doi: https://doi.org/10.4995/WDSA-CCWI2022.2022.14821

INVESTIGATION OF GROUNDWATER CONSUMPTION TO COPE WITH THE INADEQUATE PIPED WATER SUPPLY IN CONTINUOUS AND INTERMITTENT SUPPLY SYSTEMS: A CASE STUDY IN BANGALORE, INDIA

B.N. Priyanka[1], Bharanidharan B.[2], Sheetal Kumar K.R.[3], M.S. Mohan Kumar[4]; V.V. Srinivas[5], Sanjana R Nibgoor[6] and Kishore Y.[7]

[1]Research Associate, Interdisciplinary Centre for Water Research (ICWaR), Indian Institute of Science (IISc), Bangalore, Karnataka, (India).
[2,3]Research Scholar, Department of Civil Engineering, IISc, Bangalore, Karnataka, (India).
[4]Formerly Professor, Department of Civil Engineering and ICWaR, IISc, Bangalore, Karnataka, (India).
[5]Professor, Department of Civil Engineering, Associate faculty ICWaR, IISc, Bangalore, Karnataka, (India).
[6,7]Project Assistant, ICWaR, IISc, Bangalore, Karnataka, (India).

[1] *E-mail: priyankabn@iisc.ac.in; [2] E-mail: bharanib@iisc.ac.in; [3] E-mail: sheetalkumar@iisc.ac.in;*
[4], E-mail: msmk@iisc.ac.in;[5] E-mail: vvs@iisc.ac.in; [6] E-mail: sanjanan@iisc.ac.in;
[7]E-mail: kishorey@iisc.ac.in

Abstract

Although the supply of piped water to the Indian cities is increasing, the demand is not always fulfilled. This gap in water demand and supply is usually bridged by using alternate sources of water, mostly groundwater. Bangalore, the capital city of Karnataka, is one of the fastest developing metropolitan cities in India and is also facing piped water supply issues. The groundwater is the main source of alternate water supply in the city. In the present study, a District Metered Area (DMA) is selected in the Bangalore South-West division; this DMA has both intermittent and continuous water supply systems. The water distribution network (WDN) of study DMA contains four inlets and five supply zones. The first is a continuous water supply system whereas the other four are intermittent systems. The impact of inequitable consumption in the study DMA is evaluated using Lorenz Curve and Gini Coefficient and the consumption of groundwater to cope with insufficient water supply is analyzed. The data used for the present investigation are from the field flowmeters, consumer meter reading, and door-to-door questionnaire survey are used for the analysis. The questionnaire survey includes RR (revenue register) number, presence of wells/borewells, horsepower (HP) of the pumps used, building type, the number of inhabitants, and the floors in each building. In the continuous supply system, a questionnaire survey was untaken for 80% of the connections, whereas in the intermittent supply system random sampling was used. The questionnaire survey analysis showed that only 27% of the consumers in the continuous supply system rely on piped water supply, whereas others used groundwater as well as piped water supply. The study illustrated the gap in groundwater consumption between supply zones within intermittent water supply systems. Reliability on groundwater was high even in continuous supply systems indicating insufficient pressures resulting in unsatisfied demands. The study indicated that just increasing the access to the piped water supply to the consumers is not sufficient, the acceptable quality with adequate pressure of water should be delivered to reduce the use of groundwater. The inferences from the study can be used to regulate groundwater extraction.

Keywords
Groundwater consumption; Intermittent water supply, Continuous water supply; Lorenz Curve and Gini Coefficient.

1 INTRODUCTION

Bangalore, the capital city of Karnataka, is facing an imbalance in the rates of water demand and supply due to rapid population growth and industrialization. About 70% of the municipal water to the city is supplied by the Bangalore Water Supply and Sewerage Board (BWSSB), which is also responsible for sewage disposal. Currently, 60% of the BWSSB water supply is met by the Cauvery River which is drawn from about 100 km against an elevation of 540 m and the rest water demand is met by groundwater pumping (Mohan Kumar et al., 2011). The gap between the water supply and demand in the city is satisfied mostly by groundwater, even at the DMA (District Metered Area) level. The groundwater consumption is not only in intermittency areas but also seen in areas with continuous water supply. To understand the reason for groundwater consumption in the 24/7 system and intermittent supply system, J.P. Nagar Phase 1 DMA in the south division of Bangalore, Karnataka, India (Figure 1)was selected.

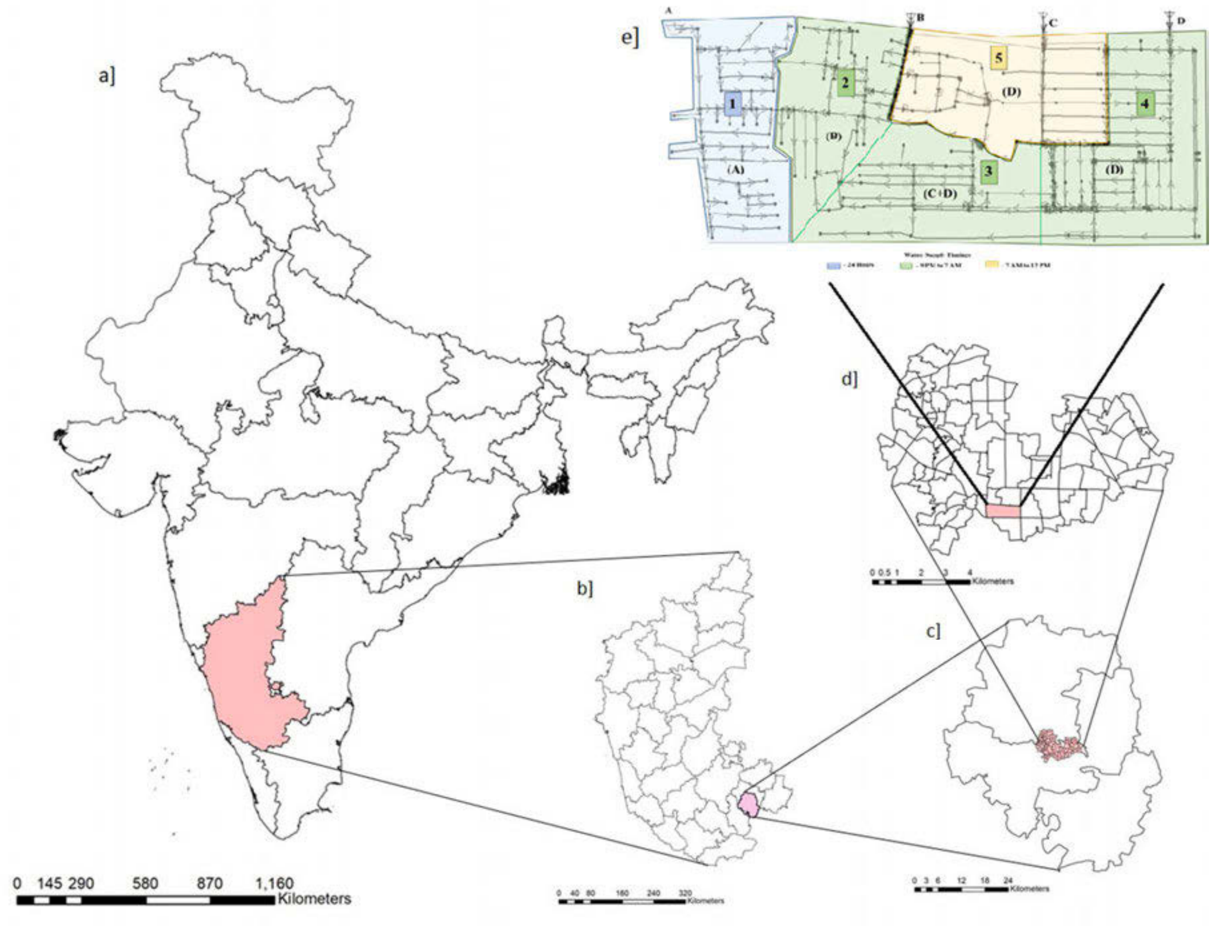

Figure 1. Geographic description of the selected DMA within a) country: India, b) state: Karnataka, c) district: Bangalore urban, and taluks: Bangalore South d) division: Southwest division 4 e) DMA: J P Nagar Phase 1 with water distribution pipe network, four inlets (named A, B, C, D), and five supply zones (supply zone 1 is continuous and zones 2, 3, 4 & 5 are intermittent).

The aerial extent of the pilot service DMA is 0.68 km^2 and the population is about 22158 (as per BWSSB J.P. Nagar Phase 1 DMA report, 2013). The topographic elevation of the DMA varies from 898.58 m to 918.54 m. There are 2399 properties with 295 without RR (revenue register) numbers which includes vacant plots. The total length of the pipeline in pilot DMA is 22174 m and the pipe diameters range from 100 mm to 300 mm with a weighted average diameter of 125 mm.

The pipelines are of cast iron, PVC, ductile iron, and mild steel, out of which PVC is of majority with 10608 m in length and 32 years of age.

There are 4 inlets to the J.P. Nagar Phase 1 DMA (Figure 1e), which is serviced by Cauvery 2nd stage 1200 mm diameter transmission main. The supply schedule for zone 1 through inlet A (Figure 1e) is 24 hours every day. For zones 2, 3, and 4 the supply schedule is from 21:00–7:00 through inlets B, C+D, and D, respectively on alternate days, and for zone 5, the schedule is from 7:00–12:00 through inlet D on alternative days.

2 METHODOLOGY

2.1 Inequity Analysis

In the past several researchers have used economic indices to evaluate the inequality in water supply, consumption, supply hours, time of supply, etc., (e.g. Guragai et al., 2017; Malakar et al., 2017; Sheetal Kumar et al., 2018). For the inequity study, we have used the Lorenz curve and Gini Coefficient (GC), which are most commonly used.

The Lorenz curve is a graphical representation of the distribution of water. The deviation curve from the 45-degree equality line is called the Lorenz curve. Farther the Lorenz curve is with respect to the 45-degree perfect equality line, the more unequal is the distribution. Gini Coefficient is a value computing the ratio of the area enclosed by the line of equality and the Lorenz curve to the area under the line of equality. A higher GC value represents a more inequity and varies between 0 and 1. To plot the Lorenz curve, water consumption is considered in terms of liters per capita (lpcd), this data is converted as weighted consumption and then cumulative consumption is estimated. These cumulative consumption values are plotted on y-axis and the cumulative population on the x-axis.

2.2 Estimation of Groundwater Consumption

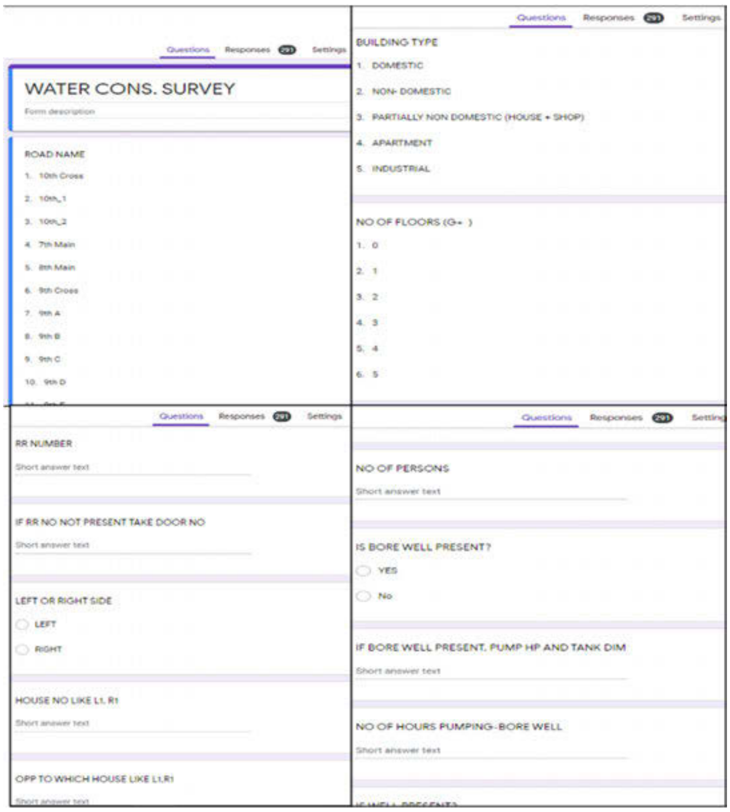

Figure 2. Google forms papered for door-to-door questionnaire survey.

Door to door questionnaire survey was carried out to estimate groundwater consumption in J.P. Nagar phase 1 DMA. The data collected during this survey are details regarding RR number, presence of wells/borewells, horsepower (HP) of the pumps used, building type, the number of inhabitants, the floors in each building, time of pumping, and hours of pumping (Figure 2). In the continuous supply system, a questionnaire survey was taken for 80% of the connections, whereas in the intermittent supply system random sampling was used.

The groundwater consumption in each house was calculated using the following equation.

$$Q_p = 249.84 \frac{P_{hp} \times \eta}{H \times SG} \tag{1}$$

where Q_p is the pump flow rate in l/s; P_{hp} is the pump horsepower; η is the pump efficiency (assumed as 50%); H is the dynamic head in ft; SG is the specific gravity of water.

3 RESULTS AND DISCUSSION

3.1 Inequity in BWSSB Water Consumption

The data used for this analysis is collected from consumer meter readings based on RR numbers for a period of 54 months i.e., from January 2017 to June 2021. This data is analyzed streetwise in the continuous system (Figure 3) and supply zone-wise in the intermittent system (Figure 4). For the figure

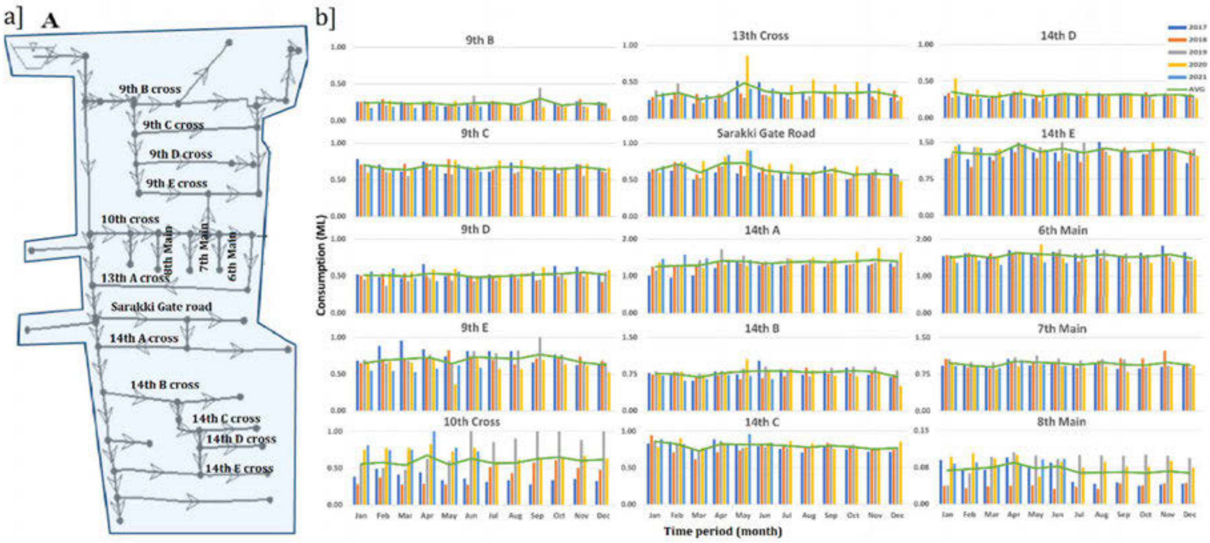

Figure 3. Continuous system a)streetwise pipe network along with flow directions, and b) streetwise monthly water consumption over 54 months i.e., from January 2017 to June 2020.

The bar graph shown in Figure 2b, describes the monthly water consumption in each street averaged over meter readings at each house. The data shown for 54 months are color-coded yearly. From the figure, it is evident that the streetwise average monthly water consumption is constant for almost all streets (except the 10^{th} cross and 8^{th} main), indicating water consumption in all the seasons is the same. The water consumption on the 10^{th} cross and 8^{th} main are increased from the year 2019, due to the replacement of pipes and reducing leakage losses. From the data, it was evident that the 8^{th} main road consumes the least BWSSB with an average usage of 0.06–0.08 ML, whereas the consumption on the 6^{th} main road is highest with an average usage of 1.5–1.6 ML. The 9^{th} crossroads and the 14^{th} crossroads, being the residential areas, are seen with an average usage of 0.5–0.6 ML and 0.7–1.0 ML, respectively. The 10^{th} crossroad and the Sarakki Gate road, with the majority of non-domestic firms, consume around 0.6 ML of water supplied from BWSSB.

To understand the streetwise inequity, Lorenz cure and GC value are estimated for the BWSSB water consumption in the continuous supply system. From Figure 3a, it can be seen that in most of the streets the mean water consumption over 54 months is less than CPHEEO (Central Public Health and Environmental Engineering Organisation) standards of 135 lpcd (except in streets 14th A and 14th E). While in 9 streets the consumption is less than half the standard value (i.e., < 68 lpcd). This could be due to low network pressure, the use of alternate sources, and so on. The Lorenz curve and GC = 0.33 (Figure 3b) show that inequity exists. This analysis indicates due to unsatisfied demands, consumers use alternate sources, especially groundwater

a)

Street	Consumption (lpcd)	Population
8th Main	16	182
9th B	22	288
14th D	33	317
13th A Cross	41	336
9th D	44	355
9th E	59	336
9th C	61	336
Sarakki Gate Road	64	298
14th B	66	326
14th C	83	336
10th Cross	127	192
14th A	141	317
14th E	147	288
Total	903.16	3907

b)

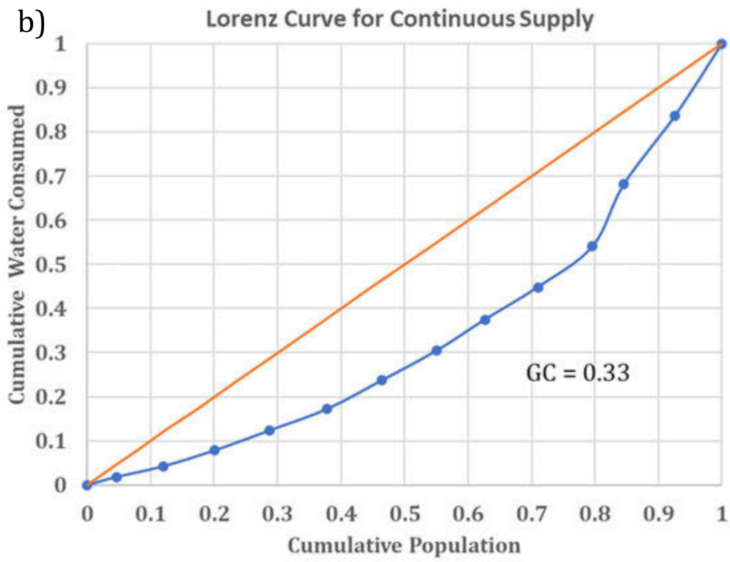

Figure 4. Continuous system a) streetwise BWSSB water consumption data, and b) Lorenz curve to evaluate inequity.

The bar graph shown in Figure 4b, describes the monthly water consumption in each supply zones over meter readings at each house. The data shown for 54 months are color-coded yearly. From the figure, it is evident that the zone-wise average monthly water consumption is constant, indicating water consumption in all the seasons is the same. Figure 4b illustrates that the water consumption in all supply zones varies from 10.1–17.8 ML and the consumption value in supply zone 4 is less whereas supply zone 5 consumes the highest.

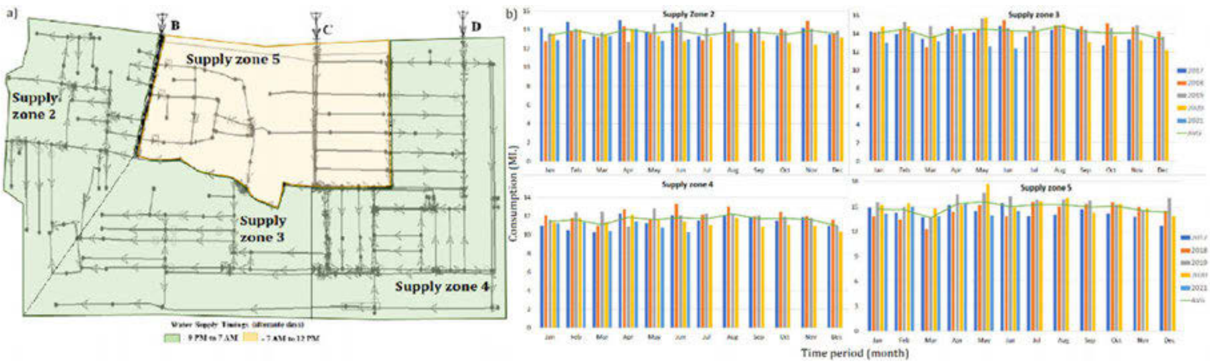

Figure 4b. Intermittent system a) supply zone-wise pipe network along with flow directions and b) supply zone-wise monthly water consumption over 54 months i.e., from January 2017 to June 2020.

To understand the supply zone inequity, Lorenz cure and GC value are estimated for the BWSSB water consumption in the intermittent supply systems. From Figure 5a, it can be seen that in all the supply zones the mean water consumption over 54 months is less than CPHEEO standards of 135 lpcd. This could be due to low network pressure, unpredictable supply times, duration of supply the use of alternate sources, and so on. The Lorenz curve and GC = 0.13 (Figure 5b) show that inequity exists. This analysis indicates due to unsatisfied demands, consumers use alternate sources, especially groundwater.

a)

Supply zone	Consumption (lpcd)	Population
Supply zone 5	72	6291
Supply zone 3	78	5196
Supply zone 4	88	3863
Supply zone 2	89	4412
Total	327	19762

b)

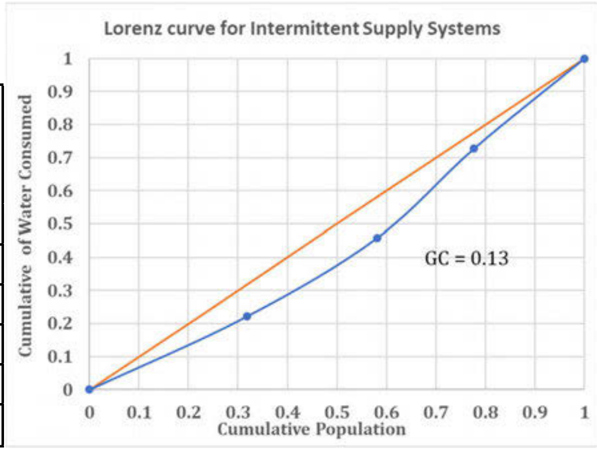

Figure 5. Intermittent systems a) supply zone-wise BWSSB water consumption data, and b) Lorenz curve to evaluate inequity.

3.2 Estimation of Groundwater Consumption

From the door-to-door questionnaire survey, it was seen that 73% of RR numbers in the continuous supply system (Figure 6a) and 84% of RR numbers in the intermittent supply system use both BWSSB and groundwater (Figure 6b). Figure 6c shows the percentage of connections using groundwater in each supply zone in the intermittent supply systems. Supply zone 5 has more number wells, whereas supply zone 4 has fewer among the four zones. The questionnaire survey was done for 80% of the connections in a continuous system whereas for the intermittent system random sampling was done at very few points.

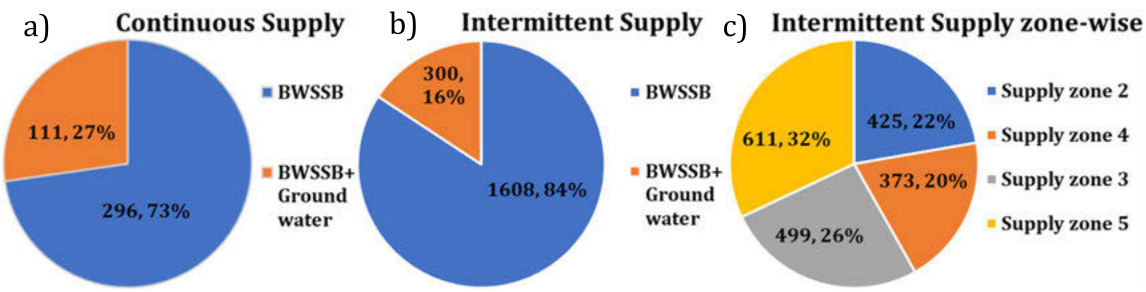

Figure 6. Pie chart showing the number of connections using groundwater a) in the continuous supply system, b) in the intermittent supply systems, and c) in the supply zones of the intermittent supply system.

As illustrated earlier in Figures 2 and 4, the consumption of BWSSB water does not change with the season, the same concept is assumed for groundwater consumption. Thus, the survey was done once i.e., in October 2021 to estimate the consumption and for the other months, the groundwater consumption is assumed to be the same. Equation (1) is used to estimate daily groundwater consumption from known pump running time, from this data monthly consumption is estimated.

From Figure 7a it is seen that the 13^{th} A cross pumps more groundwater of greater than 1.4 ML, whereas the 7^{th} main road consumes the least about 0.06 ML. In the intermittent system, supply zone 5 extracts groundwater of about 13 ML in a month whereas, supply zone 3 consumes groundwater of less than 4ML per month (Figure 7b).

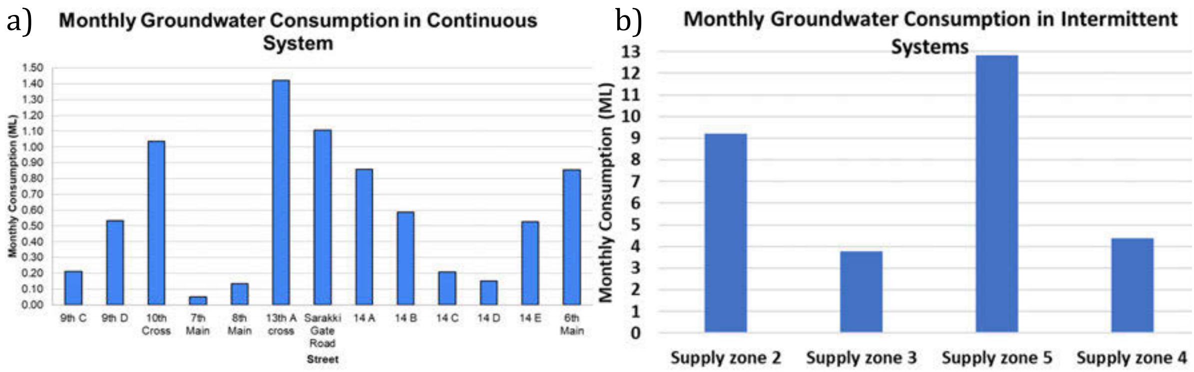

Figure 7. a) Streetwise monthly groundwater consumption in a continuous system and b) Supply zone-wise monthly groundwater consumption in the intermittent system.

The inequality in groundwater consumption is estimated using the Lorenz curve and GC for both continuous and intermittent systems. From Figure 8a, it can be seen that all the streets consume groundwater more than CPHEEO standards of 135 lpcd. While in 11 streets the consumption is more than twice the standard value (i.e., > 270 lpcd). This indicates consumers are exploiting the groundwater more than required. The GC of 0.13 indicates there exists an inequity even in groundwater consumption in a continuous system (Figure 8b).

a)

Street	Consumption (lpcd)	Population
14th E	192	32
9th E	213	106
14th A	230	116
9th D	282	117
8th Main	291	64
14th B	303	75
14th D	303	75
9th B	334	43
Sarakki Gate Road	375	142
9th C	419	47
10th Cross	453	91
14th C	495	104
13th A Cross	505	106
Total	4393	1114

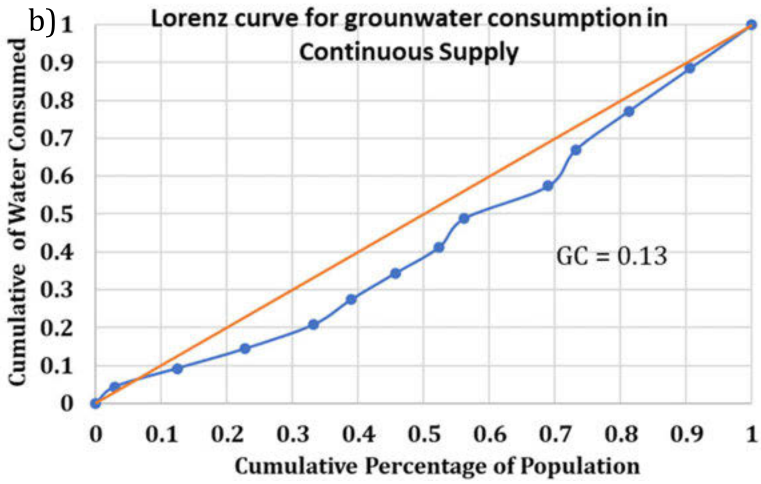

Figure 8. Continuous system a) streetwise groundwater consumption data, and b) Lorenz curve to evaluate inequity.

From Figure 9a, it can be seen that in all the supply zones the groundwater consumption is more than the CPHEEO standards of 135 lpcd. All the supply zones consume groundwater more than twice the standard value (i.e., > 270 lpcd). This indicates consumers are overexploiting the groundwater more than required. The Lorenz curve and GC = 0.3 (Figure 9b) show that inequity exists. This analysis indicates due to unsatisfied demands, consumers use groundwater water more than required.

a)

Supply zone	Consumption (lpcd)	Population
Supply zone 2	314	976
Supply zone 5	356	1200
Supply zone 3	384	328
Supply zone 4	403	364
Total	1458	2867

b)

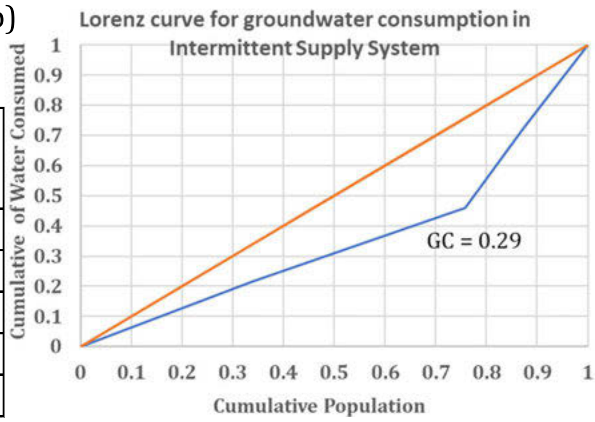

Figure 9. Intermittent system a) zone-wise groundwater consumption data, and b) Lorenz curve to evaluate inequity.

4 SUMMARY AND CONCLUSIONS

The investigation includes evaluating the demand within the DMA level. J.P. Nagar Phase 1 DMA was selected as the study DMA due to the presence of both continuous and intermittent supply systems. The consumption of BWSSB water in both continuous and intermittent for an average of 54 months is mostly less than the standard required consumption of 135 lpcd. This is mainly due to low network pressure, unpredictable supply times, duration of supply, and the use of alternate sources. Thus the inequality consumption in continuous and intermittent is evaluated using Lorenz Curve and Gini Coefficient for both BWSSB water and groundwater. To estimate the monthly groundwater consumption, a door-to-door questionnaire survey is used for the analysis. Some of the questions asked are RR number, presence of wells/borewells, horsepower (HP) of the pumps used, building type, the number of inhabitants, and the floors in each building. The survey was conducted for 80% of connections in the continuous supply system, whereas very few numbers random sampling was done for the intermittent supply system.

The results showed that inequality in both BWSSB and groundwater consumption exists in between the streets of a continuous system and in between supply zones of an intermittent supply system. Even though the water was supplied 24/7 the exists an inequity of 0.33 and the groundwater consumption was more than 190 lcpd in all the streets in a continuous system. The reliability of groundwater was very high in continuous supply systems due to insufficient pressures resulting in unsatisfied demands. In the intermittent zone, the groundwater consumption was more than twice the standard required demand as BWSSB water consumption n all the supply zones was less than 90 lpcd. This indicates just increasing the piped water supply will not be sufficient, regulation on the usage of groundwater extraction is needed.