

Analysis of Urban Population Growth Pattern for Chennai – Zone V, Royapuram

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ABSTRACT: Graph-cellular automata (GCA) is implemented for zone V of Chennai city. The population, population density, educational institution, industries, etc were taken as attribute. It is shown that GCA with particular structural properties defined in terms of the relationships between subsets of cells is a useful generalization of traditional cellular automaton (CA). The population data from Chennai census 1981, 1991, and 2001 were used to develop the GCA and the results are enumerated. The obtained results are compared with census data 2011.

KEYWORDS: Graph cellular automata, urban growth rate.

I. INTRODUCTION

The work focuses to develop a computational modeling which (i) reproduce efficiently the underlying pattern of the urban growth dynamics, (ii) express in linguistic terms the ideas and results acquired and (iii) sustain a generic model independent from data limitations for Chennai Metropolitan Area.

Formally, a graph-CA model consists of a directed graph G , and a set of allowed cell (or vertex) states $S = \{S_j\}$. G consists of spatial elements represented by the vertex set $V(G)$ and directed relations between those elements represented by the arc set $E(G)$. In any graph, the neighbourhood of a vertex v_i consists of all the other vertices (or locations) in $V(G)$ to which it is adjacent. In the context of building a dynamic proximal model we may regard the in-neighborhood of v_i , $N_{in}(v_i)$ as the set of influencing locations. We use a '(t)' superscript to indicate the particular state attaining at a vertex, or the collective state in a neighbourhood, at time t , as opposed to the set of allowed states S and its elements $\{S_j\}$ (with no superscript). Thus, $S_j^{(t)}$ is the state of location v_i at time t , and the cellular automaton aspect of the model is incorporated according to

$$S_i^{(t+1)} = f[S_i^{(t)}],$$

where $S_i^{(t)}$ is the set of states of the in-neighbours of v_i at time t , that is,

$$S_i^{(t)} = \{S_j^{(t)} \mid v_j \in N_{in}(v_i)\}.$$

Note that $S_i^{(t)}$ will always be some combination of the allowed cell states in S . Also, in most cases, $v_i v_j \in E(G)$, so that $v_j \in N_{in}(v_i)$, and the state of a location at time $(t + 1)$ is partly dependent on its state at time t , as we would expect.

II. ZONE V

Royapuram zone with 18 wards, situated in the Northern piece of Chennai City, Tamil Nadu, India, is most known for the Royapuram Railway Station, the main railroad station of south India opened in 1856, and is today the most seasoned surviving rail route station of the Indian subcontinent. The St. Peters Church, Royapuram is a standout amongst the most unmistakable and most established chapels and point of interest in the district. Royapuram angling

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harbor is one of the biggest angling harbor in the coromandal drift. The locale existed as an outstanding settlement amid the Chola times, however the name Royapuram is gotten from a Tamil moniker St. Peter, Royappa, regarding St. Peters's Church in the zone. From the fourteenth century, the past Vijayanagara Rulers controlled this district . Buckingham canal is the only canal which touches the zone at Moolakotharam Canal road and moves about 2.75 km.

Royapuram has a profound history taught inside itself and has been a piece of the Chennai (Madras) city for a considerable length of time. It is simply not withstanding the current improvements that Royapuram got pushed out to the fringe of the Chennai. The Chennai's Port Trust situated on the shores of Royapuram. The unbelievable Robinson Park renamed as Arignar Anna Poonga after late boss clergyman of Tamil Nadu Arignar Anna is situated here. This stop has seen different noteworthy exercises, for example, the introduction of DMK and parcel of open arouses amid the early piece of the 1960s. Presently it has been changed into a green stop with parcel of offices for walkers. There are spots of religious interests, for example, Kalmandapam Angalamman Temple, St. Mary's Church and Shafia Mosque.

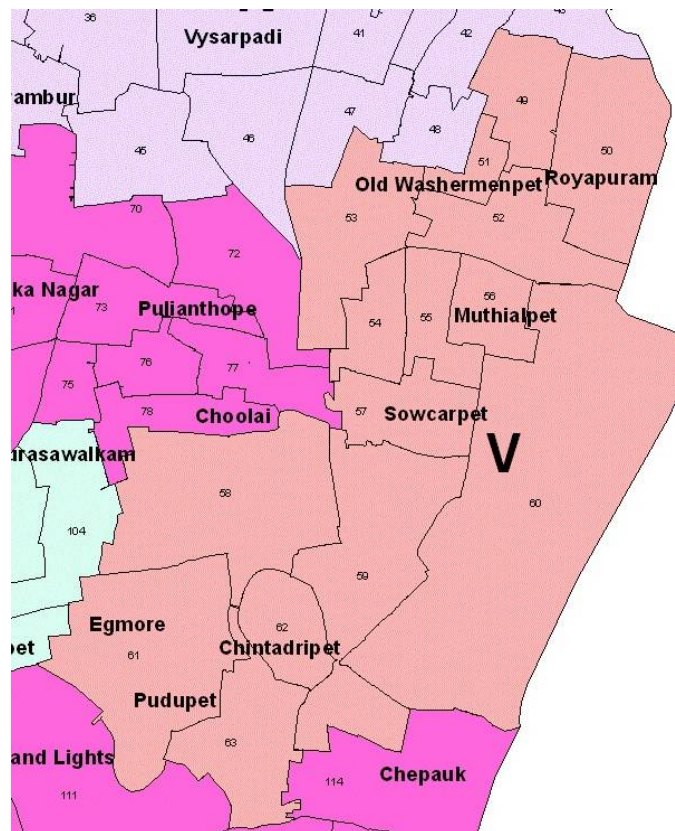


Fig. 1:Ward map of Royapuram (Zone V)

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III. GCA FOR ROYAPURAM

Graph-cellular automata (GCA) is implemented for Royapuram for the population taken as attribute. It is shown that GCA with particular structural properties defined in terms of the relationships between subsets of cells is a useful generalization of traditional cellular automaton (CA).

Each ward is considered as a vertex. Two vertices are connected if the two wards are adjacent on the map. Thus obtaining a ward graph of Royapuram zone (see Fig 2.)

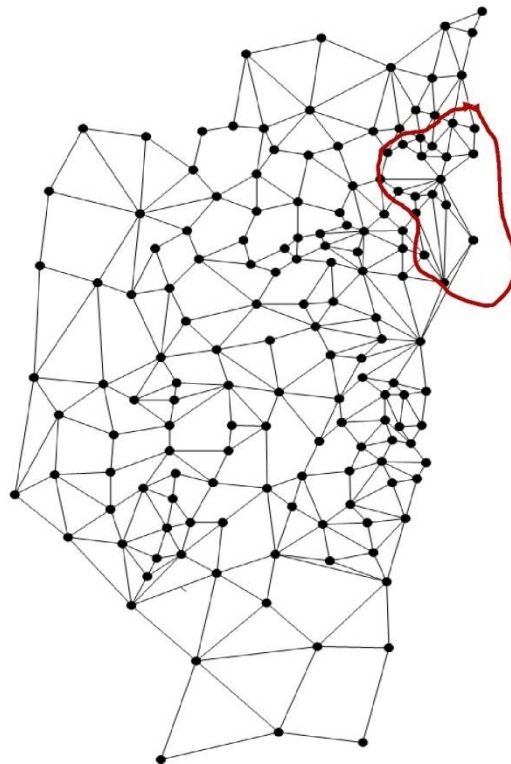


Fig. 2:The graph obtained by the Royapuram zone (highlighted), where each vertices represents the wards and the edges represents their adjacency.

IV. ANALYSIS OF POPULATION GROWTH BASED ON GCA:

Consider, s_i^t is the state value of the ward i at time t , and the cellular automaton aspect of the model is incorporated according to which,

$$s_i^{t+1} = f(s_k^t), k \in [N(i)]$$

where s_k^t is the state values of the in-neighbors of s_i at time t . The state value could be any attributes that signifies certain factors such as populations, workers, transportation, educational institution, migrations, geological factor, etc. Initially we consider the population, which is a major factor in influencing the urbanization. To analyze the growth pattern of population through graph cellular automata model, vary many transition rules had been experimented and among them six certain transition rules have been identified which mimics the growth behavior of wards in Chennai city. The identified transition rules are as follows:

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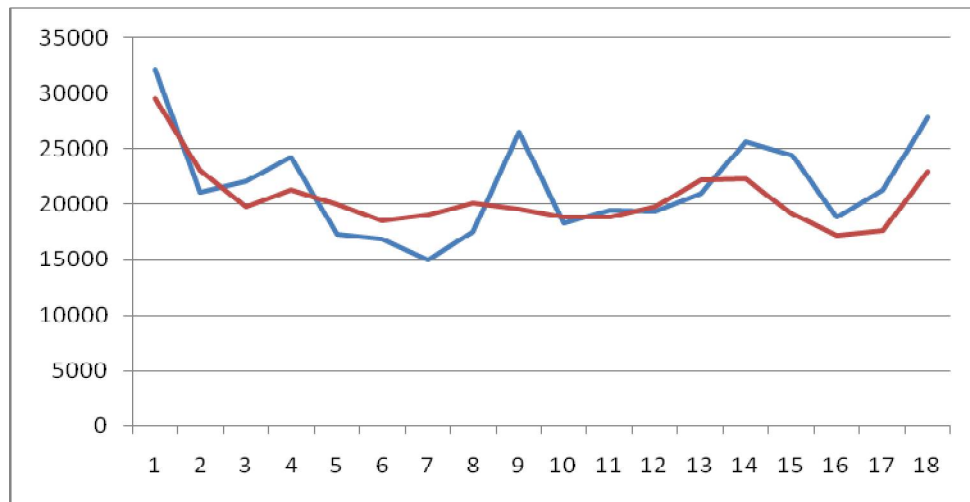
RULE 1: The s_i^{t+1} the population for the ward i at the time $t + 1$, is given by

$$s_i^{t+1} = \frac{\sum_{k \in [N(i)]} (s_k^t)}{|[N(i)]|}$$

where, s_k^t is the population for the ward k at the time t , $[N(i)]$ represents the closed neighborhood of ward i and $|[N(i)]|$ represents its cardinality.

Rule 1		Actual census			GCA estimation from		
Ward No.	Ward Name	1991	2001	2011	1991	2001	2011
0014	Tondiarpet	27765	32090	35130	29499	31297	31598
0015	Sanjeevirayanpet	20874	21055	19952	23046	24080	23830
0016	Grace Garden	19832	22032	22947	19777	21205	21122
0017	Ma. Po. Si. Nagar	22445	24200	24670	21310	23893	24793
0018	Royapuram	15199	17250	16424	19970	21354	21135
0019	Singara Garden	16872	16807	15457	18424	19181	18388
0020	Narayanappa Naicken Garden	15451	15006	13276	18951	19116	17997
0021	Old Washermaenpet	17692	17510	16044	20122	19663	17919
0022	Meenakshi Ammanpet	25500	26481	26177	19491	20980	21040
0023	Kondi Thope	16770	18244	18434	18791	21122	22169
0024	Seven Wells (North)	16589	19438	21002	18761	20451	20858
0025	Amman Koil	18113	19329	19261	19778	21552	22042
0026	Muthialpet	20291	20907	20239	22144	23340	23252
0027	Vallal Seethakkadhi Nagar	25475	25593	24426	22289	23518	23463
0028	Katchaleeswarar Nagar	21341	24391	26156	19088	20935	21499
0029	Seven Wells (South)	16832	18766	19415	17159	19310	20178
0030	Sowcarpet	15905	21238	25286	17605	19470	20051
0031	Basin Bridge	22047	27742	32152	22842	26291	28456

Table 1. Census and Rule 1 GCA estimated populations for the zone 5 (Royapuram)



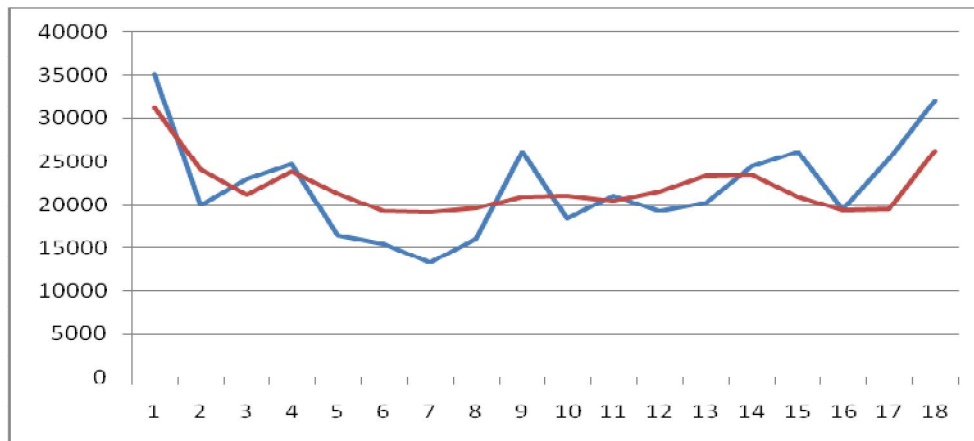
Graph 1. Census data 2001 (blue) and Rule 1 GCA estimated data from 1991 (red)

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Graph 2. Census data 2011 (blue) and Rule 1 GCA estimated data from 2001 (red)

RULE 2: The s_i^{t+1} the population for the ward i at the time $t + 1$, is given by

$$s_i^{t+1} = \left(\prod_{k \in [N(i)]} (s_k^t) \right)^{1/|[N(i)]|}$$

where, s_k^t is the population for the ward k at the time t , $[N(i)]$ represents the closed neighborhood of ward i and $|[N(i)]|$ represents its cardinality.

Rule 2		Actual census			GCA estimation from		
Ward No.	Ward Name	1991	2001	2011	1991	2001	2011
0014	Tondiarpet	27765	32090	35130	133101	141444	140712
0015	Sanjeevirayanpet	20874	21055	19952	22552	23375	22772
0016	Grace Garden	19832	22032	22947	19369	20588	20127
0017	Ma. Po. Si. Nagar	22445	24200	24670	20820	23309	23907
0018	Royapuram	15199	17250	16424	19626	21010	20659
0019	Singara Garden	16872	16807	15457	18126	18821	17863
0020	Narayanappa Naicken Garden	15451	15006	13276	18782	18906	17687
0021	Old Washermaenpet	17692	17510	16044	19792	19310	17473
0022	Meenakshi Ammanpet	25500	26481	26177	19217	20668	20550
0023	Kondi Thope	16770	18244	18434	18456	20695	21552
0024	Seven Wells (North)	16589	19438	21002	18494	20252	20689
0025	Amman Koil	18113	19329	19261	19552	21370	21851
0026	Muthialpet	20291	20907	20239	21951	23172	23060
0027	Vallal Seethakkadhi Nagar	25475	25593	24426	22124	23382	23308
0028	Katchaleeswarar Nagar	21341	24391	26156	18865	20772	21275
0029	Seven Wells (South)	16832	18766	19415	17061	19125	19759
0030	Sowcarpet	15905	21238	25286	17495	19280	19597
0031	Basin Bridge	22047	27742	32152	21913	24947	26506

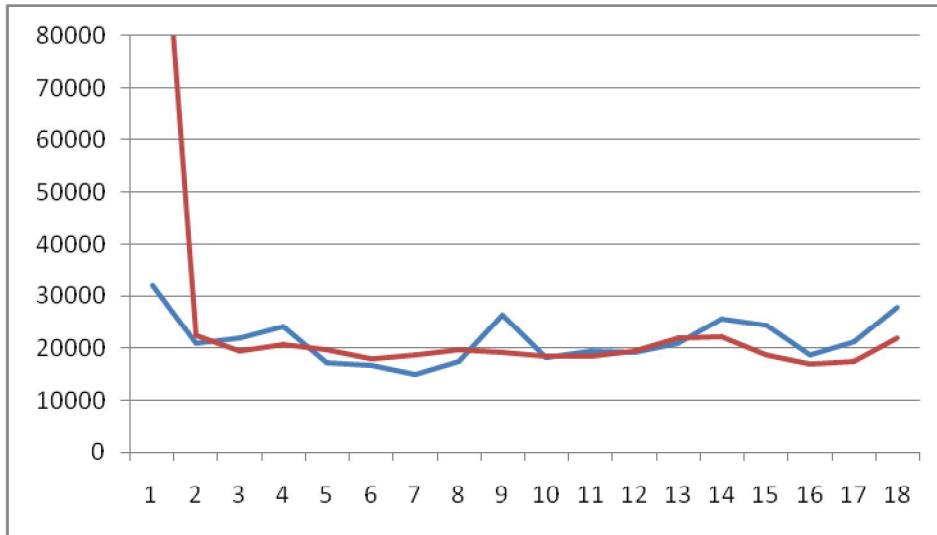
Table 2. Census and Rule 2 GCA estimated populations for the zone 5 (Royapuram)

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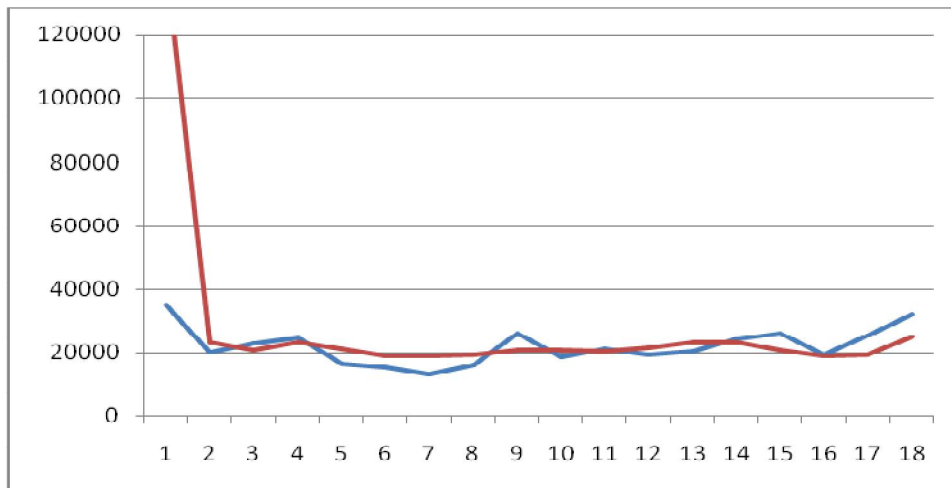
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Graph 3. Census data 2001 (blue) and Rule 2 GCA estimated data from 1991 (red)



Graph 4. Census data 2011 (blue) and Rule 2 GCA estimated data from 2001 (red)

RULE 3: The s_i^{t+1} the population for the ward i at the time $t + 1$, is given by

$$s_i^{t+1} = \frac{\sum_{k \in [N(i)]} (\mu_k^t \times s_k^t)}{\sum_{k \in [N(i)]} (\mu_k^t)}$$

where, s_k^t is the population for the ward k at the time t , $[N(i)]$ represents the closed neighborhood of ward i and μ_k^t represents membership value between s_k^t and s_i^t . The μ_k^t signifies how much the s_k^t has its influence on s_i^t by considering various parameters such as geological factors, educational institution, industries, transportation etc.

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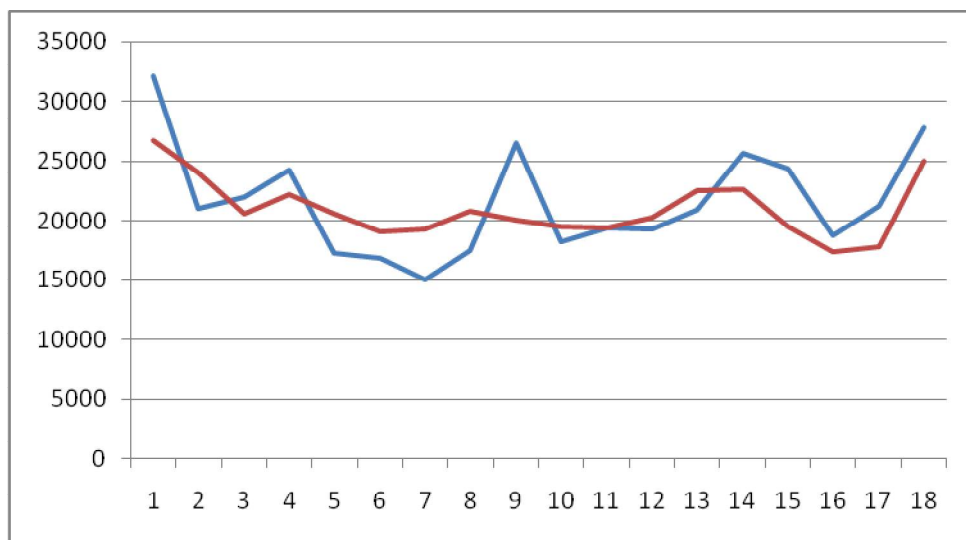
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Rule 3		Actual census			GCA estimation from		
Ward No.	Ward Name	1991	2001	2011	1991	2001	2011
0014	Tondiarpet	27765	32090	35130	26770	28853	29976
0015	Sanjeevirayanpet	20874	21055	19952	24019	25481	25958
0016	Grace Garden	19832	22032	22947	20645	22563	23349
0017	Ma. Po. Si. Nagar	22445	24200	24670	22278	25095	26611
0018	Royapuram	15199	17250	16424	20662	22031	22040
0019	Singara Garden	16872	16807	15457	19096	19971	19525
0020	Narayanappa Naicken Garden	15451	15006	13276	19293	19527	18610
0021	Old Washermaenpet	17692	17510	16044	20783	20408	18922
0022	Meenakshi Ammanpet	25500	26481	26177	20076	21645	22121
0023	Kondi Thope	16770	18244	18434	19524	22028	23513
0024	Seven Wells (North)	16589	19438	21002	19382	20905	21230
0025	Amman Koil	18113	19329	19261	20259	21938	22442
0026	Muthialpet	20291	20907	20239	22530	23666	23625
0027	Vallal Seethakkadhi Nagar	25475	25593	24426	22623	23786	23769
0028	Katchaleeswarar Nagar	21341	24391	26156	19570	21274	21953
0029	Seven Wells (South)	16832	18766	19415	17373	19693	21010
0030	Sowcarpet	15905	21238	25286	17840	19865	20977
0031	Basin Bridge	22047	27742	32152	24993	29357	32853

Table 3. Census and Rule 3 GCA estimated populations for the zone 5 (Royapuram)



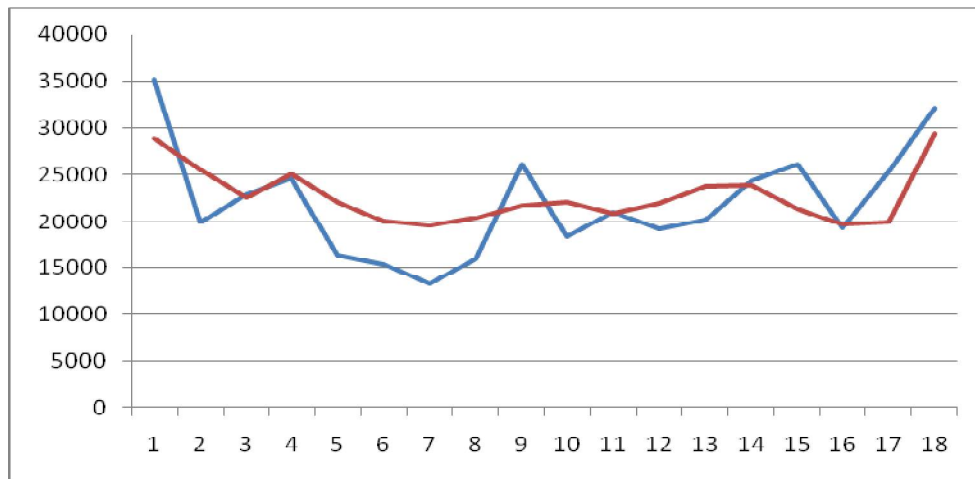
Graph 5. Census data 2001 (blue) and Rule 3 GCA estimated data from 1991 (red)

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Graph 6. Census data 2011 (blue) and Rule 3 GCA estimated data from 2001 (red)

RULE 4: The s_i^{t+1} the population for the ward i at the time $t + 1$, is given by

$$s_i^{t+1} = s_i^t + \frac{\sum_{k \in (N(i))} (\mu_k^t \times s_k^t)}{\sum_{k \in (N(i))} (\mu_k^t)}$$

where, s_k^t is the population for the ward k at the time t , $(N(i))$ represents the open neighborhood of ward i and μ_k^t represents membership value between s_k^t and s_i^t . The μ_k^t signifies how much the s_k^t has its influence on s_i^t by considering various parameters such as geological factors, educational institution, industries, transportation etc.

Rule 4		Actual census			GCA estimation from		
Ward No.	Ward Name	1991	2001	2011	1991	2001	2011
0014	Tondiarpet	27765	32090	35130	54350	60275	63934
0015	Sanjeevirayanpet	20874	21055	19952	45360	47168	46726
0016	Grace Garden	19832	22032	22947	40613	44687	46370
0017	Ma. Po. Si. Nagar	22445	24200	24670	44663	49598	51924
0018	Royapuram	15199	17250	16424	36841	40203	39497
0019	Singara Garden	16872	16807	15457	36368	37319	35645
0020	Narayanappa Naicken Garden	15451	15006	13276	35348	35213	32634
0021	Old Washermaenpet	17692	17510	16044	39006	38423	35470
0022	Meenakshi Ammanpet	25500	26481	26177	44844	47499	47780
0023	Kondi Thope	16770	18244	18434	36776	40908	42764
0024	Seven Wells (North)	16589	19438	21002	36571	40686	42290
0025	Amman Koil	18113	19329	19261	38758	41725	42246
0026	Muthialpet	20291	20907	20239	43323	45175	44578
0027	Vallal Seethakkadhi Nagar	25475	25593	24426	47253	48876	48022
0028	Katchaleeswarar Nagar	21341	24391	26156	40624	45133	47356
0029	Seven Wells (South)	16832	18766	19415	34293	38608	40679
0030	Sowcarpet	15905	21238	25286	34088	40797	45117
0031	Basin Bridge	22047	27742	32152	47512	57385	65140

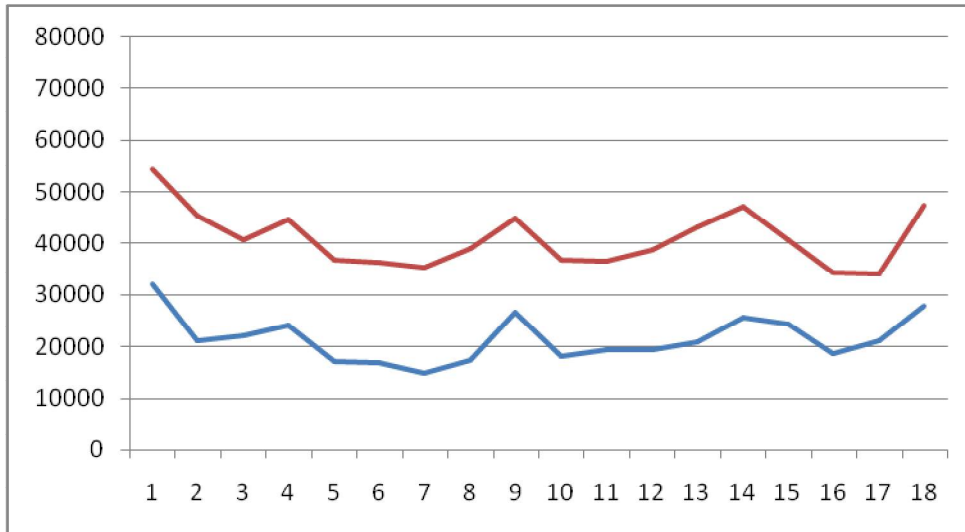
Table 4. Census and Rule 4 GCA estimated populations for the zone 5 (Royapuram)

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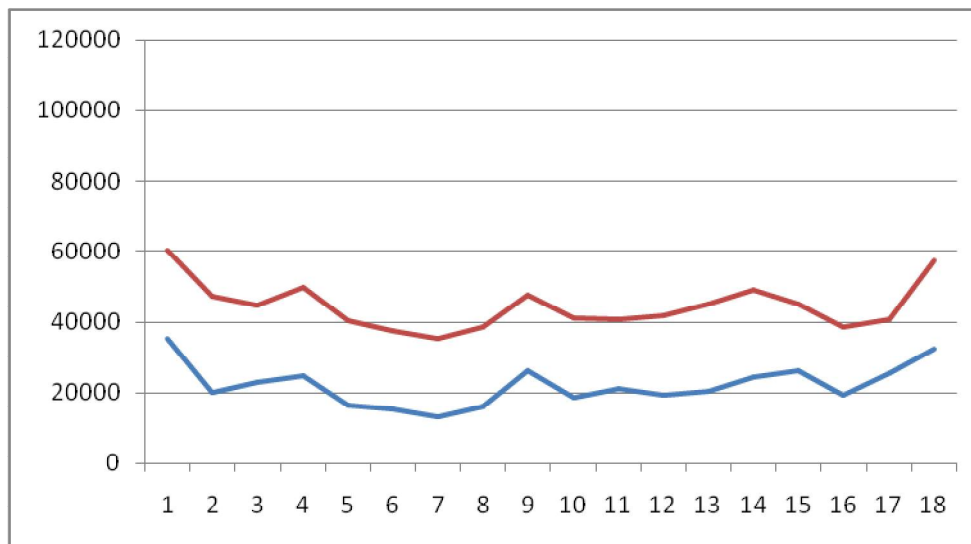
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Graph 7. :Census data 2001 (blue) and Rule 4 GCA estimated data from 1991 (red)



Graph 8.Census data 2011 (blue) and Rule 4 GCA estimated data from 2001 (red)

RULE 5: The s_i^{t+1} the population for the ward i at the time $t + 1$, is given by

$$s_i^{t+1} = s_i^t + \frac{\sum_{k \in (N(i))} (\mu_k^t \times s_k^t)}{2 \times \sum_{k \in (N(i))} (\mu_k^t)}$$

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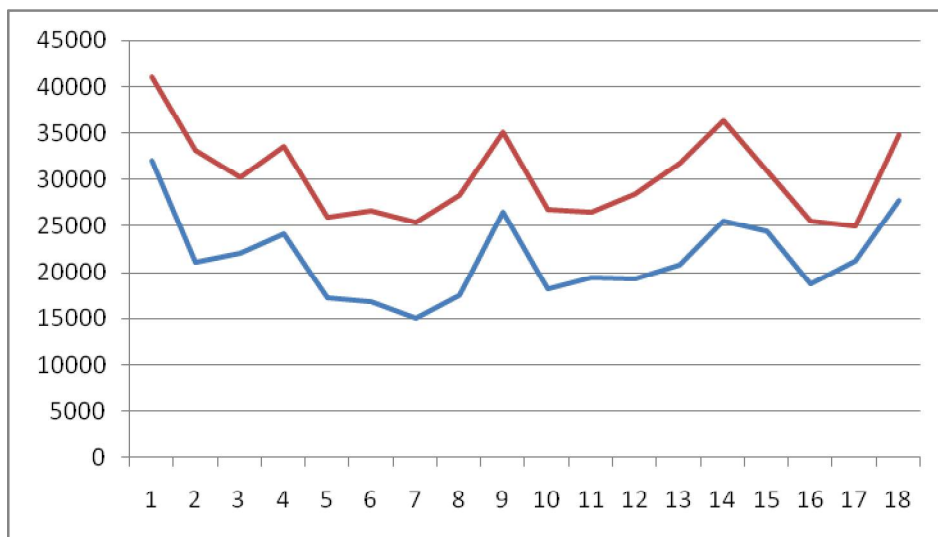
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where, s_k^t is the population for the ward k at the time t , $(N(i))$ represents the open neighborhood of ward i and μ_k^t represents membership value between s_k^t and s_i^t . The μ_k^t signifies how much the s_k^t has its influence on s_i^t by considering various parameters such as geological factors, educational institution, industries, transportation etc.

Rule 5		Actual census			GCA estimation from		
Ward No.	Ward Name	1991	2001	2011	1991	2001	2011
0014	Tondiarpet	27765	32090	35130	41057	46182	49532
0015	Sanjeevirayanpet	20874	21055	19952	33117	34112	33339
0016	Grace Garden	19832	22032	22947	30223	33359	34658
0017	Ma. Po. Si. Nagar	22445	24200	24670	33554	36899	38297
0018	Royapuram	15199	17250	16424	26020	28726	27961
0019	Singara Garden	16872	16807	15457	26620	27063	25551
0020	Narayanappa Naicken Garden	15451	15006	13276	25400	25109	22955
0021	Old Washermaenpet	17692	17510	16044	28349	27966	25757
0022	Meenakshi Ammanpet	25500	26481	26177	35172	36990	36979
0023	Kondi Thope	16770	18244	18434	26773	29576	30599
0024	Seven Wells (North)	16589	19438	21002	26580	30062	31646
0025	Amman Koil	18113	19329	19261	28436	30527	30753
0026	Muthialpet	20291	20907	20239	31807	33041	32408
0027	Vallal Seethakkadhi Nagar	25475	25593	24426	36364	37234	36224
0028	Katchaleeswarar Nagar	21341	24391	26156	30982	34762	36756
0029	Seven Wells (South)	16832	18766	19415	25563	28687	30047
0030	Sowcarpet	15905	21238	25286	24997	31017	35201
0031	Basin Bridge	22047	27742	32152	34779	42563	48646

Table 5. Census and Rule 5 GCA estimated populations for the zone 5 (Royapuram)



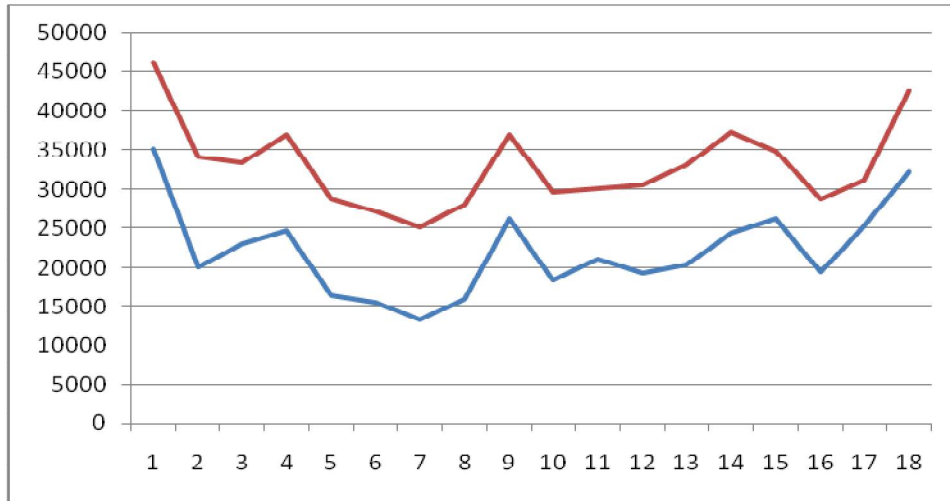
Graph 9. Census data 2001 (blue) and Rule 5 GCA estimated data from 1991 (red)

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Graph 10. Census data 2011 (blue) and Rule 5 GCA estimated data from 2001 (red)

RULE 6: The s_i^{t+1} the population for the ward i at the time $t + 1$, is given by

$$s_i^{t+1} = s_i^t + \frac{\sum_{k \in (N(i))} (\mu_k^t \times s_k^t)}{4 \times \sum_{k \in (N(i))} (\mu_k^t)}$$

where, s_k^t is the population for the ward k at the time t , $(N(i))$ represents the open neighborhood of ward i and μ_k^t represents membership value between s_k^t and s_i^t . The μ_k^t signifies how much the s_k^t has its influence on s_i^t by considering various parameters such as geological factors, educational institution, industries, transportation etc.

Rule 6		Actual census			GCA estimation from		
Ward No.	Ward Name	1991	2001	2011	1991	2001	2011
0014	Tondiarpet	27765	32090	35130	34411	39136	42331
0015	Sanjeevirayanpet	20874	21055	19952	26995	27583	26645
0016	Grace Garden	19832	22032	22947	25027	27695	28803
0017	Ma. Po. Si. Nagar	22445	24200	24670	28000	30549	31483
0018	Royapuram	15199	17250	16424	20610	22988	22192
0019	Singara Garden	16872	16807	15457	21746	21935	20504
0020	Narayanappa Naicken Garden	15451	15006	13276	20425	20057	18115
0021	Old Washermaenpet	17692	17510	16044	23021	22738	20901
0022	Meenakshi Ammanpet	25500	26481	26177	30336	31735	31578
0023	Kondi Thope	16770	18244	18434	21771	23910	24517
0024	Seven Wells (North)	16589	19438	21002	21584	24750	26324
0025	Amman Koil	18113	19329	19261	23274	24928	25007
0026	Muthialpet	20291	20907	20239	26049	26974	26324
0027	Vallal Seethakkadhi Nagar	25475	25593	24426	30920	31413	30325
0028	Katchaleeswarar Nagar	21341	24391	26156	26162	29576	31456
0029	Seven Wells (South)	16832	18766	19415	21197	23726	24731
0030	Sowcarpet	15905	21238	25286	20451	26127	30244
0031	Basin Bridge	22047	27742	32152	28413	35152	40399

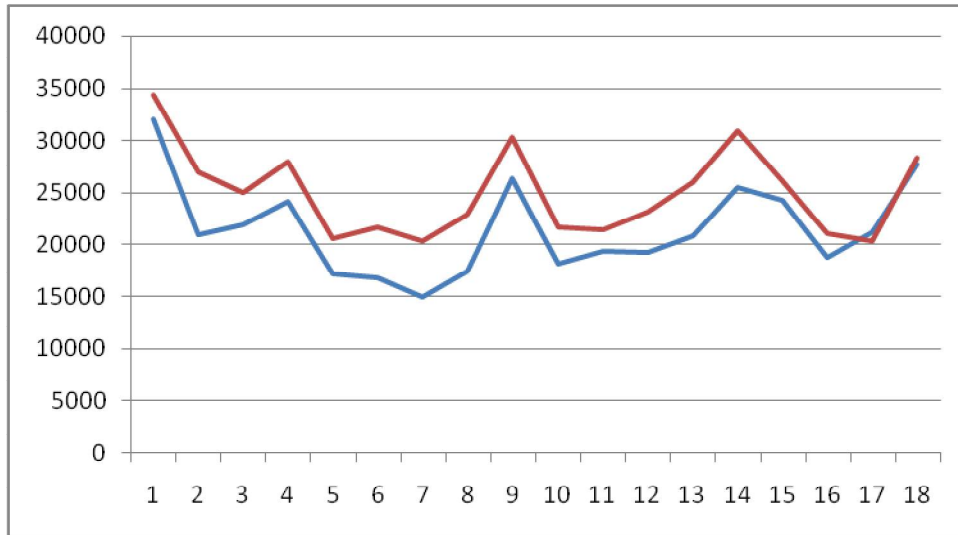
Table 6. Census and Rule 6 GCA estimated populations for the zone 5 (Royapuram)

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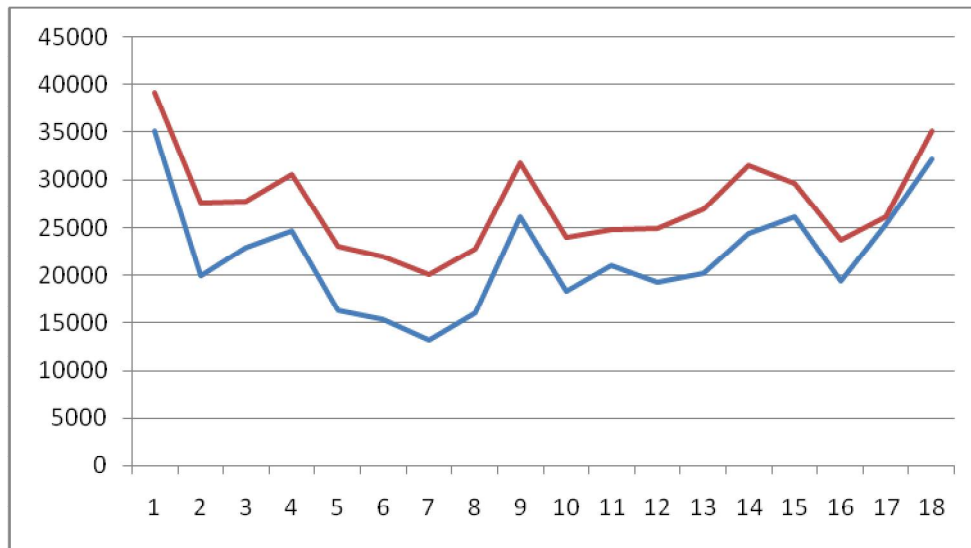
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Graph 11.Census data 2001 (blue) and Rule 6 GCA estimated data from 1991 (red)



Graph 12.Census data 2011 (blue) and Rule 6 GCA estimated data from 2001 (red)

V. TRANSITION RULES

From the above estimation it is observed that certain GCA rule attain more accuracy for certain wards. Considering all possible decadal comparison with all possible GCA rule, we the best GCA rule is assigned to the particular wards. The following table 7 illustrates the rule assignments. The Graph 13, 14 that the estimated data almost coincides with the actual census data.

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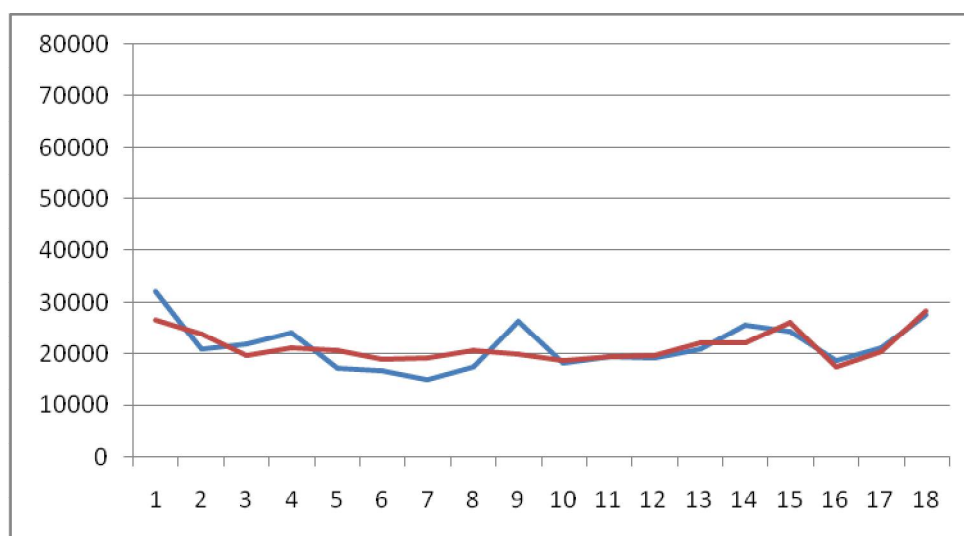
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Ward No.	Ward Name	Transition Rule No	Actual census			Best Estimation		
			1991	2001	2011	1991	2001	2011
0014	Tondiarpet	2	27765	32090	35130	26770	28853	29976
0015	Sanjeevirayanpet	2	20874	21055	19952	24019	25481	25958
0016	Grace Garden	1	19832	22032	22947	19777	21205	21122
0017	Ma. Po. Si. Nagar	1	22445	24200	24670	21310	23893	24793
0018	Royapuram	2	15199	17250	16424	20662	22031	22040
0019	Singara Garden	2	16872	16807	15457	19096	19971	19525
0020	NarayanappaNaicken Garden	2	15451	15006	13276	19293	19527	18610
0021	Old Washermaenpet	2	17692	17510	16044	20783	20408	18922
0022	MeenakshiAmmanpet	2	25500	26481	26177	20076	21645	22121
0023	KondiThope	1	16770	18244	18434	18791	21122	22169
0024	Seven Wells (North)	2	16589	19438	21002	19382	20905	21230
0025	Amman Koil	1	18113	19329	19261	19778	21552	22042
0026	Muthialpet	1	20291	20907	20239	22144	23340	23252
0027	VallalSeethakkadhi Nagar	1	25475	25593	24426	22289	23518	23463
0028	Katchaleeswarar Nagar	6	21341	24391	26156	26162	29576	31456
0029	Seven Wells (South)	2	16832	18766	19415	17373	19693	21010
0030	Sowcarpet	6	15905	21238	25286	20451	26127	30244
0031	Basin Bridge	6	22047	27742	32152	28413	35152	40399

Table 7. Census and Rule 6 GCA estimated populations for the zone 5 (Royapuram)



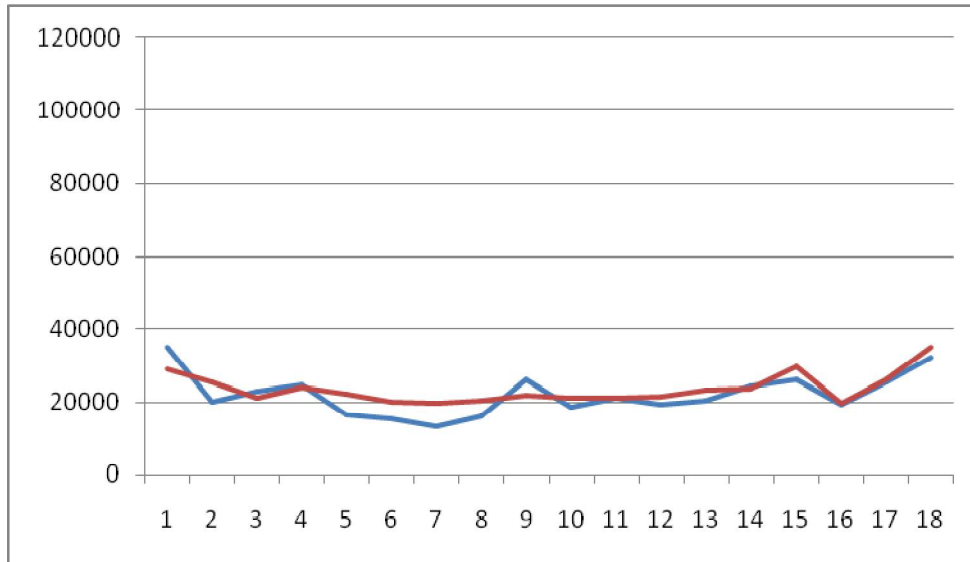
Graph 13. : Census data 2001 (blue) and assigned transition GCA rules estimated data from 1991 (red)

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Graph 14. Census data 2011 (blue) and assigned transition GCA rules estimated data from 2001 (red)

With respect to the assigned transition rule, the estimated data for few decades are obtained. With which the polynomials which describes the growth pattern is computed using the following function. The years were considered as x_i and the estimated population were considered its corresponding f_i .

$$f(x) = \frac{(x - x_2)(x - x_3)}{(x_1 - x_2)(x_1 - x_3)} f_1 + \frac{(x - x_1)(x - x_3)}{(x_2 - x_1)(x_2 - x_3)} f_2 + \frac{(x - x_1)(x - x_2)}{(x_3 - x_2)(x_3 - x_1)} f_3$$

The obtained growth polynomial for each of the wards from their respective transition GCA rules is given below:

0014	Tondiarpet	$-4.80x^2+19369.90x-19511112.10$
0015	Sanjeevirayanpet	$-4.93x^2+19806.80x-19888220.87$
0016	Grace Garden	$-7.80x^2+31404.40x-31581301.60$
0017	Ma. Po. Si. Nagar	$-8.08x^2+32490.30x-32650233.23$
0018	Royapuram	$-6.80x^2+27282.50x-27343044.70$
0019	Singara Garden	$-6.61x^2+26454.66x-26469377.06$
0020	NarayanappaNaicken Garden	$-5.76x^2+22997.36x-22955164.61$
0021	Old Washermaenpet	$-5.56x^2+22138.06x-22035624.51$
0022	MeenakshiAmmanpet	$-5.46x^2+21973.18x-22064822.72$
0023	KondiThope	$-5.10x^2+20589.64x-20777456.55$
0024	Seven Wells (North)	$-5.99x^2+24064.38x-24147953.39$
0025	Amman Koil	$-5.88x^2+23620.90x-23719977.03$
0026	Muthialpet	$-5.88x^2+23606.52x-23649434.64$
0027	VallalSeethakkadhi Nagar	$-5.90x^2+23669.10x-23714477.20$

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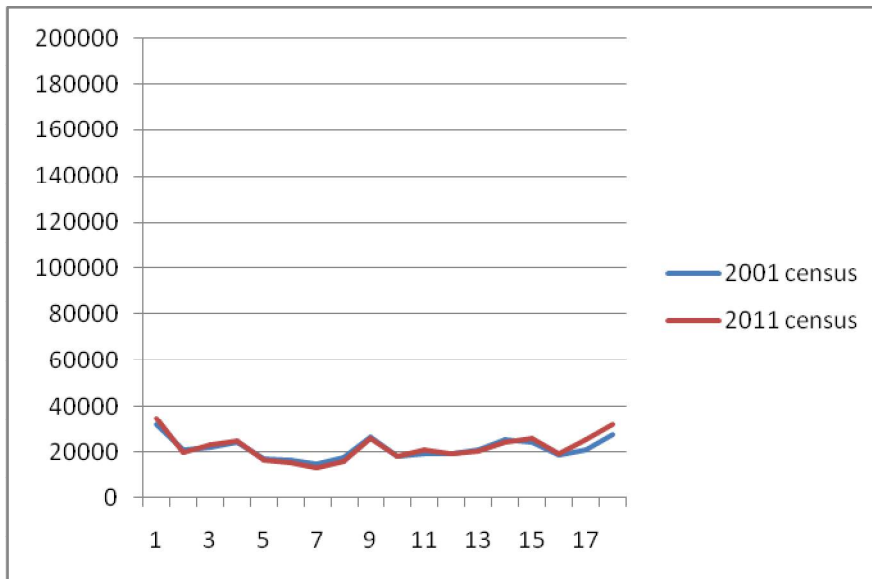
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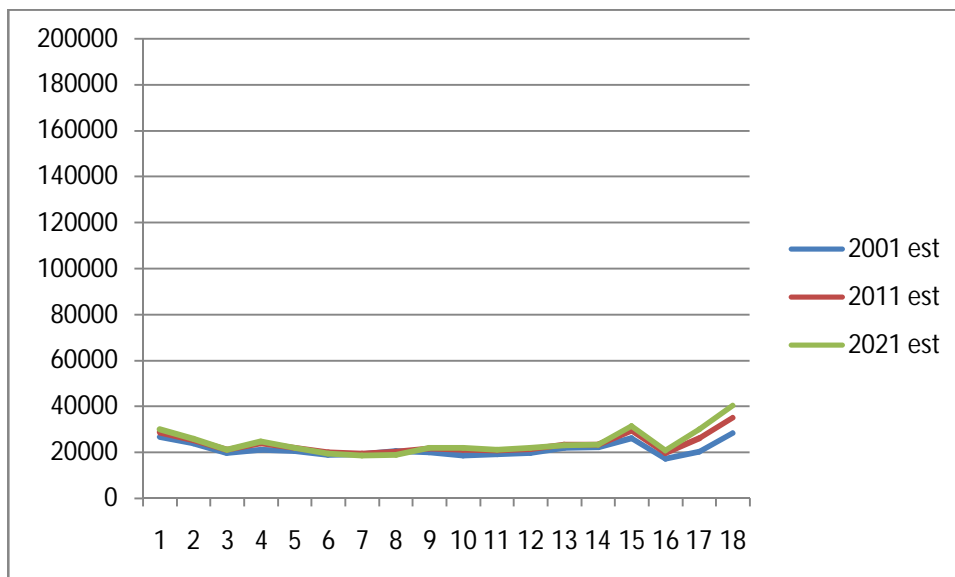
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0028	Katchaleeswarar Nagar	$-7.67x^2+30960.04x-31210776.37$
0029	Seven Wells (South)	$-5.02x^2+20251.88x-20424253.86$
0030	Sowcarpet	$-7.79x^2+31685.24x-32164850.44$
0031	Basin Bridge	$-7.46x^2+30454.22x-31033894.76$

Table 8.Population growth polynomial ward-wise for the zone 5 (Royapuram)



Graph 15.Census 2001 and 2011 for zone 5 (Royapuram)



Graph 16.Estimated data from GCA transition rules for zone 5 (Royapuram)

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Further, the increase in error for few wards which was observed during analysis were due to influence of various other factors such as, the wards lying on the peripheral of Chennai city, or influence of other factors such as industries, educational institution, transportation, etc

VI. CONCLUSION

It is found that the results obtained for Chennai populations using GCA and that of the actual census data coincides almost similar. The GCA modeling is more appropriate for investigation. Further Fuzzy GCA would be studied as future work. Also GCA for other causal attribute would be further analyzed.

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