International Journal of Scientific & Engineering Research, Volume 5, Issue 10, October-2014
ISSN 2229-5518

Assessment of Poverty with reference to Accessibility to Safe Drinking Water Resources using Fuzzy Variables

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Abstract— The basic needs of a household are food, dress and house. By observing down one's housing conditions, dressing styles and food habits, we get an impression on their financial status. In rural villages, the housing patterns and dress styles are same and it is difficult to get correct details on the quantity and quality of their food consumption. Also among the poor, very often the food consumption level of quantity and quality varies. Drinking water, as a natural resource in villages plays a vital role, not only as a component in food but also on the health conditions and social status. Access to safe drinking water is a visible criterion of one's economic status in rural villages. As there are many factors which are not quantifiable with regard to accessibility of drinking water, we have to use fuzzy concepts to estimate one's financial status. In this paper we use fuzzy sets and criterions to analyze the accessibility of drinking water with special reference to villages in Nalanda District, Bihar, India.

Index Terms— Accessibility, Drinking water, Fuzzy sets, Linguistic variables, etc.

1. INTRODUCTION

Any tool to measure poverty has to consider the basic needs like sufficient quantity of hygienic food, housing conditions and dressing patterns. By casual observations on one's living conditions and dressing styles we can easily decide on the level of financial status of a person. In rural areas like the villages in Nalanda district, Bihar, the housing conditions and dressing style are pretty same on normal days. Some houses differ in their style and construction model. Majority of houses in a village have the same pattern. So to observe one's level of poverty or wealth; we have to look into their food habits and as a researcher one may not get full details. The food consumption in quantity and quality varies depending on many factors like agricultural seasons, job market demands and socio cultural calendar cycles.

In this paper we are focusing on accessibility of drinking water, a basic component of food and natural resources to understand and bring out a measurable scale. In urban areas too the drinking water which is also called as "blue gold" has generated big business. When drinking water became a salable commodity, no wonder, water purification systems and purified drinking water sale and distribution fetches sizeable income and thus economy flourishes. In this paper we are focusing on the rural villages in Nalanda district, Bihar, India.

2. NEED FOR FUZZY APPROACH

Fuzzy logic may be viewed as an attempt at formalization/mechanization of two remarkable human capabilities. First, the capability to converse, reason and make rational decisions in an environment of imprecision, uncertainty, incompleteness of information, conflicting information, partiality of truth and partiality of possibility- in short, in an environment of imperfect information. Second, the capability to perform a wide variety of physical and mental tasks without any measurements and any computations [1]. In fact, one of the principal contributions of fuzzy logic is its high power of precision.

In this perspective, a house is a visible or easily perceivable indicator to state one's level of poverty; whereas access to safe drinking water is a latent indicator. The act of fetching drinking water as an indicator includes discomfort; lose of energy, and social stigma etc. To study issues of discomfort, lose of energy and social stigma, etc we have apply fuzzy concepts.

3. STUDIES ON POVERTY

The early literature on fuzzy poverty measurement concentrated on deriving poverty membership functions. For instance, Cerioli and Zani in the year 1990 introduced a straight – line membership function for a given dimension such as income. In the year 2006, Chakravarty generalized Cerioli and Zan's membership to allow it to change non-linearly. While Cerioli and Zani's approach needs a specification of two income levels such that an individual becomes "definitely poor"or definitely non-poor". Cheli and Lemmi in the year 1995 presented a "Totally" and Relative approach" in which the degree of poverty membership depends on an individual's relative rank in the distribution [2].

So far, in India poverty has been measured on the basis of Calories approach, Poverty line approach and Relative Poverty line approach. Calories approach or minimum food consumption is related to fulfilling certain nutritional standards. Poverty measure with reference to poverty line is often known as absolute poverty. Absolute poverty line is measured at a certain income amount or consumption expenditure amount per year. For example, Dr. S. Tendulkar used this method with additional expenditure on health and education. Poverty measured without reference to poverty line is known as Relative poverty. This approach looks at poverty in terms of a certain minimum consumption expenditure per person or

preferable per household. For example, C. Rangarajan committee suggests that any household failing to meet minimum consumption expenditure on food and non-food items (Education, clothing, conveyance, and house rent) would be identified as poor [3]. These approaches are purely based on the low level of income. Low income is just one indicator of poverty. As demonstrated in this document, the numbering for sections upper case Arabic numerals, then upper case Arabic numerals, separated by periods. Initial paragraphs after the section title are not indented. Only the initial, introductory paragraph has a drop cap.

3.1 Head Count Ratio (HCR)

The simplest and most known measure of poverty is the Head Count Ratio which indicates the proportion of poor people in the studied population. It is computed by taking the ratio between the number of poor unit determined in the identification step and the total population.

With Z the poverty line, y the income of household I (if I is poor the Y < Z), N the total population and Q the population considered as poor we can specify HCR.

HCR = Q/N

This index provides simple quantitative information about the incidence of poverty in a given society. It is useful and often referred to as it is easily understandable.

The main weakness of HCR is that it cannot take into account the intensity of Poverty. For instance in a situation where a poor get poorer the HCR does not change. Therefore, beside the Head Count Ratio we need other indexes of poverty. To overcome this drawback we use Poverty Gap. [4]

3.2 Poverty Gap

The Poverty gap is the mean distance of the poverty line for the whole population, expressed as a percentage of the threshold value [4].

$$PG = \frac{1}{N}\sum_{i=1}^{n}\frac{G_i}{Z} = \frac{1}{Z}\sum_{i=1}^{Q}(1-\frac{y_i}{Z});$$

where Gi = z- yi , (if z > yi , else Gi = 0) and z is the poverty line and yi is the mean income of the population .

Here, in the case of a poor getting poorer (or richer but still under the poverty line) whereas the incidence of poverty (HCR) would be unchanged, the depth (PG) would change. [4]

3.3 Sen Index

The Sen Index gathers together in the same scalar the information concerning the incidence of poverty, the intensity of poverty and inequalities between the poor [4].

Ps = H [I+K (1 – I) Gp]

with Gp, the Gini coefficient between the poor, I, the Income Gap, I = (1-Yq)/(z), Yq the main income of the poor, and k = q/((q + 1)) . If there is no inequality between the poor, we have Gp = 0 and then Ps =PG.

3.4 Multidimensional approach

Multidimensional poverty approach drew inspiration from Amartya Sen's idea of using deprivation and not just income while measuring poverty. He defined poverty as the lack of fundamental capabilities that leads to opportunities for basic functionings. It has been argued that an individual's well-being is essentially multidimensional. Therefore, an individual's poverty status must also be analyzed from multidimensional perspective. However, there are many problems associated with this approach including difficulties in aggregating deprivations on several scores or dimensions derived from different sources.

This ambiguity and uncertainty often lead us into situations where poverty status classification is not clear- cut. If we allow an individual's or a household's poverty status to have some level or degree of ambiguity and incorporate it into poverty measurement, we are led to have a new literature of measurement called Poverty Fuzzy Measurement.

3.5 Poverty Measurement Fuzzy approach

There is "no sharp borderline between poor and non-poor." In the fuzzy approach the poverty status of an individual or a household is indicated by a real number between zero (clearly a non-poor) and one (clearly a poor). One's belongingness in this set is referred as poverty membership function. And fuzzy poverty membership is sought using one's accessibility membership function. We study accessibility to safe drinking water as in indicator of financial status.

4. PRELIMINARIES

4.1 Access to safe drinking water:

This includes distance, time spent and practice of equal opportunity to every member of the population to collect safe drinking water from the source.

4.1.1 Convenient distance:

In urban area, a distance of 200 meters from a home to public stand post or common water point may be considered reasonable access. In rural area a reasonable access implies that a person does not have to spend a disproportionate part of the day fetching water.Access to safe drinking water is measured by proportion of population with access to an adequate amount of safe drinking water located within a convenient distance from user's dwelling.

4.1.2 Adequate amount:

WHO (World Health Organization) suggests 20 liters of safe drinking water per person per day.

4.1.3 Safe drinking water:

Water that does not contain biological or chemical agent directly detrimental to health. It includes treated safe water and untreated but uncontaminated, public tank, hand pump, tap water, protected spring, bore-holes, well etc.

4.2 Fuzzy Linguistic variables

Linguistic variable is a variable whose values are words in a natural language. For example "the poor" and "accessibility" are the linguistic variables as follow.

Table 1: Fuzzy Variables

Low accessibility	Poor
Very Low accessibility	Very poor
Medium accessibility	Moderately poor
High accessibility	Non-poor
Very High accessibility	Not poor at all

4.3 Fuzzy Set and membership function

A fuzzy set is a set containing elements that have varying degrees of membership in the sets. Fuzzy sets have been introduced by Lotfi A. Zadeh (1965). A fuzzy set allows its members to have different grades of membership (membership function) in the interval [0, 1]. Mathematically it is defined as follows:

4.3.1 Fuzzy Set

A fuzzy set A in X is expressed as a set of ordered pairs defined as

$$A = \{(x, \mu_A(x)) \mid x \in X, \mu_A(x) : X \to [0,1] \}$$

A fuzzy set is totally characterized by a membership function (MF).

4.3.2 Membership Function

Membership function is a mapping of X on [0, 1]. It gives the degree of membership of a element in a given fuzzy set. For example: X = "accessibility to safe drinking water" with U distances = {2km, 2.5km, 1km,0.5km, 0.2km ..,0.001}, and μ(accessibility) = 0.01/2km + 0.001/2.5km + 0.2/1km + 0.5/0.5km + ….+ 1/0,001km is called a fuzzy membership of "accessibility."

5. ACCESSIBILITY FUNCTION

Accessibility is observed as minimum amount of safe water required which is proportional to the population with the sum of the constraints to fetch water from distant sources and the required frequency. And the final sum is multiplied by the number (per person and per day) of a household. Accessibility Membership Function is given by the following formula:

$$\mu = \left\{ \frac{\text{Min amt. of water reqrd}}{\text{f}\times[\text{d}+\text{t}+\text{E}lt+\text{S}tga+\text{D}\,ft+\text{FC}t+W\,\text{t}]} \right\} \times \text{N}$$

{Where; f – Frequency, d – Distance, t – Time taken, E*lt* – Energy left, S*tga* – Stigma, D*ft* – Discomfort, FC*t* – Fuel cost, W*t* – Waiting time and N – Number of person per family}.

5.1 Generalized form

Let x_i denote the degree of accessibility. Then the Accessibility membership function is defined by

$$\mu_{\tilde{A}}(x_i) = \left\{ \frac{M_i}{f_k \sum C_j} \right\} \times N = m;\ \forall i, j = 1,2,...n \text{ ---------(1)}$$

where, Mi - refers to the amount of water fetched in litre (Min, Max);
Cj - refers to the number of constraints faced in fetching the total amount of water; such as
distance, time, energy spent, stigma attached, discomfort, fuel cost, waiting time etc.
- refers to the number of frequencies.
N- refers to the number of persons (per day) in a house.
Final value is obtained by dividing the result by 100 keeping in mind that a household should have 100% accessibility to be considered a poor or non-poor.

5.2 C++ Program for the equation (1)

```
#include <iostream>
#include <math.h>
#include <stdio.h>
int main()
{
   float td, tt, el, sf, dc, fc, wt, famfv;
   printf("Program for Fuzzy Accessibility Membership Function Values\n");
   printf("Enter Travelled Distance?");
   scanf("%f", &td);
   printf("\nTime taken?");
   scanf("%f", &tt);
   printf("\nEnter Energy left?");
   scanf("%f", &el);
   printf("\nEnter Stigma left?");
   scanf("%f", &sf);
   printf("\nEnter Discomfort?");
   scanf("%f", &dc);
   printf("\nEnter Fuel cost?");
   scanf("%d", &fc);
   printf("\nEnter Waiting time?");
   scanf("%f", &wt);
   famfv = td+tt+el+sf+dc+fc+wt;
   famfv = 20 / (2 * famfv);
   famfv = (famfv *5) /100;
   printf("\nFuzzy Accessibility Membership Function Value=%f",famfv);
  return 0;
}
```

5. 3 Fuzzy Categorization

Let us consider a set E of n households and let $\tilde{A}$ be a subset of consisting of the poor, such that a fuzzy membership is given by $\mu_{\tilde{A}}(x_i)$ where $(i = 1,2,3,...,n)$ denote for each household in $\tilde{A}$ and $\mu : \tilde{A} \to [0,1]$.

Then we have the following critical limits in the given subset to identify the upper and lower bounds or grade or degree or membership or level of the poor.

1) $\mu_{\tilde{A}}(x_i) = 0$ if i^{th} a household is certainly poor;
2) $\mu_{\tilde{A}}(x_i) = 1$ if i^{th} household is non - poor;
3) $0 < \mu_{\tilde{A}}(x_i) < 1$ if i^{th} household exhibits a partial membership in the subset of .

6. CASE STUDY

We selected a random sample of 11 households from Amba Village, Nalanda District, Bihar, India from the available data by field work done by us. They are represented by household-1, household-2 … household -11 of are five members respectively.

In our study we have included seven 'process factors' that play a significant role in fetching water. They are as follows: Distance, Time taken to reach the common water point, Energy left in the person after fetching water or cycling, Stigma felt while walking, Discomfort or pain faced by the person, Fuel cost and Waiting time at the water point. In the survey enquires were made to the women folk or children. The data and calculations focus to the on foot factor process, because majority of the women or people walk to fetch water. A very few people use cycle or motor bike. Common water point distances are in consideration: 2km, 1km, 500m, 200m, 100m, 50m, 30m, 20m, 10m, 5m, 1m etc. to show variations. We evaluate accessibility in the following manner.

Using the formula (1), we calculate the accessibility membership value for the first household.

$$\mu_{\tilde{A}}(x_1) = \left\{ \frac{20 \text{ litres of water per person per day}}{2 \times [4 \text{ hr} + 1 \text{ hr} + \frac{20}{100} + \frac{90}{100} + \frac{80}{100} + 0 + \frac{1}{4} \text{ hr}]} \right\} \times 5 \text{ person}$$

$$= \frac{20}{14.3} \times 5 = 1.3986 \times 5 = 6.993 = \frac{6.993}{100} = 0.06$$

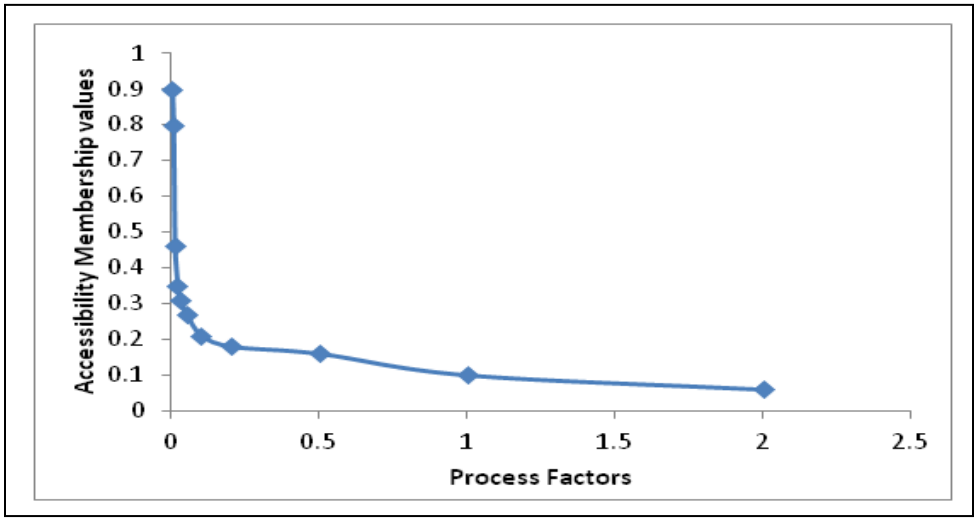
Similarly, accessibility membership values for every other household are calculated and given in the following table

Table 2. Fuzzy Accessibility Membership Values

Amba Village	CWPD (km)	d (km)	t (hr)	E *lt* (%)	S *tga* (%)	D *ft* (%)	F *ct* (Rs)	Wt (hr)	FAMV
H- 1	2	4	1	0.20	0.90	0.8	0	0.25	0.06
H- 2	1	2	0.5	0.40	0.90	0.8	0	0.16	0.10
H- 3	0.5	1	0.25	0.60	0.60	0.5	0	0.08	0.16
H- 4	0.2	0.4	0.16	0.80	0.70	0.6	0	0.08	0.18
H- 5	0.1	0.2	0.08	0.90	0.50	0.4	0	0.06	0.21
H- 6	0.05	0.1	0.04	0.95	0.40	0.3	0	0.05	0.27
H- 7	0.03	0.06	0.03	0.98	0.30	0.2	0	0.016	0.31
H- 8	0.02	0.04	0.166	0.99	0.2	0.1	0	0.016	0.35
H- 9	0.01	0.02	0.166	0.99	0.1	0.05	0	0.016	0.46
H- 10	0.005	0.01	0.08	1	0	0	0	0	0.8
H- 11	0.001	0	0.002	0.04	1	0	0	0	0.9

{Where; H – Households, CWPD – Common Water Point Distance, f – Frequency, d – Distance, t – Time taken, E*lt* – Energy left, S*tga* – Stigma, D*ft* – Discomfort, FC*t* – Fuel cost, W*t* – Waiting time and FAMV – Fuzzy Accessibility Membership Values }.

Figure 1. Graphical representation of FAMV



6.1 Observation and Findings

Whenever and wherever there is scarcity of safe drinking water and a common safe drinking water resource point is located at a pretty longer distance and as there are many process factors involved in fetching water, there is a gradual change in the degree of accessibility to water resources. This change is very well pointed out through the fuzzy membership values as we have noted in the above graph.

6.2. Classifications of the poor

Classifying the level of poverty without lose of generality, we assign the membership grade in accordance with the definition of fuzzy subset such as:

(i) 1 stands for non poor and 0 stands for the poor.

(ii) Any values between 0 and 1 is graded as poor or non poor as it is found closer to 0 or 1.

6.3 Results and Interpretations

From the fuzzy subsets analysis of poverty, it clear that the problem of identifying the poor takes a combination of many process factors. Using fuzzy variables along with the accessibility membership function we find that Household-1, household -2, household-3, and household-4 are very poor. The next category could be househould-5 and household-6 are poor; household-7, household-8 and household-9 are moderately poor or somewhat poor and household-10 and household-11 are non-poor. Hence, any policy of eradication of poverty could be made according to their level of poverty. And household-10 and household -11 can be considered non-poor.

Table 3. Result using Fuzzy Variables

Low accessibility	**Very low accessibility**	**Medium accessibility**	**High accessibility**
0.21, 0.27	0.06, 0.1, 0.16, 0.18	0.31, 0.35, 0.46	0.8, 0.9
Poor	***Very poor***	***Moderately poor***	***Non -poor***
Household-5 Household-6	Household-1 Household-2 Household-3 Household-4	Household-7 Household-8 Household-9	Household-10 Household-11

7. Conclusion

Safe drinking water has been used as a factor to study one's level of poverty. The issues included in fetching or collecting safe drinking water possesses many attributes which are fuzzy in nature. We have used inherent fuzziness and captured the level of poverty of eleven households. Our result shows that impreciseness is accounted as measureable factor using fuzzy approach. Accessibility to safe water is an easily observable indicator to assess one's level of poverty.

ACKNOWLEDGMENT

I acknowledge the financial support provided by UGC Rajiv Gandhi National Fellowship (RGNF). I also thankfully acknowledge the financial assistance provided by Patna Jesuit Society (PJS). I am also grateful to my institution PG and Research Department of Mathematics, Loyola College, Chennai – 34, Tamil Nadu.

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