Application of Inequity Indices for Water Supply between District Metered Areas – A Case Study on Bangalore South Zone, India

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ABSTRACT

Bangalore is one of the fastest growing cities in India with over 10 million residents. The city has unequal distribution of water supply between and within District Metered Areas (DMAs). Physical and economical aspects of the DMA, like terrain, inadequate infrastructure, high Unaccounted For Water (UFW), socio-economic status, etc. lead to this inequity. In this study, we assess inequity in intermittent water supply between various DMAs of Bangalore South division using Lorenz curve, Gini coefficient, Thiel indices, Atkinson index, generalized entropy index and Hoover Index. Bulk flowmeter and consumer meter data feeding to specific DMAs were collected for a period of 18 months. Inequity indices were calculated for both supply and consumption at each DMA. The results show significant inequity throughout the duration of study indicating inadequate infrastructural capacity and low operational efficiency. It was evident from the study that even with considerable savings in UFW inequity remained more or less the same. A redistribution scheme is also proposed to reduce inequity. This study is a step towards developing an equity-based supply model for Bangalore South division.

Keywords: Inequity indices; Equitable supply; Intermittent supply; DMA

1 Motivation

Equitable distribution of drinking water is one of the critical components of Operation and Management (O&M) of a water distribution system. Understanding the level of inequity in the system is an important first step before developing a demand and supply model for equitable distribution among District Metered Areas (DMAs). Earlier works on the use of inequity indices for water supply in India [1] and the world [2] have inspired us to use similar methods to understand the inequity in distribution at a finer geographical scale of DMAs in this study area. This study can be used as a building block for monitoring and control of equitable distribution in city-scale intermittent water supply systems.

2 Introduction

Water distribution network planning and operation is an important component for customer satisfaction. The main objective of water authorities is to supply the required amount of clean water at sufficient pressure and also meet the continually increasing demand. Due to inadequate supply of water and the unprecedented increase in demand it is difficult to satisfy all customers' needs [3]. In developing countries like India, 24x7 supply is still a distant dream. Indeed, even partially satisfying customers' needs with the present intermittent supply needs significant intervention in operation and infrastructure. For the ease of operation, water utilities have divided large networks into DMAs. There is inequity in the distribution of clean water among the different DMAs. The amount of water supplied to the DMAs in an intermittent supply system depends on various aspects like the type of connections in the DMA, revenue generation potential at the DMA, socio-economic aspects of the population in the DMA, time of supply, Unaccounted For Water (UFW) supply needs, etc.

Ensuring equitable access to water at all levels is very important for social equity [4]. Overall economic development and social prosperity is dependent on efficient water resource management [5]. Broadly speaking, there are four elements of Inequity: social, spatial, gender base and intergenerational [6]. In our water distribution system, only the social and spatial aspects matter.

Bangalore, one of the largest cities in India facing severe water distribution problems due to population growth, lack of source water, high amount of leakage in water distribution system (WDS) and improper management of water resources. Due to over exploitation of ground water and change in the land-use pattern, many reservoirs which were supplying to the city have effectively gone dry [7]. At present the city gets water from the river Cauvery, located around 100 kms away, in four stages with difference in elevation of about 400m between Water Treatment Plant (WTP) and the city. The city receives 1,350 Million Liters per Day (MLD) of water, which is distributed to an area of about 570 km^2 serving 10 million people. Bangalore has largely undulating terrain leading to unequal distribution of water. Ensuring equitable supply across different DMAs remains a major challenge for the water boards. Indeed, a scientific method to measure inequity is an essential first step before intervention for better water distribution management.

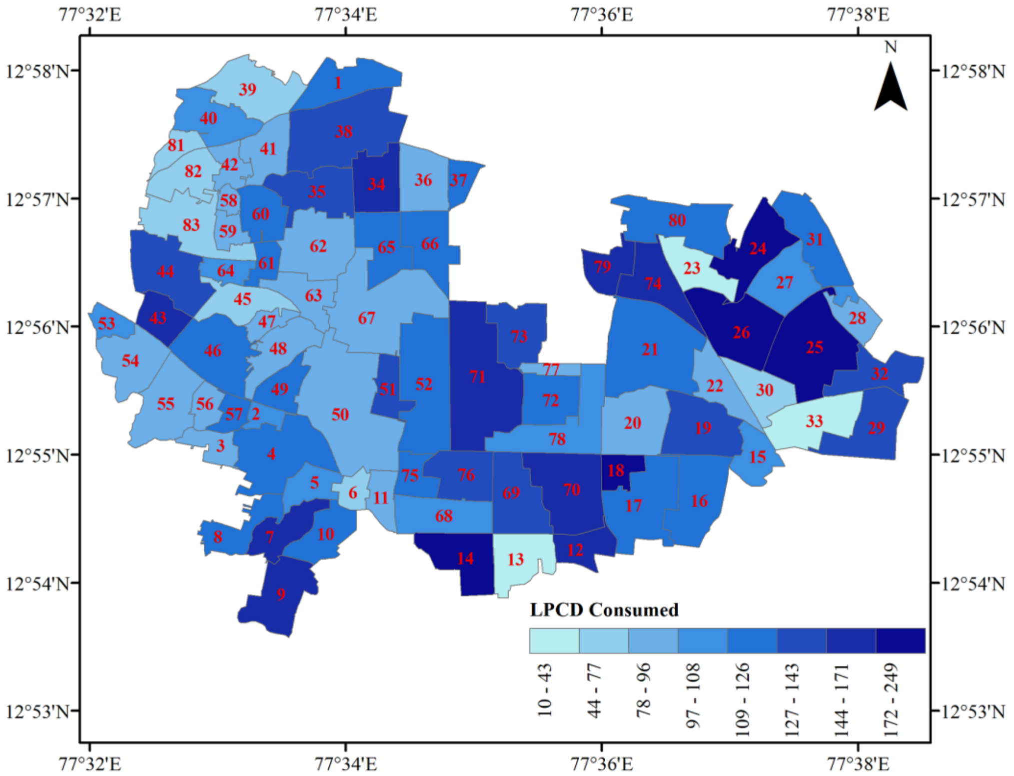
Inequity can be quantified through some of the indices applied in the field of economics to assess income inequality. Gini coefficients which are estimated from Lorenz curves have remained a standard measure for income inequality estimation [8]. A Lorenz curve shows the resource availability for a specific set of population. Different inequality indexes have been used in the past for assessing inequity in distribution in environmental indicators [9], health care [10], energy consumption [11], and river water use [12]. Inequality in water supply among Indian cities [1] and among countries [2] were examined using Gini coefficient and Theil index [13]. Theil Index [13], a commonly used inequity measure, can further estimate inequity between and within DMAs. In this study, we quantify inequity based on Liters Per Capita per Day (LPCD) consumption using Gini index, Theil index, Atkinson's index, General Entropy (GE) index, and Hoover index (HI). These inequity indices were analyzed over a period of 18 months for 83 DMAs of Bangalore South division.

The rest of the paper is organized as follows. Section 3 provide information on data acquired and the methodology used. Section 4 discusses various results on inequity measures. Section 5 concludes the paper with a discussion of the research outputs.

3 Data and Methods

3.1 Datasets

Flow meter data for 83 DMAs and the consumption corresponding House Service Connections (HSC) were collected from the Bangalore Water Supply and Sewerage Board (BWSSB). Each DMA has one or more inlets. A total of 216 flowmeters are installed in the study area with a sampling rate of one every 15 minutes. There are 0.162 million HSC and the consumer data is collected once in a month. We have this data for a period of 18 months. Additionally, population data was collected using a door to door survey by a third-party vendor. Figure 1 shows DMA names and boundaries and average LPCD usage in the study area. The water consumed by public areas, stand posts, slums, etc., were measured and added to the consumer meter readings to calculate overall LPCD. From the data, Revenue and UFW were segregated for inequity calculations. Here, we have not considered alternate sources of water supply to individuals (such as bore wells and water tankers), but only the Cauvery water supply network has been measured.



ID	DMA_NAME	ID	DMA_NAME	ID	DMA_NAME	ID	DMA_NAME
1	Chalavadi palya Chikkalalbagh	22	Maruti Nagar	43	Vidya Nagar	64	Muneshwara Block
2	Gururaja Layout	23	CARP Quarters	44	Giri Nagar	65	Gandhi Bazar NR Colony
3	Chikkalasandra	24	Kormangala 7th 8th Blk	45	Srinivasanagar	66	Basavanagudi
4	Padmanab Nagar	25	Koramangala 3rd 4th Block	46	Kathriguppa	67	Thyagaraja Nagar
5	Bendre Nagar	26	KHB Colony	47	Vivekananda Nagar	68	JP Nagar I Phase
6	Eshwar Nagar	27	Koramangala 6th Block	48	Chanammanakere	69	JP Nagar II Phase
7	Kumarswamy Layout 2nd Stage	28	Shrinivagalu Tank Bed Layout	49	Banagiri Nagar	70	JP Nagar III Phase
8	BHCS Layout	29	Jakkasandra	50	BSK 2nd Stage	71	Jayanagar 4th Block
9	ISRO Layout	30	Siddhartha Colony	51	Shastri Nagar	72	Jayanagar 4th T Block Central
10	Kumarswamy Layout 1st Stage	31	Ejipura Ravi Tent area	52	Jayanagar 7th Block	73	Byrasandra
11	Pragathipura	32	Koramangala 1st Block	53	Dwaraka Nagar	74	Hombegowda Nagar Central
12	Dollars Layout	33	KSRP Quarters	54	Hosakerehalli	75	Shakambarinagar
13	JP Nagar V Phase	34	Shankarapuram	55	Ittamadu	76	ITI Layout
14	Jaraganahalli	35	K G Nagara Gavipuram	56	Bhuvaneshwari Nagar	77	Jayanagar 4th T Block North East
15	Madiwala	36	V V Puram	57	Kamakya	78	Jayanagar 4th T Block South
16	IAS Colony	37	Mavalli	58	Kalidasa Layout	79	Hombegowda Nagar West
17	Kuvempu Nagar	38	K R Market Chamarajpete	59	Raghavendra Block	80	Hombegowda Nagar North
18	Mico Layout	39	J J Nagar	60	Srinagar	81	New Guddadahalli
19	Venkateshwar Layout	40	Old Guddadahalli	61	Nagendra Block	82	New Timber Yard
20	Gurappana Palya	41	Azad Nagar	62	Gavipuram Ext Hanumanth Nagar	83	Avalahalli Byatarayanapura
21	Suddgunte Palya	42	Vittal Nagar	63	Ashok Nagar		

Figure 1: *DMAs in the study area with average LPCD consumption*

Table 1 shows the water supply to the Bangalore South division from the Cauvery river. Improvement to water distribution system, reduction in UFW & leakage control in the study area was awarded to vendor on June 2012. The data on initial state of the system and later were collected to evaluate change in inequity over Operation and Management (O&M) phase.

Table 1 – Water supplied to study area from various stages of Cauvery Water Supply

Stage	Supply (MLD)	Diameter (mm)
Stage I	79	1200
Stage II	112	1200
Stage III	41	1750
Stage IV	39	1600

3.2 Lorenz curve and Gini coefficient

To plot the Lorenz curve, cumulative percentage of water supplied and population to each DMAs are calculated. Cumulative percentage of population is then plotted against cumulative percentage of water supplied to obtain the Lorenz curve. The ratio of area enclosed by the equality line and the Lorenz curve divided by the total area under the equality line gives the Gini coefficient, The Gini coefficient varies between 0 and 1, where 0 signifies equality and 1 signifies total inequality. The Gini coefficient is easy to interpret and is widely used in various disciplines.

3.3 Theil Index

The Theil index is a good measure of inequality which can be broken down into two components (i) within group inequality and (ii) across group inequality [13]. Theil T and Theil L, variants that are defined below, measures were calculated to study inequity in water supply across DMAs. The equation to calculate water-supply weighted Theil index and population-weighted Theil index are given by:

Water supply weighted Theil T index = $T_T = \frac{1}{n}\sum_i^n \left(\frac{q_i}{\bar{q}}\right) \ln\left(\frac{q_i}{\bar{q}}\right)$ (1)

Population weighted Theil L index = $T_L = \sum_i^n \mathrm{t}_i \ln\left(\frac{\bar{q}}{q_i}\right)$ (2)

Here t_i is the population share of DMA i in total population of study area, q_i is the water supply for DMA i, and $\bar{q}$ is the average water supplied in the study area.

3.4 Atkinson Index (AI)

The Atkinson Index AI is used to evaluate fairness of social distribution [14]. We use it to evaluate inequality in LPCD consumption across DMAs of the study area. It ranges between 0 and 1; 0 shows maximum equality in distribution, while 1 indicates an extremely skewed distribution. The Atkinson Index is defined is as follows [15]:

Atkinson Index = $A_\varepsilon = 1 - \frac{1}{\bar{q}}\left[\frac{1}{n}\sum_{i=1}^{n}[q_i]^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$ (9)

We choose the epsilon parameter (ε) values of 0.1, 0.5 and 1 [16] for the inequity analysis.

3.5 Generalized Entropy (GE) index

The GE index is derived from information theory and is a measure in redundancy of data. The equation for GE is given by

$$GE\ (\alpha) = \frac{1}{n\alpha(\alpha-1)}\sum_{i=1}^{n}\left[\frac{q_i}{\bar{q}} - 1\right] \quad (10)$$

where α is a parameter that can be chosen to meet a social planner's objectives, we have assumed as 0.25, 0.5 and 0.75 in our study.

3.6 Hoover Index (HI)

The Hoover Index HI is a usually measure of income metrics; this is an indication of the total community income that has to be redistributed to achieve equality and is also known as the Robin Hood Index [17]. It can be interpreted as the longest vertical distance of the Lorenz curve from the equality curve. The equation for HI is given by

Hoover Index = $HI = \frac{1}{2}\frac{\sum_{i=1}^{n}|q_i - \bar{q}|}{\sum_{i=1}^{n} q_i}$ (11)

4 Results and discussion

4.1 Per capita supply and consumption

The average LPCD consumption over a period of 18 months for 83 DMAs in the study is shown in Figure 2. In this figure, consumption is the sum of measured customer consumption, slum consumption, public consumption etc. A similar figure (not included in the paper) has the total supply to the DMA as measured by the flowmeters (which includes the above cumulative consumption and in addition UFW). A reference at 135 LPCD is drawn to show the general guidelines for per capita use in India [18]. Average consumption is as high as 250 LPCD and as low as 9 LPCD in the study area indicating significant inequality. Areas like Koramangala, KHB Colony, etc., classified as high income residential areas, have average water consumption of about 250 LPCD; this is 85% higher than design guidelines. Areas like CARP & KSRP Quarters, J P Nagar etc., are supplied with 40 LPCD, around 35% of standard requirement. For comparison, this is lesser than that in some African countries [2]. Only 24 out of 83 DMAs get higher supply than the guideline value of 135 LPCD.

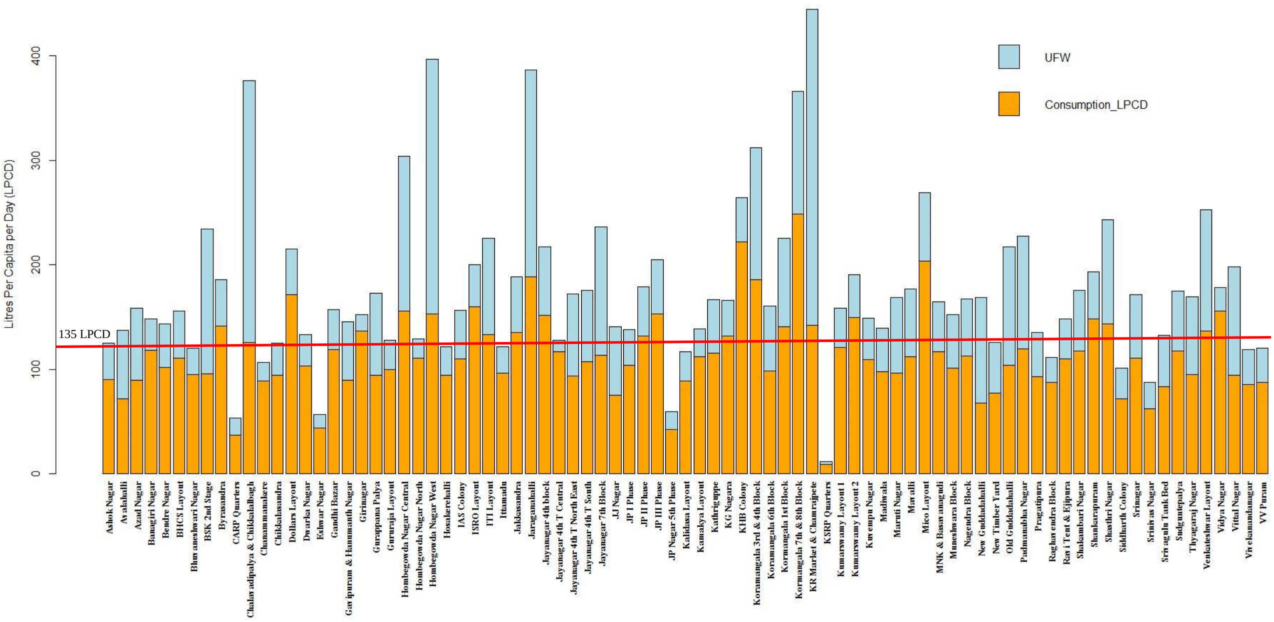
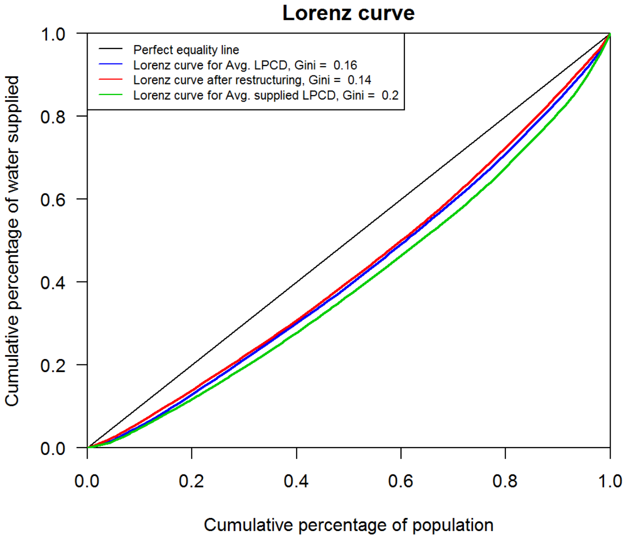


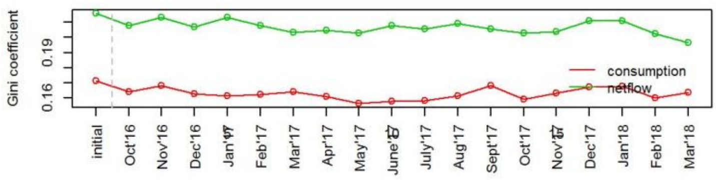
Figure 2: Shows 18 months averaged LPCD consumption for 83 DMAs showed in orange, light blue bars indicates UFW and red horizontal line is the guideline value of 135 LPCD

4.2 Understanding inequity between DMAs using Lorenz curve and GINI coefficient

The Lorenz curve was plotted with cumulative percentage of water supply versus ranked distribution of cumulative percentage of population. Figure 3 shows the Lorenz curve plotted for average supply and average consumption for a period of 18 months for 83 DMAs. The Gini coefficient was calculated to be 0.2 (average supply) and 0.16 (average consumption). The DMAs are spread out with CARP Quarters (SE3DMA13) as the lowest and Koramangla (SE3DMA02) as the highest consuming DMAs. Most of the DMAs consumed around 100 LPCD (the data was averaged out for period of 547 days). We also plot the Lorenz curve for a possible localized redistribution (some water from DMAs 24, 25, 26 redistributed to DMAs 23, 28, 30, 33, and some water from DMA 14 redistributed to DMA 13; see Figure 1). The new Gini index improves from 0.16 to 0.14. The hydraulic feasibility of this redistribution is yet to be ascertained.

Variation in Gini coefficient for a period of 18 months is plotted in Figure 3 (b). The first point corresponds to Gini index before UFW reduction project commenced. Through the period, UFW reduction activity was carried out and there was substantial reduction in UFW. However, the reduction in UFW did not result in an improvement in equitable distribution as can be seen from Figure 3 because the Gini coefficient is roughly a constant across the 18-month period and is moreover close to the value prior to UFW reduction project commencement.





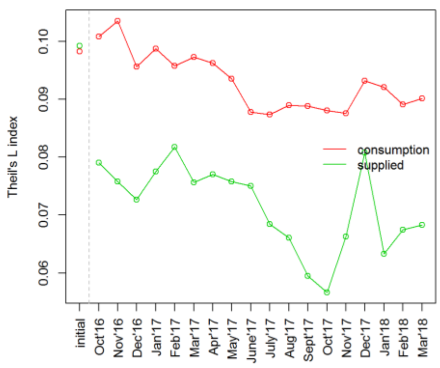
(b)

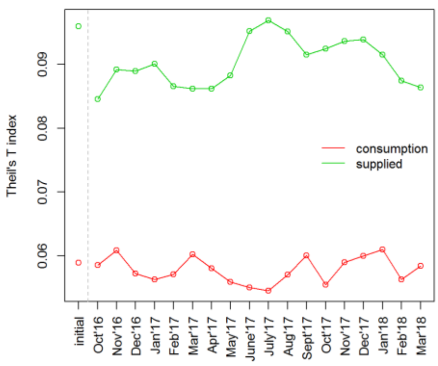
(a)

Figure 3 – (a) Shows Loren curve for Average supplied, consumed and restructured LPCD and (b) shows the variation in GINI index for initial stage followed by 18 months for consumption and net flow

4.3 Understanding inequity between DMAs using Theil index, General Entropy and Hoover Index

Theil L and Theil T index were calculated for a period of 18 months for both net flow and consumption. Figure 4 shows the variation of Theil L and Theil T. Theil L (Fig 4 (a)) was found to be between 0.06 to 0.1 for supplied and consumed respectively. Similarly, Theil T (Fig 4(b)) varies between 0.06 to 0.09. Similar to conclusions drawn from Lorenz curve analysis, it was found that inequality exists between DMAs and also there was not much of an improvement with UFW reduction.





(a) (b)

Figure 4 – (a) Shows variation in Thiel's L for supply and consumption, (b)similarly for Thiel's T

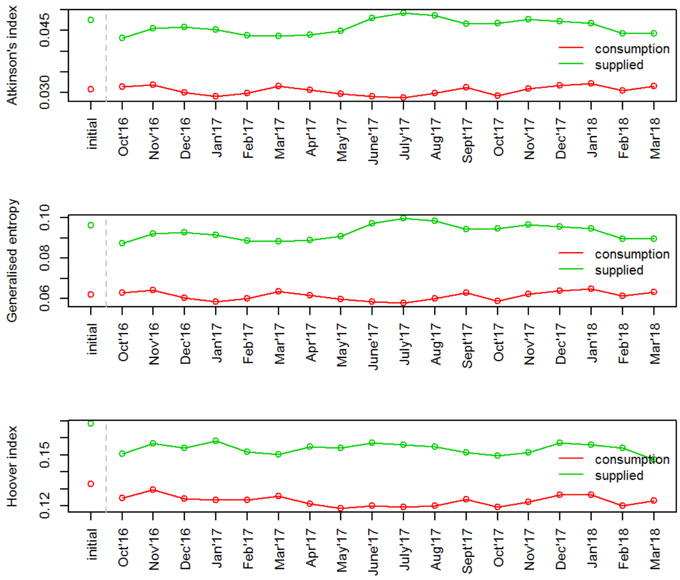


Figure 4: Shows variation of Atkinson index (epsilon – 0.5), Generalized Entropy (alpha – 0.5) and Hoover Index over a period of 18 months.

Atkinson index (AI) for three values of epsilon (0.1, 0.5 and 1) were analyzed for the study period (not included in the paper). Figure 4 shows AI (0.5) roughly a constant across the 18-month period and is moreover close to the value prior to UFW reduction. Similar results were observed for GE (0.25) and HI, all showing variation in inequity with time, marginally. Understanding inequity within and between groups using Theil index was not explored in this work. It has to be carried out after creating groups based on connections, revenue generation potential, socio-economic aspects, time of supply, UFW. It is clear from the above figures that the change in inequity indices for the duration of study is not substantial, indicating that the study area is predominantly a supply driven system. These are typical characteristics of an intermittent water supply network. Achieving equity in such a system needs supply control and scheduling based on weighted equitable demand models for each DMAs. Equitable demand models are generated based on socio-economic grouping, DMA population, type of connections, revenue generation potential etc.

Conclusions

In this work inequity indices in water supply were calculated for Bangalore South division consisting of 83 DMAs for a period of 18 months using standard indices like Gini, Theil, Atkinson Index, Generalized Entropy and Hoover Index. The study area is under rehabilitation to reduce UFW, and presently the UFW has been reduced from 49% to 33%. Gini index over the past 18 months did not show much change in inequity even though substantial UFW reduction was observed. This re-appropriated water could potentially be used to reduce inequity in water distribution. How to do this is a subject of future investigation. One such exploration was the redistribution from the 4 oversupplied DMAs to 5 neighboring undersupplied DMAs (see Figure 3) and the improvement in Gini index from 0.16 to 0.14). Other such redistributions and their feasibility need exploration. Theil L and Theil T index were calculated for the same data sets to explain the inequity. Other inequality indices like AI, GE and HI were calculated and the comparisons were made to understand demand-supply gap.

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