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Economic Feasibility Study of Community Scale Reverse Osmosis Plants in Jaipur, Rajasthan

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Abstract: This study presents a performance analysis in terms of energy and other costs related to the unit cost of water produced in 16 identical community scale reverse osmosis units installed at Jaipur. The energy consumptions indicated that these plants suffer from accelerated fouling of membranes due to scaling by hardness causing substances, which results in a significant loss of useful life of the membranes.

The study shows that the overall cost of water production has four major components. Energy cost varies between Rs. 0.025 and 0.079 per litre. Salary cost varies between Rs. 0.04 to 0.20 per litre. Spares and chemical cost varies between Rs. 0.01 to 0.04 per litre. In addition, repayment of capital invested has also been considered with and without solar integration to arrive at realistic cost estimates over a perceived life cycle of the system. The breakeven achieved by selling 4600–5200 litre water @ Rs. 0.2 per litre per day if repayment of capital investment is not considered, as these units were installed under CSR, while it varies between 8800 and 9600 litre if repayment of capital investment is also considered as an independent business venture. This analysis substantiates that potential exists for the long-term sustainability of these systems.

Key words: Corporate social responsibility, total dissolved solid, solar integration, reverse osmosis.

Introduction

Water scarcity is one of the most serious global challenges and needs urgent attention; population growth, industrialisation, and climate change have exacerbated this problem. More than one billion people worldwide lack adequate access (Pichel et al., 2019) to potable water, and almost two million children die each year due to inadequate access to clean water and basic sanitation facility. Worldwide, consumption of water for municipal, industrial and agricultural uses is expected to increase substantially and aggravate this already gloomy situation (Imbrogno et al., 2017).

The fact that only around 0.8% of the total earth's water is fresh water is compelling numerous researchers in an endeavour to develop more sustainable technological solutions (Christopher et al., 2019) that would meet increasing water consumption. Creating new sources of high-quality water through reclaiming, recycling, and reusing water remains the only way to address these challenges.

Reverse osmosis (RO) technology is a widely adopted technology for getting potable water from raw brackish/saline water by passing it at high pressure through a thin film composite polyamide membrane. Significant development has been witnessed in membrane technology with respect to materials, synthesis techniques, modification and modules over the last few decades (Shenvi et al., 2015). The desalination process (Yehia et al., 216) has served as a promising

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alternative to deliver a huge quantity of fresh water and is gaining popularity due to a significant drop in the energy needed for RO desalination from 12 KWh/M^3 to approx. 2 KWh/M^3 over the past two decades (Imbrogno et al., 2017). International Desalination Association (IDA) has statistically shown that by 2015, up to 16,000 desalination plants have been installed in more than 150 countries where the production of fresh water has achieved 90 million M^3/day worldwide (Goh et al., 2016). According to a recently published report (Tech Sci Research, 2017), India's water desalination market is all set to grow at a CAGR of 22% for the next five years for providing clean drinking water to each individual through the installation of community-scale drinking water treatment plants.

RO plants are easy to install, operate, maintain, and can help remove multiple pollutants. This was the reason for their adoption in the Rajasthan state, where groundwater has a high concentration of fluorides, nitrates and total dissolved salts (Jianhua et al., 2016). These units require a moderate amount of energy to operate as compared to other desalination (Henthorne et al., 2015) processes.

Various studies conducted on the public perception of Community RO plants (Khaiwal et al., 2019), (Emmanuel et al., 2019) and economic study (Atab et al., 2016) show that the sustainability of these plants is a concern due to operational and maintenance cost (Capocelli et al., 2019) apart from the awareness among users. Numerous researchers have done a lot of research work on RO plants whereas limited work was encountered in the literature for community RO plants towards cost analysis, chemical consumption, membrane replacement, manpower and detail analysis of techno-economic feasibility with managerial intervention. Therefore, the present study aims at a detailed analysis of techno-economic feasibility and proposes managerial interventions to achieve long-term sustainability of these community RO plants.

Bosch Limited, Jaipur has also installed clean drinking water plants nearby one of its manufacturing units located at SP-663, RIICO Industrial Area, Sitapura, Jaipur. Bosch has installed these RO plants under Corporate Social Responsibility (CSR). It works on a tripartite partnership model, as per the following roles: Bosch limited for providing Capital Investment for complete infrastructure

1. Gram Panchayat for providing land and water supply.
2. Society for operation & maintenance of the plants.

Details of the RO plant room accommodating RO equipment, water storage tanks and other accessories are shown in Figures 1. RO plant equipment is shown in Figure 2. The single line diagram of the RO plant is shown in Figure 3.

In the present study, a techno-economic analysis of 16 community-based reverse osmosis units installed in district Jaipur of Rajasthan having identical capacity of 1000 litre per hour (LPH) and different geographical expanse had been carried out to assess their long-term sustainability. Various parameters considered for evaluation are power consumed, raw water quality, operator salary, membrane replacement, pre-filter replacement, chemical consumption, operation & maintenance (O&M), etc., which have a significant impact on the economic viability of the plant. The objective of the study was to understand the cost apportionment among major parameters for operating a community-based RO plant to assess their long-term commercial viability and sustainability. The data generated can help develop design principles of such systems for their large-scale rural interventions.

Figure 1: RO plant room accommodating RO equipment, water storage tanks and other accessories.

Figure 2: RO plant equipment.

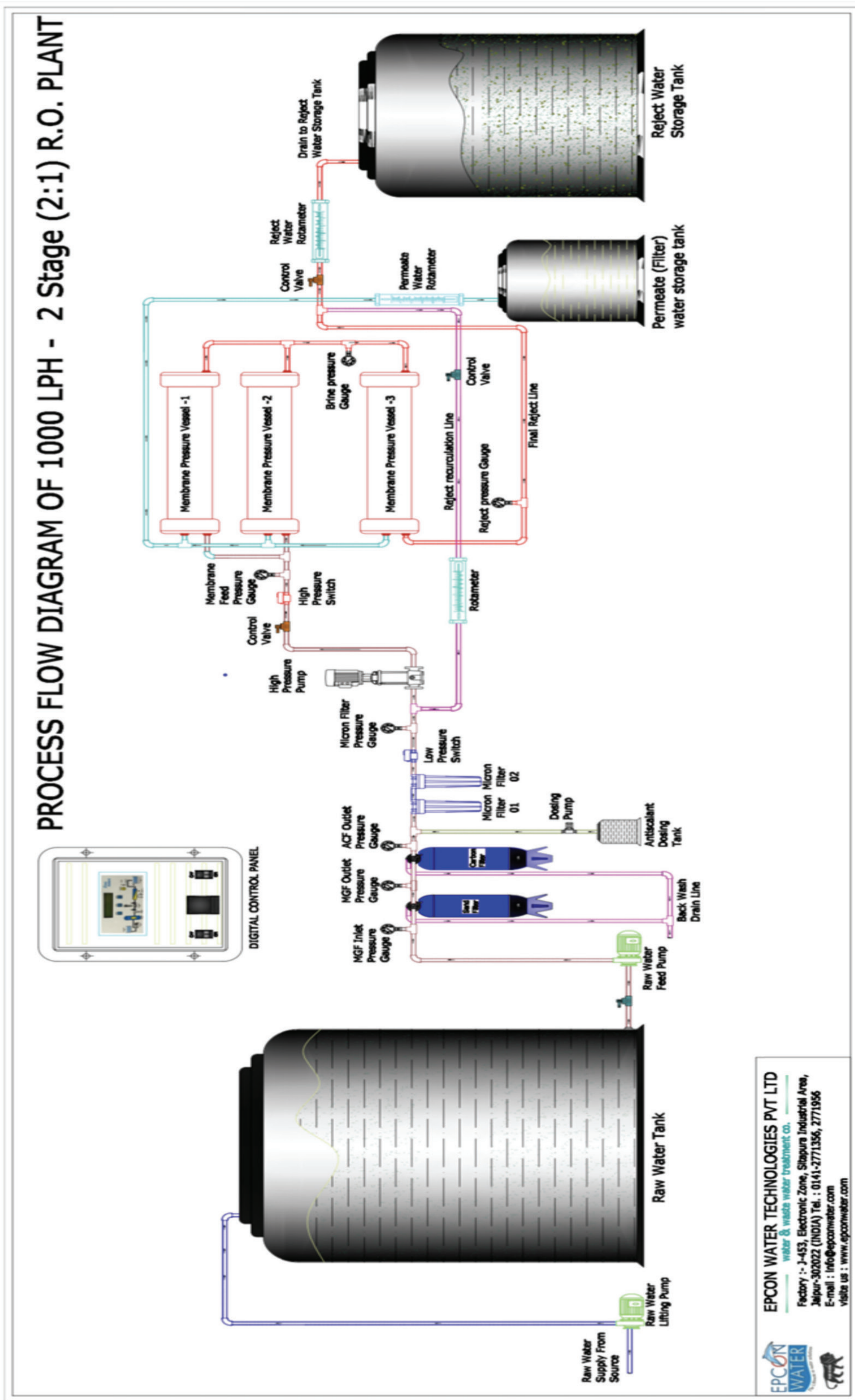

Figure 3: Single line diagram of the RO plant operation.

Methodology

This section presents the details of the RO plants covered under the study along with the other parameters.

Coverage Area of the Study

These plants are installed in areas where the groundwater is not fit for drinking purposes due to high values of either of the chemical parameters like TDS, nitrates and fluorides. The locations of 16 RO plants covered under the study are shown on Google map in Figure 4. Location GPS coordinates of RO plants situated near the Jaipur area are shown in Table 1.

Table 1: GPS coordinates of the RO plants under study

Sl No.	*Site*	*Location coordinate*	
1	Siroli	26°48’07.4”N	75°54’14.2”E
2	Prahladpura	26°44’10.8”N	75°52’53.4”E
3	Sukhdevpura	26°44’50.6”N	75°49’14.3”E
4	Shyapura	26°46’43.3”N	75°46’25.9”E
5	Bhondo Ki Dhani	26°45’06.5”N	75°50’05.9”E
6	Mohanpura	26°42’43.01”N	75°49’49.64”E
7	Pawaliya	26°44’37.9”N	75°41’03.2”E
8	Vatika	26°42’49.5”N	75°48’22.0”E
9	SKN	26°46’03.8”N	75°49’29.9”E
10	Muhana	26°47’54.6”N	75°43’46.1”E
11	Sahbhagita	26°44’19.0”N	75°49’34.9”E
12	Vijaypura	26°53’56.6”N	75°54’57.7”E
13	Vidhani	26°46’50.2”N	75°52’31.4”E
14	Mathurawala	26°45’13.8”N	75°52’19.7”E
15	Sri Kishanpura	26°47’58.6”N	75°51’52.6”E
16	Bad Shyopur	26°45’08.6”N	75°49’44.9”E

Figure 4: Google location of the RO plants under study.

Table 2: Raw water quality

Plant/ parameters	*Siroli*	*Watika*	*Shri Ram Ki Nanqal*	*Muhana*	*Prahladpura*	*Sahbhgita*	*Vijaypura*	*Sukhdevpura*	*Shaypura*	*Bhondo KI Dhani*	*Mohanpura*	*Vidhani*	*Mathurawala*	*Shri Kishanpura*	*Bad Shoypur*	*Pawaliya*
Color	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Turbidity	BDL	BDL	BDL	BDL	BDL	4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	58	BDL	BDL
pH	8.06	7.34	7.36	7.4	7.31	7.38	7.39	7.6	7.27	7,39	7.46	7.55	7.70	7.44	7.41	7.35
Hardness	108	720	170	310	540	170	300	100	130	180	180	390	160	240	140	360
Iron	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Chloride	204.42	973.88	154.28	139.81	511.05	139.81	366.41	144.64	72.32	395.34	269.99	356.77	376.05	520.69	202.49	327.84
TDS	1449	3201	1433	877	2224	1218	1746	1044	828	2156	1608	1592	2377	2502	1440	1903
Calcium	17.6	168	36	64	104	40	48	20	28	32	28	64	24	40	20	56
Maqnesium	15.55	72.9	19.44	36.45	68.04	17.01	43.74	12.15	14.58	24.3	26.73	55.89	24.3	34.02	21.87	53.46
Nitrate	11.44	16.76	15.83	3.71	13.76	16.4	14.17	16.79	13.69	18.38	15.34	14.7	16.79	16.02	18.51	14.31
Fluoride	2.9	1.54	1.26	1.3	1.11	1.24	1.77	1.32	2.6	1.45	1.33	1.14	1.47	1.48	1.35	3.25
Alkalinity	712.8	673.2	811.8	425.7	871.2	673.2	594	504.9	405.9	950.4	782.1	485.1	1207.8	1227.6	752.4	772.2

Equipment Used

Following equipment used for data collection:Electricity Meter (Make Genus, Jaipur Meter)

1. Mechanical Water Meters (Make Dasmesh, Janta)
2. Portable TDS meter (Make Hanna)
3. Portable pH Meter (Make Hanna)

RO Plant Specifications

All RO plants considered in this study are of similar specifications as mentioned below:

1. 1,000 LPH RO plant capacity (Make Epcon)
2. 20 × 20 Ft^2 room provided for installation of RO plant and other accessories.
3. Water ATM for 24×7 Water distribution (Make Aster)
4. 10000 litres product water storage and 5000 litres Raw Water Storage capacity (Make Polycon)
5. Water sold at Rs. 0.20 per litre cost as per Government of Rajasthan recommendations.
6. Operation & Maintenance (O & M) of Plant is done by Society (Green Future Foundation) using the generated revenue.

Data Collection and Processing

Data of the following parameters were collected from all individual plants for the period of one year from 1st April 2019 to 31st March 2020.

1. RO plant specification (All the 16 plants are of similar specifications as shown in the section on RO Plant Specifications)
2. Raw water source, cost of water (Table 8)
3. Raw Water Quality (Table 2)
4. Electricity Consumption & Cost (Table 8)
5. Product water Quantity, Quality & revenue generated (Table 8)
6. Operator Salary, Management/Supervision Charges (Table 8)
7. Spare & Chemicals/other consumables (Table 8)
8. Miscellaneous Expenses (Table 8)

The above data were analysed and contributions of individual parameters to the total cost were calculated. Data from different plants were compared to understand the reasons for major variations. After identification of major variations in cost components, alternatives are suggested to minimise them.

Results and Discussion

Observations of different cost components of the 16 plants compiled and their impact were studied on the total cost of production of water. Detailed calculations for one of these RO plants along with the break even calculations are presented in the following sections.

Capital Expenditure Calculation

Table 3 shows the capital cost of three major components of these plants obtained from their records. Since they all have similar specifications and are installed by the Bosch Registered Agency under similar contract conditions, their capital cost is approximately the same barring a minor variation due to the commissioning period only.

Table 3: Plant, building and machinery cost

Sl No.	*Particulars*	*Cost in Rupees*
1	RO Plant cost including machinery and installation	360000
2	Land cost	100000
3	Civil and other cost	835700
	Total cost	1295700

Table 4 shows the EMI calculation for the capital investment in case an individual entrepreneur (return on capital investment) does the installation. Here the payback period is considered as 10 years only to have the invested amount back and the plant life is still continued (average life can be taken as 30 yrs). As a power, cost plays a major role in water production cost; in addition to this, the solar integration possibility (Hafeez et al., 2021) was also studied to reduce/eliminate the dependence on electric power cost and its inflation. Table 5 shows the detailed investment and saving calculations for solar integration. Since the interest on capital constitutes a substantial fraction of the total cost, smaller capacity RO plants should be installed at places where less demand is available, which is not likely to increase much, to bring down its contribution.

Table 4: Capital expenditure EMI calculation

Sl No.	*Particulars*	*Details*
1	Principal amount	1300000
2	Rate of interest	12%
3	Tenure in years	10
4	EMI per month	18651

Table 5: Saving calculation from solar integration

Sl No.	*Particulars*	*Details*
1	Solar installation cost 4 kW plant	200000
2	Solar generation (kWh)	5600
3	Power cost saving INR (@ 8 Rs/kWh)	44800
4	Monthly power saving INR	3733
5	Principal amount INR	200000
6	Rate of interest	12%
7	Tenure in years	10
8	EMI per month INR	2869
9	Net saving per month due to solar integration INR	864

Detailed Operating & Maintenance Cost Calculations

The operation and maintenance costs incurred under different heads are calculated on an annual basis by assuming the change of RO membranes in an average period of 4 years. Detailed calculations for one plant located at Siroli village are shown in the following section.

Tables 6 and 7 show a summary of expenses incurred under various major heads of expenditure calculated on an annual basis to derive the unit cost of water produced for the Siroli plant. A pie chart shown in Figure 5 indicates the fractional costs. It is observed that the expenditure on salary plays a significant role and accounts for about 50% of the total water production cost. Optimisation of deployed work force should be the major criterion to make a plant sustainable. RO plant can serve a cluster of villages around plants to increase the demand and/or by integration with an industry/commercial establishment for better economic returns with the excess water produced. Another alternative is to install a cluster of RO plants thereby facilitating a centralised operation & management of plants through minimal work force resources after enhancing the demand as suggested previously. Apart from this, attachment of few distribution centers (water ATMs) with a single RO plant or an integrated cluster of plants to increase the serving area.

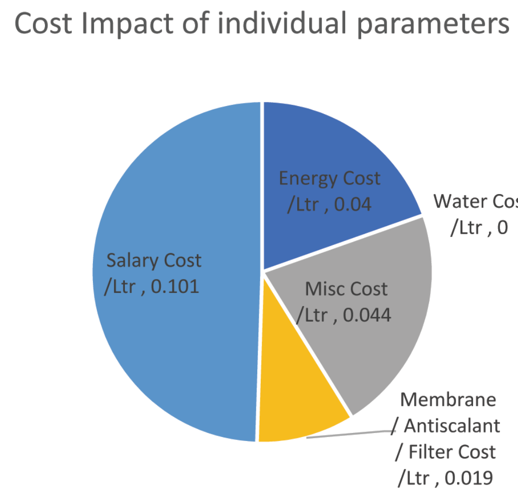

Figure 5: Cost impact of individual parameter on water production at Siroli plant.

It is also observed that Breakeven of the plant arrived at 231 cans (4620 litres water) per day selling if the repayment of capital invested is not considered. If repayment of capital invested is considered, then

Table 6: Annual summary of the expenses and the total water produced

Electricity charges (Rs.)	*Misc. expenses (Rs.)*	*Spare & chemical cost (Rs)*	*Salary (Rs.)*	*Water produced (L)*
64,805	70,200	30,844	163,500	1,613,119

Table 7: Impact of O&M cost on water production in Rs.

Energy cost/litre	0.040
Water cost/litre	-
Miscellaneous cost/litre	0.044
Spare & Chemical cost/litre	0.019
Salary cost/litre	0.101
Total cost/litre	0.205
Selling cost/litre	0.200

the breakeven arrives at the sale of approximately 550 cans per day. Breakeven calculation done assuming all other costs is considered to be constant except for salary and repayment of capital invested return cost. Here the assumption is that 1.3 MINR is the capital investment and the monthly installment of the same @ 12% interest rate for a period of 10 years is 18651 INR per month.

Energy cost is about 20% and substantial reduction is possible by deploying solar integration. Electricity consumption for one year is ~6600 kWh. Solar plant of 4kW can generate ~ 5600 kWh (based upon actual minimum generation from Solar plant installed at the Bosch premises) units annually. Since the plant is installed under CSR, hence increasing the capital cost of the plant and machinery by only 15% only (plant installation cost is 1.3 MINR and solar plant cost is 0.2 MINR), the energy cost can be reduced by 75%. This will result in the reduction of water production costs as well as it will take care of inflation associated with the commercial supply of electricity. Investment and saving calculations with solar integration are shown in Table 5.

Summary Results of all 16 RO Plants

Table 8 presents a summary of similar cost calculations for all the 16 plants put together. The energy cost varies from Rs. 0.025 to 0.079 per litre of RO water produced. The average cost is 0.035 INR/litre if only the RO plant is operated, while the average cost increases to 0.04 $\pm$ 0.01 Rs./litre of water produced if the consumption for both the plant operation and withdrawal of groundwater is combined. In cases where the energy cost is relatively less, the feed water for RO is procured from an external source. In some cases, energy costs are high, due to the additional energy consumption for providing additional facilities like water-cooling; reject water pumping for use by the society for other purposes than drinking. Solar integration is suggested to optimise energy cost as the average insolation in Jaipur is quite high across the year and it may offer a viable proposition.

The cost of procuring feed water varies between 0 to 0.0549 Rs/Litre of water produced**.** Where the cost of water withdrawn from a bore well is taken as Rs. 0 (zero) and the pumping charges are included in the energy consumption, while in some cases, it is recommended that the plants should have their own dedicated bore well for their operations for ensuring long term sustainability, which can also be operated with solar pumps.

Operator salary constitutes a major portion of the water production cost. Salary cost varies between 0.0420 to 0.2009 Rs/litre of water produced, which is due to the payment of fixed minimum wages to the operators as per government regulations. Increasing the water demand can bring down the production cost. Only three plants (Prahladpura, Bhondo Ki Dhani, Pawaliya) out of 16 are not able to meet the breakeven due to less number of consumers associated with them. Workforce optimization should be the major criterion to make a plant sustainable by using some measures suggested in the section: Detailed Operating & Maintenance Cost Calculations. Information, education and consultation (IEC) activities should also be taken up regularly to increase awareness among users, particularly encouraging them to use this water not just for drinking, but for the preparation of food also.

The cost of consumables varies between 0.0143 to 0.0457 Rs./litre of water produced. It varies due to a highly variable quality of raw water leading to differential consumption of chemicals and frequency of changing the pre-filters. Average cost is 0.017 Rs./litre.

Some additional technological interventions are also being scrutinised like integration with vacuum membrane distillation (VMD) for recovery of potable water from the reject stream as most of these areas face acute water scarcity; reuse of reject membranes for low-end applications for cost recovery etc. for exploring long-term sustainability measures. Studies are also underway to calculate health benefits in some tangible terms due to the availability of better quality water.

Conclusions

Community RO plants can play a key role in providing safe drinking water to society at a nominal cost. Community RO plants, if managed efficiently are self-sustained as reflected in the cost estimations shown in this study. This study has indicated that an overall cost optimisation can be achieved with simple interventions and these plants offer a viable business model to ensure their long-term sustainability.

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Table 8: Summary of cost analysis of all 16 RO plants

Plant/ parameters	*Energy cost/ltr*	*Water cost/ltr*	*Misc cost/ltr*	*Spare & chemical cost/ltr*	*Salary cost/ltr*	*Capital cost/ltr*	*Total Cost/Ltr*	*Selling cost/ltr*	*Average cans daily*	*Water source and charges*
Siroli	0.0402	0.0000	0.0435	0.0191	0.1014	0.1233	0.3275	0.2	221	B/w, Single Elecric Meter, No Water charge
Prahladpura	0.0412	0.0000	0.0411	0.0457	0.1607	0.5075	0.7962	0.2	54	B/w, single Elecric Meter, No Water charge
Sukhdevpura	0.0488	0.0000	0.0090	0.0180	0.0580	0.0908	0.2245	0.2	300	B/w, single Elecric Meter, No Water charge
Shyapura	0.0495	0.0000	0.0116	0.0207	0.0820	0.1525	0.3163	0.2	178	B/w, single Elecric Meter, No Water charge
Bhondo Ki Dhani	0.0622	0.0000	0.0029	0.0389	0.2009	0.3736	0.6785	0.2	73	B/w, single Elecric Meter, No Water charge
Mohanpura	0.0790	0.0000	0.0064	0.0167	0.0651	0.0996	0.2667	0.2	273	B/w, single Elecric Meter, No Water charge
Pawaliya	0.0599	0.0000	0.0452	0.0310	0.1603	0.2982	0.5946	0.2	91	B/w, single Elecric Meter, No Water charge
Sumel	0.0329	0.0000	0.0016	0.0315	0.1315	0.3060	0.5035	0.2	89	B/W, No Charge
Vatika	0.0496	0.0292	0.0112	0.0143	0.0526	0.0588	0.2158	0.2	463	PHED, Fix Charge 4144 / Month
SKN	0.0504	0.0000	0.0295	0.0162	0.0445	0.0582	0.1988	0.2	468	B/W, No Charge
Muhana	0.0377	0.0212	0.0167	0.0244	0.1305	0.1755	0.4060	0.2	155	B/w, Fix charge 2000/Month
Sahbhagita	0.0476	0.0088	0.0069	0.0198	0.0631	0.1218	0.2680	0.2	223	B/w, single Elecric Meter, 2000 water charge
Vijaypura	0.0373	0.0391	0.0412	0.0146	0.0420	0.0648	0.2389	0.2	420	B/w, single ElecricMeter, Tanker
Vidhani	0.0256	0.0549	0.0243	0.0214	0.1028	0.1719	0.4008	0.2	158	RIICO, Water through Meter
Mathurawala	0.0424	0.0000	0.0197	0.0235	0.0985	0.1735	0.3577	0.2	157	B/W, Separate Meters
Sri Kishanpura	0.0564	0.0064	0.0355	0.0195	0.0649	0.0993	0.2819	0.2	274	B/W, Separate Meters
BaadShyopur	0.0314	0.0049	0.0161	0.0178	0.0585	0.0859	0.2145	0.2	317	B/W, Separate Meter

B/w – Bore well, PHED/RIICO – Public Health Engineering Department (Government Water Supply)

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