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Role of Physiochemical and Social Indicators in Water Poverty Index-A Case Study of Vellore Taluk, Tamil Nadu, India

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Abstract: Application of Indices and Indicators in a country's development will have both positive and negative sides. Though it helps us to understand the synopsis of vigorous issues, the incorrect use of indicators in a specific issue may lead to inapplicability of the index, especially in cases of water resource management. The present paper analyses the role of physiochemical and social indicators in the determination of Water Poverty Index (WPI) for Vellore Taluk, Tamil Nadu, India. Five main indicators: Resources (R), Access (A), Capacity (C), Use (U) and Environment (E) and twenty two sub indicators have been taken for framing the index. The methodologies used are Questionnaire Survey, Delphi study and the weighted average method. The Index value of Vellore Taluk was found to be in severe water poverty of 20.92. During the study, the sub-indicators R1, R4, A1, A2, C2, C3, U1, U2, E3 and E4 played a significant role in the evaluation of WPI. In-depth study on the physiochemical and social indicators in WPI gives the status of water poverty of a particular area which will be useful to the policy maker for the effective management of water resources planning.

Key words: Delphi study · Indicators · Indices · Water Poverty Index

INTRODUCTION

As per Neo Malthusianism theory, the demand for the population growth is exponential even though the resources are fixed. This concept advices us to use of indicators in the assessment of water scarcity or stress in terms of per capita renewable freshwater [1]. For the past two decades, there are plenty of indices and indicators were developed to evaluate the vulnerability status of the water (both quantitative and qualitatively). The difficulty in facing the characterisation of water scarcity is that includes more number of equally important factors for the water supply, demand and its usage. The criteria for the selection of indicators also have the greater influence on water scarcity evaluation as it fits to scientific decision and/or policy decision (Brown and Matlock, 2011).

During 1986, Falkenmark applied her first indicator based approach on water scarcity in the rural villages of South Africa (Sub-Saharan) in which she defined the water scarcity as a function of number of people per flow unit of fresh water. This index is widely known as 'Falkenmark Index' and also the originator of Water Scarcity Index (WSI). WSI is a straightforward as well as easy to use indicator method with the available data. Thus, this simple methodology have some limitations as it measures country level water scarcity and fails to take into the account of some important indicators such as accessibility, usability and spatial distribution of water (Quentin *et al*., 2014). In 1996, Gleick introduced an improved method of WSI by considering Basic Water Requirements (BWF) for human beings such as drinking, cooking, sanitation, bathing and other hygienic activities. There were insufficient data and analyses have been taken in Gleick's analysis. And also other utilisation of water for industry, agriculture and the environment have not been considered and hence the method was not sufficient enough in the estimation of water scarcity. In the late of 1990s, there were lot of approaches to measure water scarcity applied by various authors. Among which the supply side approach by Raskin *et al*.,

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[2] and demand management side approach by Seckler *et al*., [3] were distinguished as milestones in the development of indices in water management. As they did not focus on the application of indicators beyond the traditional method and hence there were in need of further improvement in the development of indices.

Furthermore, the water scarcity has been taken beyond the conventional method by Ohlsson and Turton, 1999. They defined the water scarcity as a function of adoptability and categorized as first order and second order scarcities in which the former one related to the supply and demand side indicators as per WSI and later one focused on the social, ecological and economic indicators. Here, the Water Scarcity Index (WSI) and the Human Development Index (HDI) were combined so as to attain the Social Water Scarcity Index (SWSI). Hence, the perception of water scarcity lengthens its pathway in the development of Water Poverty Index (WPI) by linking physical estimates of water availability (physiochemical indicators) with socio economic indicators which reflects poverty [4].

The compilation of indicators and sub-indicators needed for the estimation of water poverty index is based on the scale (micro or macro, regional or continental) and varies for different countries based on their physical, economic and social dimensions (Crystal Fenwick,[5] Lawrence *et al*., [6]). Sullivan *et al*., [7], investigated the significance of integrated indicators in the estimation of WPI in which five important indicators: Resources (R), Access (A), Capacity (C), Use (U) and the Environment (E) have been chosen for framing the methodology. Each Indicator has its own sub indicators or components and the weighted average of the normalised values of all the sub indicators and its weights give us the final index value of water poverty. This study examines the influence of indicators and sub indicators in the concluding value of Water Poverty Index of Vellore taluk, Tamil Nadu, India.

MATERIALS AND METHOD

Study Area: Vellore Taluk, an administrative headquarters of Vellore district in the state of Tamil Nadu which spreads over an area of 87.915 Square kilometres and is located in the mid of two well-known South Indian capitals: about 145 kilometres west of Chennai (Capital of Tamil Nadu); 211 kilometres east of Bengaluru (Capital of Karnataka). Its geography be made up of black calcareous soil and or red non-calcareous soil and belongs to North Eastern Agro Climatic Zone. The region experiences an average annual rainfall of 795 mm [8]. Taluk can be defined as the subdivision of a district consists of group of several villages and municipalities. A total of 23 locations in Vellore taluk in which 2 belong to the municipality (Having population in between 20,000 and 50,000; it can be neither a village nor a town), 6 town Panchayats (A town consists of 20,000 or 25,000 people in number) and 15 village Panchayats (A small settlement with few hundred to thousands of people) have been taken for the WPI study (Figure 1).

Materials and Methods

WPI Methodology: The WPI is calculated by using the weighted average method (Sullivan *et al*., 2006; Van der vyver, 2013[9]; and Xin *et al*., 2011[10]). The normalised value of each component is achieved from the sum of the normalized values of all the sub-components.

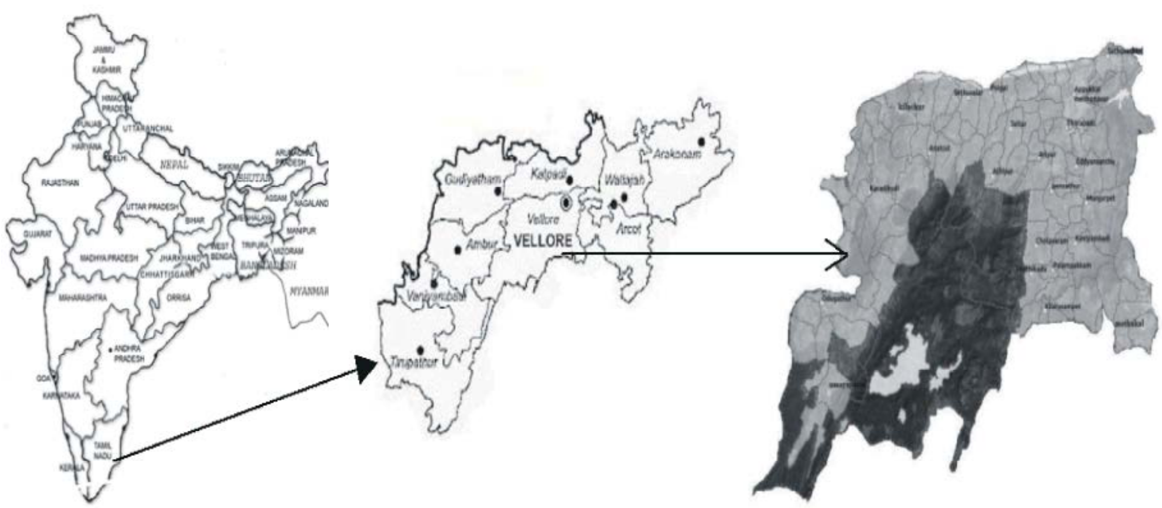

Fig. 1: Study villages of Vellore Taluk

Table 1: Classes of Water Poverty Index

Water poverty class	Score
Severe	0 - 47.9
High	48.0 - 55.9
Medium	56.0 - 61.9
Medium Low	62.0 - 67.9
Low water poverty	68.0 - 100.0

Table 2: Source, Scores assigned and the obtained values of Indicators

			Scores assigned				
WPI Indicators	Sub-indicators	Source	Fair (1)#	Acceptable(0.67)#	Poor (0.33)#	Risky (0)#	Values Obtained
Resources	Quantitative measure - Resources Availability (R1)	Data from Tamil Nadu Water Board	≥ 135 lpcd	71 to 135 lpcd	41 to 70 lpcd	≤ 40 lpcd	0.117
	Quantitative measure - Reliability of resources (R2)	Questionnaire survey	Always sufficient*	For human and livestock*	Only for human*	Not sufficient for human*	0.405
	Quantitative measure - Rainfall variability (R3)	Indian Meteorological Department-Vellore District)	>1000 mm	700 - 900 mm	500 - 700 mm	< 500 mm	0.364
	Qualitative measure - Resources Availability (R4)	Questionnaire survey	Yes = 1	No = 0	0.509		
	Qualitative measure - Water Quality (R5)	Water quality data from experimental data (Water Quality Index of water samples)	< 25	26 - 50	51 - 75	> 75	0.323
	Qualitative measure - Rainfall variability (R3)	Questionnaire survey	Yes = 1		No = 0		0
Access	Percentage people access to piped water supply (A1)	Questionnaire survey	Yes = 1		No = 0		0.200
	Percentage people access to sanitation (A2)	Questionnaire survey	Yes = 1		No = 0		0.586
	Time required for water collection (A3)	Questionnaire survey	0 - 30 minutes*	30 - 60 minutes*	60 - 120 minutes*	> 120 minutes*	0.379
	Distance travelled for water collection (A4)	Questionnaire survey	< 1 km*	1 - 2 km*	2 - 5 km*	> 5 km*	0.513
Capacity	Monthly Income (C1)	Questionnaire survey	> Rs 7,501 per month	Rs 4,501 - 7,500 per month	Rs 2,501 - 4,500 per month	< Rs 2,500 per month	0.193
	Percentage people primary school completion (C2)	Questionnaire survey	Ratio equals to 1	Ratio in between 0.33 to 067	Ratio in between 0 to 0.33	None	0.420
	Ratio of female to male primary school completion-C3	Questionnaire survey	Ratio equals to 1	Ratio in between 0.33 to 067	Ratio in between 0 to 0.33	None	0.103
	Percentage people reported water related illness (C4)	Questionnaire survey	No = 1		Yes = 0		0.129
	Percentage people reported water related illness (C5)	Questionnaire survey	Yes = 1		No = 0		0.129
USE	Ratio of domestic to basic water requirement (U1)	Questionnaire survey	Ratio equals to 1	Ratio in between 0.33 to 067	Ratio in between 0 to 0.33	None	0.389
	Ratio of livestock to basic water requirement (U2)	Questionnaire survey	Ratio equals to 1	Ratio in between 0.33 to 067	Ratio in between 0 to 0.33	None	0.057
	Use of local water treatment (U3)	Questionnaire survey	> 25%	10 - 25%	5 - 10%	< 5%	0.157
Environment	Quantitative measure of water quality for environment (E1)	From the sub indicators of Resources	Average of normalized values obtained in R1, R2 and R3				0.295
	Qualitative measure of water quality for environment (E1)	From the sub indicators of Resources	Average of normalized values obtained in R4, R5 and R6				0.277
	Percentage people reported change in soil fertility (E3)	Questionnaire survey	No = 1		Yes = 0		0
	Percentage people reported change in Tree cover (E3)	Questionnaire survey	No = 1		Yes = 0		0

Data source from Gine and Foguet 2009, Garriga and Foguet 2010

Table 3: Mean weights from the experts

Indicators	Mean Weights from experts
Resources - R	2.75
Access - A	1.83
Capacity - C	1.58
Use - U	2.00
Environment - E	1.83

Data Source: Guppy 2014 adopted from Centre for Ecology and Hydrology (2005)

$$WPI = \frac{w_r R + w_a A + w_c C + w_u U + w_e E}{w_r + w_a + w_c + w_u + w_e} \quad (1)$$

where,
R, A, C, U, E - weights of the indicators (from Delphi study) and w_r, w_a, w_c, w_u, w_e – normalized values of the indicators (from questionnaire survey, secondary and experimental data).

Normalization of Sub-indicators: The sub-indicators are normalized to keep their values in the range of 0 to 1 (Nardo *et al*., [11]) and the sum of the expert's weights should be 10 and the final value of indicators are multiplied by 10, so as to attain the WPI value within 0 and 100 (Table 1). The maximum value of 100 is considered to be the best situation and 0 being the worst. Table 1 shows the categorisation of WPI score adopted by Guppy [12]. Each indicator is divided into various sub-indicators and is normalized using the Eq (2) (Nardo *et al*., 2005).

$$X = \frac{(X_a - \min X_c)}{(\max X_c - \min X_c)} \quad (2)$$

where,
X= Normalized value of a particular indicator; X_a= Value of the variable; min X_c = Value of variable with 2.5 percentiles so that the minimum value will not be below "0"; max X_c= Value of variable with 97.5 percentiles so that the minimum value will not be greater than "1". The indicators with continuous variables are normalized within a unit interval (0, 1) and the remaining are divided into 4 point scale scores (Table 2) of fair (1), acceptable (0.67), poor (0.33) and risky (0) (Table 2).

Estimation of Indicator Values: The indicators and sub indicators used in the WPI methodology were investigated by Sullivan, [13]; Gine and Perez-Foguet, [14]; Garriga and Foguet, [15] and Crystal Fenwick, 2010. The name of the chosen indicators, assigned values and the obtained normalised values in the present study were illustrated in Table 2.

Estimation of Weights for the Indicators: Delphi method is used for the estimation of indicators weights in which experts from the different fields of water related Government Organisations such as Public Works Department and Academic Institutions of environmental discipline and also political leaders of the region, Village Administrative Officers, farmers and journalists who faces the day to day water issues. The same kind of study were analysed by the authors, Singg and webs, 1979 and Sudha and Ravichandran, 2013. The values obtained from the present study have been illustrated in Table 3.

RESULTS AND DISCUSSION

Water Poverty Index: The Water Poverty Index of the Vellore Taluk has been estimated from the chosen indicators and it was arrived as 20.92 which is categorized under severe water poverty as per the data adopted by Guppy, 2014 (Table 1). The same kind of study has been adopted by Xin *et al*., (2011) for the nine districts of yellow river basin in which six districts were classified under unsafe and highly recommended for water conservation and management plans. Guppy, 2014, applied the concept of WPI in the assessment of water potential in Combodia and Vietnam and concluded that the former one belongs to severe water poverty and the later one lies in between high to severe water poverty which is similar to our present study [16-20].

Role of Indicators in Framing WPI: Indicators are tools which communicate the key issues in a simplified way to the policy makers as well as to the public. It can be defined as the function of simplification, quantification and transformation. Hence, the indicators can be useful in finding the solution for crucial issues and make the decision maker to get in to the action (Feitelson and Chenoweth, 2002). In the present study, there were 5 indicators comprising of 22 sub-indicators were used to frame the WPI. From the analysis, the normalisation of sub-indicator values were high for the indicator w_r(1.718) and w_a (1.678) respectively while the indicator Capacity (w_c) holds the value of 0.970. Use (w_u) gains the value of 0.603. The Environment (w_e) has attained the least value of 0.573. The values of indicators according to Delphi study have computed to be 2.75, 1.83, 1.58, 2.00 and 1.83 correspondingly for the components R, A, C, U and E (Fig 2). The normalisation data of sub-indicators of each indicator and the value of indicators from the Delphi study are used for the computation of WPI (Eq. 1).x

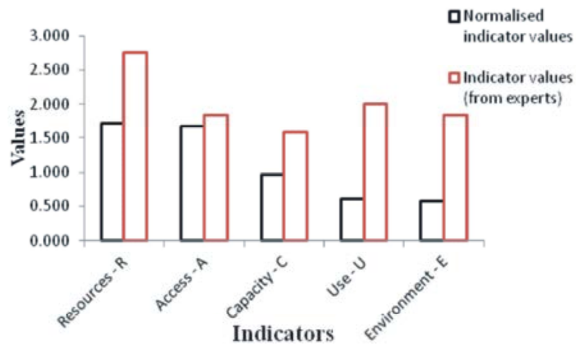

Fig. 2: Indicator values

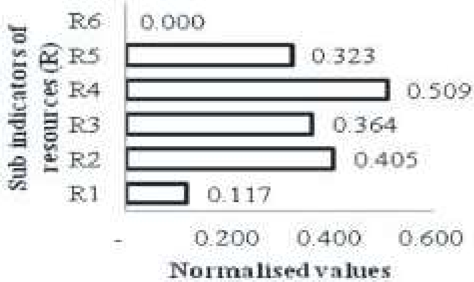

Fig. 3: Sub-indicators of Resources

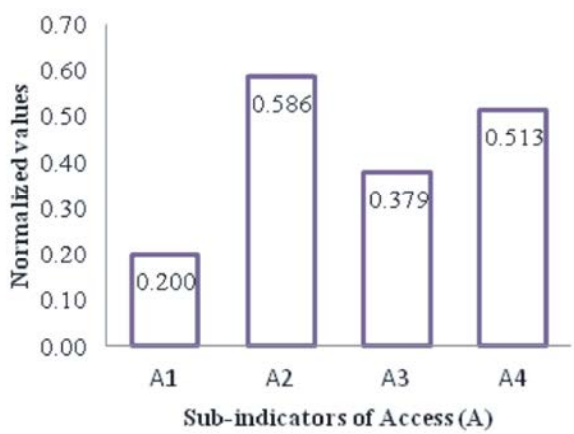

Fig. 4: Sub-indicators of Access

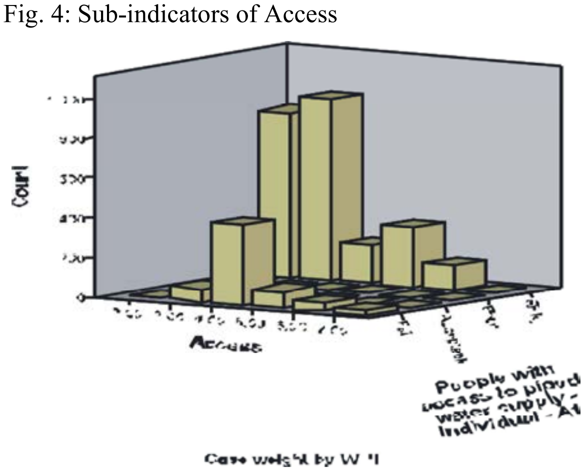

Fig. 5: People with access to piped water supply - A1

The Indicator resources (R) comprising of six sub indicators R1, R2, R3, R4, R5 and R6 in which the first three are related to the quantitative measure of water potential and the next three meant for the qualitative measures. Among the six sub-indicators, R2, R3 and R4 were found to be in the range of poor to acceptable category (0.405, 0.364 and 0.509) whereas R6 was found to be in the range of risky (0) and R5 belonged to slightly in risky condition (Fig 4). The risky condition of R6 was mainly due to changes in the rainfall pattern, which often brings the bulk of rainfall in a short duration leading to an increase in surface flow and a decrease in groundwater recharge (Haga *et al*., 2005). It was observed that the Qualitative measure of resource availability (R4) has a higher value (0.509) whereas the availability of resources R1 has a lower value (0.117). This may be due to the fact that the public have access to the resource, such as through overhead tank piped connections in the study area, even though the quantitative availability of water in it was not sufficient enough. About 65% of the respondents opined in support of this interpretation.

The percentage people with access to piped water supply (A1), sanitation (A2), waiting time (A3) and distance travelled (A4) are the sub-indicators which are used to frame the indictor Access (A). Out of which, A1 and A2 determine the magnitude of the indicator ‘A’ because of their low (0.200) and high (0.586) values respectively and the other two A3 and A4 were observed to be in the range of poor to acceptable (Fig 4). This is mainly due to the government incentive scheme to the people for the improvement and awareness of sanitation facilities. Though it gives the higher value to A2, accessibility to the piped water supply (A1) by the individual is still in problem which can be graphically represented by Fig. 5.

The value of indicator Capacity (C) is estimated from the sub-indicators of C1 to C5 in which primary school completion rate of the respondents (C2) has the higher value of 0.421. Even though the primary school completion rate is in nearly acceptable category, the female to male primary school completion ratio is in risky condition (0.103). This indicated the ignorance of female education in the study area and about 50% of the female respondents were categorized under risky (Fig 7). There were very few residents who reported the water borne diseases and many of these referred to them in general terms (allergies, fever, cold, etc.) so that the sub-components C4 and C5 were also to be low values (0.129) which indicated that the unawareness about the water-related diseases or illness and the non-participation in the

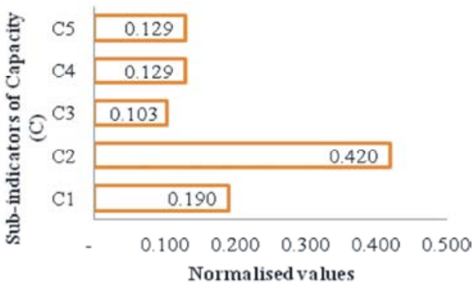

Fig. 6: Sub-indicators of Capacity

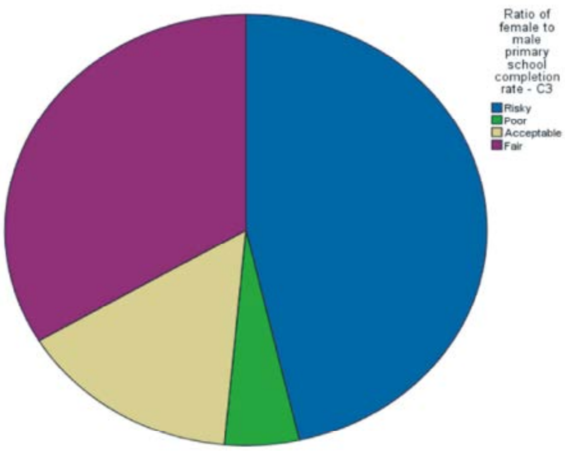

Fig. 7: Ratio of female to male primary school completion-C3

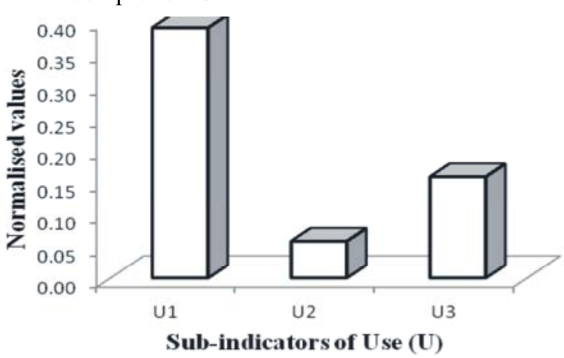

Fig. 8: Sub-indicators of Use

trainings related to hygiene and health. The analysis also represented that the average monthly income (C1) was in the range of risky to poor (0.193) Fig 6.

The water allocation for different uses such as domestic and livestock and the facilities used to treat the water were put into the component Use (U). The ratio of domestic to basic water consumption (U1) influences the significance of 'U' as it holds the maximum value of 0.389 which denotes the major use of water for the domestic consumption whereas very little quantity of water was allocated for livestock consumption (0.057) (Fig 8). The results from the survey stated that only 16% of the people use simple water treatment methods such as boiling, filtering, etc. in the study area (0.157).

The density of tree cover or forest mainly depended on the characteristics, holding capacity of soil and rainfall intensity in the study area (Baker *et al*., 2003). More than 80% of the respondents were reported that there is negative change in the soil fertility and tree cover so that the indicators E3 and E4 were attained the null values. The quantitative measure of water for environment (E1) and the qualitative measure of water for environment (E2) gained the poor to acceptable values (0.295 and 0.277) (Table 3) [21-26].

The present study demonstrates the role of physiochemical, socio- economical indicators in the micro level assessment of WPI of Vellore Taluk, Tamil Nadu. The indicators and sub-indicators required to estimate the WPI is dependent on the scale (micro or macro) and these can be different for different countries or regions especially based on their physical, social and economic dimensions (Crystal Fenwick, 2010).

CONCLUSION

The micro level assessment of Water Poverty Index for Vellore Taluk, Tamil Nadu, India has been achieved in the present study which lies in the category of severe water poverty (20.92) as per the classification followed by Guppy (2014). R1, R4, A1, A2, C2, C3, U1, U2, E3 and E4 are some of the most important indicators which influenced the estimated value of WPI. Water supply demand, access to piped water supply, female education, domestic water consumption and soil and water conservation played a considerable role in the determination of this index value. The study of such micro level assessment with the aid of indices will provide us a snap-shot of water poverty of an area which will be useful for the policy or decision maker to find the right solution in water resources planning and management issues.

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