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Integrated Rainwater Drainage System for Groundwater Improvement and Economic Benefit

Manisha D. Desai* and Jayantilal N. Patel

Department of Civil Engineering, Sardar Vallabhbhai National Institute of Technology, Surat, India

ABSTRACT

Groundwater is a precious resource, both for yield and quality. This paper demonstrates the imaginative, progressive and innovative approaches of simulated renovations giving substantial advantages to the general public. Utilising groundwater to stimulate wells, in conjunction with a rainwater conservation framework, is proposed in this review. The unique plan and cost correlations as well as groundwater quality change are examined for the procedures of the tempest water seepage framework with and without reviving wells. The region chosen for study is Bhimrad, a new urban centre in Surat City in Gujarat State, India. Two rainwater structures are considered: (1) a traditional rainwater water drainage system excluding groundwater revive wells, and (2) a rainwater drainage system including groundwater revive wells. This paper shows that due to determination of the optimal diameter of revive wells, cost saving in the modified system is possible, along with improvement in groundwater contamination. The use of a modified rainwater drainage system would economically benefit the SMC (Surat Municipal Corporation) by conserving 25.43% of their reserve funds.

Keywords: Economic benefit, groundwater contamination, optimal diameter, rainwater conservation

INTRODUCTION

The establishment and design of common assets are a fundamental part of managing the economy for the success of human life (Schirmer, 2013). As indicated by Kellagher (2008), the 21st century has a new way of dealing with configuring rainwater seepage, utilising maintainability pointers to demonstrate and to gauge framework execution instead of outline criteria to meet a base level of administration. In previous research, the majority of software and models were developed based on basic rainfall-runoff relationship. Many urban runoff models have been developed and verified. Research today focusses on sustainable development

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E-mail addresses:
mpvashi@gmail.com (Manisha D. Desai)
jnp@ced.svnit.ac.in (Jayantilal N. Patel)
*Corresponding Author

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of rainwater management approaches to reduce the damage caused by impervious cover and to maximise the infiltration rate by using techniques like LID, BMP and WSUS.

Following this concept, research and surveys were conducted for sustainable planning of rainwater drainage systems in the selected research area, Bhimrad in Surat, India, and a plan was proposed for the new urban area. A novel integrated approach rainwater drainage system conjunction with groundwater recharge wells is used in the present research.

The objectives of this research are:

(1) To study a traditional rainwater drainage system that does not use a revive well;
(2) To modify planning of a rainwater drainage system that uses a revive well;
(3) To provide an economic solution for the rainwater drainage system of Bhimrad, and;
(4) To present a quality prediction system for groundwater in the future using an artificial revive well.

METHODOLOGY

Study Sites

Surat City, settled on the banks of the Tapi Basin near the estuary of the Arabian Sea, is the eighth greatest city of India and is a leading business centre, considering its valuable diamond and textile endeavours. The drainage systems established in Surat City were notably poor in the past, and during the months of heavy rain, various areas in Surat City experienced transient flooding and blockage of rainwater. Precipitation from June to October is dynamic, with a typical reading of 1143 mm. Surat City experienced uncontrollable floods in 1998, 2006 and late 2013. A modified rainwater drainage system should be provided in order to reduce water logging and flooding issues. Also, revived groundwater would meet the future requirements of new urban areas that are developed in Surat City. This paper reviews the issues relevant to this topic and provides choices derived from research for methods to update living conditions for the general public located in urban zones such as Bhimrad. It also provides configurations to decrease the level of the water table to enhance groundwater contamination at a lower cost.

Method of Designing a Traditional Rainwater Drainage System Using GIS

Firstly, a traditional rainwater system was designed as part of this study, with medium flow and maximum discharge of each watershed. These were determined using rational methods. The hydrological response was significantly influenced by land cover and the changes in land cover due to time affected floods were assessed (Nutchanart, 2011). It is important to decide the correct rate for impenetrable surfaces and land when utilising cover mapping in ARC GIS (Boulos, 2005). This decision is based on several GIS applications that incorporate technologies to utilise effective management for urban rainwater collection systems (Bryant, 2000). On that premise, the catchment zone of every drainage and pipe system was outlined in light of superimposing the current shape of the review zone in ARC GIS and DEM (Digital Elevation Model) by utilising the hydrology application in GIS, which naturally creates stream lines, and the introduction of the channels and catchment regions of each proposed depletion was surveyed for adequacy. For the engineering design of various components, this traditional rainwater drainage system was prepared (CPHEEO, 2013). The peak streams can be utilised using Manning's formula to acquire the measurements for each depletion section (Harpalani, 2013). This is an iterative procedure to guarantee deplete measurements, and subsequently, it can withstand the peak overflow computed.

As the surface of drains deteriorates with the passage of time, a roughness coefficient was measured for the design period, assuming reasonable conditions in drains. The roughness coefficient `n' was believed to be similar for every channel and was given a value of 0.013 for the outline.

Method of Designing a Rainwater Drainage System Combined with a Revive Well

A sustainable rainwater drainage system combined with groundwater revive wells was proposed and discussed by Nolan (2006), including factors influencing groundwater recharging. Rainwater drainage system designs are based on engineering analysis, which takes into consideration artificial groundwater revive, runoff rates, pipe-flow capacity, hydraulic grade lines and discussions about experimental investigations for particle breakage using natural sand (Hattamleh, 2013). Following this, dirt attributes (penetrability) are completed with molecule estimate dissemination, with the assistance of a hydrometer test (Carrier III, 2003). The century-old Hazen formula was used to gauge permeability on the basis of soil particle size (D_{10}). Hydrogeological and geophysical parameters for more profound groundwater assets were recorded with the assistance of the electric resistivity technique in the examination zone (D. R. Kumar, 2012). Soil parameters were established by determining the steady-state infiltration rate using a single-ring infiltrometer and double-ring infiltrometer (Neris, 2012). Outlining of the casing pipes, which drive water into the aquifer, is a critical component of the bore well. Its distance across is kept shorter than the width of the bore well to suit gravel pressing in the annular space between the casing pipe and the bore well.

The drag of the revive well is made 5 cm bigger than that of the energise pipe, facilitating the lowering of the pipe. Thus, for a casing of size 20 cm, a minimum bore of 25 cm is necessary. The measure of the gravel pack should be a thickness twice that of the traverse of the gravel. The size of a tube well drilled with a reverse rotary gear should be about 30 cm in diameter. On the screen, the section is 20 cm; therefore, the thickness of the gravel pack will be 5 cm up to the base of the pipe. The design of the well screen is the most fundamental piece of the revive well. Small or no enhancement in well efficiency results in open areas greater than 25%, whereas efficiency falls rapidly as the open area decreases to 10%. Hence, it may be concluded that other than slotted pipes it is desirable to provide an open area of about 20% for well screens (Athens, 1970).

The separation crosswise should ensure that the extent of the opening is available on the screen for a stream of water. Entrance velocity of the screen should not be more than 3 m/sec to prevent clogging of the screen. In areas where adequate sand thickness is not available, a minimum velocity of 5 cm/sec is permitted. On the off-chance that an event of the homogeneous water table aquifer emerges, the last one third of the aquifer is screened. In the case of the homogeneous artesian aquifer, 75-90% of the thickness of the water-bearing sand ought to be utilised for screening. For an aquifer thickness of less than 8 m, a screening of 75% is satisfactory. No less than 30 cm of aquifer profundity at the top and base of the screen ought to be left unscreened to protect against a mistake if there should be an occurrence of the arrangement of the revive well screen amid the establishment of the opening. To prevent clogging, the minimum length of the well screen for a non-gravel pack well is determined by:

$$H = \frac{Q_O}{A_O V_e} \qquad [1]$$

In the above equation, 'H' is the minimum length of well screen in metres, 'Q_o' is the maximum expected discharge capacity of well screen in m^3/min, 'A_o' is taken as the effective open area per metre length of the well screen, m^2, and 'V_e' is the entrance velocity at the screen, m/min.

This equation is used to compute the length of the screen in a gravel pack. The normal estimation of the permeability of the aquifer and the gravel pack is utilised to decide the passageway speed of the screen. The length of the screen provided on a revive well depends on the thickness of the aquifer available. When the permissible value of entrance velocities is greater than the result of excessive recharging, the well is a failure due to the design of the revive well screen (Walton, 1970). A design of a well screen chamber is provided to check the fine soil particles moving in the rainwater flowing into the drain. The water, after screening, is allowed to enter the revive well pipe (Kamra, 2012). In the sand-based rainwater filtration system for groundwater revive wells, the screen chamber includes different layers of sand, gravel and brickbats to remove suspended impurities from the rainwater (S. K. Kumar, 2012).

Cost Analysis

The procedure has been discussed above; correlations of the cost appraisals are now made, in light of the necessity for a new urban range in Surat City as T. P. - 42 and 43 – Bhimrad. The quantity of material was calculated and the SOR (Schedule of Rate) of (GWSSB-SOR, 2014-2015) was used.

Method for Groundwater Quality Analysis

For water quality index, groundwater quality parameters were analysed (Dohare, 2014). Groundwater samples were collected from seven locations in the study area during the pre-monsoon and the post-monsoon period of 2015. The collected samples were tested in the laboratory and analysed for concentration of different parameters in water quality for drinking purposes. To acquire data from previous years, different interpolation techniques of GIS were used, as suggested by Garnero (2013). The method includes information about artificial revive wells followed by quantifying the change in chemical composition of groundwater for the study area (Sharma, 2008). In conjunction with improving the groundwater quality with an artificial revive well, it is very much necessary to analyse the behaviour of the aquifer during this recharging process (Sharma, 2011). Future prediction of groundwater quality was determined using GIS software along with a dilution equation, as follows:

$$C_3 = \frac{C_1V_1 + C_2V_2}{V_1 + V_2} \quad [2]$$

where, C_3 is the changed concentration of a particular groundwater quality parameter in a water sample after artificial recharging and V_1 is the quantity of water available in the well. This amount of water is added to the well through artificial revive, and C_2 is the grouping of fresh water (rainwater) parameters. An ERDAS Model was prepared in GIS software to determine groundwater quality dilution from 2015-2050. Future prediction of groundwater quality was made from 2015 to 2050 and change in groundwater quality assessed to arrive at the Groundwater Quality Index (GWQI) using GIS (Gorai, 2013). This Groundwater Quality Index can be computed using the ERDAS Modeller in GIS, as it is a powerful tool for modelling water quality.

RESULTS AND DISCUSSION

Traditional Rainwater Drainage System

To compute impervious surface area with the help of land use and land cover mapping in GIS. To make impenetrable land cover, a Google map of the review territory (Bhimrad) was accessed through ArcMap's implicit base guidework. The streets, structures, waterways, springs, water bodies and other existing areas utilised were found by digitising the Google map. A land use impact boundary shape file was created for the study area, shown in Figure 1.

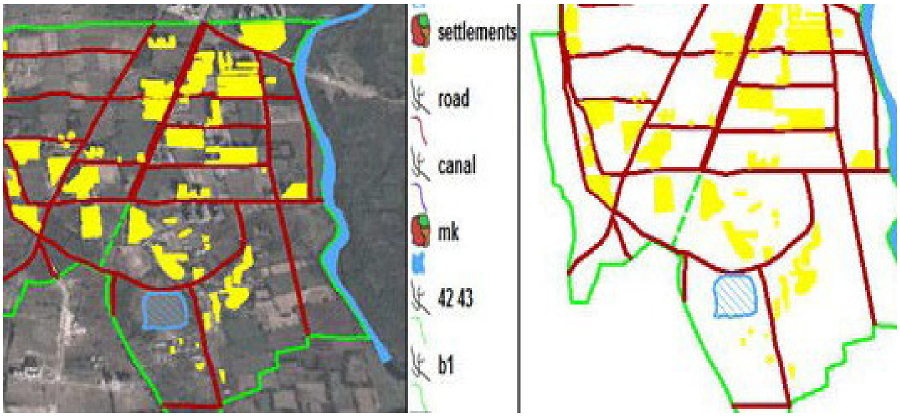


Figure 1. Digitising shape file of impervious land cover

Rainwater drainage network in GIS. Catchments and pipe networks were delineated based on their flow direction, flow accumulation, stream link, conditional stream, stream order and stream shape, as shown in the figure below, and are all derived from a digital elevation model in Arc GIS as per Figure 2. Since rainwater runoff from inverse sides of a stream can encounter diverse conditions, catchments were additionally subdivided by the seepage organise layer, enabling arrival on each side to be analysed independently in reasonable investigations. Detailed drawings of rainwater drainage networks with catchments are shown in Figure 3. Flow direction is based on a digital elevation model Figure 2 with stream locations imposed on it.

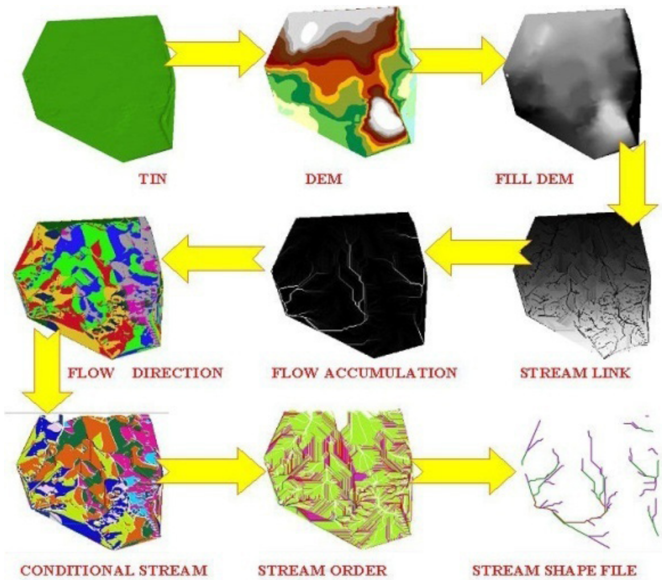


Figure 2. DEM and hydrology application results in ArcGIS

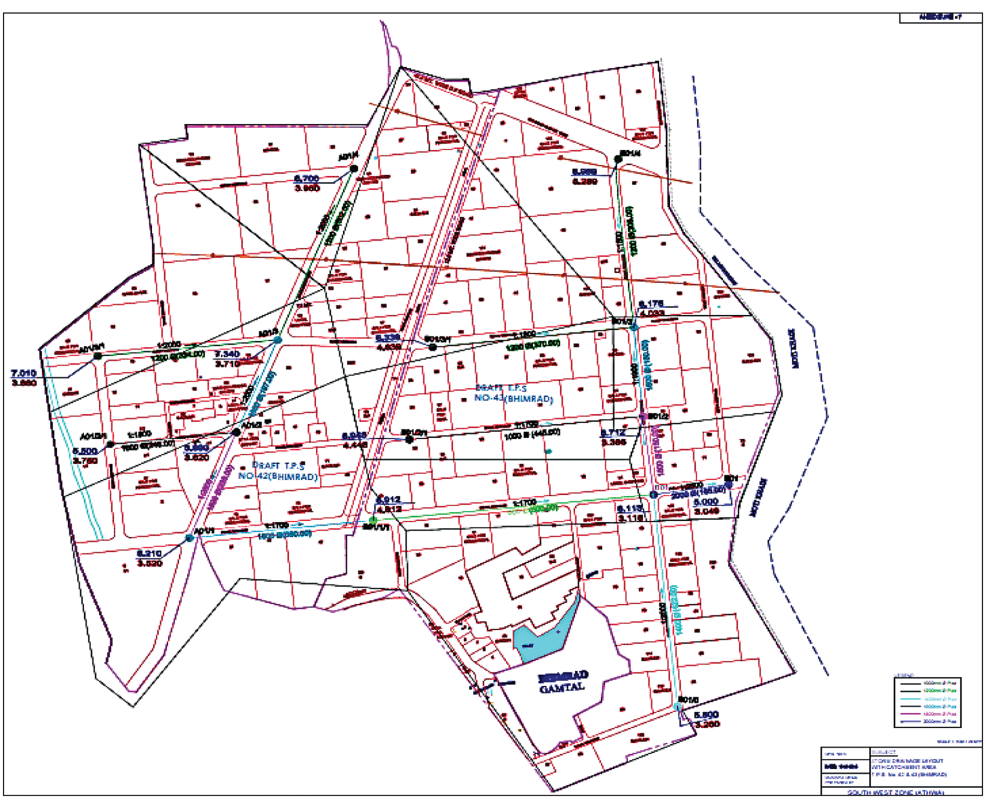


Figure 3(a). Storm water drainage network with detail

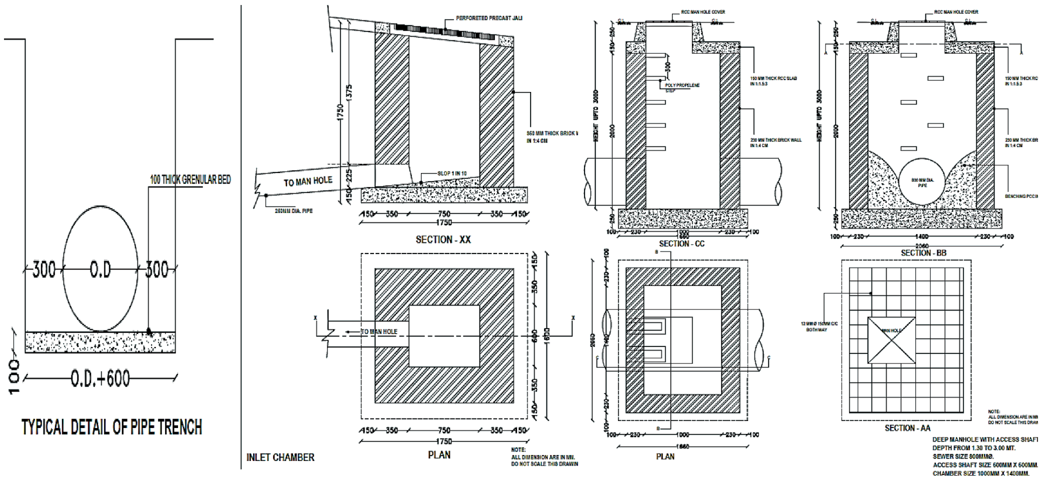


Figure 3(b). Structural details of Storm water drainage system

Engineering design of traditional rainwater drainage system. The layout of the storm drainage system is formulated in such a way that a maximum area can be drained out. The proposed drains are generally laid along roads, as marked on the town-planning scheme of this area (Basu, 2012). To facilitate the inlet chamber connection, the drains are provided with the minimum initial depth, depending on the site conditions. The diameter of the drains varies from 800 mm to 2000 mm. Thereafter, RCC double ducts of 2.2 m X 1.2 m to 3.5 m X 1.2 m sizes are proposed, shown in Figure 3(a) and Figure 3(b). The depth of drains at the outfall is kept above R.L. 3.0 m to minimise back flooding from the creek into the drain, based on studies estimating flooding and its control by section modification in Mithi Creek at Surat (Jariwala, 2012). The design of the traditional rainwater drainage system is given in Table 1.

Table 1

Design of conventional storm drainage system for TP-42 & 43 – Bhimrad, Surat, India

Section					Estimated Time of Concentration (t_c)			Average Rainfall Intensity from Graph (I_c)	Runoff Coefficient from Graph (C)	Actual Runoff (q)	Profile Shape & Size		Slope of Drain	Flow Full (Q) = A.V	Full Flow Velocity (v)
U/S Side	D/S Side	Cum. Length of Drain Section	Total Increment	Eq. 100% Imp. Area	Time of Inlet (t_i)	Time of Flow (t_f)	(t_c)				Pipe Dia Provided	No of Pipes			
		(mt)	hectare	hectare	(minutes)	(minutes)	(minutes)	(mm/hr)		(m^3/s)	mm		1 in L	(m^3/s)	m/s
AO1/4	AO1/3	502	98381	60996	0.00	9.301	9.301	99	0.473	0.80	1000	1	1400	0.76	0.96
AO1/3/1	AO1/3	335	120677	74820	0.00	6.198	6.198	119	0.315	0.78	1200	1	2000	1.03	0.91
AO1/3	AO1/2	699	219058	135816	9.30	12.942	22.243	66	0.599	1.50	1200	1	1400	1.23	1.09
AO1/2/1	AO1/2	245	99817	61886	0.00	4.542	4.542	143	0.210	0.52	1000	1	1700	0.69	0.88
AO1/2	AO1/1	934	318875	197702	22.24	17.295	39.538	51	0.677	1.91	1200	1	1200	1.33	1.18
AO1/1	BO1/1/1	1264	539806	334680	39.54	23.411	62.949	42	0.744	2.88	1200	2	1800	2.17	0.96
BO1/1/1	**BO1/1**	1764	605770	375577	62.95	32.671	95.620	34	0.804	2.89	1200	2	2000	2.06	0.91
BO1/4	BO1/3	305	148101	91822	0.00	5.648	5.648	129	0.263	0.87	1000	1	1200	0.82	1.04
BO1/3/1	BO1/3	370	170514	105719	0.00	6.852	6.852	119	0.315	1.10	1200	1	1800	1.09	0.96
BO1/3	BO1/2	550	382985	237451	6.85	10.185	17.037	75	0.569	2.80	1200	1	600	1.88	1.66
BO1/2/1	BO1/2	445	114679	71101	0.00	8.241	8.241	105	0.420	0.87	1000	1	1200	0.82	1.04
BO1/2	**BO1/1**	700	497664	308552	17.04	12.963	30.000	58	0.642	3.18	1200	1	450	2.17	1.92
BO1/0	**BO1/1**	422	261922	162392	0.00	7.815	7.815	111	0.368	1.84	1200	1	1200	1.33	1.18
BO1/1	BO1	1929	1409404	873831	95.62	35.726	131.346	30	0.837	6.05	1200	2	500	4.12	1.82

Design of Rainwater Drainage System with a Revive Well

Results of geological strata for groundwater level with the help of electric resistivity experiment. In this exploration, an unconfined aquifer was planned as a revive well for which Wenner's technique for electrical resistivity was used. The actual geological strata of a bore well of the study area were classified as per IS 1498: 1970 (Reaffirmed, 1997). The electrical resistivity method was extremely useful for determining the average condition of different strata up to a depth of 30 m or more. The depth of groundwater can be anticipated by utilising this test for the depth of the aquifer and the type of aquifer (confined or unconfined). Winner's method for conducting an electrical resistivity survey was launched. Five resistive zones were distinctly outlined (Point 1: N- S; Point 2: N-S; Point 2: E-W; Point 2: NE-SW; Point 3: N-S). The results were computed for electric resistivity from Figure 4 (Winner's Method IS-3043), and determined for a deeper geological condition. It was not possible to drill a bore well up to 30-40 m. Alongside this investigation, estimations were made for a depth of up to 80 m for the geographical strata and unconfined aquifer for a revive of groundwater. The overview obtained from the electric resistivity test was utilised for areas of various strata in groundwater. Glacial till was defined as an unconsolidated, heterogeneous mixture of clay, sand, pebbles, cobbles and boulders, as shown in Table 2. Thus, the electrical resistivity method was useful for obtaining a soil profile with reasonably reliable results.

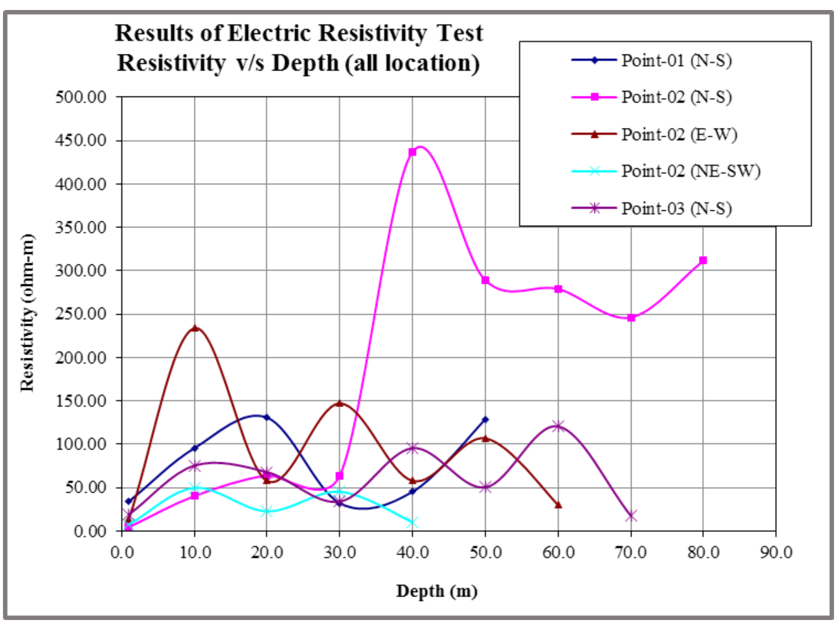


Figure 4. Results of electric resistivity test (all location)

Table 2
Identification of soil from resistivity

Sr. No.	Depth from GL	Electrical Resistivity (Ohm.m.)	Visual Identification of Soil
1.	1.0	4.40	Clay (Saturated) and Silt
2.	10.0	40.21	Clay (Saturated) and Silt
3.	20.0	64.09	Clay (Saturated) and Silt
4.	30.0	64.09	Clay (Saturated) and Silt
5.	40.0	437.31	Glacial Till (Clayey Sand, Pebbles, Cobble, & Boulders)
6.	50.0	289.03	Glacial Till (Clayey Sand, Pebbles, Cobble, & Boulders)
7.	60.0	278.97	Glacial Till (Clayey Sand, Pebbles, Cobble, & Boulders)
8.	70.0	246.30	Glacial Till (Clayey Sand, Pebbles, Cobbles, & Boulders)
9.	80.0	311.65	Glacial Till (Clayey Sand, Pebbles, Cobbles, & Boulders)

Result of value of permeability using Hazen's formula with the help of hydrometer test of soil. By checking the test samples, a summary of grain size distribution parameters could be provided under a dominant soil type (clay, silt, sand). The typical curves are shown in Figure 5, Figure 6 and Figure 7. Unlike for the most common soil type, gradation curves for layers with higher silt and clay content exhibit different shapes from the dominant soil. The finest 10% of the material from testing at various depths of the borehole is derived from this graph. The after-effect of R.L. -9.00 to -9.45 m and the estimation of D_{10} of 0.000039 were acquired. Another two-depth test indicates a rate better than 10% and appears in Figure 5. Three samples of different depths were analysed and the results are shown in Tables 3a, 3b and 3c. The different depths were R.L. -1.5 to 1.95, R.L. -4.5 to -4.95 and R.L. -7.0 to -7.45, respectively in which R.L. -4.50 to -4.95 had 10% finer materials than did the other samples. The other two samples had a particle size not more than 10%. The value of D_{10} taken from R.L. -4.50 to -4.95 is 0.000116 is shown in Figure 6. The third borehole was provided on the opposite side of the creek, located in the northern side of the study area. A hydrometer test investigation was done from three distinct depths of the borehole opening, the depths of which were about R.L.4.5 to -4.95, R.L. -7.5 to -7.95 and R.L. -13.0 to -13.45. After carrying out the analysis and calculations, the graph of particle size to percentage finer was plotted, and 10%

finer particles of the value D_{10} was marked and used in Hazen's formula to find the hydraulic conductivity. From the examination, two D_{10} qualities were obtained, one from the top strata at about R.L. -4.5 to -4.95 of D_{10} around 0.000027 and another from the depth of R.L. -13.0 to -13.45 of D_{10} at around 0.000802, shown in Figure 7.

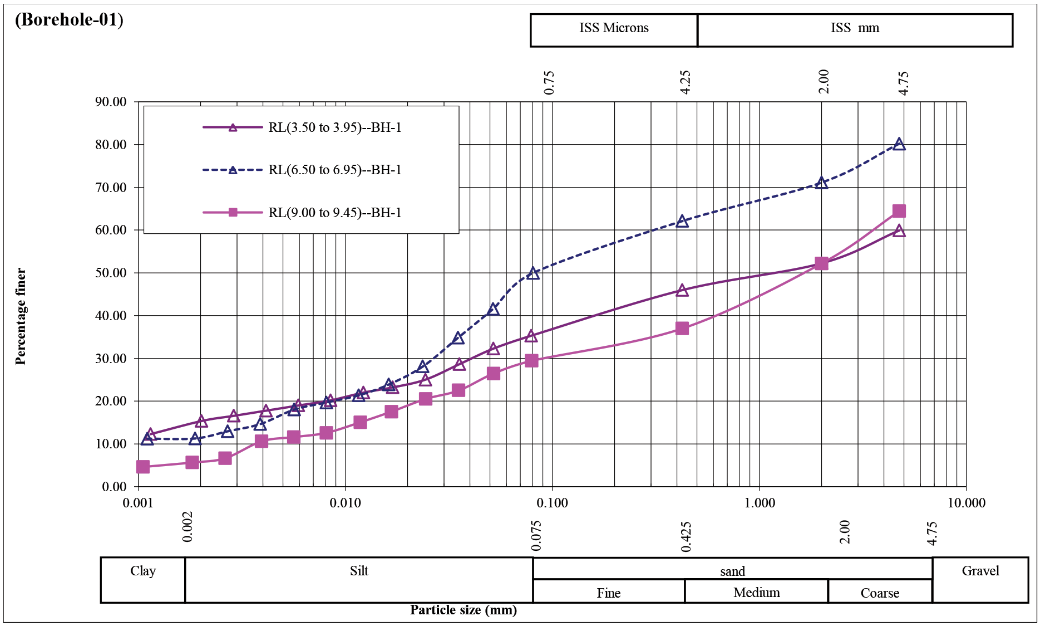


Figure 5. Particle size distribution curve (sieve and hydrometer analysis – Borehole no. 1)

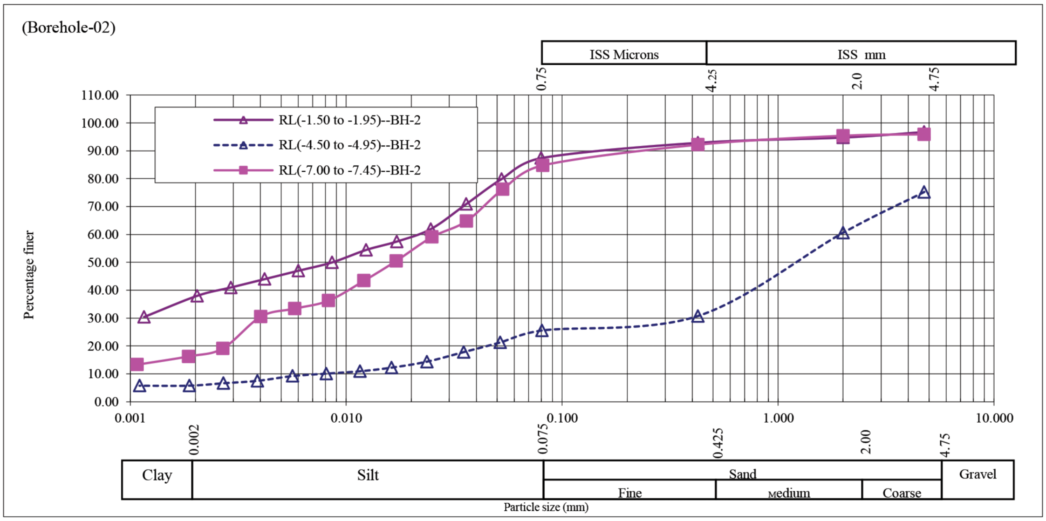


Figure 6. Particle size distribution curve (sieve and hydrometer analysis – Borehole no. 2)

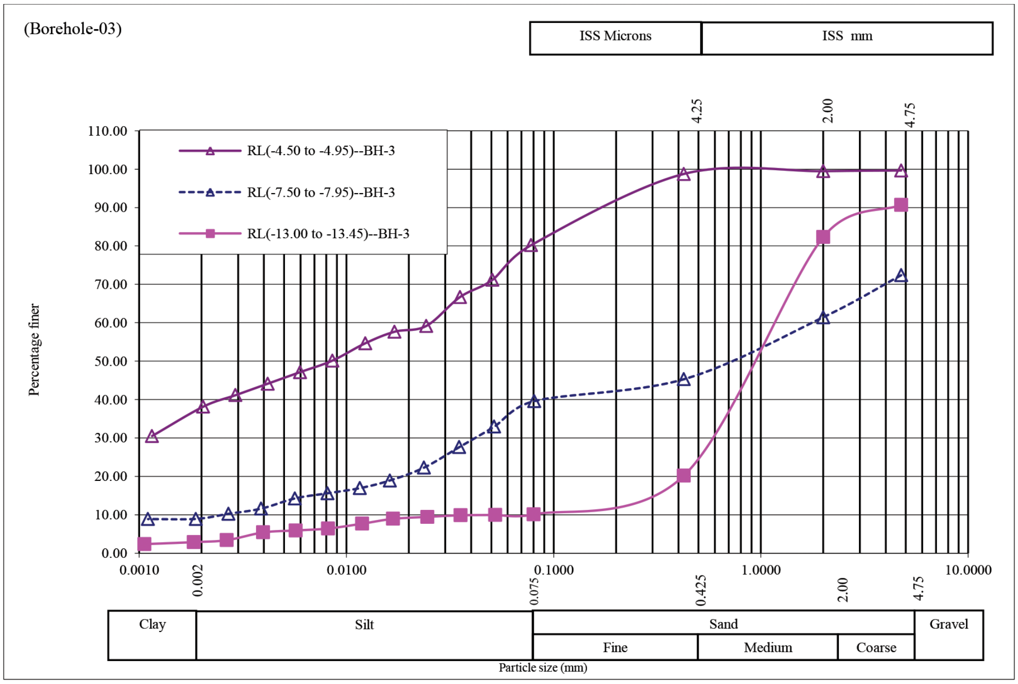


Figure 7. Particle size distribution curve (sieve and hydrometer analysis – Borehole no. 3)

Estimate of Permeability Using the Hazen Formula

From the above results, three different boreholes were found to have a 10% finer grain particle size of D_{10} value, conducted at a different level below the ground. A total of four numbers of D_{10} values were obtained, from which two D_{10} values were of the third borehole. A permeability test was conducted (k) using the Hazen formula from the particle size distribution test (Hazen, 1892; Vuković 7 Siro, 1992; Doing, 2007). From the above outcomes, a high penetrability consequence of 7.29 x 10^{-8} at the top strata of R.L. -4.5 to -4.95 was obtained, from which the separation of the creek was vast. The same borehole depth of R.L. was about -13.00 to -13.45, and had less porosity after the effects of 6.43 x 10^{-5} than different areas taken for a decision to release the revive well (Patel & Desai, 2011).

Result of infiltration rate using the single- and double-ring infiltrometer test. Calculation by Horton's method (for single-ring infiltrometer)

$$\boldsymbol{F} = f_c + (f_o - f_c)e^{-kt} \quad [3]$$

Initially, the results showed the infiltration rate of a single-ring infiltrometer rate as 26.3 cm/hr and a double-ring infiltrometer rate of 21.5 cm/hr. After an hour, it demonstrated estimations of around 3.29 cm/hr and 1.82 cm/hr individually, and after two and a half hours, it indicated rates of around 1.34 cm/hr and 1.10 cm/hr. Based on the outcomes appearing in Table 3 and Figure 8, and the literature on this topic, it can be inferred that the reviewed region has a great penetration rate, which can help for artificial groundwater revive in unconfined aquifer (Patel, 2011).

Table 3
Results of horton's equations for single-ring infiltrometer and double-ring infiltrometer

Time	Single-Ring Infiltrometer	Double-Ring Infiltrometer	Result by Horton's Equation for SRI	Result by Horton's Equation for DRI
0	26.3	21.5	26.3	21.5
0.25	14.7	12.3	14.58242065	9.951805745
0.5	9.3	7.9	8.356907931	4.940905145
0.75	5.8	3.8	5.049312785	2.766615011
1	3.4	1.9	3.291997982	1.82316433
1.25	2.9	1.2	2.358342205	1.413789714
1.5	2.2	1.1	1.862293854	1.236157137
1.75	1.6	1.1	1.59874494	1.159080222
2	1.3	1.1	1.458722238	1.12563562
2.25	1.3	1.1	1.384328621	1.111123604
2.5	1.3	1.1	1.344803529	1.104826666

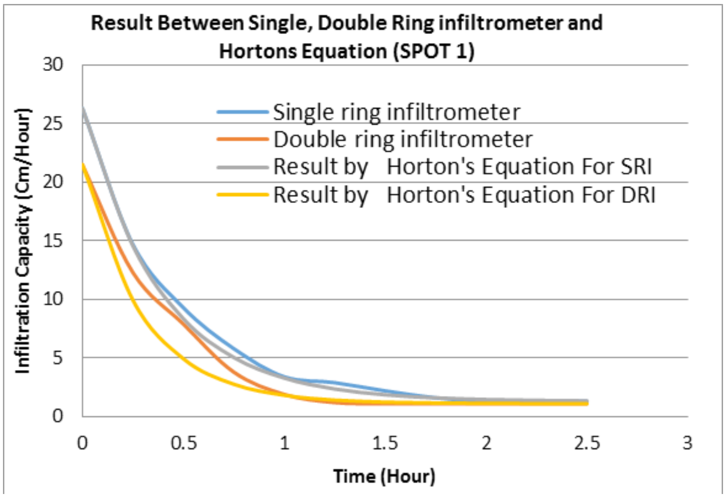


Figure 8. Graph of infiltration rate by SRI and DRI

Results of modified design of the rainwater drainage system with a revive well. In this exploration, distinctive geotechnical parameters and their effect on artificial groundwater revive methods utilised for urban foci are viewed (Patel, 2011). The configuration is for an unconfined aquifer as a revive well, with an abutting rainwater drainage framework. From a past study on electric resistivity exploration, the unconfined aquifer depth h_2 was taken as 35 m and depth of h_1 was taken as 20 m. The hydrometer test determines the value of D_{10} in grain size analysis and permeability k = 6.43 x 10^{-5} m/sec is determined from the Hazen formula. Radius of influence R was taken as 100 m, with a calculating revive rate Q and sample calculation of Artificial Revive as Unconfined Aquifer:

$$Q = \pi k \frac{(h_2 - h_1)}{ln(\frac{r_2}{r_1})} \qquad [4]$$

where, 'Q' is the rate of water entering the revive well, 'h_2' is the depth of water in the revive well above the impervious stratum, 'h_1' is the depth of the water table in an unconfined aquifer, 'r_2' is the radius of influence and 'r_1' is the radius of the well.

For all different sizes (diameters) of revive wells, the results of revive rate Q are shown in Table 4. These different sizes (diameter) of revive wells are used to determine the optimum size diameter of revive wells that can be more beneficial than others. Based on these outcomes, when the distance across the revive well expands, the revive rate likewise increases. By having two revive wells (with and without rainwater drainage frameworks) in every catchment area of the rainwater drainage frameworks, the revive rate is expanded. The rainwater drainage system is modified as, due to the provision of a revive well, the actual runoff of the rainwater drainage system of the catchment area decreased. In the outline, two revive wells in every catchment territory of rainwater depletion was given. One well was provided on the upstream side of each rainwater drain and another one on the perpendicular road where the rainwater drain was not available. Modified design of the rainwater drainage system was as per Table 5-6 and Figure 9. A detailed cross-section of the revive well, which provides a rainwater drainage system, is shown in Figure 10.

Table 4
Results of recharge rate for different diameters of well

Sr. No.	**Diameter of Recharge Well m**	**Radius of Recharge Well (R) m**	**Recharge Rate (Q) m³/sec**
1.	0.15	0.075	0.0231565
2.	0.225	0.1125	0.0245395
3.	0.25	0.125	0.024926
4.	0.30	0.15	0.025625
5.	0.35	0.175	0.026247
6.	0.45	0.225	0.027329
7.	0.50	0.25	0.0278095
8.	0.60	0.3	0.0286825

Table 5

Modified design of the storm water drainage system with recharge well (rw dia 15 cm-30 cm)

Section		Length of Drain	Actual Runoff (q)	Old Diameter of Pipe (D)	15 cm dia			22.5 cm dia			25 cm dia			30 cm dia		
U/S Node	D/S Node				Well Discharge (Qw)	Cum. Discharge (q')	Pipe Dia Provided	Well Discharge (Qw)	Cum. Discharge (q')	Pipe Dia Provided	Well Discharge (Qw)	Cum. Discharge (q')	Pipe Diaprovided	Well Discharge (Qw)	Cum. Discharge (q')	Pipe Dia Provided
			(m^3/s)	(mm)	(m^3/s.)	(m^3/s)	(mm)	(m^3/s)	(m^3/s)	(mm)	(m^3/s)	(m^3/s)	(mm)	(m^3/s)	(m^3/s)	(mm)
AO1/4	AO1/3	502.27	0.795	1000	0.069469	0.7258	800	0.0736	0.7216	800	0.0748	0.7205	800	0.0769	0.7184	800
AO1/3/1	AO1/3	334.68	0.780	1200	0.069469	0.7110	800	0.0736	0.7069	800	0.0748	0.7057	800	0.0769	0.7036	800
AO1/3	AO1/2	196.58	1.501	1200	0.069469	1.2925	1000	0.0736	1.2800	1000	0.0748	1.2766	1000	0.0769	1.2703	1000
AO1/2/1	AO1/2	245.25	0.517	1000	0.069469	0.4471	600	0.0736	0.4429	600	0.0748	0.4418	600	0.0769	0.4397	600
AO1/2	AO1/1	235.06	1.909	1200	0.069469	1.4917	1000	0.0736	1.4668	1000	0.0748	1.4599	1000	0.0769	1.4473	1000
AO1/1	BO1/1/1	330.31	2.883	1200*2	0.069469	2.4666	800	0.0736	2.4417	800	0.0748	2.4348	800	0.0769	2.4222	800
BO1/1/1	**BO1/1**	500.00	2.885	1200*2	0.069469	2.3990	800	0.0736	2.3700	800	0.0748	2.3618	800	0.0769	2.3472	800
BO1/4	BO1/3	305.00	0.866	1000	0.069469	0.7970	800	0.0736	0.7928	800	0.0748	0.7917	800	0.0769	0.7896	800
BO1/3/1	BO1/3	370.00	1.103	1200	0.069469	1.0333	1000	0.0736	1.0292	1000	0.0748	1.0280	800	0.0769	1.0259	800
BO1/3	BO1/2	180.00	2.801	1200	0.069469	2.5923	1200	0.0736	2.5799	1200	0.0748	2.5764	1200	0.0769	2.5701	1200
BO1/2/1	BO1/2	445.00	0.869	1000	0.069469	0.7994	800	0.0736	0.7952	800	0.0748	0.7941	800	0.0769	0.7920	800
BO1/2	**BO1/1**	150.00	3.180	1200	0.069469	2.8322	1200	0.0736	2.8115	1200	0.0748	2.8057	1200	0.0769	2.7952	1200
BO1/0	**BO1/1**	422.03	1.844	1200	0.069469	1.7744	1000	0.0736	1.7703	1000	0.0748	1.7691	1000	0.0769	1.7670	1000
BO1/1	BO1	165.00	6.046	1200*2	0.069469	5.0737	1000	0.0736	5.0156	1000	0.0748	4.9993	1000	0.0769	4.9700	1000

Table 6

Modified design of the storm water drainage system with recharge well (rw dia 35 cm-60 cm)

Section		Length of Drain	Actual Runoff (q)	Old Diameter of Pipe (D)	35 cm dia			45 cm dia			50 cm dia			60 cm dia		
U/S Node	D/S Node				Well Discharge (Qw)	Cum. Discharge (q')	Pipe Dia Provided	Well Discharge (Qw)	Cum. Discharge (q')	Pipe Dia Provided	Well Discharge (Qw)	Cum. Discharge (q')	Pipe Dia Provided	Well Discharge (Qw)	Cum. Discharge (q')	Pipe Dia Provided
			(m^3/s.)	(mm)	(m^3/s)	(m^3/s)	(mm)	(m^3/s)	(m^3/s)	(mm)	(m^3/s)	(m^3/s)	(mm)	(m^3/s)	(m^3/s)	(mm)
AO1/4	AO1/3	502.27	0.795	1000	0.0787	0.7165	800	0.0820	0.7133	800	0.0834	0.7118	800	0.08605	0.7092	800
AO1/3/1	AO1/3	334.68	0.780	1200	0.0787	0.7018	800	0.0820	0.6985	800	0.0834	0.6971	800	0.08605	0.6944	800
AO1/3	AO1/2	196.58	1.501	1200	0.0787	1.2647	1000	0.0820	1.2549	1000	0.0834	1.2506	1000	0.08605	1.2428	1000
AO1/2/1	AO1/2	245.25	0.517	1000	0.0787	0.4378	600	0.0820	0.4345	600	0.0834	0.4331	600	0.08605	0.4305	600
AO1/2	AO1/1	235.06	1.909	1200	0.0787	1.4361	1000	0.0820	1.4166	1000	0.0834	1.4080	1000	0.08605	1.3923	1000
AO1/1	BO1/1/1	330.31	2.883	1200*2	0.0787	2.4110	800	0.0820	2.3915	800	0.0834	2.3829	800	0.08605	2.3672	800
BO1/1/1	**BO1/1**	500.00	2.885	1200*2	0.0787	2.3341	800	0.0820	2.3114	800	0.0834	2.3013	800	0.08605	2.2829	800
BO1/4	BO1/3	305.00	0.866	1000	0.0787	0.7877	800	0.0820	0.7845	800	0.0834	0.7830	800	0.08605	0.7804	800
BO1/3/1	BO1/3	370.00	1.103	1200	0.0787	1.0241	800	0.0820	1.0208	800	0.0834	1.0194	800	0.08605	1.0168	800
BO1/3	BO1/2	180.00	2.801	1200	0.0787	2.5645	1200	0.0820	2.5547	1200	0.0834	2.5504	1200	0.08605	2.5426	1200
BO1/2/1	BO1/2	445.00	0.869	1000	0.0787	0.7901	800	0.0820	0.7869	800	0.0834	0.7854	800	0.08605	0.7828	800
BO1/2	**BO1/1**	150.00	3.180	1200	0.0787	2.7859	1200	0.0820	2.7696	1200	0.0834	2.7624	1200	0.08605	2.7493	1200
BO1/0	**BO1/1**	422.03	1.844	1200	0.0787	1.7652	1000	0.0820	1.7619	1000	0.0834	1.7605	1000	0.08605	1.7578	1000
BO1/1	BO1	165.00	6.046	1200*2	0.0787	4.9439	1000	0.08199	4.8984	1000	0.083429	4.8782	1000	0.08605	4.8416	1000

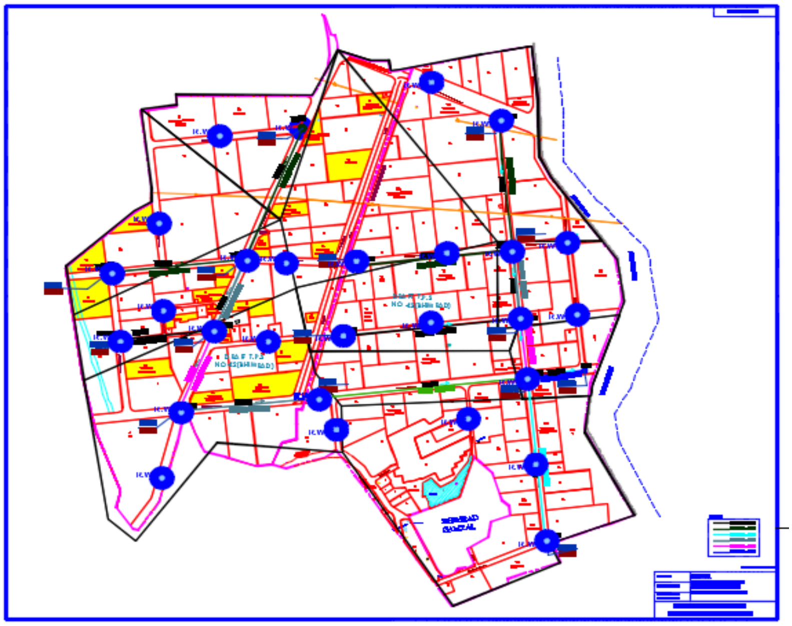


Figure 9. Plan of modified design of the storm water drainage system with recharge well

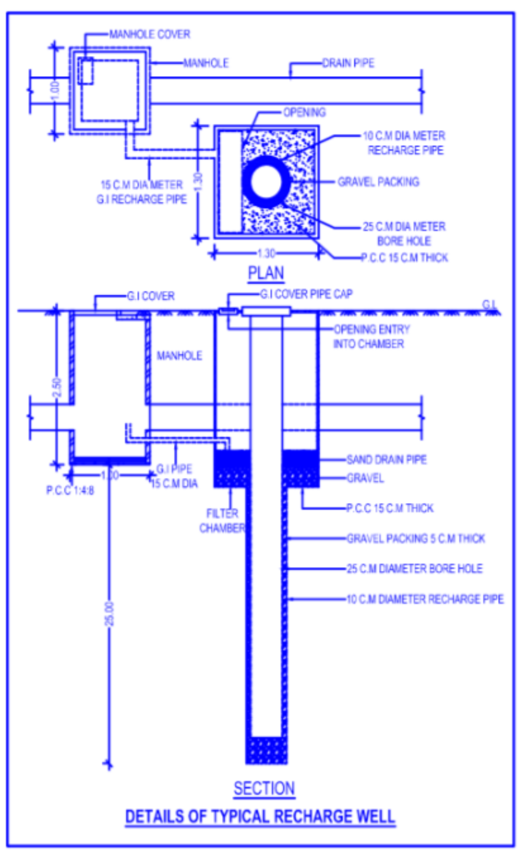


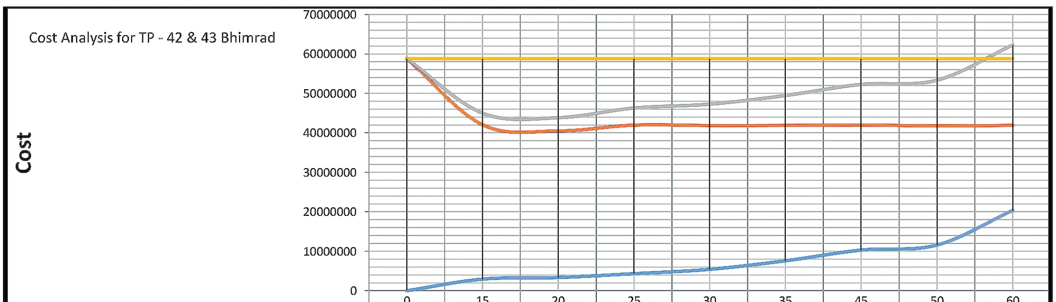
Figure 10. C/S of recharge well with storm water drainage system

Cost Analysis and Economic Aspect

This study attempted to conserve water through the use of groundwater revive and diminish the cost of providing for a rainwater drainage framework; in this way, the study achieved numerous advantages at the same time (Wolf, 2015). The different costs, for example, were:

(1) Total cost of revive wells and net cost of the rainwater drainage framework with groundwater revive wells;
(2) Total cost of rainwater drainage system without groundwater revive wells; and
(3) Total cost of the rainwater drainage system with groundwater revive, excluding revive wells.

The above figure indicates the variation in cost for different diameters of groundwater revive wells. According to Figure 11, it is clear that the cost of rainwater drainage frameworks stays steady, as there are no new building developments. The cost of groundwater revive wells increases with the increase in the diameter of the revive wells.



	0	15	20	25	30	35	45	50	60
Different Dia. RW cost	0	2939221.145	3344994.244	4328667.056	5415646.981	7587092.715	10304533.69	11574437.82	20349333.33
Storm water drainage cost without different dia of RW	58783658.16	42045027.01	40481704.1	41956985.06	41848708.3	41874753.98	41973992.04	41760668.13	41891706.64
Storm water drainage cost with different dia of RW	58783658.16	44984248.15	43833733.87	46285652.11	47264355.28	49461846.7	52278525.73	53335105.95	62241039.97
Conventional Storm water drainage cost	58783658.16	58783658.16	58783658.16	58783658.16	58783658.16	58783658.16	58783658.16	58783658.16	58783658.16

Dia. of RW

Figure 11. Cost analysis for TP - 42 & 43 Bhimrad

As seen in Figure 12, the sparing of the cost of the rainwater drainage framework with groundwater revive shifts from 9.5% to 25.5%, when contrasted with the regular rainwater drainage framework for the reviewed territory. The highest value of percentage savings falls between 25% and 26%, when the diameter of the revive well is kept at 20 cm.

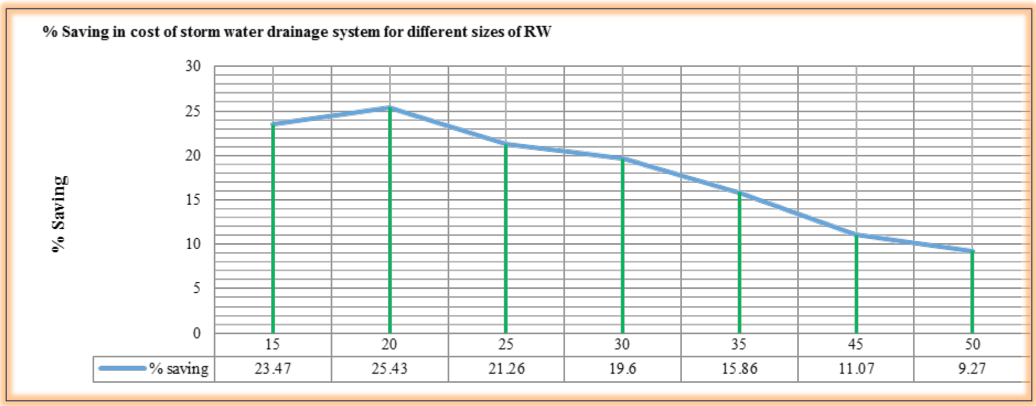
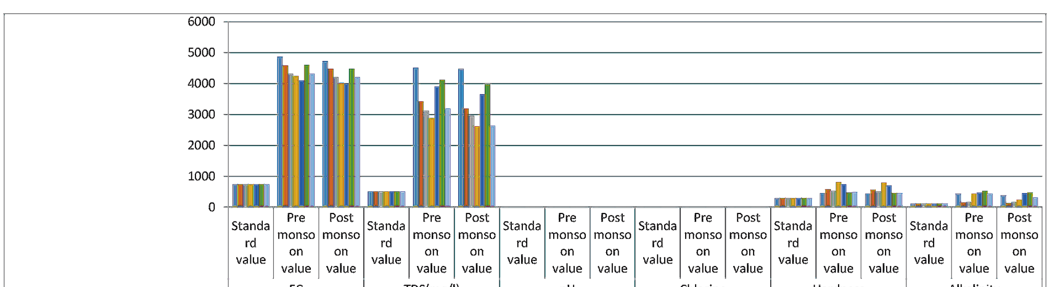


Figure 12. Percentage saving in cost of storm water drainage system for different sizes of RW

Future Groundwater Quality Prediction by Artificial Revive

Results of different parameter tests for groundwater quality in laboratory (Pre-monsoon & post-monsoon 2015). For groundwater quality assessment, experimental work was conducted during the pre-monsoon and post-monsoon period of 2015; its results are shown in Figure 13. As per the record of the Collector's Office, Surat, the highest rainfall for Surat City was 1400 mm as of October 31, 2015. The concentrations of each parameter test results were changed for the pre-monsoon and post-monsoon periods. When an artificial revive was provided, it proved beneficial for the groundwater quality, thereby making it both usable and sustainable for future water demands of rapid increases in urbanisation.



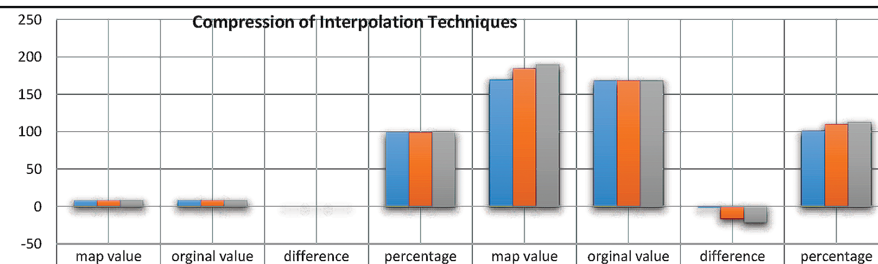
	EC			TDS(mg/l)			pH			Chlorine			Hardness			Alkalinity		
	Standard value	Pre monsoon value	Post monsoon value	Standard value	Pre monsoon value	Post monsoon value	Standard value	Pre monsoon value	Post monsoon value	Standard value	Pre monsoon value	Post monsoon value	Standard value	Pre monsoon value	Post monsoon value	Standard value	Pre monsoon value	Post monsoon value
Aakash Era	750	4865	4723	500	4513	4486	7	7.74	7.68	0.2	0.2	0.22	300	450	430	120	440	390
Halpati Niwas	750	4583	4478	500	3416	3187	7	8.25	8.2	0.2	0.4	0.37	300	580	570	120	150	140
Aakash Evenue	750	4320	4219	500	3127	2956	7	8.11	8.05	0.2	0.3	0.24	300	520	510	120	160	160
Ashirwad Enclave (Near Khadi)	750	4249	4015	500	2896	2619	7	7.99	7.84	0.2	0.3	0.1	300	810	790	120	430	240
Santosh Height (Near Khadi)	750	4106	3998	500	3910	3649	7	7.92	7.62	0.2	0.1	0.11	300	740	710	120	480	450
Aastha Flats (Near Khadi)	750	4598	4476	500	4126	3973	7	8.1	8	0.2	0.4	0.3	300	470	460	120	520	480
Swagat Residency (Near Khadi)	750	4320	4213	500	3189	2646	7	7.47	7.59	0.2	0.3	0.23	300	490	450	120	440	310

Figure 13. Results of pre-post monsoon sample test results – 2015

Result of acquiring past-year groundwater quality data using interpolation techniques in GIS. Groundwater quality data, relating to previous years, at separate locations of Surat City, were collected from the GWSSB. The GWSSB is the government body that regularly checks and monitors yearly groundwater quality for different important parameters for domestic use.

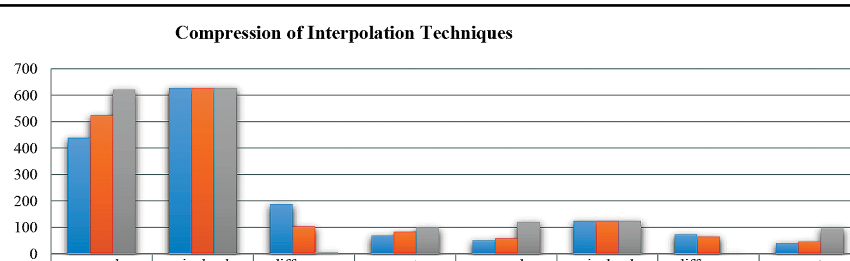
Thereafter, all collected data were sorted by year, according to pre-monsoon and post-monsoon seasons for all locations adjoining the study area; finally, all sample point locations near the study area were marked on the map of Surat City and converted into shape files by attribute, with location name of GWQ parameter concentrations. The programme generated a point data of selected locations by digitisation.

A point location map from the previous year's data was generated in ARC GIS with the help of different techniques of interpolation to extract data from maps. Three interpolation techniques, IDW, Kriging and Natural Neighbour, were used to acquire the previous years' GWQ concentration data relating to four different parameters i.e. pH, total hardness (TH), total dissolved solid (TDS) and chlorides (CL) for a validation check of the interpolation map values with original values and for values of each parameter concentration observed by the GWSSB in 2006. These are shown in Figure 14 and Figure 15. The results were analysed and comparisons of all three interpolation methods of the GWQ parameter were made and matched with their original values of the IDW interpolation technique. The results for pH were matched, showing a value of 99.14% for IDW; 98.77% for Kriging; and 100% for Natural Neighbour. When measuring TH, TDS, and CL, all parameters using the Natural Neighbour method gave the nearest values when compared with original values, showing, therefore, that the Natural Neighbour technique was the most suitable for acquiring previous years' missing data of GWQ for an area.



	pH: map value	pH: orginal value	pH: difference	pH: percentage	TH: map value	TH: orginal value	TH: difference	TH: percentage
IDW	8.04	8.11	0.07	99.13686806	169.395	168	-1.395	100.8303571
KRIGING	8.01	8.11	0.1	98.76695438	184.19	168	-16.19	109.6369048
NATURAL NEIGHBOUR	8.11	8.11	0	100	189.691	168	-21.691	112.9113095

Figure 14. Comparative graph of interpolation techniques of pH and TH



	TDS: map value	TDS: orginal value	TDS: difference	TDS: percentage	CL: map value	CL: orginal value	CL: difference	CL: percentage
IDW	439.432	628.58	189.148	69.90868306	51	124.53	73.53	40.95398699
KRIGING	524.666	628.58	103.914	83.4684527	58.6	124.53	65.93	47.05693407
NATURAL NEIGHBOUR	622.281	628.58	6.299	98.99790003	121.611	124.53	2.919	97.65598651

Figure 15. Comparative graph of interpolation techniques of TDS and CL

The extent of coverage between this new polygon and the underlying polygons is utilised as the weights. Groundwater quality data are extracted from seven points of the study area by the GIS interpolation method of Natural Neighbour with its map of groundwater quality. The previous years of 2004, 2006, 2008, 2011, 2012, 2013 pre-monsoon and post-monsoon, and the 2014 pre-monsoon groundwater quality parameters, like pH, electric conductivity, TH, TDS and CL, were extracted. Past-year data can be used for analysis of groundwater quality of an area. From an extracted map of the study area, contrast colour and raster datasets with pixel values were generated. Colour can help render each raster dataset as a single seamless image. In Natural Neighbour interpolation, the map randomly selected seven sample data set pixel values of the study area, and acquired the missing data of the past year.

Groundwater quality index was computed in ERDAS programming of GIS, utilised for getting a GWQI outline. Based on the analysis, GWQ was decreasing year by year with the increase in urbanisation in the area. As future water demands are not likely to be met by SMC, the study provided the design of groundwater for domestic purposes. Based upon the graphical analysis shown in Figure 16, post-monsoon GWQ was increasing faster than pre-monsoon GWQ, with natural infiltration of rainwater. Post-monsoon GWQI was improving with artificial revive wells, thereby proving that the artificial revive wells were beneficial.

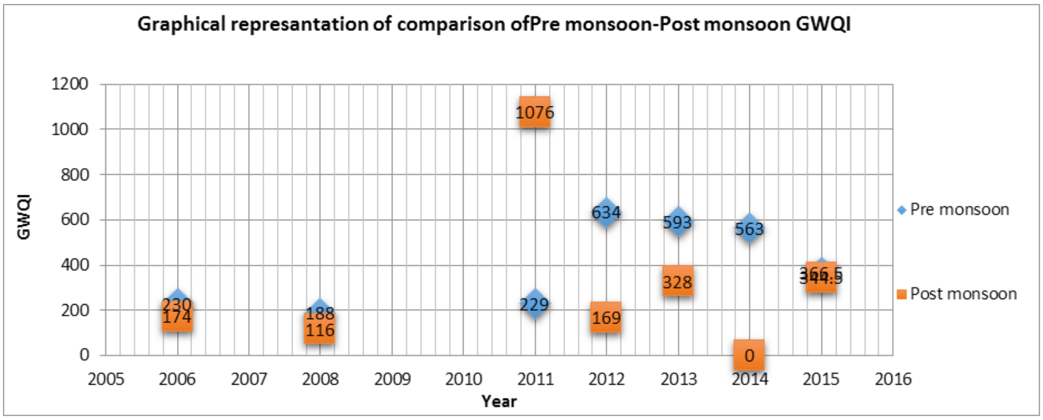


Figure 16. Graphical representation of comparison of pre-monsoon-post-monsoon GWQI

Results of the reduction in concentration of various parameters under various dilution conditions for future GWQ in GIS. Groundwater quality improvement predictions, after the use of artificial revive wells, from 2015 to 2050, were determined with the help of GIS software using the dilution equation (Sharma & Patel, 2010). In the model, an initial concentration map was taken as an input parameter for the first stage. In the second-stage formula, dilution was used to determine changes in concentration after the use of artificial revive wells in the form of a concentration map. From the map, well distribution in seven location results was established. This procedure was carried out for each groundwater quality parameter, including pH, electrical conductivity, total dissolved solids, chlorine, total hardness and alkalinity. The information found comprised groundwater quality and contamination parameters, and a correlation was made with the underlying fixation and focus after dilution. A change in the reduction of actual concentrations containing compounds of each parameter generally results after a dilution of groundwater quality concentrations. The percentage of change in actual concentrations was determined for each parameter for well distribution in the seven locations, and an improvement of the groundwater quality year by year (up to 2050) was predicted. There was a 4% reduction in concentration for the year 2015, showing pH reduction up to 1.5-2.5%, EC reduction up to 11-12%, TDS reduction up to 12-13%, Cl reduction up to 8-9%, TH reduction up to 10-12% and alkalinity reduction up to 7-8%. These results showed that artificial revive can improve groundwater quality.

Results of the yearly GWQI (Groundwater Quality Index) (2015-2050) in GIS. Groundwater quality in the study area was determined in pre-monsoon and post-monsoon seasons for the next 36 years (2015-2050), and the summarised statistical outcome of observed analysis is shown in Figure 17. The results showed that GWQI had improved every year, with the effect of dilution in the study area. In 2015, GWQI pre-monsoon was 357 and in 2050, GWQI pre-monsoon was 69.4.

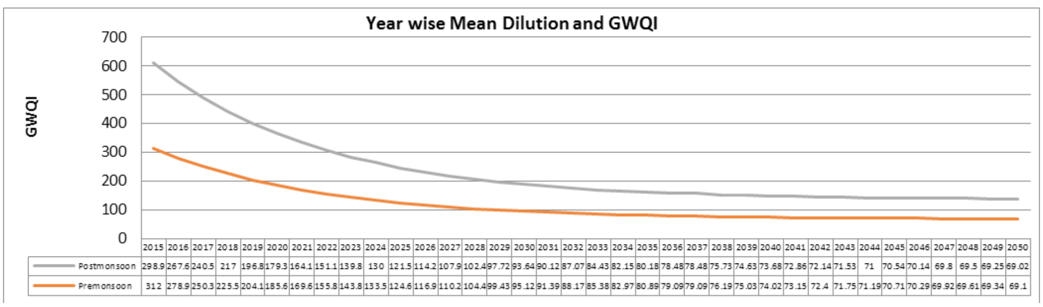


Figure 17. Year-wise mean dilution and GWQI

CONCLUSION

The development of new techniques for rainwater drainage systems, in conjunction with groundwater recharging, is advantageous in many ways. Different diameters of revive wells were used to study their economic advantages and to calculate all diameters as the revive rates with artificial revive well and pipe diameter of rainwater drain are inversely proportional to each other, that is, with the increase in revive rates enabled by the use of artificial revive well, the pipe diameter of rainwater drains decreased, and vice-versa. As discussed earlier, cost savings from 9-10% to 25-26% were observed for the different sizes of revive wells, compared with traditional rainwater drainage systems. The optimal pipe diameter considered in the study was 20 cm. The total cost of the rainwater drainage system without a groundwater revive well was INR5.5 cr to 6.0 cr, whereas the total cost of a rainwater drainage system with a groundwater revive well of diameter 20 cm was INR4.0 cr to 4.5 cr, which indicated savings of 25-26%.

Artificial revive wells, with and without rainwater drainage networks, have already been proposed for the research area and have proven to be helpful in satisfying future demands for water. Dilution results for future groundwater quality, including percentage reduction in concentration of 2015, showed 2-12% for different parameters. After artificial revive, concentrations of groundwater quality parameters were reduced and quality improved with time. The results showed that GWQI was improving each year through the effect of the dilution technique in the study area, enhancing groundwater contamination.

In this study, an attempt was made in the direction of conserving water through groundwater revive as well as reducing the cost of rainwater drainage systems, thus achieving two-fold benefits. This research included the design of a rainwater drainage system combined with groundwater revive wells to save water as well as to decrease the total cost of the traditional rainwater system.

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