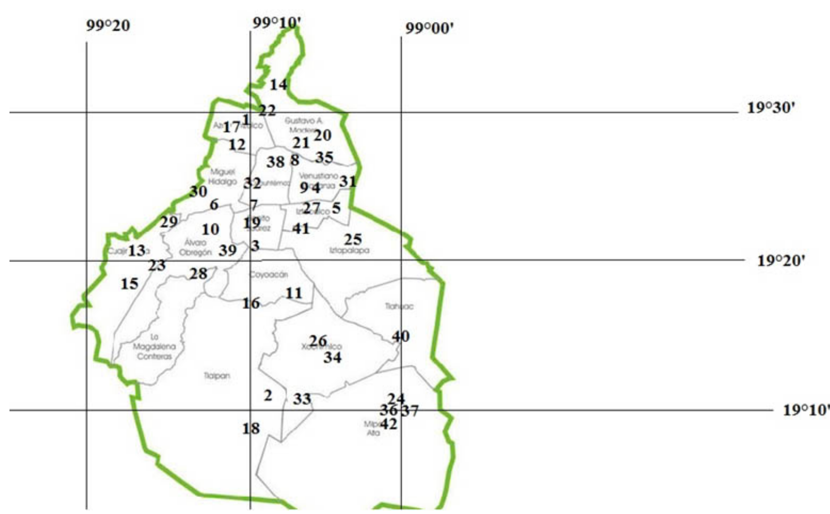

Table 2. Meteorological Stations and their data.

No.	Station	Latitude	Lenght	Precipitatioin (mm)	height (m)
1	Aquiles Serdán	19.4690	99.1900	29.6	2255
2	Calvario	19.2030	99.1490	5.6	2726
3	Campo exp. Coyoacán	19.3510	99.1720	0.0	2260
4	Cincel 42	19.4160	99.1160	11.5	2326
5	Agrícola Oriental	19.3994	99.0750	9.0	2235
6	Colonia América	19.4125	99.2010	12.8	2271
7	Colonia Escandón	19.4014	99.1770	15.5	2245
8	Colonia Guerrero	19.4500	99.1330	5.5	2252
9	Colonia Moctezuma	19.4278	99.1050	15.0	2235
10	Colonia Santa Fe	19.3800	99.2330	8.2	2422
11	Colonia Santa Ursula Coapa	19.3033	99.1480	3.0	2256
12	Colonia Tacuba	19.4590	99.1890	48.5	2255
13	Cuajimalpa	19.3500	99.3000	3.7	2777
14	Cuautepec Barrio Bajo	19.5420	99.1300	11.0	2390
15	Desierto de los leones	19.3139	99.3097	1.0	2995
16	Desviación alta al Pedregal	19.2969	99.1822	2.5	2296
17	Egipto 7	19.4750	99.1861	46.3	2248
18	El Guarda	19.1344	99.1731	7.0	2990
19	General Anaya	19.3667	99.1667	14.8	2240
20	Gran Canal km. 06 + 250	19.4767	99.0914	10.9	2239
21	Gran Canal km. 3 + 0	19.4500	99.1000	7.0	2239
22	Hacienda la Patera	19.5128	99.1583	19.0	2240
23	La Venta Cuajimalpa	19.3330	99.3000	1.6	2850
24	Milpa Alta	19.1906	99.0219	4.2	2420
25	Morelos 77	19.3667	99.0833	1.8	2240
26	Moyoguarda	19.2500	99.1000	19.5	2260
27	Playa Caleta 454 Colonia Marte	19.3953	99.0978	40.0	2235
28	Prensa Ansaldo	19.3333	99.2167	3.6	2363
29	Presa Mixcoac	19.3667	99.2667	8.2	2576
30	Presa Tacubaya	19.3972	99.2125	9.4	2340
31	Puente La Llave	19.4292	99.0528	16.8	2234
32	Rodano 14	19.4250	99.1736	25.8	2250
33	San Francisco Tlalnepantla	19.1967	99.1286	5.0	2620
34	San Gregorio Atlapulco	19.2167	99.0833	2.5	2549
35	San Juan de Aragón	19.4653	99.0792	8.0	2240
36	San Lorenzo	19.1750	99.0311	6.7	2640
37	Santa Ana Tlacotenco	19.1789	99.0028	1.5	2595
38	Tacuba 7	19.4358	99.1389	15.0	2247
39	Tarango	19.3600	99.2125	8.5	2340
40	Tláhuac	19.2628	99.0036	2.0	2240
41	Unidad Modelo	19.3667	99.1167	25.3	2229
42	Vertedor Milpa Alta	19.1833	99.0167	3.4	2488

Table 3. Comparison between the real values, GIDS an CAR values (precipitation in mm).

No.	Station	Real values	GIDS	CAR
1	Aquiles Serdán	29.6	43.54708730	18.13306050
2	Calvario	5.6	5.87271486	1.90176251
3	Campo exp. Coyoacán	0.0	12.46647750	13.74801020
4	Cincel 42	11.5	16.52224490	14.52668200
5	Agrícola Oriental	9..0	18.70288490	14.77312000
6	Colonia América	12.8	15.78198760	16.05062610
7	Colonia Escandón	15.5	15.96269800	15.77033800
8	Colonia Guerrero	5.5	16.55868430	16.91449280
9	Colonia Moctezuma	15.0	13.58017660	16.07995660
10	Colonia Santa Fe	8.2	10.99395480	13.16479470
11	Colonia Santa Ursula Coapa	3.0	8.20519621	11.88382310
12	Colonia Tacuba	48.5	29.70074580	17.77277850
13	Cuajimalpa	3.7	5.17625468	7.91776604
14	Cuautepec Barrio Bajo	11.0	20.36182170	18.19798050
15	Desierto de los leones	1.0	4.25044963	3.74885015
16	Desviación alta al Pedregal	2.5	7.10264409	11.46528390
17	Egipto 7	46.3	32.75961070	18.39880020
18	El Guarda	7.0	3.37399113	3.88831576
19	General Anaya	14.8	8.18501367	14.51780740
20	Gran Canal km. 06 + 250	10.9	11.93400330	17.59346250
21	Gran Canal km. 3 + 0	7.0	13.81951100	16.74920360
22	Hacienda la Patera	19.0	21.64244500	19.54123170
23	La Venta Cuajimalpa	1.6	4.46643943	6.31600964
24	Milpa Alta	4.2	4.11263125	4.36189009
25	Morelos 77	1.8	17.36629500	13.64685010
26	Moyoguarda	19.5	5.63424256	9.46273152
27	Playa Caleta 454 Colonia Marte	40.0	11.59329700	14.86778950
28	Prensa Ansaldo	3.6	8.50914931	12.17472510
29	Presa Mixcoac	8.2	8.93395538	10.92702260
30	Presa Tacubaya	9.4	13.36072430	14.68361810
31	Puente La Llave	16.8	13.00712770	15.59759740
32	Rodano 14	25.8	17.53078610	16.49147660
33	San Francisco Tlalnepantla	5.0	5.65078360	2.93058716
34	San Gregorio Atlapulco	2.5	8.31775587	4.13663145
35	San Juan de Aragón	8.0	12.5280829	17.05344500
36	San Lorenzo	6.7	3.24743605	0.87733255
37	Santa Ana Tlacotenco	1.5	3.71297673	1.33900113
38	Tacuba 7	15.0	13.05640860	16.54831070
39	Tarango	8.5	9.16147932	13.38221730
40	Tláhuac	2.0	7.19707185	9.17970602
41	Unidad Modelo	25.3	13.22846390	14.14739500
42	Vertedor Milpa Alta	3.4	3.91651850	3.11414782

Table 4. MSE in GIDS and CAR.

No.	Station	GIDS	CAR
1	Aquiles Serdán	97.26062230	65.74535050
2	Calvario	0.03718670	6.83848026
3	Campo exp. Coyoacán	77.70653050	94.50389210
4	Cincel 42	12.61147170	4.58040207
5	Agrícola Oriental	47.07298750	16.66445750
6	Colonia América	4.44612493	5.28328511
7	Colonia Escandón	0.10704472	0.03654133
8	Colonia Guerrero	61.14724910	65.14532290
9	Colonia Moctezuma	1.00794919	0.58315309
10	Colonia Santa Fe	3.90309169	12.32459340
11	Colonia Santa Ursula Coapa	13.54703380	39.46115640
12	Colonia Tacuba	176.70598000	472.08107200
13	Cuajimalpa	1.08966394	8.89477521
14	Cuautepec Barrio Bajo	43.82185320	25.90546140
15	Desierto de los leones	5.28271141	3.77808858
16	Desviación alta al Pedregal	10.59216630	40.18815810
17	Egipto 7	91.67107140	389.23847500
18	El Guarda	6.57397018	59.27771000
19	General Anaya	21.87902210	0.03981633
20	Gran Canal km. 06 + 250	0.53458146	22.40122030
21	Gran Canal km. 3 + 0	23.25286550	47.52348500
22	Hacienda la Patera	3.49125787	0.14646580
23	La Venta Cuajimalpa	4.10823750	11.12037350
24	Milpa Alta	0.00381665	0.01310420
25	Morelos 77	121.15477000	70.17392860
26	Moyoguarda	96.12961460	50.37337920
27	Playa Caleta 454 Colonia Marte	403.47038700	315.81400200
28	Prensa Ansaldo	12.04987350	36.76295500
29	Presa Mixcoac	0.26934525	3.71832614
30	Presa Tacubaya	7.84366834	13.95831020
31	Puente La Llave	7.19294029	0.72288600
32	Rodano 14	34.18994900	43.32430430
33	San Francisco Tlalnepantla	0.21175965	2.14123474
34	San Gregorio Atlapulco	16.92314170	1.33928125
35	San Juan de Aragón	10.25176740	40.98243320
36	San Lorenzo	5.96009892	16.95172810
37	Santa Ana Tlacotenco	2.44863300	0.01296032
38	Tacuba 7	1.88877375	1.19863299
39	Tarango	0.21877744	11.91802300
40	Tláhuac	13.50477790	25.77408930
41	Unidad Modelo	72.86099190	62.19029890
42	Vertedor Milpa Alta	0.13339568	0.04085573

Regarding the fig. 2, it is to notice the error in station 12 and 17 in the CAR method and exhibit a similar error both methods in station 27. Still, there are just a few stations in which the error is little.

3. Improvements of the methods

It can be seen in figures 3, 4, 5 the graphic representation of the precipitation values against latitude, and height.

It is to be noticed a great variability, which can´t be adjusted by a polynomial. Therefore, to improve accuracy this work proposes to make the analysis to the next criteria:

- Consider the rainfall behaves as a parabolic way regarding time. It means, it begins at time $t = 0$, reaches a maximum and then rain stops. If the graphic in figure 3, it is to notice the rainfall beginning and ending.

- Then the regression could be modeled as a polynomial.

The graphic 4 shows the precipitation values against the latitude coordinate using the criteria above.

If the stations nearby are gathered, the variation of the rainfall against the coordinates become similar to more linear form. Figure 5 shows the variation for the stations 14, 1, 22, 12, 17; which are closer one to another.

It is to noticed that a linear trendline describes with a minor error the behavior of the variation. To improve the method it was taken by segments: stations 1,14, 22, 17,12 and 20, 21, 35, 8, 38.

The MSE between the two segments for first using GIDS and CAR are shown in figure 6.

4. Results

The fig. 3 shows a great variability in values for the meteorological stations. It was shown in figure 2 the MSE in CAR and GIDS. It reaches values near 400. The figure 3 shows the

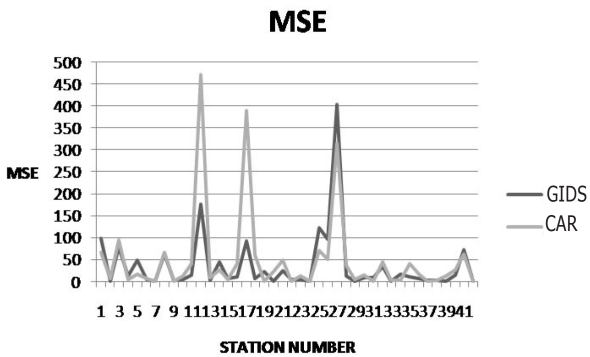

Fig. 2. MSE IN CAR AND GIDS vs. STATION.

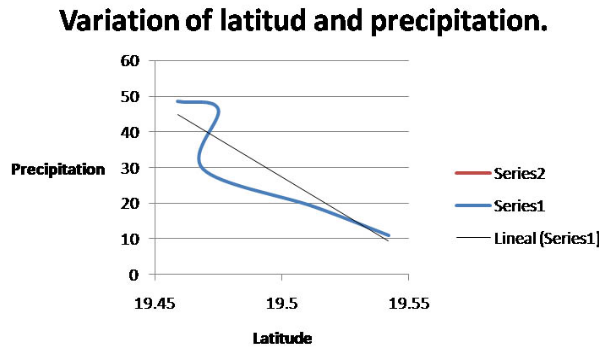

Fig. 5. Variation of precipitation and latitude.

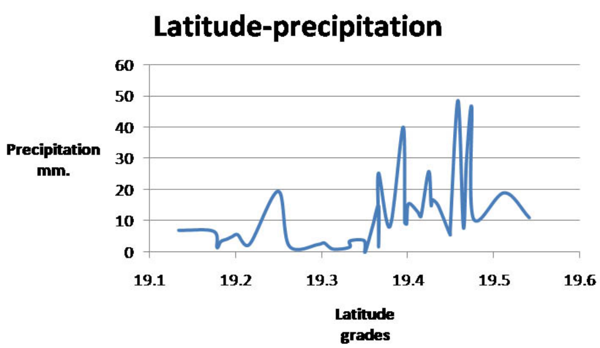

Fig. 3. Latitude vs. precipitation.

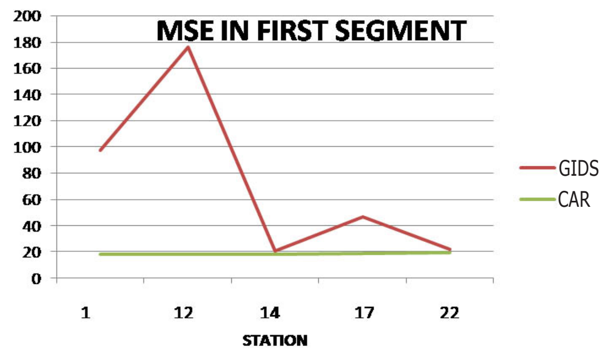

Fig. 6. MSE in CAR and GIDS in first segment.

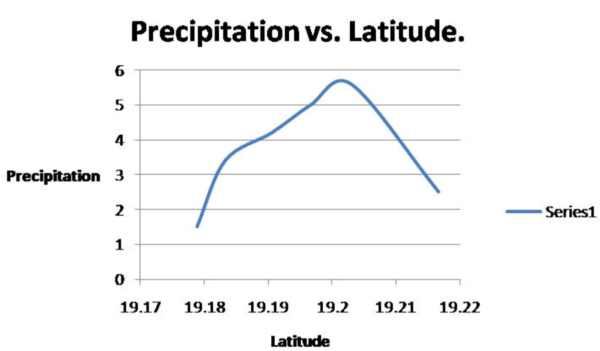

Fig. 4. Latitude vs. Precipitation using the criteria above.

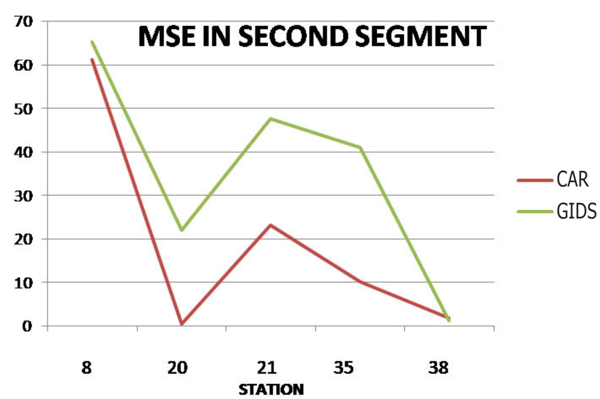

Fig. 7. MSE in CAR and GIDS in second segment.

variability of the values of precipitation. So, because of the variability it was sought to divide in segments. The segment 1 of nearby stations shows a more linear behavior which can be described, with less error, in a linear trendline. Figures 6 and 7 show that dividing in segments, the error can be improved.

5. Conclusion

Two methods that have been applied only in Canada (GIDS) and China (CAR) were assessed in the case of Mexico City. If it is taken into account once with all the values of the meteorological stations, it should be possible to notice that they display a similar behavior reaching values of MSE of a little more of 400, which made them inaccurate in some cases. Figure 3 shows this variability. This can be linearized by dividing in segments for nearby stations. Figures 6 and 7 shown the reduction of the MSE, from values of 400 to values of maximum 160. If it is compared which method is more accurate, it could be said that is the CAR method. Dividing in segments and applying the CAR method for the case in Mexico City are the formulas to improve efficiency.

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