NOVEL STORMWATER DRAINAGE SYSTEM WITH MULTIPLE BENEFITS FOR NEW URBAN AREA OF SURAT CITY (INDIA)

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Abstract - The management and planning of natural resources play an important role in the prosperity and economy in human life. Sustainable integrated approach of stormwater drainage system in conjunction with groundwater recharge has been considered in this research for multiple benefits. This research paper is focused on stormwater design and rain water harvesting with achieving overall economy and improvement of groundwater quality. The artificial saving of rain water, reduction in stormwater drainage system components and economical analysis is the major achievement of this research work. The study area selected is T.P.S. (Town Planning Scheme) – 42 & 43 – Bhimrad, a new urban area of Surat city (India) which has frequent urban flood problem in rainy days. The economical diameter of groundwater recharge well to be used in integrated approach is 20 cm. Due to reduction in pipe sizes in proposed integrated approach, the benefit cost (B/C) ratio is 1.49.

Index Terms – Economical Analysis, Integratedpproach, Benefit-Cost, Rainwater Harvesting

INTRODUCTION

To forecast the total life-cycle project cost of different alternatives is a vital step in any decision-making activity (Wolf et al. 2015). In urban Stormwater management, there are costs for the stormwater control practices plus costs for stormwater conveyance components and the recharge wells which are to be estimated prior to commencement of project with the help of various agencies involved like, developers, city planners, engineers, funding agencies, government and private agencies (Fan et al. 2000). The cost play major role in the decision making process when multiple objectives needed to be considered for desired benefits. This paper presents the estimated cost and benefits of the proposed integrated system in the study area (Bhimrad area of Surat city situated in India) for economical analysis. The features of stormwater site plan that greatly affect the total cost of satisfying the minimum requirements for stormwater controls in new developments are discussed. Management of natural resources also play a vital role in achieving economy and prosperity of human life (Thurston 2006). Planning also play a vital role in management of any engineering project. The economic costs and benefits of managing stormwater using recharge-wells which compares costs or benefits, or both, between recharge well and conventional controls (Vanaskie 2010). This paper presents economic cost comparison of stormwater Drainage System with and without artificial groundwater recharge wells.

Novel Integrated stormwater drainage system in conjunction with artificial groundwater recharge wells is designed for study area. By applying the sustainable integrated approach the goals can be fulfilled at a lower cost compared to the conventional system. It is obvious that planning and design of novel integrated system is much more complex compared to traditional system. It is proposed to construct the groundwater recharge wells in the study area separately as wells along with stormwater drainage system in novel design.

II. STUDY AREA

Bhimrad area is situated at the outskirts almost 10 Kms away from the main Surat city, with Latitude 21°8'59"N and longitude 72°47'46"E. Reduce level of Bhimrad is 3-7 m and SH-5 is 9 m, therefore because of difference in levels. Bhimrad is more prone to water logging due to heavy and light Rainfall. A decade back ground water of Surat used to fulfil general water requirements of people but now it has been difficult to do so from past few years. Water level has been depleted to an extent. Since last 5 years groundwater depth from surface has reduced from 100 to 125 feet. From 2-3 decade back, Surat used to have 8 wells but as time passed due to Urbanization, Presently there are 5-6 wells which contains water and other 3 are dead without any water level since last 15-20 years.

Bhimrad, consist 3 water sources, out of which two were totally dead lakes and the last one gets filled up to 5-7 feet when canal overflows. These lakes get filled in rainy season with Rain water, apart from that no water gets collected in summer and winter season. The levels of Water table get change every year depending upon the rainfall. If rainfall is low, water table decreases and vice versa. Every year approximately 4 to 5 feet of depth decrease is noted. Bhimrad is lying in plane area, therefore no pothole or hills are noticed. Bhimrad doesn't contain any boulders or hard rocks. Yellow Soil and black cotton Soil is more dominated in that area. Due to the fact that Arabian Sea is near to Bhimrad i.e. approximately 16kms, Saline water is also found in the taste (i.e. it's not sweet) and due to salinity, water is hard.

As the Water flows downstream in the drain the quantity of discharge of groundwater recharge increase, which create cumulative effect in reduction of discharge in stormwater drain.

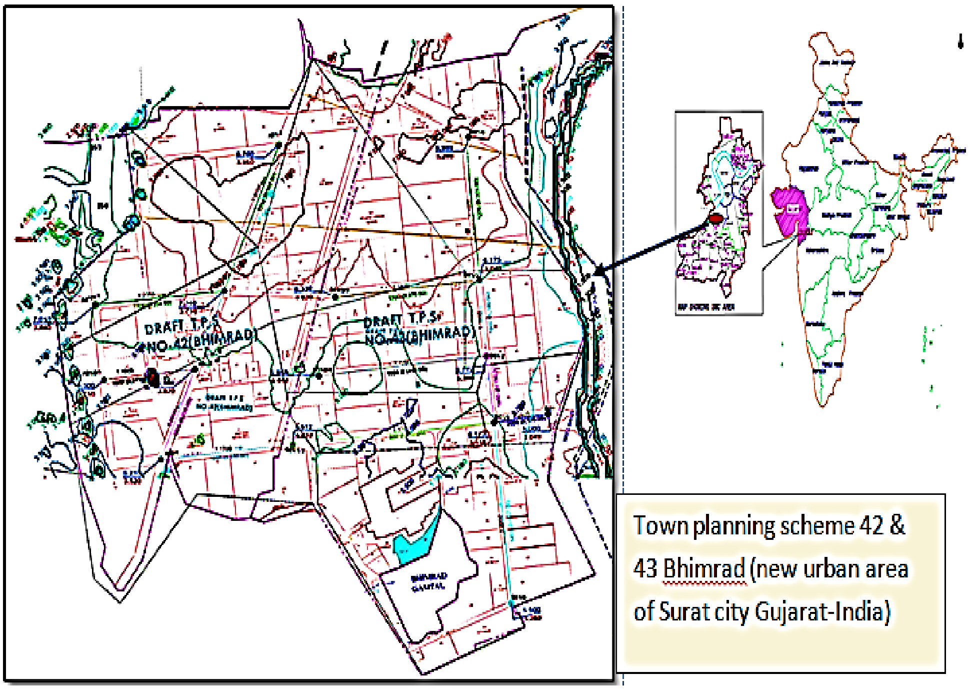

Fig.1. Location Map of Study Area (TPS 42 and 43 Bhimrad)

III. RESULTS AND DISCUSSION

3.1. Novel Stormwater Drainage Design

In this novel integrated design, two types of groundwater recharge wells are proposed to be provided in each catchment area of stormwater drainage system. One type of well is proposed near the manhole along each stormwater drain and another type is proposed on the transverse direction of the road where the stormwater drain is not available.

Sample calculation for well diameter of 15 cm is shown here. Same way different diametesr of well were considered and recharge rates are calculated using following formula.

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$$Q_R = \pi k \frac{(hw - H)}{ln\left(\frac{r_o}{r_w}\right)} \text{....... (for unconfined aquifer)} \qquad \text{.................. 1}$$

Where,

Q_R = rate of water entering into recharge well
k =hydraulic conductivity (6.43 x 10^{-5}m/sec)
h_w =depth of water in recharge well above impervious stratum (35m)
H= depth of water table in unconfined aquifer (20m)
r_o = radius of influence (100m)
r_w = radius of well
Q = 3.14x(6.43x10^{-5}) x $((35)^2 – (20)^2)$ / ln (100/0.075)
=3.14 x 0.00006432 x ((1225 – 400)) / ln (100/0.075)
= 0.0231565m^3 / sec

For different size (diameter) of recharge wells, computed recharge rate is shown in Table 1.

Table1: Results of Recharge Rate for Different Diameter of Well

Sr. No.	Diameter of Recharge well m	Radius of Recharge Well (R) M	Recharge Rate (Q) m^3 / sec
1.	0.15	0.075	0.023156
2.	0.20	0.10	0.024121
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	0.027809
8.	0.60	0.3	0.028682

3.2. Economical Analysis

The quantities of different items and cost of stormwater drainage system as well as recharge wells with different diameters are calculated. The diameters of pipe of stormwater drainage system at different node points for different sizes of recharge well are calculated. Similarly, the gradient of underground stormwater drainage system at different node points for different sizes of recharge wells is calculated. It is observed from the calculation that with the use of larger diameter of recharge well, the pipe diameter and gradient of underground stormwater drainage system reduces, which results in reduction of cost of integrated planning approach of stormwater drainage system.

The cost comparison is made for different diameters of RW. From Table 2 and Table 3, it is clear that cost of traditional stormwater drainage system remains highest cost, as there are no recharge wells constructed. The cost of groundwater recharge wells increases with the increase in the diameter of the recharge wells. The net cost of the stormwater drainage system without groundwater recharge wells decreases with an increase in the diameter of the recharge well. The total cost of the integrated stormwater drainage system in conjunction with groundwater recharge well is found minimum in study area when the diameter of the groundwater recharge well is 20 cm.

The total cost of the traditional stormwater drainage system without groundwater recharge well is INR 58783658 /-, whereas the total cost of novel sustainable integrated stormwater drainage system with conjunction of groundwater recharge well have diameter 20 cm is INR 40481704 /-, which indicate the saving of 25.43%. It shows the direct (tangible) benefit in capital cost of modified stormwater drainage system.

Benefit cost ratio is calculated for novel integrated artificial recharge design for study area to imitate the project is viable or not.

Step: 1

Capital Recovery Factor (CRF):

It is the ratio of a constant annuity is to the present value of receiving that annuity for a given length of time (using an interest rate).

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where,

i = Rate of interest per year

n = Number of years

Here, interest rate of interest as 7% and the project life as 50 years are considered.

$$CRF = \frac{0.07(1+0.07)^{50}}{(1+0.07)^{50} - 1}$$

= 0.0725

Step: 2

Annual Recharge Volume of Water for Whole Study Area:

For one well,

Annual recharge volume = Recharge rate (m^3/sec.) ×Annual duration of rainfall (in sec.) ……………… 3

= 0.024121 × (1600 × 60)

= 2315.616 m^3 (in one well)

For whole study area, total 22 numbers of wells are proposed.

Total annual recharge volume = Annual recharge volume of one well x Total nos. of well ……………… 4

= 2315.616 × 22

= 50943 m^3

Step: 3

Annual Benefit of Water with Artificial Recharge

Annual Saving Cost = Total annual recharge volume × Water Charges ………..…… 5

As per Surat Municipal Corporation (SMC) water charges are considered as 12/- (INR) per 1000 liters for all residential and religious purpose.

Annual Saving Cost = Total annual recharge volume × Water Charges ……………… 6

= (50943 x1000/1000) × 12

= 611322.624 /- (INR)

≈ 611323 /- (INR)

Step: 4

Each Year Uniform Cash Flow (A):

A = P x CRF ……………… 7

Where,

P =Total initial cost of recharge well

In these research total proposed well in study area is 22 nos. Out of these 14 nos of wells are proposed with manhole adjoining with stormwater drainage system and another 8 nos. proposed without manhole which are independent.

For 14 nos. of recharge wells with manhole;

A = P x CRF

= 2223724.01 x 0.0725

= 161219.991 /- (INR)

≈ 161220 /- (INR)

For 8 nos. of recharge well without manhole;

A = P x CRF

= 1121270.23 x 0.0725

= 81292.092 /- (INR)

≈ 81292 /- (INR)

Total Annual Cash Flow = 161219.991 + 81292.092

= 242512.083 /- (INR)

≈ 242512 /- (INR)

Now, operation, maintenance and repairs (OMR) cost is considered as 5% of total the capital costs.

OMR = Capital cost x 0.05

= (2223724.01 + 1121270.23) x 0.05

= 167249.712 /- (INR)

≈ 167250 /- (INR)

Final Annual cost = total annual cash flow + OMR ……………… 8

= 242512.083 + 167249.712

= 410061.795 /- (INR)

≈ 410062 /- (INR)

OR

Annual Cost = (CRF + OMR costs) x (Capital cost of recharge well) ………………9

= (0.0725 + 0.05) x (2223724.01 + 1121270.23)

= 409761.794 /- (INR)

≈ 409762 /- (INR)

Step: 5

Benefit for Proposed Artificial Recharge Well in Study Area

Benefit = Annual Saving Cost - Annual Cost ………………10

= 611322.624 - 409761.794

= 201560.83 /- (INR)

≈ 201561 /- (INR)

Graphical representation of actual benefit of proposed modified design of stormwater drainage system is shown in Figure 2**.**

Step: 6

Benefit Cost Ratio (BCR):

BCR = Annual Benefit of Water with Recharge / Annual Cost of recharge well

= 611322.624 / 409761.794

= 1.492

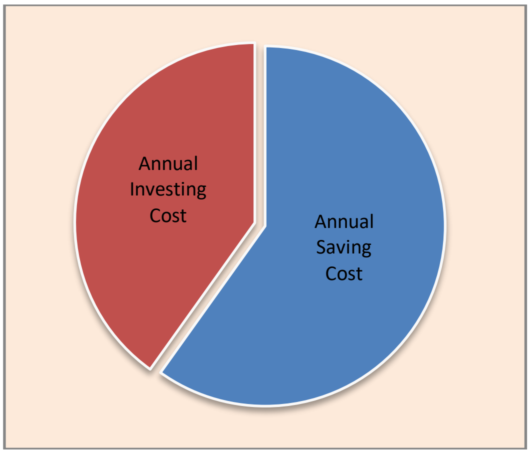

Fig.2. Benefit of Proposed Project

BCR <1.0 - in economic terms, the costs exceed the benefits. Solely on this criterion, the project should not proceed.

BCR = 1.0 - Costs equal the benefits, which means the project should be allowed to proceed, but with little viability.

BCR > 1.0 - The benefits exceed the costs, and the project should be allowed to proceed.

Here, BCR = 1.492 which is greater than 1.0. So, the project can be allowed to proceed.

Years	Rate of Interest	CRF	Annual Benefit of Water with Artificial Recharge in Lac(INR)	Uniform Cash flow(A) in INR	Benefit Cost Ratio (BCR)
10	0.07	0.1424	6.113	6.435	0.95
15	0.07	0.1098	6.113	5.345	1.14
20	0.07	0.0944	6.113	4.83	1.27
25	0.07	0.0858	6.113	4.543	1.35
30	0.07	0.0806	6.113	4.368	1.4
35	0.07	0.0772	6.113	4.256	1.44
40	0.07	0.075	6.113	4.181	1.46
45	0.07	0.0735	6.113	4.131	1.48
50	0.07	0.0724	6.113	4.096	1.49

Table 2: BCR for Different Life of RW

For different values of life of recharge wells, Benefit Cost Ratio (BCR) was also computed and the results are shown in Table 4 and Figure 3.The results show that for the life of recharge well more than 15 years, the project is economically viable and the benefits exceed the costs i.e. BCR > 1. If the life of recharge well is less than 15 years, the project is not beneficial.

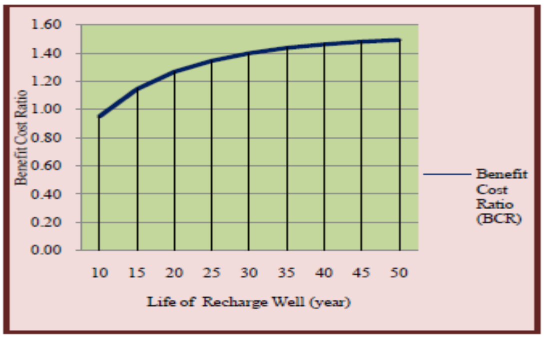

Fig.3. BCR for Different Values of RW Life

3.3. Quality Improvement

Due to recharge of groundwater after implementation of proposed integrated scheme, there will be improvement in quality of groundwater every year. The improvement of in quality is computed for the years 2015 to 2045 in terms of Ground Water Quality Index (GWQI) which is computed using following formula.

Assign a weight/ weightage factor (Gwi) to groundwater quality parameter as per its relative significance and Determine Relative Weight (Gwr). The range of such weightage factors may be framed out according; here its scope is set between 1 to 5 where 1 weightage factor can be assigned to least important parameter and 5 weightage factor assigned to most contributive parameters to overall groundwater quality.

Relative Weight (Gwr) = Gwi / (Gwi + Gwi_{+1}………Gwn) ……………… 11

Determine Quality Rating (qi) for each parameter:

Quality Rating (qi) = (Ci / DSi) x 100 ……………… 12

Where,

qi = quality rating

Ci = concentration of each chemical parameter in each water sample in mg/l

DSi = Indian drinking standard for each chemical parameter according to BIS-10500, 1991

Compute the GWQI

Sli = Gwr x qi ……………… 13

GWQI = ∑ Sli ……………… 14

Where,

Sli = sub-index of ith parameter

The computed results are shown in Table 3.

Year	2015	2025	2035	2045	Percentage Improvement (from 2015 to 2045)
Pre-monsoon					
Maximum	356.74	135.01	83.32	71.27	80.02
Minimum	267.27	114.16	78.46	70.14	73.76
Mean	312.01	124.58	80.89	70.71	77.34

Post-monsoon					
Maximum	345.07	132.29	82.69	71.12	79.39
Minimum	252.72	110.76	77.67	69.95	72.32
Mean	298.90	121.53	80.18	70.54	76.40

Table 3. Year wise Mean Dilution and GWQI (2015-45)

CONCLUSIONS

The proposed integrated approache have both tangible and intangible benefits. The novel stormwater drainage system is found more cost effective than traditional one. The total cost of traditional stormwater drainage system is INR 58783658/-, whereas the total cost of the integrated stormwater drainage system is INR 40481704 /-, which indicate the saving of cost. The Benefit Cost Ratio (BCR) for the proposed integrated approach is 1.492, for the considered life of groundwater recharge well as 50 years. The improvement in quality of groundwater in terms of GWQI is 72.32 to 80.02 percentage from year 2015 to 2045.

This proposed integrated approach is more favourable than the 'do nothing' option. The proposed approach can be a guideline of regular practices to provide stormwater management for Surat Municipal Corporation and other organizations too. The proposed integrated approach also helps in solving the stormwater disposal problem in the study area partially.

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