VARIATION OF MONTHLY RAINFALL AND MONTHLY EVAPORATION IN BABYLON

By
Dr. Salah Tawfeek Ali Al-Baz'az, Dr. Omran Issa Mohammed, and Mu'amer Hazim Ali Al-Ta'ee

ABSTRACT

In Babylon Governorate there exists a single meteorological observing station which is located at Hilla city. An observation at this station is a point observation. In order to determine variation of rainfall and of evaporation in Babylon Governorate records at nearby stations should be considered. These stations are Baghdad, Kerbala'a, Najaf, Diwaniya, Kut, Hai, and Ramadi stations which are located outside the boundary of Babylon. In this study the Thiessen polygons method is used to define zone of influence for each of these stations and, hence, monthly mean rainfall are computed. It is found that the monthly mean rainfall are 15.159, 18.08, 22.719, and 15.339 mm/month for the winter months November, December, January, and February respectively. The monthly mean evaporation are found to be 266.912, 288.057, and 259.936 mm/month for the summer months Jun, July, and August respectively.
Key words: Babylon; Thiessen's polygons; Rainfall; Evaporation.

1. THIESSEN'S POLYGONS METHOD

In the Thiessen polygons method, the rainfall recorded at each gauging station is given a weightage on basis of the area which it represents. This method is better than the arithmetic mean method which gives equal weightage to all the stations. The following procedure is followed to compute the average rainfall depth by using Thiessen's polygons method (Wisler and Brater, 1959; Chow, V. T., 1964; Wilson, 1983; Linsley et. al., 1988):

1. The positions of the rain gauge stations are marked on the plan of the catchment area over which the average rainfall depth is required.
2. The adjacent rain gauge stations are joined by straight lines. Thus, the entire area is divided into a series of triangles. The rain gauge stations which are outside the catchment area but are in its neighbourhood should also be considered.
3. Perpendicular bisectors are erected on each of these lines to form polygons around stations. Each polygon contains one and only one rain gauge station. The entire area within any polygon is nearer to the rain gauge station contained therein than any other rain gauge station. Thus, each polygon represents the area of the influence of that rain gauge station.
4. The boundary of the catchment is taken as the outer limit of the Thiessen polygons to find the area of each one of these polygons.
5. The average depth of monthly rainfall over the entire area is computed by using the following equation:

$$P_{av} = \frac{P_1A_1 + P_2A_2 + P_3A_3 + ... + P_nA_n}{A_1 + A_2 + ...A_n} \quad .....(1)$$

Or,

$$P_{av} = \frac{\sum_{i=1}^{n} P_i A_i}{A} \quad \text{.....(2)}$$

where P_i (mm) is the amount of rainfall at a gaugin station, A_i (km^2) is the area corresponding to the rain gauge, and A (km^2) is the total area.

2. RELEVANT METEOROLOGICAL STATIONS

Babylon Governorate lies in the Middle Euphrates Region of Iraq and is bounded by six governorates which are Baghdad, Kerbala'a, Najaf, Diwaniya, Wasit, and Anbar. One of the two main rivers of Iraq, Euphrates, passes through Babylon as shown in Figure 1.

In Babylon there is only one meteorological gauging station which is located in Hilla. In this study seven additional gauging stations are used for calculating mean rainfall and mean evaporation for Babylon using Thiessen's polygons method. These stations are located in Baghdad, Kerbala'a, Najaf, Diwaniya, Kut, Hai station at Hai, and Ramadi stations. According to the Iraqi Meteorological Organization these eight stations and the periods of observation of rainfall and evaporation are as given in Table 1.

Table 1: The meteorological stations that are used to calculate mean rainfall and mean evaporation for Babylon Governorate.

Station	Period of Observation of Rainfall	Period of Observation of Evaporation	Location	
			Latitude (North)	Longitude (East)
Hilla	1970–2006	1978-2006	32° 29′	44° 26′
Baghdad	1971-2006	1971-2006	33° 19′	44° 25′
Kerbala'a	1971-2006	1976-2006	32° 36′	44° 01′
Najaf	1971-2006	1971-2006	32° 00′	44° 20′
Diwaniya	1971-2006	1971-2006	31° 59′	44° 55′
Kut	1971-2003	1988-2002	32° 30′	45° 49′
Hai	1970-2006	1976-2006	32° 10′	46° 02′
Ramadi	1970-2006	1981-2006	33° 25′	43° 18′

Source: Iraqi Meteorological Organization (The data are in mm/month).

3. COMPUTING MEAN RAINFALL FOR BABYLON

The locations of the gauging stations which are used in this study is shown in Figure 2 which also shows the Thiessen polygons. The zone of influence for each station is given different colour in Figure 3. The areas of the Thiessen polygons are determined using AutoCAD software and monthly rainfalls are computed using Equation 2 as shown in Table 2.

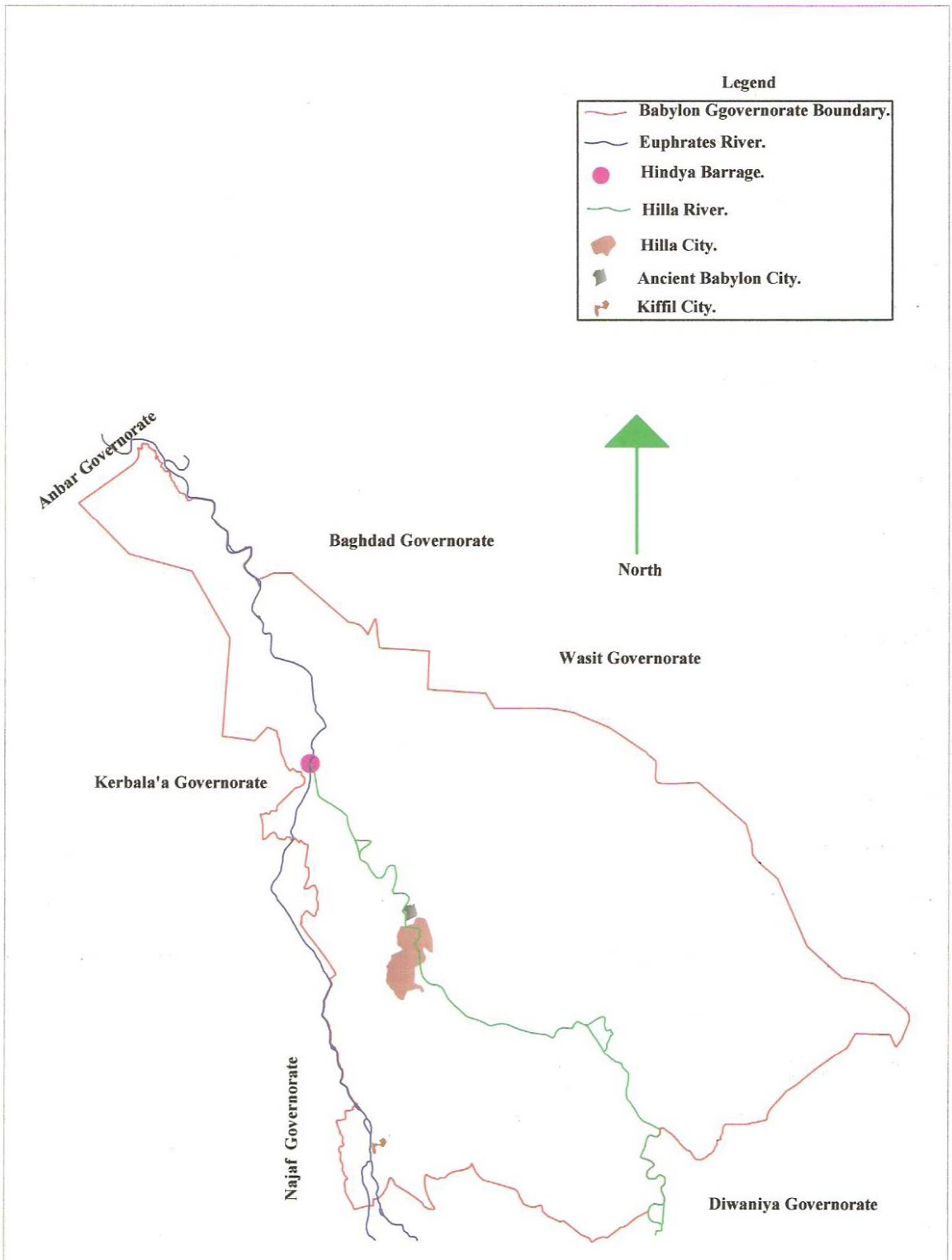

Figure 1: Map of Babylon Governorate

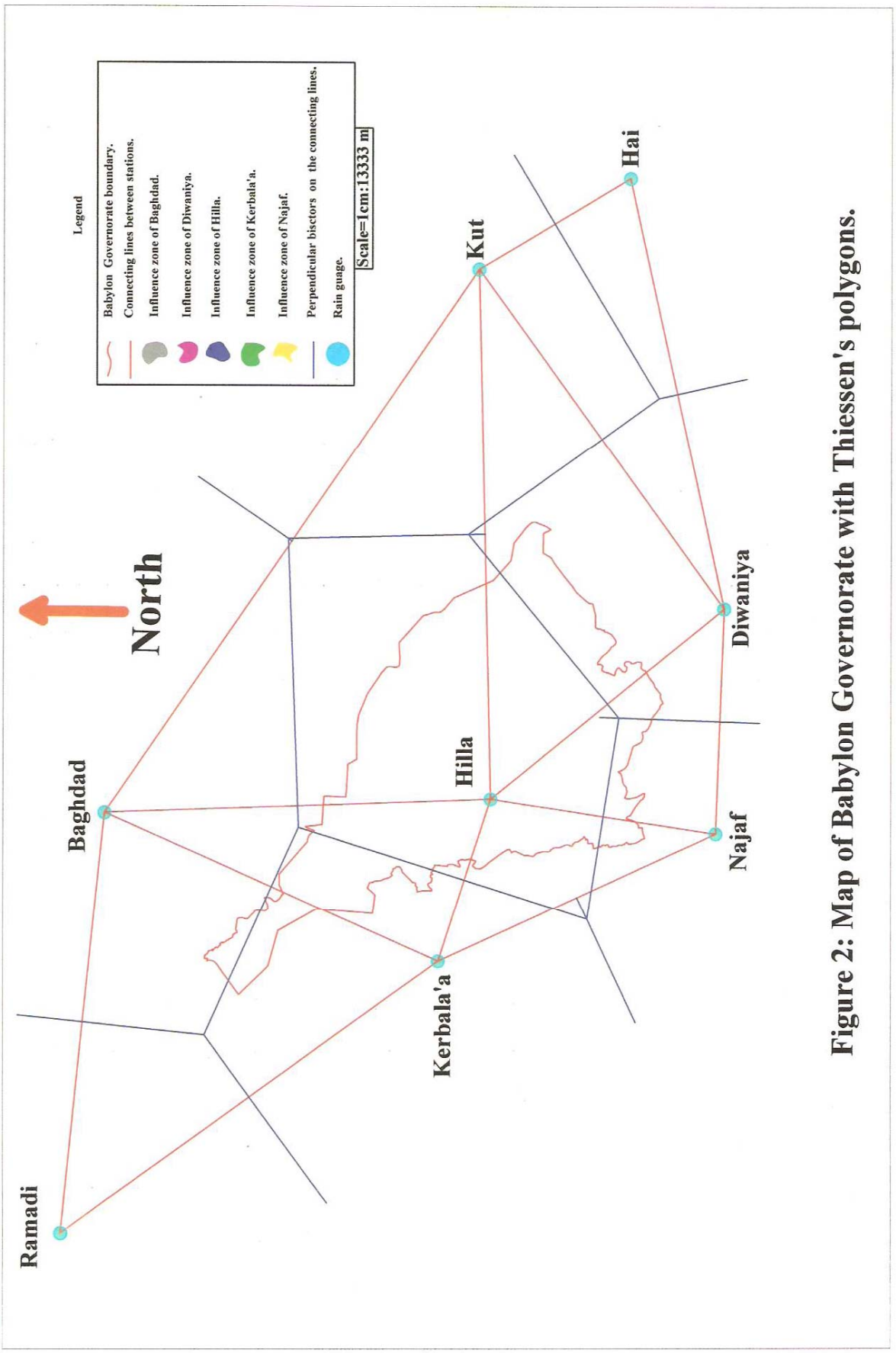

Figure 2: Map of Babylon Governorate with Thiessen's polygons.

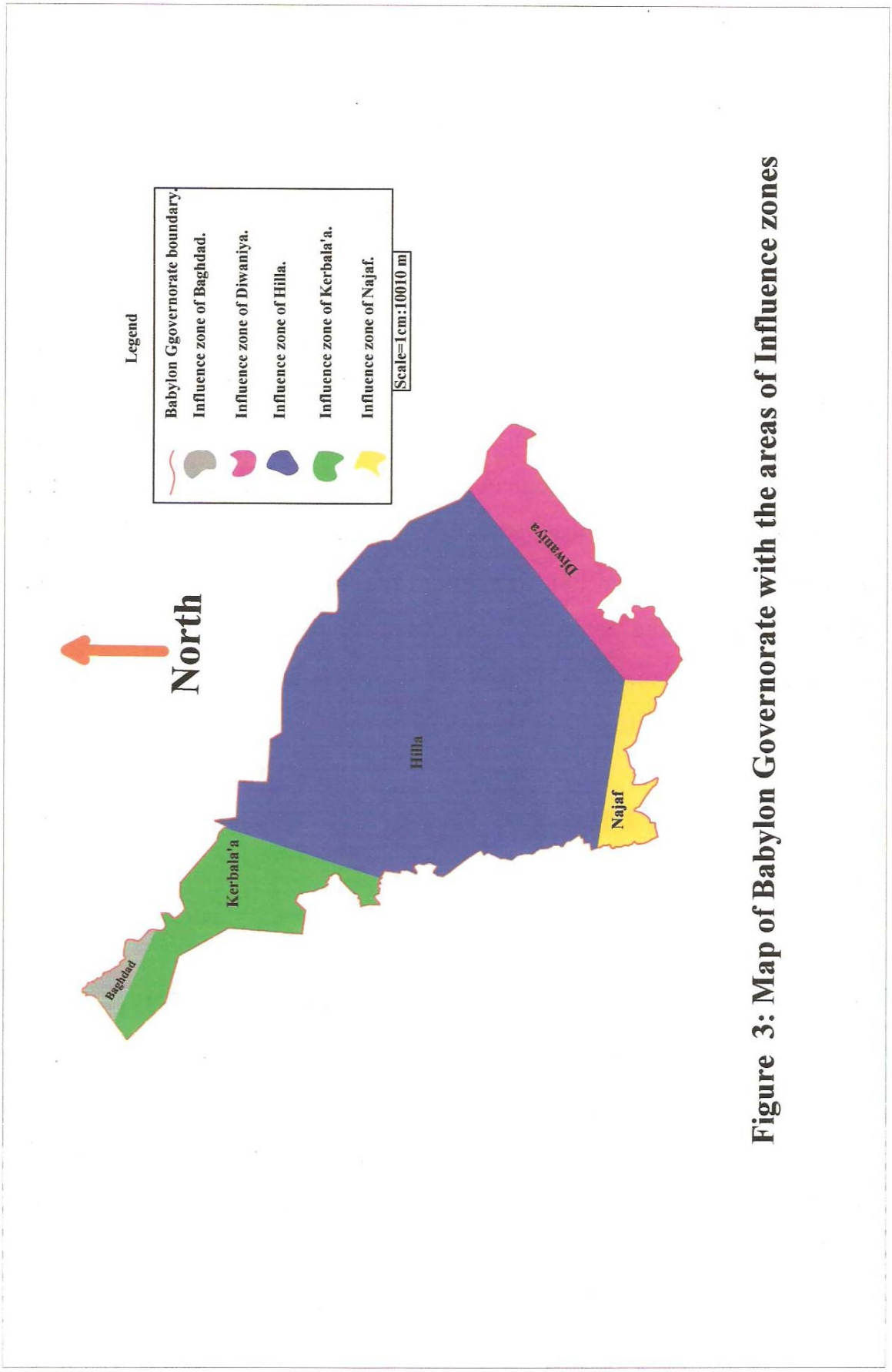

Figure 3: Map of Babylon Governorate with the areas of Influence zones

Table 2: Calculation of mean monthly rainfall, P_{av} (mm/month), for Babylon Governorate by using Thiessen's polygons method.

Month	Station	i	P_i † (mm/month)	A_i (Km^2)	$P_i \times A_i$	$\sum A_i$	$\sum P_i \times A_i$	P_{av} (mm/month)
Jan.	Hilla	1	23.208	3388.555	78640.544	4791.356	108854.957	22.719
	Baghdad	2	27.138	73.359	1990.841			
	Kerbala'a	3	19.167	572.326	10969.585			
	Najaf	4	19.432	192.589	3742.450			
	Diwaniya	5	23.934	564.526	13511.537			
	Kut	6	33.168	0.000	None			
	Hai	7	32.234	0.000	None			
	Ramadi	8	23.392	0.000	None			
Feb.	Hilla	1	14.996	3388.555	50814.772	4791.356	73492.611	15.339
	Baghdad	2	19.406	73.359	1423.614			
	Kerbala'a	3	14.744	572.326	8438.234			
	Najaf	4	15.180	192.589	2923.495			
	Diwaniya	5	17.524	564.526	9892.496			
	Kut	6	20.461	0.000	None			
	Hai	7	20.178	0.000	None			
	Ramadi	8	17.532	0.000	None			
Mar.	Hilla	1	14.916	3388.555	50543.688	4791.356	73848.105	15.413
	Baghdad	2	23.547	73.359	1727.381			
	Kerbala'a	3	17.279	572.326	9889.102			
	Najaf	4	15.197	192.589	2926.797			
	Diwaniya	5	15.519	564.526	8761.137			
	Kut	6	24.881	0.000	None			
	Hai	7	24.876	0.000	None			
	Ramadi	8	14.079	0.000	None			
Apr.	Hilla	1	12.552	3388.555	42532.642	4791.356	62759.640	13.099
	Baghdad	2	15.824	73.359	1160.855			
	Kerbala'a	3	13.743	572.326	7865.397			
	Najaf	4	14.353	192.589	2764.213			
	Diwaniya	5	14.944	564.526	8436.534			
	Kut	6	13.744	0.000	None			
	Hai	7	14.959	0.000	None			
	Ramadi	8	14.313	0.000	None			
May	Hilla	1	2.048	3388.555	6940.263	4791.356	12846.270	2.681
	Baghdad	2	3.133	73.359	229.859			
	Kerbala'a	3	4.182	572.326	2393.364			
	Najaf	4	4.441	192.589	855.320			
	Diwaniya	5	4.300	564.526	2427.464			
	Kut	6	4.171	0.000	None			
	Hai	7	4.292	0.000	None			
	Ramadi	8	5.636	0.000	None			

Jun	Hilla	1	0.059	3388.555	200.803	4791.356	251.369	0.052
	Baghdad	2	0.067	73.359	4.891			
	Kerbala'a	3	0.061	572.326	34.975			
	Najaf	4	0.056	192.589	10.699			
	Diwaniya	5	0.000	564.526	0.000			
	Kut	6	0.000	0.000	None			
	Hai	7	0.049	0.000	None			
	Ramadi	8	0.084	0.000	None			

Table 2: Cont.

Month	Station	i	P_i † (mm/month)	A_i (Km^2)	$P_i \times A_i$	$\sum A_i$	$\sum P_i \times A_i$	P_{av} (mm/month)
Jul.	Hilla	1	0.000	3388.555	0.000	4791.356	0.000	0.000
	Baghdad	2	0.000	73.359	0.000			
	Kerbala'a	3	0.000	572.326	0.000			
	Najaf	4	0.000	192.589	0.000			
	Diwaniya	5	0.000	564.526	0.000			
	Kut	6	0.000	0.000	None			
	Hai	7	0.000	0.000	None			
	Ramadi	8	0.004	0.000	None			
Aug.	Hilla	1	0.000	3388.555	0.000	4791.356	0.000	0.000
	Baghdad	2	0.000	73.359	0.000			
	Kerbala'a	3	0.000	572.326	0.000			
	Najaf	4	0.000	192.589	0.000			
	Diwaniya	5	0.000	564.526	0.000			
	Kut	6	0.000	0.000	None			
	Hai	7	0.000	0.000	None			
	Ramadi	8	0.000	0.000	None			
Sept.	Hilla	1	0.081	3388.555	273.691	4791.356	755.632	0.158
	Baghdad	2	0.032	73.359	2.373			
	Kerbala'a	3	0.274	572.326	156.981			
	Najaf	4	0.000	192.589	0.000			
	Diwaniya	5	0.571	564.526	322.587			
	Kut	6	0.056	0.000	None			
	Hai	7	0.405	0.000	None			
	Ramadi	8	0.178	0.000	None			
Oct.	Hilla	1	4.146	3388.555	14049.471	4791.356	19015.486	3.969
	Baghdad	2	3.018	73.359	221.372			
	Kerbala'a	3	3.485	572.326	1994.470			
	Najaf	4	3.317	192.589	638.844			
	Diwaniya	5	3.740	564.526	2111.329			
	Kut	6	2.678	0.000	None			
	Hai	7	3.968	0.000	None			
	Ramadi	8	7.748	0.000	None			

Nov.	Hilla	1	15.984	3388.555	54162.665	4791.356	72630.274	15.159
	Baghdad	2	12.926	73.359	948.276			
	Kerbala'a	3	11.127	572.326	6368.429			
	Najaf	4	13.133	192.589	2529.331			
	Diwaniya	5	15.272	564.526	8621.573			
	Kut	6	15.226	0.000	None			
	Hai	7	18.039	0.000	None			
	Ramadi	8	17.100	0.000	None			
Dec.	Hilla	1	17.623	3388.555	59716.767	4791.356	86629.607	18.080
	Baghdad	2	21.006	73.359	1540.964			
	Kerbala'a	3	17.860	572.326	10221.745			
	Najaf	4	17.453	192.589	3361.206			
	Diwaniya	5	20.883	564.526	11788.925			
	Kut	6	20.205	0.000	None			
	Hai	7	22.697	0.000	None			
	Ramadi	8	17.479	0.000	None			

† Source: Iraqi Meteorological Organization.

Comparison is made between the average of the observed monthly rainfall (mm/month) in Hilla and the computed monthly mean rainfall (mm/month) in Babylon Governorate by using Thiessen's polygons' method as shown in Figure 4.

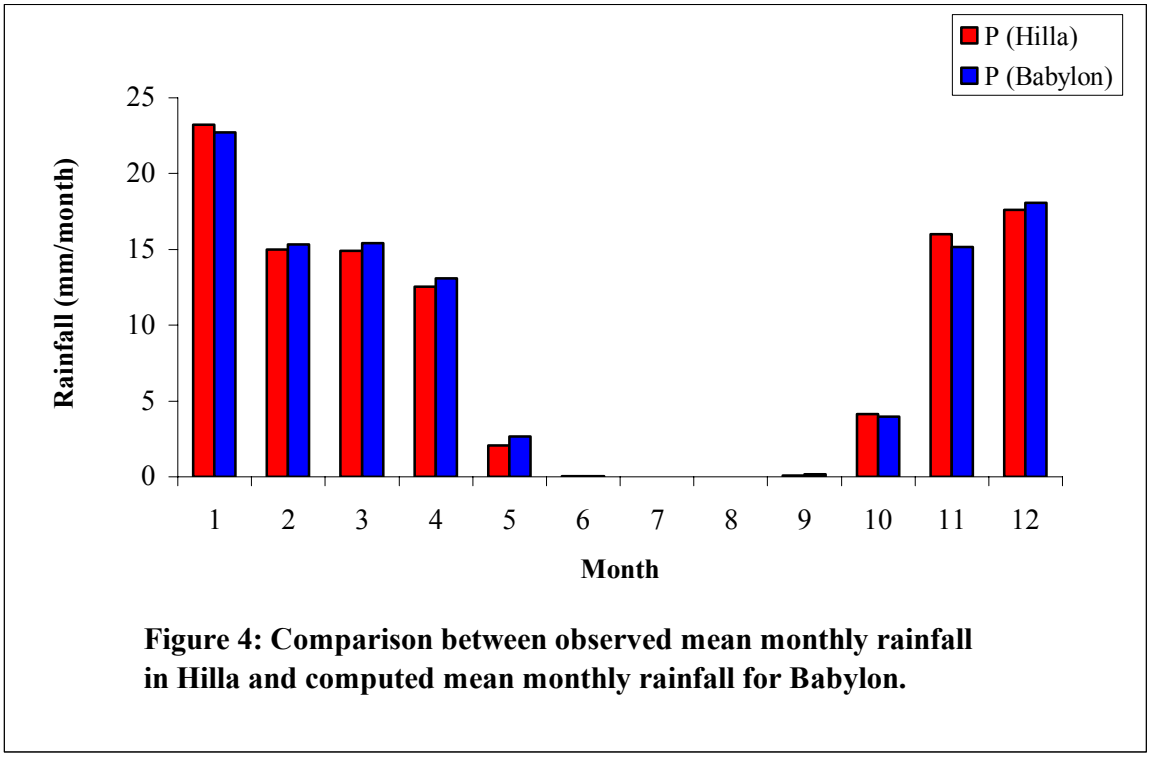

Figure 4: Comparison between observed mean monthly rainfall in Hilla and computed mean monthly rainfall for Babylon.

It is clear that Hilla rainfall values can not be applied to the whole area of Babylon because rainfall varies with location as indicated by records of different gauges.

4. COMPUTING MEAN EVAPORATION FOR BABYLON

In a similar manner as described in Section 3 of this paper, we know apply the Thiessen polygons method to estimate the mean evaporation for Babylon Governorate (average evaporation over the whole Babylon). The same stations that have been used for determining the mean depth of rainfall for Babylon Governorate are used to compute mean monthly evaporation. Hence, Figures 2 and 3 which indicates zones of different rainfall are also applicable to evaporation. Calculation of monthly evaporation is as shown in Table 3.

Table 3: Calculation of monthly mean evaporation, E_{av} (mm/month), for Babylon Governorate by using Thiessen's polygons method.

Month	Station	i	E_i † (mm/month)	A_i (Km^2)	$E_i \times A_i$	$\sum Ai$	$\sum E_i \times A_i$	E_{av} (mm/month)
Jan.	Hilla	1	36.363	3388.555	123219.656	4791.356	197657.384	41.253
	Baghdad	2	48.199	73.359	3535.871			
	Kerbala'a	3	45.068	572.326	25793.561			
	Najaf	4	59.521	192.589	11463.108			
	Diwaniya	5	59.599	564.526	33645.189			
	Kut	6	42.275	0.000	0.000			
	Hai	7	71.106	0.000	0.000			
	Ramadi	8	47.501	0.000	0.000			

Table 3: Cont.

Month	Station	i	E_{ai} † (mm/month)	A_i * (Km^2)	$E_{ai} \times A_i$	$\sum Ai$	$\sum E_{ai} \times A_i$	E_{av} (mm/month)
Feb.	Hilla	١	52.827	3388.555	179006.048	4791.356	286826.571	59.863
	Baghdad	2	71.014	73.359	5209.531			
	Kerbala'a	3	69.348	572.326	39689.835			
	Najaf	4	84.683	192.589	16308.988			
	Diwaniya	5	82.569	564.526	46612.169			
	Kut	6	79.158	0.000	0.000			
	Hai	7	88.133	0.000	0.000			
	Ramadi	8	67.820	0.000	0.000			
Mar.	Hilla	١	93.182	3388.555	315751.223	4791.356	500659.560	104.492
	Baghdad	2	126.450	73.359	9276.256			
	Kerbala'a	3	125.554	572.326	71857.552			
	Najaf	4	141.377	192.589	27227.678			
	Diwaniya	5	135.595	564.526	76546.850			
	Kut	6	135.246	0.000	0.000			
	Hai	7	151.540	0.000	0.000			
	Ramadi	8	108.762	0.000	0.000			
Apr.	Hilla	١	133.814	3388.555	453435.096	4791.356	723725.302	151.048
	Baghdad	2	184.416	73.359	13528.628			
	Kerbala'a	3	185.832	572.326	106356.457			

	Najaf	4	201.827	192.589	38869.487			
	Diwaniya	5	197.574	564.526	111535.634			
	Kut	6	201.015	0.000	0.000			
	Hai	7	219.520	0.000	0.000			
	Ramadi	8	143.392	0.000	0.000			
May	**Hilla**	١	193.183	3388.555	654609.546	4791.356	1034493.206	215.908
	Baghdad	2	268.681	73.359	19710.254			
	Kerbala'a	3	253.066	572.326	144836.349			
	Najaf	4	288.200	192.589	55504.098			
	Diwaniya	5	283.128	564.526	159832.960			
	Kut	6	336.249	0.000	0.000			
	Hai	7	318.477	0.000	0.000			
	Ramadi	8	204.559	0.000	0.000			
Jun	**Hilla**	١	235.425	3388.555	797749.229	4791.356	1278870.104	266.912
	Baghdad	2	350.996	73.359	25748.836			
	Kerbala'a	3	315.439	572.326	180533.934			
	Najaf	4	375.705	192.589	72356.585			
	Diwaniya	5	358.675	564.526	202481.521			
	Kut	6	457.349	0.000	0.000			
	Hai	7	435.317	0.000	0.000			
	Ramadi	8	264.954	0.000	0.000			
Jul.	**Hilla**	١	250.250	3388.555	847985.914	4791.356	1380183.500	288.057
	Baghdad	2	377.903	73.359	27722.706			
	Kerbala'a	3	345.974	572.326	198009.741			
	Najaf	4	423.885	192.589	81635.427			
	Diwaniya	5	398.263	564.526	224829.711			
	Kut	6	481.911	0.000	0.000			
	Hai	7	497.269	0.000	0.000			
	Ramadi	8	320.577	0.000	0.000			

Table 3: Cont.

Month	**Station**	**i**	**E_i †** **(mm/month)**	**A_i** **(Km^2)**	**$E_i \times A_i$**	**$\sum Ai$**	**$\sum E_i \times A_i$**	**E_{av}** **(mm/month)**
Aug.	**Hilla**	١	225.263	3388.555	763315.071	4791.356	1245446.546	259.936
	Baghdad	2	351.604	73.359	25793.394			
	Kerbala'a	3	309.117	572.326	176915.802			
	Najaf	4	383.797	192.589	73914.896			
	Diwaniya	5	364.035	564.526	205507.383			
	Kut	6	422.046	0.000	0.000			
	Hai	7	462.455	0.000	0.000			
	Ramadi	8	295.904	0.000	0.000			
Sept.	**Hilla**	١	171.402	3388.555	580805.122	4791.356	941205.660	196.438

	Baghdad	2	257.684	73.359	18903.507			
	Kerbala'a	3	231.793	572.326	132661.369			
	Najaf	4	276.515	192.589	53253.700			
	Diwaniya	5	275.597	564.526	155581.963			
	Kut	6	323.368	0.000	0.000			
	Hai	7	355.771	0.000	0.000			
	Ramadi	8	219.681	0.000	0.000			
Oct.	**Hilla**	١	112.825	3388.555	382315.085	4791.356	626036.749	130.660
	Baghdad	2	166.798	73.359	12236.148			
	Kerbala'a	3	152.785	572.326	87442.852			
	Najaf	4	191.828	192.589	36943.813			
	Diwaniya	5	189.715	564.526	107098.851			
	Kut	6	208.894	0.000	0.000			
	Hai	7	226.960	0.000	0.000			
	Ramadi	8	151.200	0.000	0.000			
Nov.	**Hilla**	١	58.234	3388.555	197330.507	4791.356	325220.737	67.877
	Baghdad	2	86.022	73.359	6310.493			
	Kerbala'a	3	78.034	572.326	44660.716			
	Najaf	4	101.222	192.589	19494.205			
	Diwaniya	5	101.722	564.526	57424.815			
	Kut	6	92.161	0.000	0.000			
	Hai	7	121.725	0.000	0.000			
	Ramadi	8	87.655	0.000	0.000			
Dec.	**Hilla**	١	38.589	3388.555	130760.445	4791.356	208024.009	43.417
	Baghdad	2	49.397	73.359	3623.753			
	Kerbala'a	3	46.114	572.326	26392.060			
	Najaf	4	62.430	192.589	12023.250			
	Diwaniya	5	62.397	564.526	35224.502			
	Kut	6	46.211	0.000	0.000			
	Hai	7	81.610	0.000	0.000			
	Ramadi	8	53.983	0.000	0.000			

† Source: Iraqi Meteorological Organization.

Comparison is made between the average of the observed monthly evaporation (mm/month) in Hilla and the computed monthly mean evaporation (mm/month) in Babylon Governorate by using Thiessen's polygons' method as shown in Figure 5.

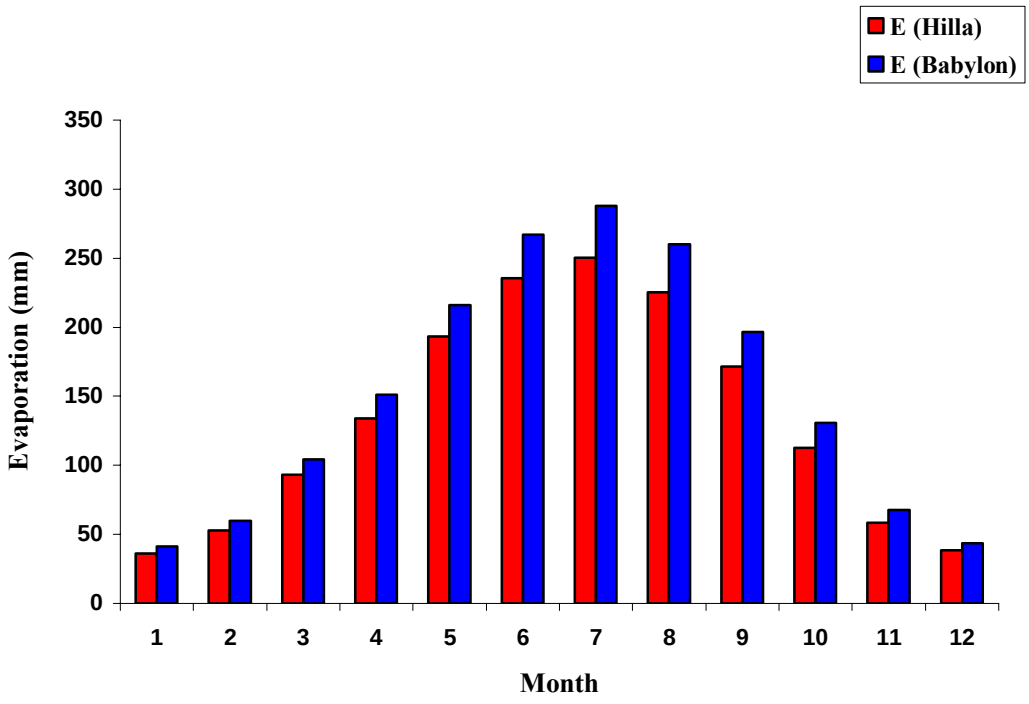

Figure 5: Comparison between observed mean monthly evaporation in Hilla and computed monthly mean evaporation for Babylon.

This figure indicates that Babylon average evaporation is greater than Hilla evaporation for all months

5. Conclusion

Rainfall and evaporation vary with location. The Thiessen polygons method is used to define zones of equal rainfall and equal evaporation in Babylon governorate. For each of these zones rainfall or evaporation is equal to that recorded by the nearest meteorological gauge. Mean values for Babylon governorate are also computed and, hence, departures of these values from those recorded in Hilla are as given in Table 4.

Table 4: Comparison of observed Hilla rainfall and evaporation with computed Babylon mean rainfall and evaporation.

Month	Rainfall (mm)				Evaporation (mm)			
	Hilla zone	Babylon average	Difference	% Departure	Hilla zone	Babylon average	Difference	% Departure
Jan.	23.208	22.719	-0.489	-2.11	36.363	41.253	4.89	13.45
Feb.	14.996	15.339	0.343	2.29	52.827	59.863	7.036	13.32
Mar.	14.916	15.413	0.497	3.33	93.182	104.492	11.31	12.13
Apr.	12.552	13.099	0.547	4.36	133.814	151.048	17.234	12.88
May	2.048	2.681	0.633	30.91	193.183	215.908	22.725	11.76
Jun	0.059	0.052	-0.007	-11.86	235.425	266.912	31.487	13.38
Jul.	0	0	0	0	250.250	288.057	37.807	15.11
Aug.	0	0	0	0	225.263	259.936	34.673	15.39
Sep.	0.081	0.158	0.077	95.06	171.402	196.438	25.036	14.61

Oct.	4.146	3.969	-0.177	-4.27	112.825	130.660	17.835	15.81
Nov.	15.984	15.159	-0.825	-5.16	58.234	67.877	9.643	16.56
Dec.	17.623	18.080	0.457	2.59	38.589	43.417	4.828	12.51

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