International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 04, April-2022

Water Self-Sufficiency of Neighbourhood using Artificial Water Ponds

Case Study of Vaijapur, Aurangabad

Saumitra Kapil Jadhav
Department of Architecture
M.G.M.U's Jawaharlal Nehru Engineering College,
Aurangabad, India

Prof. Medha Naik
Department of Architecture
M.G.M.U's Jawaharlal Nehru Engineering College,
Aurangabad, India

***Abstract*— Neighbourhoods use water for drinking, cooking, bathing, washing, and gardening in India. They significantly rely on water sources like rivers, lakes, ponds, and underground water reserves. Due to increasing population and adverse climate changes in recent years, most water resources are on the brink of drying out; in some cases, they already have.**

Rainwater is one of the most underutilized types of water resources with minimal efforts made for its harvest and storage. While some residential buildings like houses and apartments in neighbourhoods are installed with rainwater harvesting measures that collect water from roof runoffs, a significant amount of rainwater falls on impervious hard covered areas like pavements, roads, and other forms of built structures in the same vicinity which ends up in the sewer line and gets contaminated. This rainwater runoff has the potential to fulfil rising water demands on a neighbourhood scale and can be harvested and stored in artificial water ponds and used throughout the year, thereby enabling water self-sufficiency of the neighbourhoods. Such artificial water ponds will be beneficial in fulfilling the water demands of emerging and existing neighbourhoods in Vaijapur, a tehsil in Aurangabad, Maharashtra, where residents are heavily dependent on groundwater reserves during the summer season.

Keywords*— *Water self-sufficiency; neighbourhoods; rainwater harvesting; rainwater runoff; artificial water ponds

I. INTRODUCTION

India has only 4% of the total freshwater resources in the world which provides for the water demand of its 1.3 billion population. With increasing population and decreasing freshwater reserves, various regions of the country are experiencing severe drought or drought-like conditions. Vaijapur, a municipal council in the district of Aurangabad that lies in the region of Marathwada in Maharashtra, India, experienced a severe drought in 2013 and a normal drought in 2014 [1] due to extreme water scarcity. Due to insufficient surface water resources, Vaijapur faces a severe water crisis and finding reliable alternatives becomes critical.

A. Literature Review

The feasibility of the project and water harvesting technique was assessed by referring to the paper '*Assessment of Water Supply and Sanitation by Using Artificial Ponds in Nashik District, India'* [2] which used artificial water ponds to cater to the drinking water demands of the 4,500 people of Janori village in Dindori (20° 12' N latitude and 73° 43' E longitude) in the Nashik district of Maharashtra. The paper concluded that runoff water is drinkable based on the results of the tests carried out in the study area. The results were within the limit of BIS standards and the use of a storage pond system will provide the village with good quality drinking water.

B. Water Source

The primary water source for Vaijapur municipal council is a dam on the Narangi River, which is a tributary of the River Godavari. The dam provides water for agriculture and domestic use. Groundwater pumped through borewells is another source of water in the region, and in some cases, the primary source of water.

Fig. 1. Narangi Sarangi Dam Satellite Image (May-2014)

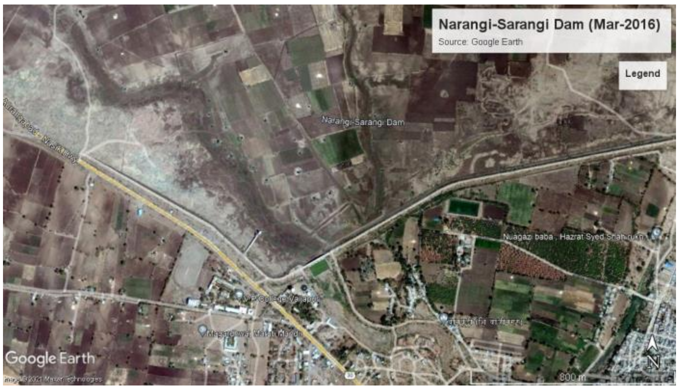

Fig. 2. Narangi Sarangi Dam Satellite Image (Mar-2016)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 04, April-2022

Fig. 3. Narangi Sarangi Dam Satellite Image (May-2017)

Fig. 4. Narangi Sarangi Dam Satellite Image (Nov-2018)

Fig. 1 to Fig. 4 shows the dry state of the river and the dam (19°55'59" N, 74°42'49" E) in recent years when the region experienced severe drought-like conditions. During such drought-like conditions, the population's water demands put a strain on groundwater sources, which in some instances, dry out due to excessive pumping of water.

C. Rainfall

The region receives rainfall from June to September, with the average, minimum, and maximum rainfall being 517.45 mm, 150 mm, and 918 mm respectively [3]. The Vaijapur tehsil experienced severe water scarcity in 2013 (severe drought) and 2014 (normal drought) when the annual average rainfall was 500.6 mm and 566.7 mm respectively [1]. Thus, efficient utilisation of rainwater becomes essential to fulfil the water demands in the region.

D. Rapid Urbanization

In recent years, numerous neighbourhoods have emerged within Vaijapur municipal council's limits. As per the data collected during the site visit of the study area, some residential projects in the vicinity have proposals of constructing 250 to 500 dwelling units (row houses), which will lead to migration from surrounding settlements to the town, thereby increasing water demands. Fig. 5, Fig. 6, Fig. 7, and Fig. 8 show the construction of multiple dwelling units (row houses) in two different neighbourhoods in Vaijapur.

Fig. 5. Jeevan Ganga Society Satellite Map (May-2014)

Fig. 6. Jeevan Ganga Society Satellite Map (May-2021)

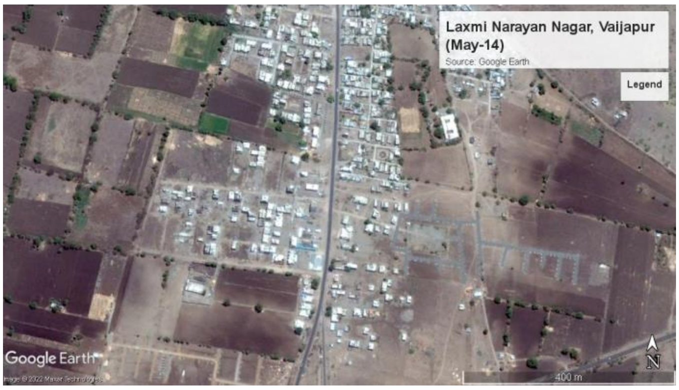

Fig. 7. Laxmi Narayan Nagar Satellite Map (May-2014)

Figure 8. Laxmi Narayan Nagar Satellite Map (May-2021)

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II. METHODS

As rapid construction of neighbourhoods is a common sighting in Vaijapur municipal council's limits, selecting an emerging neighbourhood development project and designing a rainwater harvesting module for the same will help in analysing the efficiency of artificial water ponds in catering to the needs of the neighbourhood's water demands.

A. Site Details

A newly proposed residential neighbourhood project is under development (fig. 9 and fig. 10) on the Aurangabad-Shirdi Highway in Vaijapur, Aurangabad (19°54'36.47"N latitude and 74°44'6.84"E longitude). Fig. 10 shows the identified project area that is spread over 89925.00 m^2 (22.22 acres). Out of the total project area, 41206.51 m^2 (10.18 acres) is allotted for residential development (after deduction prescribed by the local authorities and development by-laws), internal access roads cover an area of 24281.79 m^2 (6.00 acres), and land reserved for open spaces, amenity space and school is 8,937.67 m^2 (2.20 acres), 8,937.70 m^2 (2.20 acres) and 4,000.90 m^2 (0.98 acres) respectively.

B. Population

The identified neighbourhood has plots for development ranging from 70 m^2 to 600 m^2 with an average of one household per 100 m^2 area. In India, the average household population is estimated at around 4.8 to 5.00 persons per household [4]. Based on the given data, Table 1 shows the estimated population of the identified neighbourhood.

TABLE 1. ESTIMATED NEIGHBOURHOOD POPULATION

Total Plotted area for Residential Development	Total Household (1/100 m^2)	Average Population per Household	Estimated Population
41,206.51 m^2	412.06	4.8 to 5.00	1978 to 2060

(Considering 2060 as neighbourhood population for design calculations)

C. Water Demand

As prescribed in the National Building Code (NBC) of India, 2016 Volume II [5], water quantity of 70 to 100 litres per person/capita per day (lpcd) is considered adequate for domestic use and 45 lpcd for flushing needs. Based on the given

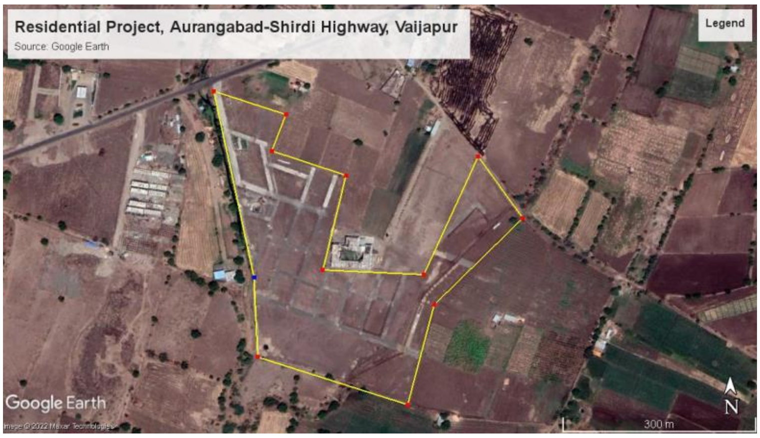

Fig. 9. Newly Proposed Residential Neighbourhood Development along Aurangabad-Shirdi Highway

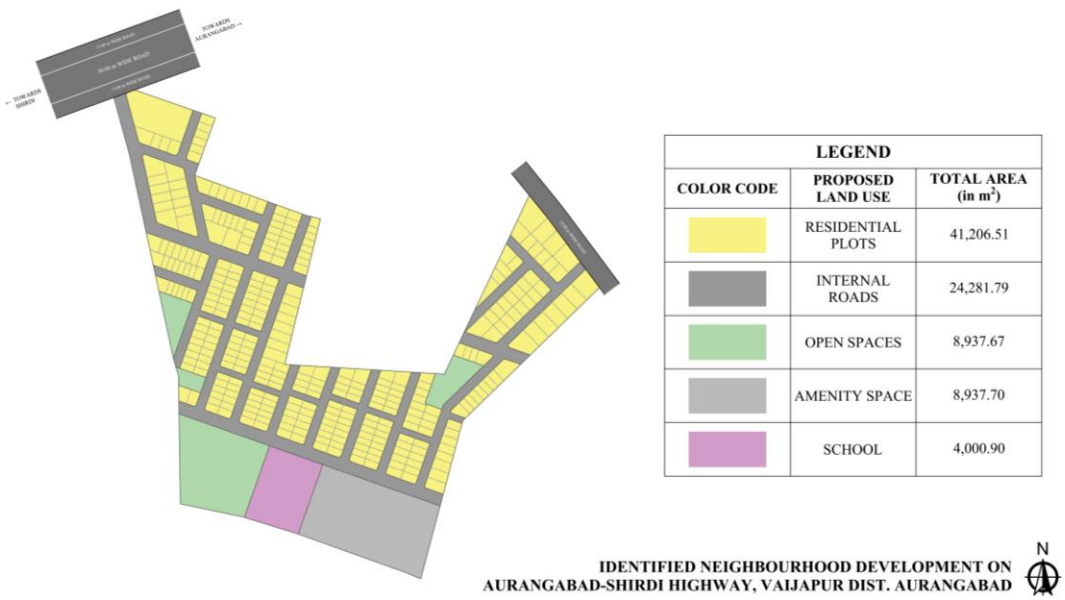

Figure 10. Land-Use Pattern of the Proposed Residential Neighbourhood Development

data, Table 2 shows the estimated water demand of the identified neighbourhood.

TABLE 2. ESTIMATED NEIGHBOURHOOD WATER DEMAND

	Water Demand Per Day (m^3)		**Annual Water Demand (m^3)**	
Estimated Population	**(excluding water for flushing systems)**	**(including water for flushing systems)**	**(excluding water for flushing systems)**	**(including water for flushing systems)**
2060	206.00	298.70	75190.00	109025.50

(Considering 100 lpcd water demand in case of residences excluding flushing systems and 145 lpcd in case of residences including flushing systems)

D. Rainwater Runoff Potential

Rainwater is one of the few scarce sources of water in Vaijapur Taluka, with the region receiving around 517.45 mm of average annual rainfall [3]. From Fig.10 in the case of the identified neighbourhood, rainwater runoff can potentially be harvested from surfaces like rooftops (41206.51 m^2), internal access roads (24281.79 m^2), open spaces (8,937.67 m^2), amenity space (8,937.70 m^2) and plot of land reserved for school (4,000.90 m^2). For calculating the potential of rainwater harvesting by collecting rainwater runoff, four cases have been presented depending on the rainfall trends in the region, taking into consideration the average annual rainfall of 517.45 mm [3] and 590.70, 867.20 mm and 716.00 mm of annual rainfall in the years 2019 [6], 2020 [7] and 2021 [8] respectively. Table 3 shows the rainfall data considered in each of the cases.

TABLE 3. CASES CONSIDERED FOR RUNOFF CALCULATIONS

Case	I	II	III	IV
Rainfall (in mm)	517.45	590.70	867.20	716.00
Year	-	2019	2020	2021

The formula for calculating rainwater runoff volume is [9],

Runoff Volume= Surface area × Runoff Coefficient × Rainfall

The runoff coefficient of different types of surfaces [9] is given in Table 4 which is considered in calculating the rainwater harvesting potential in each of the four cases.

TABLE 4. RUNOFF COEFFICIENT OF SURFACE TYPES

Surface	**Surface Type**	**Runoff Coefficient**
Rooftop	Concrete Pavement	0.95
Internal Access Roads	Cemented/Tiled Roof	0.95
Open Spaces	Turf, Average (1 to 3% Slope)	0.35
Amenity Space	Open grid grass pavement	0.50
Land reserved for school	Turf flat (0 to 1% slope)	0.25

For example,
Annual Runoff volume for a concrete pavement with a surface area of 1000 m^2 and 500 mm annual rainfall is calculated as,

$$Runoff\ Volume = 1000 \times 0.95 \times 0.50 = 475.00\ m^3$$

Table 5 to Table 12 shows the runoff calculations and rainwater harvesting potential of the identified neighbourhood in each of the four cases as shown in Table 3.

E. Comparative Analysis of the Cases

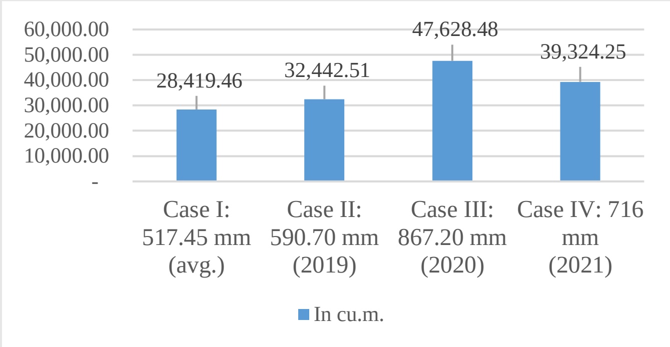

Fig. 9. Rainwater runoff harvesting potential of the neighbourhood in each of the specified cases

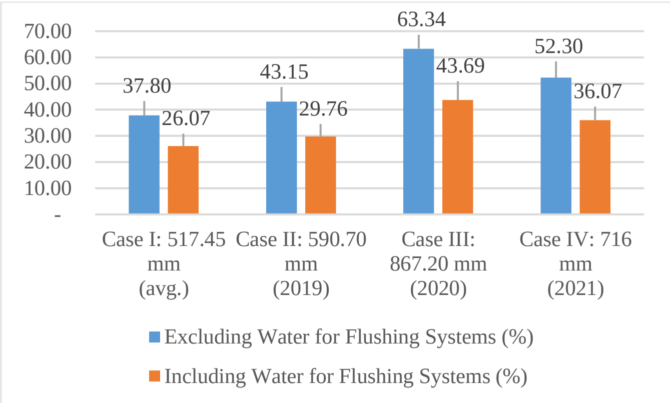

Fig. 10. Water Demand Satisfied in each of the specified cases

Fig. 11 and Fig. 12 show the comparison of the rainwater harvesting potential of the identified neighbourhood and the per cent of the water demands that can be satisfied based on the rainfall data in each of the four cases respectively.

TABLE 5. NEIGHBOURHOOD'S RAINWATER RUNOFF CALCULATIONS FOR CASE I

RAINWATER RUNOFF CALCULATIONS WITH 517.45 mm AVERAGE ANNUAL RAINFALL							
Surface	**Total Area (in m^2)**	**Area Available for Harvesting (in m^2)**	**Annual Average Rainfall (in mm)**	**Runoff Co-efficient**	**Gross Rainwater Harvested (in m^3)**	**Precipitation/ Weather Loss (10%)**	**Net Rainwater Harvested (in m^3)**
Rooftop	41,206.51	30,904.88	517.45	0.95	15192.14	1519.21	13672.93
Internal Access Roads	24,281.79	24,281.79	517.45	0.95	11936.38	1193.64	10742.74
Open Spaces	8,937.67	8,937.67	517.45	0.35	1618.68	161.87	1456.81
Amenity Space	8,937.70	8,937.70	517.45	0.50	2312.41	231.24	2081.17
School	4,000.90	4,000.90	517.45	0.25	517.57	51.76	465.81
Total	87,364.57	77,062.94	-	-	31577.18	3157.72	28419.46

TABLE 6. NEIGHBOURHOOD'S RAINWATER RUNOFF HARVESTING POTENTIAL IN CASE I

WATER DEMAND SATISFIED WITH 517.45 mm AVERAGE ANNUAL RAINFALL			
Demand Type	**Annual Neighbourhood Water Demand (in m^3)**	**Total Rainwater Harvesting Potential (in m^3)**	**Water Demand Satisfied (in %)**
Excluding Water for Flushing	75190.00	28419.46	37.80
Including Water for Flushing	109025.50		26.07
Difference	33835.50	-	11.73

Table 7. NEIGHBOURHOOD'S RAINWATER RUNOFF CALCULATIONS FOR CASE II

RAINWATER RUNOFF CALCULATIONS WITH 590.70 mm ANNUAL RAINFALL (2019)							
Surface	**Total Area (in m^2)**	**Area Available for Harvesting (in m^2)**	**Annual Average Rainfall (in mm)**	**Runoff Co-efficient**	**Gross Rainwater Harvested (in m^3)**	**Precipitation/ Weather Loss (10%)**	**Net Rainwater Harvested (in m^3)**
Rooftop	41,206.51	30,904.88	590.70	0.95	17342.74	1734.27	15608.46
Internal Access Roads	24,281.79	24,281.79	590.70	0.95	13626.09	1362.61	12263.48
Open Spaces	8,937.67	8,937.67	590.70	0.35	1847.82	184.78	1663.04
Amenity Space	8,937.70	8,937.70	590.70	0.50	2639.75	263.97	2375.77
School	4,000.90	4,000.90	590.70	0.25	590.83	59.08	531.75
Total	87,364.57	77,062.94	-	-	36047.23	3604.72	32442.51

Table 8. NEIGHBOURHOOD'S RAINWATER RUNOFF HARVESTING POTENTIAL IN CASE II

WATER DEMAND SATISFIED WITH 590.70 mm ANNUAL RAINFALL (2019)			
Demand Type	**Annual Neighbourhood Water Demand (in m^3)**	**Total Rainwater Harvesting Potential (in m^3)**	**Water Demand Satisfied (in %)**
Excluding Water for Flushing	75190.00	32442.51	43.15
Including Water for Flushing	109025.50		29.76
Difference	33835.50	-	13.39

Table 5. NEIGHBOURHOOD'S RAINWATER RUNOFF CALCULATIONS FOR CASE III

RAINWATER RUNOFF CALCULATIONS WITH 867.20 mm ANNUAL RAINFALL (2020)							
Surface	**Total Area (in m^2)**	**Area Available for Harvesting (in m^2)**	**Annual Average Rainfall (in mm)**	**Runoff Co-efficient**	**Gross Rainwater Harvested (in m^3)**	**Precipitation/ Weather Loss (10%)**	**Net Rainwater Harvested (in m^3)**
Rooftop	41,206.51	30,904.88	867.20	0.95	25460.68	2546.07	22914.61
Internal Access Roads	24,281.79	24,281.79	867.20	0.95	20004.31	2000.43	18003.88
Open Spaces	8,937.67	8,937.67	867.20	0.35	2712.76	271.28	2441.49
Amenity Space	8,937.70	8,937.70	867.20	0.50	3875.39	387.54	3487.85
School	4,000.90	4,000.90	867.20	0.25	867.40	86.74	780.66
Total	87,364.57	77,062.94	-	-	52920.53	5292.05	47628.48

TABLE 10. NEIGHBOURHOOD'S RAINWATER RUNOFF HARVESTING POTENTIAL IN CASE III

WATER DEMAND SATISFIED WITH 867.20 mm ANNUAL RAINFALL (2020)			
Demand Type	**Annual Neighbourhood Water Demand (in m^3)**	**Total Rainwater Harvesting Potential (in m^3)**	**Water Demand Satisfied (in %)**
Excluding Water for Flushing	75190.00	47628.48	63.34
Including Water for Flushing	109025.50		43.69
Difference	33835.50	-	19.66

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 04, April-2022

TABLE 11. NEIGHBOURHOOD'S RAINWATER RUNOFF CALCULATIONS FOR CASE IV

RAINWATER RUNOFF CALCULATIONS WITH 716.00 mm ANNUAL RAINFALL (2021)							
Surface	**Total Area (in m^2)**	**Area Available for Harvesting (in m^2)**	**Annual Average Rainfall (in mm)**	**Runoff Co-efficient**	**Gross Rainwater Harvested (in m^3)**	**Precipitation/ Weather Loss (10%)**	**Net Rainwater Harvested (in m^3)**
Rooftop	41,206.51	30,904.88	716.00	0.95	21021.50	2102.15	18919.35
Internal Access Roads	24,281.79	24,281.79	716.00	0.95	16516.47	1651.65	14864.83
Open Spaces	8,937.67	8,937.67	716.00	0.35	2239.78	223.98	2015.80
Amenity Space	8,937.70	8,937.70	716.00	0.50	3199.70	319.97	2879.73
School	4,000.90	4,000.90	716.00	0.25	716.16	71.62	644.54
Total	87,364.57	77,062.94	-	-	43693.61	4369.36	39324.25

TABLE 12. NEIGHBOURHOOD'S RAINWATER RUNOFF HARVESTING POTENTIAL IN CASE IV

WATER DEMAND SATISFIED WITH 716.00 mm ANNUAL RAINFALL (2021)			
Demand Type	**Annual Neighbourhood Water Demand (in m^3)**	**Total Rainwater Harvesting Potential (in m^3)**	**Water Demand Satisfied (in %)**
Excluding Water for Flushing	75190.00	39324.25	52.30
Including Water for Flushing	109025.50		36.07
Difference	33835.50	-	16.23

F. *Artificial Water Pond Design*

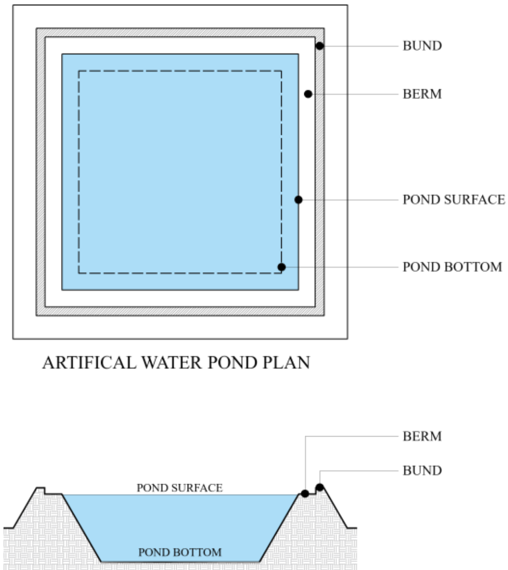

Fig. 11. Typical Layout of an artificial water pond

The identified neighbourhood site at maximum can potentially harvest up to 47,628.48 m^3 of rainwater and satisfy up to 63% (excluding water for flushing systems) or 43% (including water for flushing systems) of the total water demand based upon the calculation shown in Table 9 and Table 10.

Fig. 13 shows a typical layout and components of an artificial water pond and the following are the parameters that are essential in designing and constructing the pond:

1) Volume of the Pond

Based on the calculated data (Table 5 to Table 12), an artificial water pond of around 50,000 m^3 volume will be sufficient to store the neighbourhood's maximum rainwater runoff calculated, i.e. 47,628.47 m^3 with an additional 5% of excess storage volume.

2) Shape of the Pond

Artificial water ponds are mainly constructed in three shapes i.e. square, rectangular and inverted cones. However, as curved shape offers difficulties in construction, either square or rectangular shapes are normally adopted wherein square ponds are more economical than rectangular ponds [10]. In the case of the sidewalls of an artificial water pond, gradually inclined walls are preferred over vertical sidewalls, depending upon the angle of repose of the soil, as they are more efficient in resisting the water pressure exerted on them, thereby giving the artificial water pond a trapezoidal prism shape.

3) Dimension of the Pond

The dimensions of the artificial water pond can be calculated using the prismoidal formula based on Fig. 14 [10].

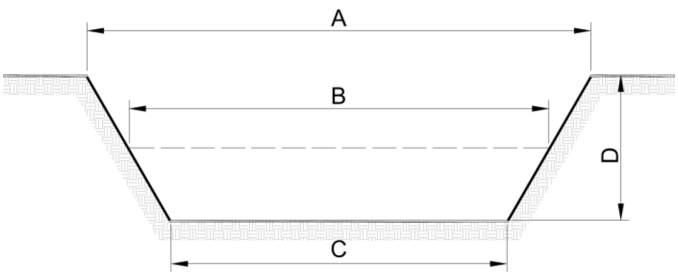

Fig. 12. Cross-section of Artificial Water Pond for estimation of surface and bottom area and sizes

$$\text{Prismoidal Formula: } V = \frac{A + 4B + C}{6} \times D \qquad \text{--- (1)}$$

Where,
V = volume of excavation (m^3)
A = area of excavation at the ground surface (m^2)
B = area of excavation at the mid-depth point (D/2) (m^2)
C = area of the excavation at the bottom of the pond (m^2)
D = average depth of the pond (m).

For constructing artificial water of approximately 50,000 m^3 of volume consider (deeper ponds are preferable to avoid water loss due to evaporation),
D = 9 m
A = 80 × 80 m = 6,400 m^2
B = 75 × 75 m = 5,625 m^2
C = 70 × 70 m = 4,900 m^2

From equation 1,

$$V = \frac{6400 + (4 \times 5625) + 4900}{6} \times 9 = 50700 \text{ m}^3$$

4) Lining of the Pond

The lining is essential in artificial water ponds to avoid seepage of water into the ground. The lining of the pond is generally done using Low-Density Polyethylene (LDPE) or 500-micron High-Density Polyethylene (HDPE) sheets or in reinforced cement concrete (RCC). Though lining done in polyethylene (PE) sheets are more economical than RCC lining, PE sheets are prone to punctures, which can result in rapid loss of stored rainwater. Therefore, for avoiding such instances, RCC lining shall be preferred over PE sheet lining as it is a comparatively more efficient and durable solution.

G. Rainwater Runoff Harvesting Process

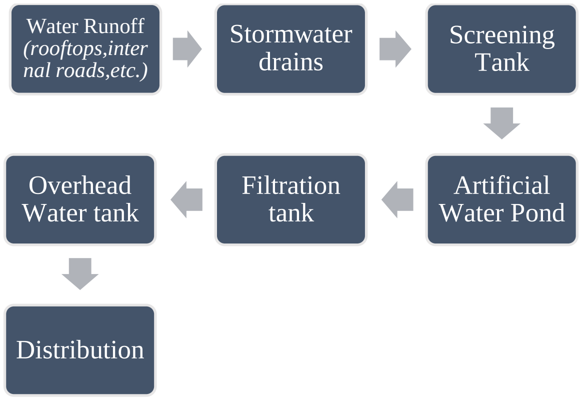

Figure 13. Rainwater Harvesting Process Flow-Chart

(Artificial Water Pond overflow drain shall be connected to percolation tank for recharging groundwater with overflowing runoff water)

III. CONCLUSION

By incorporating rainwater runoff harvesting techniques and storing it in an artificial water pond on-site, the identified neighbourhood site can achieve around 63% (excluding water for flushing systems) or 43% (including water for flushing systems) of water self-sufficiency and avoid dependency on local water grids for a period of 5 to 8 months. This technique can be implemented in other emerging neighbourhood developments in the region or any other region that experiences water shortages. Such strategies can also reduce excess extraction of ground and surface water reserves and help in replenishing the same. In addition to this, recycling and reusing discharged grey and black water on-site can further reduce the water needed for flushing systems in the neighbourhood, as the same water can be treated and reused multiple times.

IV. REFERENCE

[1] Gaikwad, S., Kale, K., & Ambedkar, B. (2015). Agricultural drought assessment of post monsoon season of vaijapur taluka using landsat 8. Https://doi.org/10.15623/IJRET.2015.0408069
[2] Kadbhane, S. (2014, February 19). Assessment of Water Supply and Sanitation by Using Artificial Ponds in Nashik District, India.
[3] Aher, K. (2015). Water Level Fluctuation in the Narangi Watershed of Vaijapur Tahsil, District Aurangabad, INDIA. Universal Journal of Environmental Research and Technology, 5, 278–284.
[4] Census of India: F – Series: Household Tables. (n.d.). Retrieved 6 April 2022, from https://censusindia.gov.in/tables_published/HH-Series/hh_series_tables_20011.html
[5] India-national-building-code-nbc-2016-vol-2.pdf. (n.d.). Retrieved 6 April 2022, from https://pusprajbhatt.files.wordpress.com/2017/12/india-national-building-code-nbc-2016-vol-2.pdf
[6] Chapter_9.pdf. (n.d.). Retrieved 6 April 2022, from https://www.imdpune.gov.in/Clim_Pred_LRF_New/Reports/Monsoon_Report_2019/Chapter_9.pdf
[7] Monsoon Report 2020.pdf. (n.d.). Retrieved 6 April 2022, from https://www.imdpune.gov.in/Clim_Pred_LRF_New/Reports/Monsoon%20Report%202020.pdf
[8] Maharashtra: Marathwada gets 131% of normal rainfall, highest among 6 divisions. (2021, September 7). The Times of India. https://timesofindia.indiatimes.com/city/aurangabad/marathwada-gets-131-of-normal-rainfall-highest-among-6-divisions/articleshow/85995039.cms

[9] Green Home Builders—IGBC Green Homes in India | IGBC. (n.d.). Retrieved 19 April 2022, from https://igbc.in/igbc/redirecthtml.htm?Redval=showgreenhomesnosign
[10] Farm ponds technical bulletin 2012.pdf. (n.d.). Retrieved 6 April 2022, from http://www.nicra-icar.in/nicrarevised/images/Books/Farm%20ponds%20technical%20bulletin%202012.pdf