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Rainwater Harvesting an Instrument to Improve Ground Water Quality and Quantitative Potential: The Case Study of Dwarka Sub-City, Delhi

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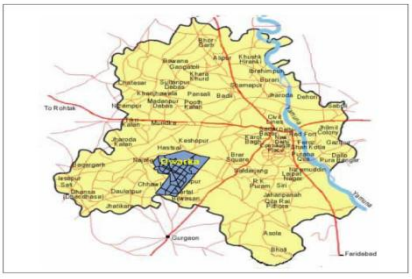
Abstract: *Dwarka scheme part of the Urban Extension of MPD–2001 of National Capital Territory of Delhi, has been planned to cater to the ever increasing housing requirements of Metropolitan Delhi. Dwarka Sub-City with a total geographical area of 5648 Ha is located in South-Western part of Delhi. The area is envisaged to become a model Sub-city of the 21st century and to house 13 lakhs people. The area is developing fast with more than 400 Group Housing Societies & 11000 DDA Residential Freehold Flats (in Four and Multistory Buildings), 3100 Residential Plots, housing colonies apart from commercial complexes, District centers, public places etc. The area with present population of 5 lakhs roughly is in severe grip of shortage of the supplied water, as it receives only Rs 2.8 MGD from the concerned water supply agency, against the requirement of 10 MGD. In view of this the balance water demand of its residents for domestic & non-domestic uses is mostly met from the Ground Water. The rampant extraction of Ground Water by Government & private authorities, has led to the depletion of fresh water layer and decline in the water table at very fast pace in last few years, raising questions about its future availability.*

This paper focuses on the methodology of Ground Water Restoration by way of recharging it with the rainwater, which otherwise goes water and leads to flooding / public havoc. The feasibility & need for implementation of Ground water Recharge Scheme in the area was established through the detailed study & analysis of the factors governing the Ground Water Discharge & Recharge in the area: such a Ground water Level behaviour, Ground water Quality, Rainwater quality, Rainfall Intensity & its distribution, Ground Water & Rainwater Potential, Aquifer Geometry & Characteristics and Ground Water requirement of the area. The Depth to Water level measured at different locations in the area was utilized to study the annual & Pre-Post Monsoon water level fluctuations. Thereafter the impact of Rainwater Harvesting on the Ground Water Quantitative Potential was established based on the mathematical calculations. The study established that the ground water restoration through artificial recharge technique would to some extent help in mitigating water crises in Dwarka Sub-City & other urban areas.

Key words: *Rain water harvesting, Ground water & rainfall potential, Rainfall Intensity, salinity, stage of ground water development, water level, land use pattern.*

I. Introduction

National Capital Territory of Delhi has experienced a explosive population growth in last few decades on account of natural population growth & massive in-migration of people from other parts of country. This has resulted into inevitable urbanization. Dwarka Sub-City located in South-West Delhi is part of the Urban Extension of MPD–2001 of National Capital Territory of Delhi and it has been planned to cater to the ever increasing housing requirements of Metropolitan Delhi. With a total area of 5648 Ha, Dwarka Sub-City is ultimately meant to house a population of about 1.3 million people. The area encompasses planned / regulated development (1- 29 sectors) and unplanned areas (Housing colonies, villages and Built-up Area), whereas the 1688 Ha is designated as built-up area and the balance 3960 Ha is under the planned / regulated development. Dwarka is developing fast with more than 400 Group Housing Societies & 11000 DDA Residential Freehold Flats (in Four and Multistory Buildings), 3100 Residential Plots, housing colonies apart from commercial complexes, District centers, public places etc in various sectors. For the present population of approximately 5 laks the present water demand of the area is 10 MGD and the water received by the area from the concerned water supply agency is approximately only 2.8 MGD thus, forcing its residents to depend to the maximum on Ground Water to fulfill their daily water demand for domestic & non domestic uses. As a result of which almost all the housing Societies, Private owners etc and some of the DDA colonies have installed tube wells/bore wells to meet their daily water requirement. The rampant extraction of Ground water



has not only resulted in decline in Water table at very fast pace in the area but also degradation in the quality of ground water, as the salinity in Ground Water increases with depth in the area.

II. Aim of the study:

The study aims to formulate the strategies to mitigate the water crisis in urban areas of India through Rainwater Harvesting technology and it lays emphasis on in-situ conservation of surplus monsoon runoff for future use i.e. Aquifer storage & Recovery technique. This besides augmenting the qualitative & quantitative potential of Ground Water would help in preventing soil erosion & flooding in urban areas. For the purpose of study Dwarka Sub-city has been taken for reference.

III. Methodology and Analysis:

The study primarily involved the in-depth study of the Land Use Master Plan of the area, Field Survey of the entire area & interaction with the residents, Consultants/Government agencies/NGO's involved in the field, so as to have a wider overview of the problem related to the scarcity of the water and Ground Water in the Sub-city. Thereafter the feasibility & need for implementation of Ground water Restoration / Recharge Scheme in the area was established through the detailed study & analysis of the factors affecting Ground Water Discharge & Recharge in the area such as total water requirement, Ground Water requirement, Ground Water Level behaviour, Ground Water Quality & its variation with depth, Rainwater quality, Rainfall Intensity & its distribution, Ground Water & Rainwater Potential, Aquifer Geometry & Characteristics and of the area.

The area is underlain by older alluvium and from the study of Tube-well strata charts (obtained from the secondary sources) and interpretation of the Geophysical survey results it was observed that a thick pile of alluvium is overlying the basement rock (located by and large at a depth of 300m b.g.l in the area) and it consists of alternate layer of silt, clay, sand and kankar. Nearly fine to medium Sand silt grade sediments occuring frequently up to the depth of 50 m along with clayey bed admixed with Coarse kankars. On the other hand after the depth of 50 m, silty–clay and clay beds with Kankars increases with depth. Beyond the depth of 100 m bgl although the clay beds are common but, the granular zones are not frequent . The presence of frequent clay beds with less frequent granular zone at deeper depth indicated non flushing conditions at deeper depth, resulting in higher concentration of Salinity with depth.

The study of the Ground Water quality & its variation with depth in Dwarka Sub-city was based on the Physico-Chemical characteristics determined for the Ground Water samples collected at widely spread 35 locations with sources varying in depth from 100 ft to 300 ft. The study indicated that the ground water in the area is generally moderately to high saline in nature with Electrical Conductivity more than the potable value of 1000 μS/cm and Total Dissolved Solids above the desirable limit of 500mg/l (although within the permissible limit of 2000mg/l) in almost entire area. It further showed that the Salinity in ground water increases with depth.

The Ground Water Level Behaviour in the area was analyzed by recording depth to Water level at 22 locations (widely spread in the area) during Pre-Monsoon period i.e. May, in the year 2007, 2008 & 2009 and during Post-Monsoon period i.e. Nov., in the year 2007 & 2008.

The observed water levels at different locations are indicated below:

Location/ Sector	Location Latitude /Longitude	G.L (m)	DTWL May 07 (mbgl)	R.L of water table (m)	DTWL Nov. 07 (mbgl)	R.L of water table (m)	DTWL May 08 (mbgl)	R.L of water table (m)	DTWL Nov. 08 (mbgl)	R.L of water table (m)	DTWL May 09 (mbgl)	R.L of water table (m)
1/1	28°35'43.61"N / 77°04'31.29"E	216	11.91	204.09	11.09	204.91	12.87	203.13	12.09	203.91	13.78	202.22
2/3	28°36'13.61"N / 77°02'25.06"E	220	9.41	210.59	9.37	210.63	10.14	209.86	9.94	210.06	10.54	209.46
3/5	28°35'45.81"N / 77°03'17.32"E	212	10.08	201.92	9.9	202.1	12.42	199.58	11.76	200.24	12.91	199.09
4/7	28°35'29.75"N / 77°04'23.97"E	216	10.99	205.01	10.56	205.44	11.58	204.42	11.36	204.64	11.75	204.25
5/8	28°34'31.73"N / 77°04'29.20"E	217	11.01	205.99	10.57	206.43	11.84	205.16	10.93	206.07	11.97	205.03
6/10	28°34'59.49"N / 77°03'23.80"E	218	9.83	208.17	9.77	208.23	10.97	207.03	10.41	207.59	11.3	206.7
7/12	28°35'47.58"N / 77°02'39.66"E	213	9.35	203.65	9.31	203.69	10.31	202.69	11.32	201.68	12.32	200.68
8/12	28°35'36"N / 77°02'28.47"E	212	9.02	202.98	9.9	202.1	10.84	201.16	10.78	201.22	11.95	200.05
9/13	28°36'03.8"N / 77°02'13.14"E	215	9.11	205.89	9.97	205.03	10.48	204.52	10.73	204.27	11.08	203.92
10/15	28°36'34.47"N / 77°01'18.03"E	215	8.98	206.02	9.11	205.89	9.27	205.73	9.91	205.09	10.01	204.99
11/16	28°36'23.26"N / 77°00'57.27"E	216	18.08	197.92	17.1	198.9	20.00	196.00	18.04	197.96	18.52	197.48
12/16	28°36'01.23"N / 77°01'05.53"E	213	13	200	12.11	200.89	12.65	200.35	12.97	200.03	13.22	199.78
13/17	28°35'27.18"N / 77°01'40.14"E	211	11.01	199.99	10.97	200.03	11.59	199.41	11.92	199.08	12.15	198.85
14/19	28°34'48.83"N / 77°02'53.14"E	214	8.83	205.17	8.71	205.29	8.97	205.03	8.43	205.57	9.19	204.81
15/20	28°34'15.26"N / 77°03'29.53"E	215	8.79	206.21	8.78	206.22	8.9	206.1	10.62	204.38	10.34	204.66
16/22	28°33'47.0"N / 77°03'19.49"E	217	9.94	207.06	9.91	207.09	10.37	206.63	10.18	206.82	10.87	206.13
17/23	28°33'32.58"N / 77°03'34.56"E	221	8.72	212.28	8.18	212.82	8.62	212.38	7.94	213.06	8.89	212.11
1823	28°33'07.31"N / 77°02'37.46"E	216	8.87	207.13	8.36	207.64	9.15	206.85	8.94	207.06	9.45	206.55

19/24	28°33'54.34"N / 77°02'04.59"E	209	8.18	200.82	8.07	200.93	8.71	200.29	8.01	200.99	9.31	199.69
20/26	28°32'48.83"N / 77°03'05.46"E	217	9.75	207.25	9.27	207.73	10.32	206.68	9.67	207.33	10.77	206.23
21/28	28°32'44.11"N / 77°01'25.19"E	212	8.83	203.17	8.09	203.91	8.99	203.01	8.75	203.25	9.19	202.81
22/Bin dapur	28°36'29.57"N / 77°03'46.44"E	214	11.97	202.03	11.18	202.82	12.97	201.03	11.88	202.12	13.99	200.01

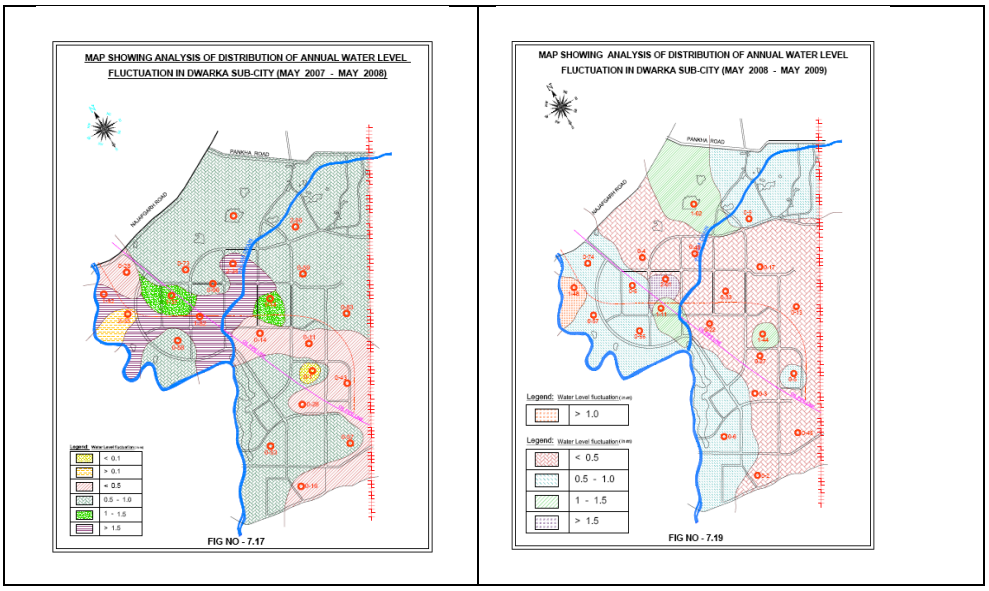
Where: G.L Ground Level , DTWL -Depth to Water level in meters below ground level, R.L of Water Table – Level above Mean Sea Level in meters

The recorded data was analyzed to obtain 'Annual & Pre-Post Monsoon water level fluctuation which are detailed below:

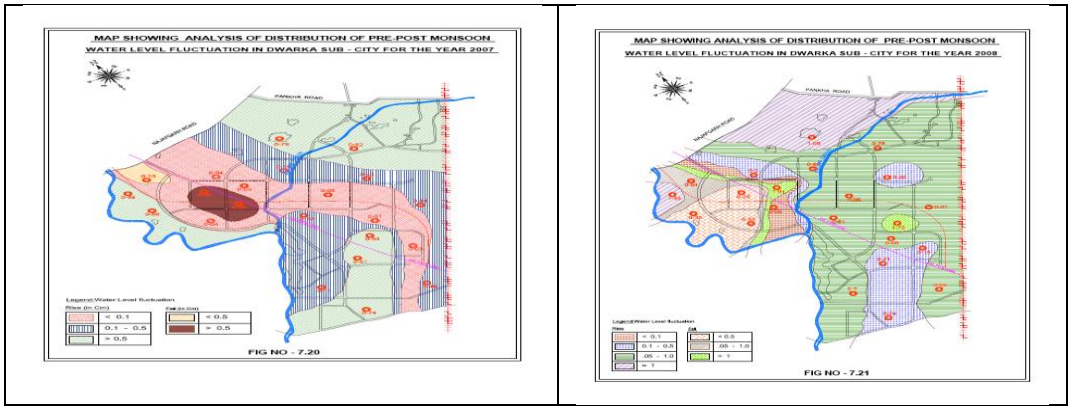
Sector	DTWL (May 07) (mbgl)	DTWL (Nov. 07) (mbgl)	WLF (Nov.07-May07)	DTWL (May 08) (mbgl)	DTWL (Nov. 08) (mbgl)	WLF (Nov.08-May08)	AWLF (Nov.08-07)	AWLF (May 08-07)	DTWL (May09) (mbgl)	AWLF (May09-08)
1	11.91	11.09	0.82	12.87	12.09	0.78	-1.00	-0.96	13.78	-0.91
3	9.41	9.37	0.04	10.14	9.94	0.2	-0.57	-0.73	10.54	-0.4
5	10.08	9.9	0.18	12.42	11.76	0.66	-1.86	-2.34	12.91	-0.49
7	10.99	10.56	0.43	11.58	11.36	0.22	-0.8	-0.59	11.75	-0.17
8	11.01	10.57	0.44	11.84	10.93	0.91	-0.36	-0.83	11.97	-0.13
10	9.83	9.77	0.06	10.97	10.41	0.56	-0.64	-1.14	11.3	-0.33
12	9.35	9.31	0.04	10.31	11.32	-1.01	-2.01	-0.96	12.32	-2.01
12	9.02	9.9	-0.88	10.84	10.78	0.06	-0.88	-1.82	11.95	-1.11
13	9.11	9.97	-0.86	10.48	10.73	-0.25	-0.76	-1.37	11.08	-0.6
15	8.98	9.11	-0.13	9.27	9.91	-0.64	-0.8	-0.29	10.01	-0.74
16	18.08	17.1	0.98	20	18.04	1.96	-0.94	-1.92	18.52	1.48
16	13	12.11	0.89	12.65	12.97	-0.32	-0.86	0.35	13.22	-0.57
17	11.01	10.97	0.04	11.59	11.92	-0.33	-0.95	-0.58	12.15	-0.56
19	8.83	8.71	0.12	8.97	8.43	0.54	0.28	-0.14	9.19	-0.22
20	8.79	8.78	0.01	8.9	10.62	-1.72	-1.84	-0.11	10.34	-1.44
22	9.94	9.91	0.03	10.37	10.18	0.19	-0.27	-0.43	10.87	-0.5
23	8.72	8.18	0.54	8.62	7.94	0.68	0.24	0.1	8.89	-0.27
23	8.87	8.36	0.51	9.15	8.94	0.21	-0.58	-0.28	9.45	-0.3
24	8.18	8.07	0.11	8.71	8.01	0.7	0.06	-0.53	9.31	-0.6
26	9.75	9.27	0.48	10.32	9.67	0.65	-0.4	-0.57	10.77	-0.45
28	8.83	8.09	0.74	8.99	8.75	0.24	-0.66	-0.16	9.19	-0.2
Bind.	11.97	11.18	0.79	12.97	11.88	1.09	-0.7	-1.00	13.99	-1.02

Where: DTWL - Depth to Water level in meters , mbgl - Meters below ground level, WLF - Water Level Fluctuation in meters, AWLF - Annual Water Level Fluctuation in meters, (-) - Minus sign indicates fall in water table

- Annual Ground Water level fluctuation during the period from May 2007 to May 2008 revealed that the Ground Water at 9.09 % locations showed rise in water table, while Ground Water at 90.91 % showed fall in water table. While the Annual Ground Water level fluctuation during the period from May 2008 to May 2009 indicated that only 4.45 % locations showed in rise in water table & 95.55% showed fall in water table presented below:



- Pre-Post Monsoon Ground Water Level Fluctuation for the year 2007 showed rise in Ground Water level in 86.36% locations & fall in Water table at 13.64 % locations. While, the Pre-Post Monsoon Ground Water Level Fluctuation for the year 2008 showed rise in Ground water level at 77.27 % locations & fall at 22.73 % locations presented below:



The study established the declining trend of Ground Water in Dwarka Sub-city further it also indicated that the areas where, the rate of natural recharge is not enough to compensate the Ground Water withdrawal rate are increasing with annual rate of decline by an large varying between 0.2 to 1m .

For the present Research, the 'Ground Water Potential was determined for each sector, by the 'Specific Yield Method' i.e. Using the formula:

Ground Water Potential (Gross Recharge) = Sector Area×W.L Fluctuation×Specific yield

Where: Area of each Sector was determined from the Interpretation of Satellite imagery & lay out Plans for sectors. Water level fluctuation (Pre-Post Monsoon) for the year 2008 was taken into account. The Recoverable Recharge was taken as 70% of the Gross Recharge.

The detailed sector-wise analysis of Ground Water Potential for Dwarka Sub-city is presented below:

Sector	**Area (Ha)**	**Water level fluctuation (m)**	**Specific Yield**	**Gross Recharge (Qgross) (m^3/year)**	**Recoverable Recharge (I = 70% of Qgross) (m^3/year))**
1	45.00	0.78	0.16	56160.00	39312.00
2	58.38	0.78	0.16	72858.24	51000.77
3	158.00	0.20	0.14	44240.00	30968.00
4	69.29	0.20	0.15	20787.00	14550.90
5	90.14	0.66	0.16	95187.84	66631.49
6	93.00	0.66	0.15	92070.00	64449.00
7	128.23	0.22	0.14	39494.84	27646.39
8	204.83	0.91	0.17	316872.01	221810.41
9	110.00	0.56	0.16	98560.00	68992.00
10	120.49	0.56	0.15	101211.60	70848.12
11	115.00	0.56	0.16	103040.00	72128.00
12	119.59	1.01	0.15	181178.85	126825.20
13	108.00	0.25	0.14	37800.00	26460.00
14	106.00	0.25	0.15	39750.00	27825.00
15	115.00	0.64	0.16	117760.00	82432.00
16	291.98	0.32	0.17	158837.12	111185.98
17	102.00	0.33	0.15	50490.00	35343.00
18	90.00	0.33	0.15	44550.00	31185.00
19	263.50	0.54	0.15	213435.00	149404.50
20	170.40	1.72	0.18	527558.40	369290.88
21	158.12	0.19	0.14	42059.92	29441.94
22	128.00	0.19	0.14	34048.00	23833.60
23	186.00	0.68	0.16	202368.00	141657.60
24	275.05	0.70	0.16	308056.00	215639.20
25	190.00	0.21	0.14	55860.00	39102.00
26	165.00	0.65	0.16	171600.00	120120.00
27	73.00	0.65	0.16	75920.00	53144.00
28	81.00	0.65	0.15	78975.00	55282.50
29	145.00	0.24	0.14	48720.00	34104.00
BUA	1688.00	1.09	0.17	3127864.00	2189504.80
Total =				**6557311.8**	**4590118.30**

BUA-Built-up Area

Since the whole infuse of the study is optimized recharging of ground water reservoir through Rainwater Harvesting system, for dilution of Salinity, hence it involved the detailed study & analysis of the Rainfall Pattern, its Quality and Rainfall potential. The rainfall pattern in the area was analyzed based on the rainfall data available from Indian Metrological Department, for a sufficiently long period. The distribution of rainfall in the area was found to be non-uniform in time & space, varying from year to year and mostly concentrated to the monsoon months from July to September. Based on the isohyetal Map of Delhi the annual rainfall in the area was observed to be 600 mm for the area **.**The rainwater samples collected during the monsoon month (July) in the year 2007 & 2008, indicated the variation of Rainwater pH from 6 to 6.5 (indicating its acidic nature) while TDS was found to be negligible.

Rainfall yearly Potential was determined for each sector considering the four factors of Rainwater Harvesting Scheme ie Roof Top Potential, Road Area Potential, Open area Potential and Total Rainwater Potential. The Rainwater Potential was determined using the formula: Rainfall Potential=A×C×I, where, A-Area of the catchment, C-runoff coefficient, I-average annual Rainfall. The runoff coefficients taken for each category of the catchment, for calculation of the Rainfall Potential is as per the prescribed values such as Roof Top-85%, Road Area-70% and Open Space/green area–30%. The Roof Top, Road Area and Open space areas for each sector were determined, on the basis of the study of the Layout Plans of the sectors and interpretation of satellite imagery. The Total rainwater potential is obtained by adding Roof Top Road Area and Open space potential. The detailed Sector-wise analysis of Rainwater Potential for Dwarka Sub-city is presented below:

Sector	Total Area (ha)	Art (ha)	Ard (ha)	Ao (ha)	Qrt (m^3/Year)	Qrd (m^3/Year)	Qo (m^3/Year)	Qrain (m^3/Year)
1	45.00	18.00	9.00	18.00	91800.00	37800.00	32400.00	162000.00
2	58.38	23.35	11.68	23.35	119095.20	49039.20	42033.60	210168.00
3	158.00	63.20	31.60	63.20	322320.00	132720.00	113760.00	568800.00
4	69.29	27.72	13.86	27.72	141351.60	58203.60	49888.80	249444.00
5	90.14	36.06	18.03	36.06	183885.60	75717.60	64900.80	324504.00
6	93.00	37.20	18.60	37.20	189720.00	78120.00	66960.00	334800.00
7	128.23	51.29	25.65	51.29	261589.20	107713.20	92325.60	461628.00
8	204.83	81.93	40.97	81.93	417853.20	172057.20	147477.60	737388.00
9	110.00	44.00	22.00	44.00	224400.00	92400.00	79200.00	396000.00
10	120.49	48.20	24.10	48.20	245799.60	101211.60	86752.80	433764.00
11	115.00	46.00	23.00	46.00	234600.00	96600.00	82800.00	414000.00
12	119.59	47.84	23.92	47.84	243963.60	100455.60	86104.80	430524.00
13	108.00	43.20	21.60	43.20	220320.00	90720.00	77760.00	388800.00
14	106.00	42.40	21.20	42.40	216240.00	89040.00	76320.00	381600.00
15	115.00	46.00	23.00	46.00	234600.00	96600.00	82800.00	414000.00
16	291.98	116.79	58.40	116.80	595639.20	245263.20	210225.60	1051128.00
17	102.00	40.80	20.40	40.80	208080.00	85680.00	73440.00	367200.00
18	90.00	36.00	18.00	36.00	183600.00	75600.00	64800.00	324000.00
19	263.50	105.40	52.70	105.40	537540.00	221340.00	189720.00	948600.00
20	170.40	17.04	17.04	136.32	86904.00	71568.00	245376.00	403848.00
21	158.12	47.44	79.06	31.62	241923.60	332052.00	56923.20	630898.80
22	128.00	51.20	25.60	51.20	261120.00	107520.00	92160.00	460800.00
23	186.00	74.40	37.20	74.40	379440.00	156240.00	133920.00	669600.00
24	275.05	82.52	55.01	137.53	420852.00	231042.00	247554.00	899448.00
25	190.00	57.00	76.00	57.00	290700.00	319200.00	102600.00	712500.00
26	165.00	66.00	66.00	33.00	336600.00	277200.00	59400.00	673200.00
27	73.00	29.20	14.60	29.20	148920.00	61320.00	52560.00	262800.00
28	81.00	32.40	16.20	32.40	165240.00	68040.00	58320.00	291600.00
29	145.00	58.00	29.00	58.00	295800.00	121800.00	104400.00	522000.00
BUA	1688.00	1012.80	337.60	337.60	5165280.00	1417920.00	607680.00	7190880.00
TOTAL	5648.00	2483..38	1231.02	1933.66	12665176.80	5170183.00	3480562.80	21315922.80

Art:-	Area of Roof Top	Ard:-	Road Area	Ao:-	Open Area
Qrt:-	Roof Top Rainwater Potential	Qrt:-	Road Area Rainwater Potential	Qo:-	Open Area Rainwater Potential
Qrain:-	Total Rainwater Potential				

The analysis of the Ground water Potential & Rainwater Potential of the area indicated that by and large the Roof Top & Road Area Rainwater Potential of the area is more than the Ground Water Potential. Thus the ideally suitable methodologies of Rainwater Harvesting for the area are Roof Top Rainwater Harvesting & Total Rainwater Harvesting However in the present study the impact assessment of Total Rainwater harvesting on annual decline rate in Ground Water level & on Ground Water Potential has been determined based on the mathematical calculations.

The Impact Assessment study of Total Rainwater harvesting on annual decline in Ground Water level is based on the following assumptions:

- Annual Water Level fluctuation for the period May 2009-2008 have been considered for calculations and the areas for which the Annual Water Level fluctuation was not available , the data of surrounding area was taken into account for calculations .
- The impact study has been undertaken considering Total Rainwater Harvesting Potential for each Sector with 30% loss.
- Ground Water requirement in m^3/year for each sector of Dwarka Sub-City (Built-up Area considered as Sector 30) are based on planned population as per zonal Plan of DDA. However, the same has been has been calculated on the following basis**:**

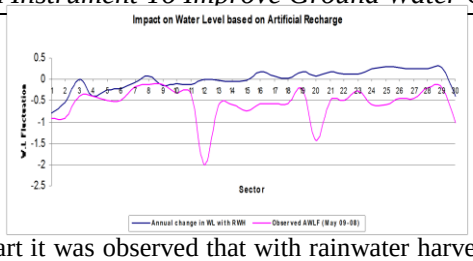
- For the purpose of calculation of the water requirement of the Dwarka Sub-city, the Per Capita Demand' has been taken as 225 LPCD
- % Occupancy in Sectors 1-15 taken as 40 %, for Sectors 16-19 taken as 30 % and for Sectors 20 – 29 taken as 20% and for Built-up Area as 70 %.
- It is assumed that Ground water is required for meeting the water demand for 50 % population of the area

• Nuclear Research Laboratory, IARI has estimated that direct Ground Water Recharge from rainfall infiltration has wide range of spatial and temporal variation, with most parts receiving less than 8 % recharge from rainfall. But on an average only 10 % of the Annual Rainfall is considered as Potential Recharge without any artificial effort Hence, in the present study, It has been assumed that in the absence of artificial recharge efforts, the Natural Recharge to Ground Water would be = Annual rainfall × Area of Sector × 10 %

Total recharge to Ground Water = Recharge through natural process + Recharge through artificial efforts. Based on the above assumptions the annual decline obtained after rainwater harvesting with artificial efforts is presented below in the table & the line Chart.

IV. Impact Assessment Of Rainwater Harvesting On Ground Water Level Based On Total Rainwater Potential

Sect.	Qrain	GW Recharge Artificially	GW Recharge Naturally	Total Recharge	GW Withdrawal	Annual deficit with RWH	Annual change in WL with RWH	Observed AWLF May 09-08
1	162000	113400	27000	140400.00	492750	-352350.00	-0.78	-0.91
2	210168	147117.6	35028	182145.60	492750	-310604.40	-0.53	-0.91
3	568800	398160	94800	492960.00	492750	210.00	0.00	-0.4
4	249452.4	174616.68	41574	216190.68	492750	-276559.32	-0.40	-0.4
5	324504	227152.8	54084	281236.80	492750	-211513.20	-0.23	-0.49
6	334800	234360	55800	290160.00	492750	-202590.00	-0.22	-0.49
7	461628	323139.6	76938	400077.60	492750	-92672.40	-0.07	-0.17
8	737388	516171.6	122898	639069.60	492750	146319.60	0.07	-0.13
9	396000	277200	66000	343200.00	492750	-149550.00	-0.14	-0.13
10	433764.4	303635.08	72294	375929.08	492750	-116820.92	-0.10	-0.33
11	414000	289800	69000	358800.00	492750	-133950.00	-0.12	-0.33
12	430524	301366.8	71754	373120.80	369562.5	3558.30	0.00	-2.01
13	388800	272160	64800	336960.00	369562.5	-32602.50	-0.03	-0.6
14	381600	267120	63600	330720.00	369562.5	-38842.50	-0.04	-0.6
15	414000	289800	69000	358800.00	369562.5	-10762.50	-0.01	-0.74
16	1051128	735789.6	175188	910977.60	369562.5	541415.10	0.19	-0.57
17	367200	257040	61200	318240.00	246375	71865.00	0.07	-0.57
18	324000	226800	54000	280800.00	246375	34425.00	0.04	-0.57
19	948600	664020	158100	822120.00	349031.25	473088.75	0.18	-0.22
20	403848	282693.6	102240	384933.60	246375	138558.60	0.08	-1.44
21	630898.8	441629.16	94872	536501.16	246375	290126.16	0.18	-0.5
22	460800	322560	76800	399360.00	246375	152985.00	0.12	-0.5
23	669600	468720	111600	580320.00	349031.25	231288.75	0.12	-0.27
24	899448	629613.6	165030	794643.60	102656.25	691987.35	0.25	-0.6
25	712500	498750	114000	612750.00	41062.5	571687.50	0.30	-0.6
26	673200	471240	99000	570240.00	102656.25	467583.75	0.28	-0.45
27	262800	183960	43800	227760.00	41062.5	186697.50	0.26	-0.45
28	291600	204120	48600	252720.00	41062.5	211657.50	0.26	-0.2
29	522000	365400	87000	452400.00	41062.5	411337.50	0.28	-0.2
30	7190880	5033616	1012800	6046416.00	12811500	-	-0.40	-1.02



From the above Chart it was observed that with rainwater harvesting the annual decline in water table can be brought down considerably.

The Impact Assessment study of Total Rainwater harvesting on increase in Ground Water Potential is based on the following assumptions:

- It is assumed that the evapo-transpiration losses or any other losses are negligible in nature. Hence Ground Water development is calculated considering that all the Rainfall runoff generated is used to recharge the Ground Water reservoir.

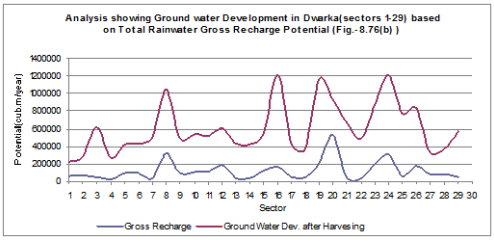
The Ground Water Development after Harvesting was obtained by adding the Rainwater Potential to Gross Recharge / Recoverable Recharge. Based on the above assumptions the % increase in Gross or Recoverable Recharge obtained is presented in the Table & Chart below:

IMPACT ASSESSMENT OF RAINWATER HARVESTING GROSS RECHARGE & RECOVERABLE RECHARGE POTENTIAL BASED ON TOTAL RAINWATER POTENTIAL

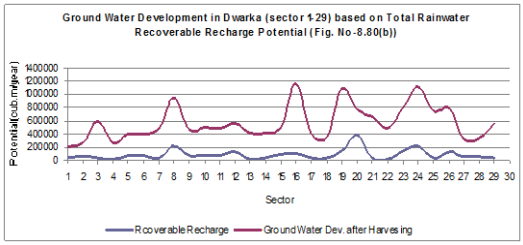
Sect.	Qrain	Q_{Gross}	G.W.D based on Gross Recharge	% inc. in Q_{Grossv}	Q_{Recv}	G.W.D based on Recoverable Recharge	% inc. in Q_{Recv}
1	162000	56160	218160.00	288.46	39312	201312.00	412.09
2	210168.00	72858.24	283026.24	288.46	51000.768	261168.77	412.09
3	568800.00	44240	613040.00	1285.71	30968	599768.00	1836.73
4	249452.40	20787	270239.40	1200.04	14550.9	264003.30	1714.34
5	324504.00	95187.84	419691.84	340.91	66631.488	391135.49	487.01
6	334800.00	92070	426870.00	363.64	64449	399249.00	519.48
7	461628.00	39494.84	501122.84	1168.83	27646.388	489274.39	1669.76
8	737388.00	316872.01	1054260.01	232.71	221810.41	959198.41	332.44
9	396000.00	98560	494560.00	401.79	68992	464992.00	573.98
10	433764.40	101211.6	534976.00	428.57	70848.12	504612.52	612.25
11	414000.00	103040	517040.00	401.79	72128	486128.00	573.98
12	430524.00	181178.85	611702.85	237.62	126825.19	557349.20	339.46
13	388800.00	37800	426600.00	1028.57	26460	415260.00	1469.39
14	381600.00	39750	421350.00	960.00	27825	409425.00	1371.43
15	414000.00	117760	531760.00	351.56	82432	496432.00	502.23
16	1051128.0	158837.12	1209965.12	661.76	111185.98	1162313.98	945.38
17	367200.00	50490	417690.00	727.27	35343	402543.00	1038.96
18	324000.00	44550	368550.00	727.27	31185	355185.00	1038.96
19	948600.00	213435	1162035.00	444.44	149404.5	1098004.50	634.92
20	403848.00	527558.4	931406.40	76.55	369290.88	773138.88	109.36
21	630898.80	42059.92	672958.72	1500.00	29441.944	660340.74	2142.86
22	460800.00	34048	494848.00	1353.38	23833.6	484633.60	1933.40
23	669600.00	202368	871968.00	330.88	141657.6	811257.60	472.69
24	899448.00	308056	1207504.00	291.98	215639.2	1115087.20	417.11
25	712500.00	55860	768360.00	1275.51	39102	751602.00	1822.16
26	673200.00	171600	844800.00	392.31	120120	793320.00	560.44
27	262800.00	75920	338720.00	346.15	53144	315944.00	494.51
28	291600.00	78975	370575.00	369.23	55282.5	346882.50	527.47
29	522000.00	48720	570720.00	1071.43	34104	556104.00	1530.61
BUA	7190880.0	3127864	10318744.00	229.90	2189504.8	9380384.80	328.42

The impact on Ground Water potential:

- Analysis of 'Ground Water Development' based on Total Rainwater Gross Recharge Potential is presented in Figures below, It is observed that post Harvesting the % increase in Gross Recharge varies from 76 to 1500% .



- Analysis of 'Ground Water Development' based on Total Rainwater Recoverable Recharge Potential is presented in Figures below, It is observed that post Harvesting the % increase in Gross Recharge varies from 1094 % to 2142.86 %.



From the above Charts it was established that post rainwater harvesting, there is considerable increase in the quantative potential of the Ground Water .

V. Conclusion:

The Dwarka scheme part of the Urban Extension of MPD-2001, has a critical role in Delhi's future development. Today Dwarka-Sub-city may boost of its massive structures, but the fact is that the Sub-city still remains parched. Each day more and more people are making Dwarka Sub-City as their home, as a result of which the Piped water supplied to the Sub-City does not match the demand of its current population thus, forcing its residents to depend to the maximum on Ground Water for meeting their domestic and non –domestic water demand . Besides this, the rainfall in the area is concentrated mostly to few monsoon months and rapid urbanization / increase in paved & semi-paved areas in Dwarka Sub-city has resulted in very little space as open green areas / unpaved areas for permitting natural recharge to ground water reservoir. The unsustainable Ground water extraction in the area has resulted in decline in water table at alarming rate in last few years and depletion of the fresh water layer. Hence, the provision of potable water to Dwarka Sub-City will be a real challenge in the coming years. To make the water supply system sustainable it is utmost important that the most precious gift of nature i.e. rainwater is harnessed for its beneficial use in most rational manner, by resorting to Rainwater Harvesting. There is need to dovetail the ground water extraction with the ground water recharge in a sustainable manner. The Government has made mandatory requirement for adoption of Rain Water Harvesting System for a Plot area of 100 sqm and above. The Central Ground Water Board (CGWB) also gives emphasis to Roof Top Rain Water Harvesting only . However, this is very small quantity as compared to the withdrawal rate. Hence, this study recommends the adoption of Total rainwater harvesting technique and from present study it has been established that implementation of the Rainwater Harvesting techniques in Urban area is a very attractive and technically feasible technique for Ground water restoration in Urban areas .

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