Research Article

Effectiveness of Hydraulic and Hydrologic Parameters in Assessing Storm System Flooding

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Storm sewer systems face many challenges in urban areas, in particular those systems which are old and surpassing their design period. This study has used data from an urbanized, subcatchment covering 360 ha of dead run watershed in the Alkadeer district, Karbala, Iraq. Physically based models, Autodesk Storm and Sanitary Analysis (ASSA) and multiple nonlinear regression (MNL), were applied. Hydrology data from 1980 to 2013 were inputted and examined over three scenarios. The results indicated that significant increase in peak flooding was produced by an increase in discharge values which may occur through a higher rainfall intensity. The model was examined and new equations were developed that may help us to better understand the hydraulic and hydrologic simulations that are identified as having the potential to better protect the environment against sudden rainfall intensities. The ratio of area of subcatchment to cross-sectional area of a pipe (A_c/A_p), the ratio of slope of subcatchment to slope of a pipe (S_c/S_p), and the ratio of velocity in subcatchment to velocity in a pipe (V_c/V_p) were the most sensitive parameters informing the ratio of runoff discharge of a subcatchment pipe discharge (Q_c/Q_p). This study suggests that a more effective management of the storm water system under critical circumstances could be achieved by limiting the above parameters and this increases the efficiency of storm water facilities.

1. Introduction

Flooding in urban storm sewer systems could cause loss of life and considerable damage [1, 2] as well as posing a threat to property and the environment and public health. Many inner cities in Iraq have been exposed to flooding for a number of reasons including poor maintenance of storm sewer systems and outmoded and limited capacity of storm systems with reference to instances of intense rain which cause blockages in pipe, electrical issues, and numerous operational problems [3]. The daily use of storm sewer systems has rapidly resulted in outdated systems because of large variations in urban land use, rising growth in population, and changing rainfall patterns [4].

City flooding during heavy precipitation is considered a natural phenomenon [5, 6]. The FACADE pattern is used in an object-oriented design to integrate storm flow and overland flow as well as implement an extensible integrated system for flood simulation in urban areas [6, 7]. Urban flooding can be simulated by a two-dimensional flow model

depending on ground elevation, land use, and type of soil; all these parameters have a large impact on the degree of surface runoff [5, 8].

Efficient drainage of the rain network has a strong connection with the length of drain and time of concentration of subcatchment affecting velocity and peak runoff discharges. Urbanization also impacts hydrology, which is typically characterized by raising the values of peak flooding and reducing the time lag thus causing an increase in runoff volume [9, 10].

Inundation and overland flow volume may increase up to ten times because of urbanization; flooding, which normally would have occurred once every 100 years, may be doubled by more than 30% increase in urbanization [11–13]. While it has been reported that regular flooding in municipal areas is probably the result of frequent high intensity and extreme rainfall events (Mailhot and Duchesne, 2009), the chance of inner city flooding may increase because of the increase in urban density, especially in low-lying areas [15]. Although many hydraulic and hydrology models have been

FIGURE 1: (a) Elevation map of Karbala city. (b) Map of study area Alkadeer district in Karbala city centre, Iraq, generated by GIS based on available data adapted from [26, 27].

TABLE 1: Data about the subcatchment area input to the model.

Element ID	Area (ha)	Drainage node ID	Average slope (%)	Equivalent width (m)
Sub-02	5.29	82	0.0100	110.00
Sub-03	5.45	81	0.0063	165.00
Sub-04	9.69	80	0.0096	194.00
Sub-05	9.26	45	0.0027	110.00
Sub-06	9.74	47	0.0043	140.00
Sub-07	5.80	83	0.0108	120.00
Sub-08	5.44	67	0.0001	120.00
Sub-09	6.37	82	0.0126	131.00
Sub-10	6.31	68	0.0000	149.00
Sub-13	10.10	Out-01	0.0122	296.00
Sub-17	2.83	50	0.0130	117.00
Sub-18	5.20	41	0.0500	140.00
Sub-19	6.36	40	0.0008	155.00
Sub-20	5.57	43	0.0008	150.00
Sub-21	6.52	38	0.0234	191.00
Sub-22	6.50	27	0.0230	263.00
Sub-23	6.51	35	0.0210	145.00
Sub-24	5.29	34	0.0123	161.00
Sub-25	7.22	32	0.0113	196.00
Sub-26	8.07	22	0.0140	272.00
Sub-27	7.59	21	0.0130	262.00
Sub-28	7.43	20	0.0120	293.00
Sub-29	6.05	19	0.0110	275.00
Sub-30	8.22	53	0.0140	250.00
Sub-31	8.30	56	0.0100	190.00
Sub-33	4.89	16	0.0006	150.00
Sub-34	6.20	17	0.0120	280.00
Sub-35	10.59	13	0.0130	300.00
Sub-36	21.74	4	0.0040	350.00
Sub-37	7.64	60	0.0019	170.00
Sub-38	5.12	79	0.0085	170.00
Sub-39	8.72	3	0.0016	300.00
Sub-40	5.70	54	0.0050	155.00
Sub-41	6.29	51	0.0036	190.00

TABLE 1: Continued.

Element ID	Area (ha)	Drainage node ID	Average slope (%)	Equivalent width (m)
Sub-42	6.15	52	0.0100	180.00
Sub-43	4.59	69	0.0280	200.00
Sub-44	3.78	70	0.0080	80.00
Sub-45	4.34	72	0.0090	200.00
Sub-46	3.21	73	0.0086	60.00
Sub-47	4.62	75	0.0130	280.00
Sub-48	3.45	59	0.0043	95.00
Sub-49	3.58	76	0.0130	110.00
Sub-50	5.44	10	0.0006	175.00
Sub-51	4.73	1	0.0200	130.00
Sub-52	8.78	77	0.0000	140.00
Sub-53	7.34	74	0.0001	115.00
Sub-54	6.26	71	0.0006	95.00
Sub-55	5.33	49	0.0166	160.00
Sub-56	4.93	48	0.0200	150.00
Sub-57	5.42	46	0.0130	125.00
Sub-58	5.02	45	0.0170	130.00

TABLE 2: Data about the storm sewer manhole input into the model.

Element ID	X coordinate	Y coordinate	Invert elevation (m)	Ground/rim (maximum) elevation (m)	Ground/rim (maximum) offset (m)	Initial water elevation (m)	Initial water depth (m)	Surcharge elevation (m)	Ponded area (m ²)	Minimum pipe cover (m)
1	405460.4	3609285.6	31.97	34.20	2.23	32.45	0.48	34.20	0.00	1.63
3	404825.9	3608476.6	38.06	39.48	1.42	38.42	0.36	39.48	0.00	0.85
4	404659.7	3608375.1	38.44	39.86	1.42	38.80	0.36	39.86	2.00	1.02
7	404655.9	3608744.5	36.58	38.95	2.37	36.94	0.36	38.95	2.00	1.97
8	404811.7	3608848.9	36.09	38.08	1.99	36.45	0.36	38.08	2.00	1.59
9	404938.3	3608941.9	35.70	37.70	2.00	36.06	0.36	37.70	2.00	1.60
10	405068.8	3609037.5	35.29	37.62	2.33	35.65	0.36	37.62	2.00	1.93
11	405234.6	3609151.3	34.64	37.02	2.38	35.12	0.48	37.02	2.00	1.78
12	404658.1	3608176.7	39.27	40.85	1.58	39.63	0.36	40.85	2.00	1.18
13	404596.4	3607913.4	40.13	41.98	1.85	40.49	0.36	41.98	2.00	1.45
14	404759.6	3608010.3	38.53	40.29	1.76	38.89	0.36	40.29	2.00	1.36
15	404878.3	3608079.2	37.91	39.75	1.84	38.27	0.36	39.75	2.00	1.44
16	405008.8	3608156.5	37.24	38.79	1.55	37.60	0.36	38.79	2.00	1.15
17	404784.4	3608253.1	38.41	40.25	1.84	38.77	0.36	40.25	2.00	1.44
18	404958.3	3608350.2	37.05	38.75	1.70	37.41	0.36	38.75	2.00	1.30
19	405101.1	3608004.8	37.14	38.72	1.58	37.50	0.36	38.72	2.00	1.18
20	404968.5	3607934.3	37.63	39.48	1.85	38.00	0.37	39.48	2.00	1.45
21	404832.3	3607858.4	38.47	40.80	2.33	38.83	0.36	40.80	2.00	1.93
22	404664.4	3607767.0	40.72	42.60	1.88	41.08	0.36	42.72	2.00	1.48
23	405493.9	3608001.8	34.80	37.23	2.43	35.16	0.36	37.23	2.00	1.59
24	405377.9	3607953.9	36.24	38.45	2.21	36.60	0.36	38.45	2.00	1.81
25	405254.4	3607738.4	37.28	39.08	1.80	37.64	0.36	39.08	2.00	1.40
27	405002.5	3607575.6	39.98	41.56	1.58	40.32	0.34	41.56	2.00	1.18
28	405186.1	3607838.8	36.66	38.81	2.15	36.99	0.33	38.81	2.00	1.75
29	404913.0	3607674.1	39.37	41.00	1.63	39.73	0.36	41.00	2.00	1.23
32	405597.4	3607779.3	34.83	36.69	1.86	35.29	0.46	36.69	2.00	1.46
33	405478.4	3607709.2	35.18	37.49	2.31	35.54	0.36	37.49	2.00	1.91
34	405375.2	3607645.4	35.48	37.62	2.14	35.84	0.36	37.62	2.00	1.74
35	405259.2	3607575.7	36.77	38.68	1.91	37.13	0.36	38.68	2.00	1.51
36	405130.1	3607494.6	38.12	40.34	2.22	38.48	0.36	40.34	2.00	1.82
37	405017.0	3607421.9	39.20	40.73	1.53	39.56	0.36	40.73	2.00	1.13
38	404886.5	3607339.0	39.84	41.46	1.62	40.20	0.36	41.46	2.00	1.22
39	404732.4	3607244.6	40.29	42.04	1.75	40.75	0.46	42.04	2.00	1.35
40	405885.4	3607961.3	33.98	35.87	1.89	34.34	0.36	35.87	2.00	1.49
41	406000.7	3608032.0	32.91	34.90	1.99	33.27	0.36	34.90	2.00	1.59

TABLE 2: Continued.

Element ID	X coordinate	Y coordinate	Invert elevation (m)	Ground/rim (maximum) elevation (m)	Ground/rim (maximum) offset (m)	Initial water elevation (m)	Initial water depth (m)	Surcharge elevation (m)	Ponded area (m ²)	Minimum pipe cover (m)
42	406148.3	3608123.2	32.06	33.97	1.91	32.42	0.36	33.97	2.00	1.31
43	405708.3	3607847.4	34.50	36.41	1.91	34.96	0.46	36.41	2.00	1.51
45	406640.0	3608803.5	26.56	28.98	2.42	27.30	0.74	28.98	2.00	1.62
46	406532.6	3608745.8	26.64	29.29	2.65	27.28	0.64	29.29	2.00	1.85
47	406399.4	3608658.9	27.60	30.31	2.71	27.70	0.10	30.31	2.00	1.91
48	406251.9	3608568.7	28.56	31.10	2.54	28.89	0.33	31.10	2.00	1.74
49	406124.8	3608492.8	29.53	32.13	2.60	30.27	0.74	32.13	2.00	1.80
50	405978.3	3608403.8	29.67	33.23	3.56	30.31	0.64	33.23	2.00	2.76
51	405719.8	3608325.1	32.05	33.31	1.26	32.53	0.48	33.31	2.00	0.56
52	405586.3	3608238.8	32.38	34.97	2.59	32.86	0.48	34.97	2.00	1.86
53	405421.3	3608133.7	34.21	36.21	2.00	34.57	0.36	36.21	2.00	1.40
54	405945.9	3608458.4	30.15	33.18	3.03	30.63	0.48	33.18	2.00	2.38
55	405370.6	3608218.8	34.06	36.36	2.30	34.54	0.48	36.36	2.00	1.52
56	405307.1	3608325.3	34.25	36.61	2.36	34.73	0.48	36.61	2.00	1.73
57	405248.2	3608424.0	34.27	36.62	2.35	34.75	0.48	36.62	2.00	1.70
58	405190.8	3608520.2	34.25	37.10	2.85	34.73	0.48	37.10	2.00	2.12
59	405137.7	3608609.2	34.40	36.68	2.28	34.76	0.36	36.68	2.00	1.64
60	405071.3	3608721.0	34.48	37.43	2.95	34.84	0.36	37.43	2.00	2.55
63	405243.4	3608075.4	35.66	38.24	2.58	36.99	1.33	38.24	2.00	2.18
65	405141.4	3608243.0	36.35	38.15	1.80	36.71	0.36	38.15	2.00	1.40
66	405620.6	3608510.6	32.12	34.62	2.50	32.48	0.36	34.62	2.00	2.10
67	405836.2	3608640.9	30.94	33.24	2.30	31.30	0.36	33.24	2.00	1.66
68	405767.8	3608758.8	31.18	33.41	2.23	31.54	0.36	33.41	2.00	1.58
69	405664.6	3608695.7	32.36	34.61	2.25	32.72	0.36	34.61	2.00	1.85
70	405557.1	3608622.9	33.33	35.33	2.00	33.99	0.66	35.33	2.00	1.60
71	405708.9	3608861.1	31.13	33.53	2.40	31.49	0.36	33.53	2.00	1.00
72	405617.9	3608812.1	32.37	34.99	2.62	32.70	0.33	34.99	2.00	2.22
73	405511.0	3608744.5	34.14	35.89	1.75	34.40	0.26	35.89	2.00	1.35
74	405649.5	3608966.5	31.50	33.97	2.47	31.86	0.36	33.97	2.00	1.87
75	405548.6	3608911.3	32.97	35.52	2.55	33.33	0.36	35.52	2.00	2.15
76	405590.9	3609065.4	31.56	34.33	2.77	32.04	0.48	34.33	2.00	2.17
77	405530.	3609166.8	31.72	34.31	2.59	32.20	0.48	34.31	2.00	1.99
79	405042.9	3608404.9	36.77	38.27	1.50	37.13	0.36	38.27	2.00	1.10
80	406334.6	3609357.0	20.61	24.95	4.34	21.10	0.49	24.95	2.00	0.00
81	406409.5	3609233.1	21.00	24.61	3.61	21.40	0.40	24.61	2.00	3.11
82	406485.9	3609106.9	22.18	27.00	4.82	22.58	0.40	27.00	2.00	4.32
83	406570.3	3608967.5	24.30	27.50	3.20	24.70	0.40	27.50	2.00	2.70

widely used to predict urban flooding, there has been limited focus on different parameters, particularly regarding rapid and frequent hydrological phenomena. Therefore, an investigation involving simulation modelling and data analysis was conducted to explore the relationship between the above factors to produce the best hydraulic and hydrologic model.

In recent decades, there has been much research into urban flooding with a focus on obtaining equations linking certain parameters involving topography, slope of pipes, varying rainfall intensity, size of watershed and runoff discharges, and major flooding parameters for developed areas. Attention has also been paid to the effects of climate change, varying hydraulic data on storm sewer systems, and the increasing availability of knowledge about changes in hydrological systems and insights. Many urban drainage systems can reach full capacity during heavy rainfall [16].

The issue of storm sewer modelling is currently one of the most dynamic areas in hydraulics and hydrology research. Many software packages have been used to simulate pipe above ground hydraulics and hydrology models in the runoff of rainfall and pollutants from urban areas, such as SWMM [17], XPSWAMM [18], ASSA [19], and MIKE MOUSE [20]. One-dimensional sewer flow models (within the storm sewer-1D) and two-dimensional overland flow (within subcatchment-2D) models have been developed and used to examine urban flooding [21].

Even though there are a number of studies conducted on flooding in storm sewer systems during heavy rainfall, these studies are still very limited in their infancy. Some 2D models with high-resolution grids have examined the consequences of storm pipes [22]. High-resolution digital terrain data and instances of flooding in inner city areas were used to simulate the multifaceted interaction between the storm flow and surcharge-induced inundations in order to

TABLE 3: Data about the storm sewer pipes input into the model.

Element ID	From (inlet) node	To (outlet) node	Length (m)	Inlet invert elevation (m)	Outlet invert elevation (m)	Average slope (%)	Pipe shape	Pipe diameter (m)	Manning's roughness
Link-01	39	38	180.76	40.29	39.84	0.2500	Circular	0.400	0.0130
Link-03	38	37	154.62	39.84	39.20	0.4100	Circular	0.400	0.0130
Link-04	37	36	134.38	39.20	38.12	0.8000	Circular	0.400	0.0130
Link-05	36	35	152.49	38.12	36.78	0.8800	Circular	0.400	0.0130
Link-06	35	34	135.36	36.77	35.48	0.9500	Circular	0.400	0.0130
Link-07	34	33	121.29	35.48	35.18	0.2500	Circular	0.400	0.0130
Link-08	33	32	138.16	35.18	34.83	0.2500	Circular	0.400	0.0130
Link-10	32	43	130.16	34.83	34.50	0.2500	Circular	0.400	0.0130
Link-11	43	40	210.49	34.50	33.98	0.2500	Circular	0.400	0.0130
Link-12	40	41	135.30	33.98	32.91	0.7900	Circular	0.400	0.0130
Link-13	41	42	173.50	32.91	32.06	0.4900	Circular	0.400	0.0130
Link-14	42	50	328.10	32.06	29.67	0.7300	Circular	0.600	0.0130
Link-15	50	49	171.48	29.67	29.53	0.0800	Circular	0.800	0.0130
Link-16	49	48	147.99	29.53	28.56	0.6600	Circular	0.800	0.0130
Link-17	48	47	172.95	28.56	27.60	0.5600	Circular	0.800	0.0130
Link-18	47	46	158.96	27.60	26.64	0.6000	Circular	0.800	0.0130
Link-19	46	45	121.96	26.64	26.56	0.0700	Circular	0.800	0.0130
Link-21	81	80	144.80	21.00	20.61	0.2700	Circular	0.500	0.0130
Link-22	82	81	147.50	22.18	21.00	0.8000	Circular	0.500	0.0130
Link-23	83	82	163.01	24.30	22.18	1.3000	Circular	0.500	0.0130
Link-24	45	83	178.12	26.67	24.30	1.3300	Circular	0.500	0.0130
Link-25	27	25	299.89	39.98	37.28	0.9000	Circular	0.400	0.0130
Link-26	25	28	121.37	37.28	36.66	0.5100	Circular	0.400	0.0130
Link-27	28	24	223.66	36.66	36.24	0.1900	Circular	0.400	0.0130
Link-28	29	23	125.55	36.24	35.24	0.8000	Circular	0.400	0.0130
Link-29	23	53	150.60	34.84	34.30	0.3600	Circular	0.400	0.0130
Link-30	53	52	195.63	34.25	32.45	0.9200	Circular	0.400	0.0130
Link-31	52	51	158.98	32.51	32.15	0.2300	Circular	0.600	0.0130
Link-32	51	54	262.46	32.15	30.20	0.7400	Circular	0.600	0.0130
Link-33	54	50	63.40	30.20	29.67	0.8400	Circular	0.600	0.0130
Link-34	29	28	318.89	39.37	36.66	0.8500	Circular	0.400	0.0130
Link-35	22	21	191.18	40.72	38.47	1.1800	Circular	0.400	0.0130
Link-36	21	20	155.89	38.47	37.63	0.5400	Circular	0.400	0.0130
Link-37	20	19	150.16	37.63	37.14	0.3300	Circular	0.400	0.0130
Link-38	19	63	158.87	37.14	35.66	0.9300	Circular	0.400	0.0130
Link-39	63	53	187.24	35.66	34.21	0.7700	Circular	0.400	0.0130
Link-40	13	14	189.79	40.13	38.53	0.8400	Circular	0.400	0.0130
Link-41	14	15	137.19	38.53	37.91	0.4500	Circular	0.400	0.0130
Link-42	15	16	151.70	37.91	37.24	0.4400	Circular	0.400	0.0130
Link-43	16	65	158.32	37.24	36.35	0.5600	Circular	0.400	0.0130
Link-44	65	63	196.11	36.35	35.66	0.3500	Circular	0.400	0.0130
Link-45	12	17	147.59	39.27	38.41	0.5800	Circular	0.400	0.0130
Link-46	17	18	199.19	38.41	37.05	0.6800	Circular	0.400	0.0130
Link-47	18	79	100.75	37.05	36.77	0.2800	Circular	0.400	0.0130
Link-48	79	65	189.60	36.77	36.35	0.2200	Circular	0.400	0.0130
Link-49	4	3	194.71	38.44	38.23	0.1100	Circular	0.400	0.0130
Link-52	7	8	187.55	36.58	36.09	0.2600	Circular	0.400	0.0130
Link-53	8	9	157.08	36.09	35.70	0.2500	Circular	0.400	0.0130
Link-54	9	10	161.77	35.70	35.29	0.2500	Circular	0.400	0.0130
Link-55	10	11	201.13	35.29	34.64	0.3200	Circular	0.400	0.0130
Link-56	11	1	262.66	34.64	31.97	1.0200	Circular	0.600	0.0130
Link-57	1	77	137.99	31.97	31.72	0.1800	Circular	0.600	0.0130
Link-58	77	76	117.99	31.72	31.56	0.1400	Circular	0.600	0.0130
Link-59	76	74	114.99	31.56	31.50	0.0500	Circular	0.600	0.0130
Link-60	74	71	120.99	31.50	31.20	0.2500	Circular	0.600	0.0130
Link-61	68	71	117.99	31.18	31.23	-0.0400	Circular	0.600	0.0130
Link-62	68	67	136.29	31.23	30.98	0.1800	Circular	0.600	0.0130
Link-63	67	54	212.99	30.98	30.20	0.3700	Circular	0.600	0.0130

TABLE 3: Continued.

Element ID	From (inlet) node	To (outlet) node	Length (m)	Inlet invert elevation (m)	Outlet invert elevation (m)	Average slope (%)	Pipe shape	Pipe diameter (m)	Manning's roughness
Link-64	75	74	115.00	32.97	31.50	1.2800	Circular	0.400	0.0130
Link-65	73	72	126.50	34.14	32.37	1.4000	Circular	0.400	0.0130
Link-66	72	71	103.37	32.37	32.13	0.2300	Circular	0.400	0.0130
Link-67	70	69	129.81	33.33	32.36	0.7500	Circular	0.400	0.0130
Link-68	69	68	120.96	32.36	31.18	0.9800	Circular	0.400	0.0130
Link-69	66	67	251.86	32.12	30.94	0.4700	Circular	0.400	0.0130
Link-70	60	59	130.10	34.48	34.44	0.0300	Circular	0.400	0.0130
Link-71	59	58	103.60	34.44	34.38	0.0600	Circular	0.600	0.0130
Link-72	58	57	112.00	34.38	34.32	0.0500	Circular	0.600	0.0130
Link-73	57	56	115.00	34.32	34.28	0.0300	Circular	0.600	0.0130
Link-74	56	55	124.00	34.28	34.24	0.0300	Circular	0.600	0.0130
Link-75	55	53	98.99	34.24	34.21	0.0300	Circular	0.600	0.0130
Link-76	3	7	317.33	38.06	36.58	0.4700	Circular	0.400	0.0130

FIGURE 2: Average monthly rainfall and temperature in the study area for the years 1980–2013 adapted from Weather Forecast for Karbala [28].

make reasonable predictions of likely flood damage in urban zones [23]. Hsu et al. [24] coupled a 2D noninterior overflow model with SWMM to estimate and simulate dynamic inundation during heavy rainfall intensities in developed areas.

The analysis of storm sewer systems in urban areas is considered as the most important measure taken to protect the environment in the event of intense rainfall. The analysis of a storm sewer system, postdesign and deployment, is considered the best way to ensure reliable up to a certain frequency or level of service and the ability to predict potential of serious flooding. Although many physically based and statistical models have been used for these purposes, the concept of having a model to simulate flows in urban sewers and to predict risk of flooding in urban areas is still comparatively inaccessible in many countries. The present work aims to investigate a model that can provide a better understanding of the ability of hydraulics and hydrology to predict and reduce risk of flooding in urban areas.

2. Methods and Materials

2.1. Study Area. Karbala is an ancient festival city, situated 100 km southwest of Baghdad, Iraq (lat.-N; 32°03'51", long.-E; 44°01'29"), in a semiarid area [25]. One of the Karbala city's districts has been chosen as the study area comprising 360 ha (3.6 km²), as shown in Figure 1(a). The percentage of impervious area is 60–80%. The topography map of the Karbala city and the layout of the storm sewer system which flows under gravity are shown in Figure 1(b) [26, 27].

2.2. Data

2.2.1. Hydraulic Data. The storm sewer system was built in 2006 [25], with the design based on a spatially uniform rainfall intensity of 13 mm/h, according to available data. The parameters used as input data for the hydraulic and hydrology models are as follows: subcatchment discharge (Q_c), discharge of pipe (Q_p), area of the subcatchment (A_c),

FIGURE 3: Rainfall intensities for the three scenarios of the model [28].

cross-sectional area of pipe (A_p), slope of subcatchment (S_c), slope of pipe (S_p), velocity in subcatchment (V_c), velocity in pipe (V_p), time of concentration in subcatchment (T_{cc}), time of concentration in pipe (T_{cp}), length of subcatchment (L_c), and length of pipe (L_p). Details of the storm sewer system were entered into the model: manholes, pipes, pump station, topography, and land use quality. There are 51 subcatchments (Table 1) with 73 manholes (Table 2) and 72 pipes with various diameters (315–800 mm) as shown in Table 3 [26, 27].

2.2.2. Hydraulic Data. The climate in Karbala is described as cold in winter (below -41°F) and hot in summer (above 131°F) [26]. Rainfall data recorded at a rain gauge station were used as input data for the hydrology model as shown in Figure 2. All of precipitation, evaporation, infiltration, surface runoff, and final surface storage have been provided by the Directorate of Karbala and Urban planning.

3. Autodesk Storm and Sanitary Analysis and Multiple Nonlinear Regressions

3.1. Methods. As illustrated in Figure 3, three scenarios of rainfall intensities have been followed. Climate changes in Iraq and particularly in Karbala city are extreme and rapid; therefore, this study has been examined using three scenarios. The first scenario used normal rainfall intensities which were

FIGURE 4: Model of the hypotheses model for the parameter ratios (3 scenarios).

recorded in Karbala city over the 33 last years [26, 27]. Moreover, the second scenario used increased rainfall intensities (multiple values), while the final scenario used rainfall intensities three times the normal rainfall intensities.

3.2. Model Description. The proposed methodology was first applied to the urban storm sewer systems in different municipalities of Karbala city based on the hydrology simulation and statistical data analysis. In this study, models based on actual hydraulic and hydrologic data were developed using Autodesk Storm and Sanitary Analysis (ASSA) [29] and multiple nonlinear regressions (MNL) in order to accurately examine all parameters involved in an urban flooding. ASSA is considered an advanced, powerful, and comprehensive model, which is used to analyse and design storm and sanitary sewer systems in urban areas [26]. ASSA uses the rational equation to examine the relationships between Q_c , A_c , S_c , V_c , T_{cc} , and L_c subcatchment parameters. Weather Forecast for Karbala [29], while the Manning equation was used to express the relationship between the storm network parameters Q_p , A_p , S_p , V_p , T_{cp} , and L_p [30]. MNL [31] is an important model for estimating the frequencies of different variables which have nonuniform distribution [32, 33].

The general method of approximation in nonlinear regression uses advanced, multiple-linear regressions that have been affected by logarithmic feature defects [34]. Nonlinear methods for a choice of free parameters and nonnormally distribution for data allowed an intercepting, nonlinear derivation. The standard nonlinear regression model is shown by the following equation:

$$y = f(\theta, x_1, x_2, x_3 + \dots) + \varepsilon \Rightarrow \varepsilon \sim N(0, V_\varepsilon), \quad (1)$$

(a)

FIGURE 5: Continued.

FIGURE 5: (a) Daily peak flooding based on three scenarios for available rainfall data (1980–2013). (b) Relationships between rainfall, runoff, and flooding over time for three scenarios of the model.

where y is the dependent variable; $x_1, x_2, x_3 \dots$ are the independent variables (possibly multivariate and often controlled by experimenter); θ is the vector of the model parameters characterizing the relationship between x and y

through the function f ; and ε is the residual error term that is assumed to be normally distributed, centred around 0 and with unknown variance (V_2). The residual error terms have commonly been assumed independent as is

FIGURE 6: Normal and detrended P-P diagrams for all the parameters entered into the model.

FIGURE 7: Normal and detrended Q-Q plots for all the parameters entered into the model.

TABLE 4: The results of Q_c/Q_p by the model equations.

Case	T_{cc}/T_{cp}	L_c/L_p	A_c/A_p	S_c/S_p	V_c/V_p	Q_c/Q_p
Minimum	1.39	0.79	110621.23	0.004	0.01	-5.74
Average	53.35	0.75	141705.79	0.25	0.20	0.98
Maximum	1276.00	5.36	802351.45	3.00	3.98	7.03

TABLE 5: Partial correlations for Q_c/Q_p , A_c/A_p , S_c/S_p , V_c/V_p , T_{cc}/T_{cp} , and L_c/L_p .

	Q_c/Q_p	A_c/A_p	S_c/S_p	V_c/V_p	T_{cc}/T_{cp}	L_c/L_p
Q_c/Q_p	1.000	-0.992	0.0128	0.287	0.136	0.182
A_c/A_p	-0.992	1.000	0.041	-0.227	-0.162	-0.235
S_c/S_p	0.0128	0.041	1.000	0.448	0.576	-0.062
V_c/V_p	0.2870	-0.227	0.448	1.000	0.493	0.073
T_{cc}/T_{cp}	0.1360	-0.162	0.576	0.493	1.000	-0.118
L_c/L_p	0.1820	-0.235	-0.062	0.073	-0.118	1.000

FIGURE 8: Correlations for all the parameters related to Q_c/Q_p .

FIGURE 9: Empirical cumulative distribution function (CDF).

normally assumed for standard nonlinear regression analysis [32, 35, 36]. Goodness of fit statistical analysis and the Nash–Sutcliffe model efficiency (NSE) was used to examine the results for the calibration and validation of the model, as shown by (2) and (3), respectively, with the relative difference error in Q_c/Q_p [37–41]:

$$NSE = 1 - \sum \frac{(Q_o(t) - Q_s(t))^2}{(Q_o(t) - \bar{Q}_o(t))^2}, \quad (2)$$

where $Q_s(t)$ denotes simulated Q_c/Q_p for time (t) ; $Q_o(t)$ is observed Q_c/Q_p for time (t) ; and $\bar{Q}_o$ is the average discharge of observed streamflow,

$$\% \text{difference} = \frac{|\sum_{i=0}^n O_i - \sum_{i=1}^n P_i|}{\sum_{i=1}^n O_i} \times 100, \quad (3)$$

where O_i is the observed data, P_i is the modelled data, and n is the number of data. In this study, two theories have been followed. The first calculates all the parameters of the sub-catchment (Q_c , A_c , S_c , V_c , T_{cc} , and L_c) without an urban storm water system, while the second includes a storm sewer system and uses Q_p , A_p , S_p , V_p , T_{cp} , and L_p . Therefore, the hypotheses examined, based on the ratios of entered parameters, include ratio of subcatchment discharge (Q_c) to discharge of pipe (Q_p); ratio of area of subcatchment (A_c) to cross-sectional area of pipe (A_p); ratio of slope of subcatchment (S_c) to slope of pipe (S_p); ratio of velocity in subcatchment (V_c) to velocity in pipe (V_p); ratio of time of concentration in subcatchment (T_{cc}) to time of concentration in pipe (T_{cp}); and ratio of length of subcatchment (L_c) to length of pipe (L_p) as shown in Figure 4.

4. Results and Discussion

4.1. Calibration and Validation of the Model. For this study, the models were tested on three scenarios applied to the 121 most intense rainy season flood events in 2013 and rainfall data from 1980 to 2013. In the first scenario, there were 29 flooding events with an event frequency less than 0.042, and these ranged between 0.126 and 6.587 cms. In the second scenario, there were 39 flooding events with an event frequency less than 0.057, and these ranged between 0.429 and 15.232 cms. In the third scenario, there were 59 flooding events with an event frequency greater than 0.077, and the range was between 0.267 and 30.76 cms as shown in Figure 5.

(a)

(b)

FIGURE 10: (a) Three model scenarios for Q_c/Q_p (a) and V_c/V_p (b) based on different rainfall intensities

The effect of rainfall intensity and surface runoff discharge on the magnitude of flooding in the storm sewer system as examined by the three model scenarios are illustrated in Figure 6.

The relationships among the parameters (Q_c/Q_p , A_c/A_p , S_c/S_p , V_c/V_p , T_{cc}/T_{cp} , and L_c/L_p) were tested using linear and nonlinear equations. The best relationships were logarithmic, normal, and detrended P-P diagrams (Figure 6). The MNLR works on the assumption that both dependent and independent variables should be nonnormally distributed. The plots showed that all points were more or

less situated along a line, particularly for Q_c/Q_p , indicating the data were not normally distributed. Normal and detrended Q-Q plot data were tested, revealing the nonlinear relationships between the parameters (Figure 7).

Equations (4)–(6) represents nonlinear (logarithmic) relationships between parameters Q_c/Q_p , A_c/A_p , S_c/S_p , V_c/V_p , T_{cc}/T_{cp} , and L_c/L_p . The first equation represents the minimum ratio of discharge in subcatchment (A_c) to pipe discharge (Q_p), the second equation denotes the average discharge ratios, while the final equation denotes maximum discharge ratios, as per the model:

$$\begin{aligned} \left(\frac{Q_c}{Q_p}\right)_{\min} = & 31.47 \times \ln\left(\frac{A_c}{A_p}\right)^{0.4} + 3.99 \times \ln\left(\frac{S_c}{S_p}\right)^{0.05} \\ & + 8.25 \times \ln\left(\frac{V_c}{V_p}\right)^{0.055} - 0.74 \times \ln\left(\frac{T_{cc}}{T_{cp}}\right)^{0.5} \\ & - 32.30 \times \ln\left(\frac{L_c}{L_p}\right)^{0.5} - 11.10, \end{aligned} \quad (4)$$

$$\begin{aligned} \left(\frac{Q_c}{Q_p}\right)_{\text{ave}} = & 46.50 \times \ln\left(\frac{A_c}{A_p}\right)^{0.4} + 9.30 \times \ln\left(\frac{S_c}{S_p}\right)^{0.05} \\ & + 13.60 \times \ln\left(\frac{V_c}{V_p}\right)^{0.055} - 0.16 \times \ln\left(\frac{T_{cc}}{T_{cp}}\right)^{0.5} \\ & - 19.96 \times \ln\left(\frac{L_c}{L_p}\right)^{0.5} - 7.75, \end{aligned} \quad (5)$$

$$\begin{aligned} \left(\frac{Q_c}{Q_p}\right)_{\max} = & 61.65 \times \ln\left(\frac{A_c}{A_p}\right)^{0.4} + 14.60 \times \ln\left(\frac{S_c}{S_p}\right)^{0.05} \\ & + 18.97 \times \ln\left(\frac{V_c}{V_p}\right)^{0.055} + 0.42 \times \ln\left(\frac{T_{cc}}{T_{cp}}\right)^{0.5} \\ & - 7.60 \times \ln\left(\frac{L_c}{L_p}\right)^{0.5} - 4.40. \end{aligned} \quad (6)$$

With the input of three values (minimum, average, and maximum) for each parameter (A_c/A_p , S_c/S_p , V_c/V_p , T_{cc}/T_{cp} , and L_c/L_p) into the above (4)–(6), the results of Q_c/Q_p (min.), Q_c/Q_p (ave.), and Q_c/Q_p (max.) are extracted as shown in Table 4.

The optimal case of $Q_c/Q_p = 1$ was based on the recommended runoff surface needed to prevent flooding. Storm sewers in urban areas are only partially designed, most concentrated downstream of streets and subareas, unlike sanitary sewers which are designed to be downstream of each house. The model examined the percentage completely filled by storm network. The results indicated that the average of Q_c/Q_p was 0.98 which supports the idea that the flood events are correctly defined. However, the maximum value of Q_c/Q_p was 7.03 meaning that the subcatchment runoff discharge was larger than the discharge in the pipes, leading to flooding in the storm sewer network as defined in this study. Dependant on the minimum, average, and maximum parameters entered into the equation model, the weight of A_c/A_p gave equations of 73.5% and therefore is considered the most effective parameter in the equation for Q_c/Q_p . The next dimensionless parameters in the model are the ratios V_c/V_p and S_c/S_p . The weight of these parameters in the model was 7.8%. The ratio of T_{cc}/T_{cp} was 7.2% influence, the lowest impact on Q_c/Q_p 3.7% with the ratio L_c/L_p . The computed water stage is overestimated if the dynamic interaction between surcharge and discharge of the manhole is neglected in the simulation [5]. However, these equations could still be used to estimate the volume of flooding.

FIGURE 11: Model calibration of Q_c/Q_p based on the parameters with a confidence interval of 95%.

Using logarithmic regressions, the correlations between parameters are reported in Table 5 and shown in Figure 8. The results showed that there are significant correlations found between dimensionless parameters listed in Table 5. As shown in Table 5, the ratios were 1, -0.992 , 0.0128 , 0.287 , 0.136 , and 0.182 for Q , A , S , V , T , and L , respectively. It was also found that Q_c/Q_p and S_c/S_p had low correlations at 0.0128 . Therefore, a regression analysis was conducted to estimate the effects of all the parameter ratios on storm water flooding.

The normality of the data was checked using the Kolmogorov–Smirnov test, and the empirical cumulative distribution function (CDF) for observation data is examined as shown in Figure 9. This figure shows a lack of mapping of the CDF line to the line representing normality (blue), providing evidence for a nonlinear distribution. Based on the model findings and its scenarios, both Q_c/Q_p and V_c/V_p increase with increasing rainfall intensity as shown in Figure 10.

Regarding the calibration of the model, Figure 11 shows the observed Q_c/Q_p versus modelled Q_c/Q_p based on the parameters with a confidence interval of 95%. The data show a trend towards the observed Q_c/Q_p data, which could be due to the nonlinear relationships for Q_c/Q_p with the other parameters.

All parameters determined during the process of calibration were used to validate the model, and the percent of difference is 2 (significant if less than 10) between observed and predicted data for Q_c/Q_p , based on the ratios of entered parameters. The efficiency of NSE was $0.33 > 0$, indicating that the model predictions were as accurate as the mean of observed data. Figure 12 presents images for the parameters A_c/A_p , S_c/S_p , and V_c/V_p predicting Q_c/Q_p , an important means to understand the relationships among the parameters, and particularly the dependence of Q_c/Q_p on the other parameters. One of the most significant current discussions

FIGURE 12: Three-dimensional surfaces of the model parameters.

regarding this model is the possibility of using the extracted model equations to predict flooding in any storm sewer and its subareas, under extremely intense rainfall.

5. Summary and Conclusions

One of the major challenges when designing a storm sewer system is identifying the likely impact of identified parameters at the planning stage in order to eliminate or mitigate frequency of flooding. Many storm sewer simulation models exist, but this study has attempted to find a more accurate way to examine the relationships between runoff discharge and storm pipe discharge, topography of subcatchment and network slope, velocity in subareas and velocity in storm pipe, size of urban areas and cross-sectional

area of storm pipe. This numerical study was carried out to determine which factor was more important based on the equations developed in the model. Conclusions drawn from this model include the following:

- (1) The computed water stage ($7.03 Q_c/Q_p$) is over-estimated when the dynamic interaction between surcharge and discharge in manholes is neglected in the simulation [6]. These equations (3)–(5) can also be used to estimate the volume of flooding, a new approach in this area of research.
- (2) This model can be used to predict flooding in urban areas and to estimate the percentage of storm networks needed in subcatchments to limit city flooding.

- (3) The calculations suggest that the use of irregular classifications of rainfall data could increase the computational complexity essential to rebuild the model and significantly increase the time required for simulation runs. In compensation, the relationship between parameters entered into the model was logarithmic, and the distribution of data is nonlinear.
- (4) This study recommends that the design and analysis procedure for a storm sewer system must include the mitigation of the risk flooding in urban areas.

These results may simplify developments in the prediction of urban flooding and thus protect resources as well as reduce flood risk. Given that storm sewer systems have historically been designed to consider limited rainfall intensity, this model can allow for varying rainfall intensities in unusual situations. The model has also established a clearer relationship between relevant parameters. It may therefore be useful worldwide in a range of different scenarios.

Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this paper.

References

- [1] S. T. Ashley and W. S. Ashley, "Flood fatalities in the United States," *Journal of Applied Meteorology and Climatology*, vol. 47, no. 3, pp. 805–818, 2008.
- [2] B. E. Montz and E. Grunfest, "Flash flood mitigation: recommendations for research and applications," *Global Environmental Change Part B: Environmental Hazards*, vol. 4, no. 1, pp. 15–22, 2002.
- [3] H. A. Obaid, S. Shahid, K. N. Basim, and C. Shreeshivadasan, "Modeling sewerage overflow in: an urban residential area using storm water management model," *Malaysian Journal of Civil Engineering*, vol. 26, pp. 163–171, 2014.
- [4] H. T. Huong and A. Pathirana, "Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam," *Hydrology and Earth System Sciences*, vol. 17, no. 1, pp. 379–394, 2013.
- [5] T. V. Hromadka II and C. Lai, "Solving the two-dimensional diffusion flow model," in *Proceedings of the Specialty Conference on Hydraulics and Hydrology in the Small Computer Age*, pp. 555–562, Lake Buena Vista, FL, USA, August 1985.
- [6] S. Lee, H. Nakagawa, K. Kawaike, and H. Zhang, "Urban inundation simulation considering road network and building configurations," *Journal of Flood Risk Management*, vol. 9, no. 3, pp. 224–233, 2016.
- [7] E. Gamma, *Design Patterns: Elements of Reusable Object-Oriented Software*, Pearson Education, Delhi, India, 1995.
- [8] S. S. Lin, H. K. Chang, S. H. Hsieh, J. T. Kuo, and J. S. Lai, *An Integrated Approach for Inundation Simulation in an Urban Area*, IAHS Publication, Wallingford UK, 2004.
- [9] L. B. Leopold, *Hydrology for Urban Land Planning: A Guidebook on the Hydrologic Effects of Urban Land Use*, 1968.
- [10] F. L. Ogden, N. Raj Pradhan, C. W. Downer, and J. A. Zahner, "Relative importance of impervious area, drainage density, width function, and subsurface storm drainage on flood runoff from an urbanized catchment," *Water Resources Research*, vol. 47, no. 12, 2011.
- [11] F. L. Ogden, H. O. Sharif, S. U. Senarath, J. A. Smith, M. L. Baeck, and J. R. Richardson, "Hydrologic analysis of the Fort Collins, Colorado, flash flood of 1997," *Journal of Hydrology*, vol. 228, no. 1, pp. 82–100, 2000.
- [12] G. E. Hollis, "The effect of urbanization on floods of different recurrence interval," *Water Resources Research*, vol. 11, no. 3, pp. 431–435, 1975.
- [13] N. A. Campana and C. E. Tucci, "Predicting floods from urban development scenarios: case study of the Dilúvio Basin, Porto Alegre, Brazil," *Urban Water*, vol. 3, no. 1, pp. 113–124, 2001.
- [14] A. Mailhot and S. Duchesne, "Design criteria of urban drainage infrastructures under climate change," *Journal of Water Resources Planning and Management*, vol. 136, no. 2, pp. 201–208, 2010.
- [15] J. Blanc, J. W. Hall, N. Roche et al., "Enhanced efficiency of pluvial flood risk estimation in urban areas using spatial-temporal rainfall simulations," *Journal of Flood Risk Management*, vol. 5, no. 2, pp. 143–152, 2012.
- [16] R. Gaudio, N. Penna, and V. Viteritti, "A combined methodology for the hydraulic rehabilitation of urban drainage networks," *Urban Water Journal*, vol. 13, no. 6, pp. 644–656, 2016.
- [17] L. A. Rossman, *Storm Water Management Model User's Manual, Version 5.0*, National Risk Management Research Laboratory, Office of Research and Development, US Environmental Protection Agency, Cincinnati, OH, USA, 2010.
- [18] B. C. Phillips, S. Yu, G. R. Thompson, and N. De Silva, "1D and 2D modelling of urban drainage systems using XP-SWMM and TUFLO," in *Proceedings of the 10th International Conference on Urban Drainage*, pp. 21–26, Copenhagen, Denmark, August 2005.
- [19] S. V. Kanitkar, A. D. Thube, and R. N. Sankhua, "Optimal design model for a fixed layout storm water network," *International Journal of Water*, vol. 10, no. 4, p. 375, 2016.
- [20] DHI and Hydraulics DH, *MIKE 21 & MIKE 3 FLOW MODEL Hydrodynamic Module Scientific Documentation*, DHI Water & Environment, Hørsholm, Denmark, 2005.
- [21] C. P. Burgess, M. A. Taylor, T. Stephenson, and A. Mandal, "Frequency analysis, infilling and trends for extreme precipitation for Jamaica (1895–2100)," *Journal of Hydrology: Regional Studies*, vol. 3, pp. 424–443, 2015.
- [22] A. Chen, S. Djordjevic, J. Leandro, B. Evans, and D. Savic, "Simulation of the building blockage effect in urban flood modelling," in *Proceedings of the 11th International Conference on Urban Drainage*, pp. 1–10, Edinburgh, UK, August–September 2008.
- [23] S. D. Seyoum, Z. Vojinovic, R. K. Price, and S. Weesakul, "Coupled 1D and noninertia 2D flood inundation model for simulation of urban flooding," *Journal of Hydraulic Engineering*, vol. 138, no. 1, p. 23, 2011.
- [24] M. H. Hsu, S. H. Chen, and T. J. Chang, "Inundation simulation for urban drainage basin with storm sewer system," *Journal of Hydrology*, vol. 234, no. 1–2, pp. 21–37, 2000.
- [25] Karbala-Iraq Governorates (KIG), *Regions and Major Cities—Statistics and Maps on City Population*, KIG, Karbala, Iraq, 2013.
- [26] Directorate of Sewerage of Karbala, "Report of operation department 2016," Rep. DSK-214, Governorate of Karbala, Karbala, Iraq, 2016.
- [27] Directorate of Karbala Urban Planning, "Planning and design department 2016," Rep. JIK-202, Governorate of Karbala, Karbala, Iraq, 2016.
- [28] World Weather Information Service, "Weather forecast for Karbala," 2016, <http://worldweather.wmo.int/en/city.html?cityId=1465>.
- [29] Autodesk, *Autodesk Storm and Sanitary Analysis Manual*, Autodesk, San Rafael, CA, USA, 2016.

- [30] Č. Maksimović, D. Prodanović, S. Boonya-Aroonnet, J. P. Leitão, S. Djordjević, and R. Allitt, "Overland flow and pathway analysis for modelling of urban pluvial flooding," *Journal of Hydraulic Research*, vol. 47, no. 4, pp. 512–523, 2009.
- [31] P. Gauckler, *Etudes Théoriques et Pratiques sur l'Ecoulement et le Mouvement des Eaux*, Gauthier-Villars, Paris, France, 1867.
- [32] G. Terdik and W. A. Woyczynski, "Rosinski measures for tempered stable and related Ornstein–Uhlenbeck processes," *Probability and Mathematical Statistics*, vol. 26, no. 2, p. 213, 2006.
- [33] D. M. Bates and D. G. Watts, *Nonlinear Regression Analysis and Its Applications*, Wiley, New York, NY, USA, 1988.
- [34] C. M. Crainiceanu and D. Ruppert, "Likelihood ratio tests in linear mixed models with one variance component," *Journal of the Royal Statistical Society: Series B*, vol. 66, no. 1, pp. 165–185, 2004.
- [35] S. Huet, A. Bouvier, M. A. Poursat, and E. Jolivet, *Statistical Tools for Nonlinear Regression: A Practical Guide with S-Plus and R Examples*, Springer Science & Business Media, Berlin, Germany, 2006.
- [36] F. Baty, C. Ritz, S. Charles, M. Brutsche, J. P. Flandrois, and M. L. Delignette-Muller, "A toolbox for nonlinear regression in R: the package nlstools," *Journal of Statistical Software*, vol. 66, no. 5, p. 1, 2015.
- [37] R. H. Shumway and D. S. Stoffer, *ARIMA Models: In Time Series Analysis and Its Applications*, Springer, New York, NY, USA, 2011.
- [38] W. An and J. M. Gianvito, "Kiski Valley WPCA Combined Sewer System Long Term Model Study," *Journal of Water Management Modeling*, 2011.
- [39] P. M. Bentler and D. G. Bonett, "Significance tests and goodness of fit in the analysis of covariance structures," *Psychological Bulletin*, vol. 88, no. 3, pp. 588–606, 1980.
- [40] H. W. Marsh, J. R. Balla, and R. P. McDonald, "Goodness-of-fit indexes in confirmatory factor analysis: the effect of sample size," *Psychological Bulletin*, vol. 103, no. 3, pp. 391–490, 1988.
- [41] J. E. Nash and J. V. Sutcliffe, "River flow forecasting through conceptual models part I—a discussion of principles," *Journal of Hydrology*, vol. 10, no. 3, pp. 282–290, 1970.
- [42] Directorate of Karbala, Weather Forecast, "Report of Accu-Weather forecast for Karbala Iraq," Rep. DWK-88, Governorate of Karbala, Karbala, Iraq, 2016.
- [43] E. Tsykin, "Multiple nonlinear regressions derived with choice of free parameters," *Applied Mathematical Modelling*, vol. 8, no. 4, pp. 288–292, 1984.