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A FUZZY APPROACH IN THE STUDY OF AMOUNT OF PESTICIDE USE IN AGRICULTURAL SUSTAINABILITY

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ABSTRACT

The level of progress of human civilization what it is now has been possible for, among other issues, the ever increasing use of pesticides in agriculture. The use of pesticides has made it easy to meet the target of one of the basic need i.e. food of such a huge population. Without the use of pesticides we may have to starve to death due to a severe food crisis. But too much use of pesticide is harmful. A pesticide may not be so harmful if it can be used in proper dose i.e. the correct quantity is very important in the exposure (use) of any pesticide. Here arises the need of fuzzy logic that helps framing an appropriate model for proper use of pesticides that can overcome the food crisis. In this article, in order to determine the correct use of pesticides compatible with agricultural sustainability we introduce fuzzy set theory and fuzzy logic to develop fuzzy rule based systems in our fuzzy model. Using five important sustainable indicators in agricultural sustainable development due to pesticides, we introduce here a fuzzy rule based system for the hypothetical fuzzified values of three of the indicators and obtain a fuzzy conclusion. Membership functions are used in the trapezoidal or triangular form to represent the fuzzy numbers associated to each indicators. We get a numerical crisp value for hypothetical data input after the defuzzification process. The discussion about fuzzy model developed in this article provides an approach to build up an way to agricultural sustainable development regarding pesticides.

KEY WORDS

fuzzy logic, fuzzy set theory, indicators of sustainability, linguistic variable, sustainable development

CLASSIFICATION

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INTRODUCTION

We all know that the sustainability or sustainable development is that which aims at the fulfillment of the needs of the present situation or generation without violating the needs of the future generation. Agriculture sustainability or Agricultural sustainable development is that by which we meet towards one of the basic need (i.e. food) among the present generation without affecting the environmental or ecological, economical and social issues. Sustainability in agriculture must include the policies of healthy ecosystem which contain the indicators such as human health, ecological or environmental safety, production target and food security.

In the period between 1950 to 2000, the world population grew from 2,5 billion to 6,1 billion which means that the population on earth increased more than double in amount in the past 50 years (1950-2000). The United Nations (UN) estimates that, by the year 2050, the population will be around 9,7 billion on earth increasing 30 % more population than in recent year 2020. Currently, the annual growth rate of the world population is about 1,2 % i.e. around 77 million people per year. Most of the population growth occurred in developing countries and it would be continued in upcoming years also.

As a result, for the increasing demand of food production with the increase of population, the use of agrochemicals (pesticides) has been increasing day-by-day in agriculture. Different agricultural poisons i.e. pesticides are used and they may be categorized into insecticides, fungicides, herbicides, rodenticides, molluscicides, nematicides, plant- growth-regulators and others based on their activities and target groups (organisms). The global pesticide market divided according to the type of pesticide used as follows: 40 % herbicides, 33 % insecticides, 10 % fungicides and 17 % other types of pesticides. In tropical countries like India, the pesticide market for crop protection is skewed towards insecticides which is about 60 % and obviously the major applications are found in rice and cotton crops. The application of herbicides and fungicides are found to be about 16 % and 18 %, respectively. The major application area of fungicides are in fruits, vegetables, and rice whether the most of the application of herbicides are found to be in rice and wheat crops.

According to World Health Organisation (WHO), around 20 thousand people die annually due to the consumption of pesticides in food and about 25 million workers connected to agriculture are suffering for pesticide poisoning every year in developing countries. Though the issues related to pesticides are always highlighted in the media as well as in research journals, the indiscriminate and excessive use of synthetic toxic agrochemicals leads to many serious consequences like environment pollution, emergence of new pests, development of insect resistance, destabilization in biodiversity, destruction of ben- eficial organism, adverse health impact on society etc.

The report of Bruntland Commission also known as ‘World Commission on Environment and Development’(WCED) after releasing “Our Common Future” in October 1987 enlighted on food security on world population growth, where the commission observed that there are many people in the world who do not get enough food, lacking of nutrients. It also states that, due to overuse of the soil and agrochemicals (pesticides), the pollution in both of water resources and foods increases as the production in the industrialized countries. On the other hand, in many developing nations, farmers especially small farmers are not provided improved technologies and subsidies or incentives by the government for sufficient food production. According to the commission, after the World War-II, pesticides have played a huge role in the increase of food production in spite of receiving clear warnings for over-reliance on chemicals. Pesticides control many pests, weeds, fungi etc and enhance food productivity but its overuse threatens the human health and the lives of the other species such as depletion of commercial fisheries, bird species are endangered and the insects that prey on pests wiped out. A study in 1983 in developing countries estimated that for pesticide poisoning approximately 10 thousand people died each year and about four hundred thousand people suffered acutely. The effect of pesticides are not limited to the regions where it is used but it travels through the food chain. The effect is less harmful if the level of use of agricultural chemicals is quite low in that areas.

There are more than 1000 pesticides used around the world to ensure food is not damaged or destroyed by pests. Each pesticides has different properties and toxicological effects. Many of the older, cheaper (off-patent) pesticides, such as dichloro-diphenyl-trichloro-ethane (DDT), aldrin, dieldrin, endrin, parathion and lindane can remain for years in soil and water. These chemicals have been banned by countries who signed 2001 Stockholm Convention – an international treaty that aims to eliminate or restrict the production and use of persistent organic pollutants. The toxicity of a pesticide depends on it’s function and other factors.

The Food and Agriculture Organization (FAO) of the United Nations estimates that, in developing countries, 80 % of the necessary increases in food production keep pace with population growth are projected to come from increases in yields and the number of times per year crops can be grown on the same land. Only 20 % of new food production is expected to come from expansion of forming land. Pesticides can prevent large crop losses and will therefore continue to play a role in agriculture. However, the effects on humans and the environment of exposure to pesticides are a continuing concern. The use of pesticides to produce food, both to feed local populations and for export, should comply with good agricultural practices regardless of the economic status of a country. Farmers should limit the amount of pesticide used to the minimum necessary to product their crops.

Since the publication of Rachel Carson’s landmark book “Silent Spring”(1962), which reveals the horrifying impacts of pesticides like DDT, scientists are continually discovering new and disturbing ways that pesticides threaten our environment and our health. The world learned about dangerous pesticides from Rachel Carson’s “Silent Spring” in 1962. Even when the link between the disappearance of birds and the chemical pesticide DDT was made, it was not banned in the United States until 1972. Thereafter, other countries discontinued the use of DDT, as well. Even after Carson had proven that DDT weakened bird eggshells and poisoned lakes leading to fish kills, pesticide manufacturers claimed the small amounts of the chemical apparent in the environment possibly be responsible. In the book, Carson mentioned problems that could arise from the indiscriminate use of pesticides. This book inspired widespread concern about the impact of pesticides on the human health and the environment.

The notion of impact of pesticides in agriculture was introduced by Aktar et al in 2009 [1]. In 2003 Andriantiatsaholiniaina et al. [2] concerns about strategies for sustainable development and introduced a model named by SAFE model in their paper. Also introducing fuzzy set theory, Cornelissen et al. [3] discussed about sustainable development, and Stojanovic introduced a mathematical model using fuzzy set about tourism sustainable development [4].

In this article a mathematical model has been prepared using Fuzzy set theory and Fuzzy logic for an “Agricultural sustainabilty” problem. Sustainability implies an ongoing dynamic development, driven by human expectations about future opportunities, and is based on present ecological, economical and social issues and informations [5]. Agricultural sustainability is the sustainability to agricultural production systems, concerning about ecological, economical and social issues, which can meet of the need for sufficient, safe, and inexpensive food products to achieving agricultural production without possible undesirable side effects [6-8].

As described in previous paragraphs, it is clear that pesticides are needed to meet the food demand of the huge population of the world. At the same time, excessive use of pesticides can cause serious hazards to public health and also it is harmful for the environment. Thus to maintain the agricultural sustainability it is important to determine the safe level of use of pesticides. In this article a completely theoretical model has been developed based on Fuzzy set theory and Fuzzy logic to achieve this goal.

METHODOLOGY

BASICS OF CLASSICAL AND FUZZY SET THEORY

Classical set i.e. crisp set theory is based on two valued logic. Let us consider the universal set U that consists of elements x (*i.e.* $x \in U$) so that if A is a subset of U (*i.e.* $A \subset U$), then each element x is either a member of A ($x \in A$) or not a member of A ($x \notin A$). In classical set theory, the words 'subset' and 'event' are synonymous, i.e., $x \in A$ means that for element x event A has occurred. A characteristic function μ_A defines an clear distinction between members of A and nonmembers of A. To each x characteristic function μ_A assigns one of two values: $\mu_A(x) = 1$ if and only if $x \in A$, or $\mu_A(x) = 0$ if and only if $x \notin A$.

Let us consider the universal set U_{SI} for the sustainability indicator (SI) "Use of Pesticide", where x is the amount of pesticide used (kg/hect) and let T be the subset "Tolerable" ($T \subset U_{SI}$). Further, we can consider for sustainability of using pesticides in agriculture of human growth and development as tolerable a maximum (threshold) amount of use of pesticide x_t. If $x \leq x_t$, then the amount of use of pesticide is tolerable, so $\mu_T(x) = 1$. If $x > x_t$, then the amount of use of pesticide is intolerable, so $\mu_T(x) = 0$ (Figure 1a). Thus Classical set (crisp set) theory provides a hard threshold x_t to determine an unambiguous distinction between tolerable amount of using pesticides ($x \leq x_t$) and intolerable amounts ($x > x_t$). A hard threshold is often unrealistic in practice, however, because two nearly indistinguishable measurements x of SI on either side of x_t will be placed in complementary subsets.

On the other hand, fuzzy set theory is based on multivalued logic. Similar to crisp set theory, $\tilde{T}$ is a fuzzy subset of U ($\tilde{T} \subset U$) and a membership function $\mu_{\tilde{T}}$ defines the partial membership or degree of membership in a fuzzy set.

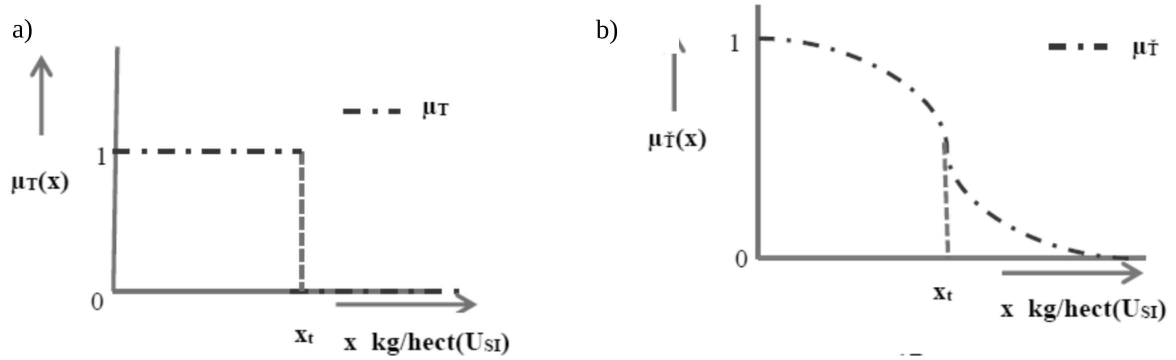

Figure 1. U_{SI} is the universal set for the sustainability indicator (SI) "Pesticide Use" and x is the amount of pesticide used (kg/hect): $x \in U_{SI}$. a) T is the classical subset "Tolerable" ($T \subset U_{SI}$) and characteristic function μ_T defines a hard threshold x_t between tolerable amounts of pesticide used ($x \leq x_t$) and intolerable amounts ($x > x_t$): μ_T assigns to each x one of two values: $\mu_T(x) = 1$ if and only if $x \leq x_t$ or $\mu_T(x) = 0$ if and only if $x > x_t$. b) $\tilde{T}$ is the fuzzy subset "Tolerable" ($\tilde{T} \subset U_{SI}$) and membership function $\mu_{\tilde{T}}$ defines a soft threshold x_t between tolerable amounts of pesticide used and intolerable amounts: $\mu_{\tilde{T}}$ assigns to each x a value $\mu_{\tilde{T}}(x)$ decreasing from 1 to 0 with increasing x.

Thus, membership function $\mu_{\tilde{T}}$ assigns to each x a value from 0 to 1, indicating the degree of membership $\mu_{\tilde{T}}(x)$ of x in $\tilde{T}$. Membership functions, therefore, are functions that maps x from U into the interval [0, 1], Figure 1b.

Consider that the poisons (pesticides) used in agriculture and the universal set for "Pesticide use" U_{SI}. Let $\tilde{T}$ be the fuzzy subset "Tolerable" ($\tilde{T} \subset U_{SI}$). Membership function $\mu_{\tilde{T}}$ is assumed to have a nonlinear form, with degree of membership $\mu_{\tilde{T}}(x)$ for agricultural sustainability in using pesticides decreasing from 1 to 0 with increasing x (amount of pesticides kg/hect), Figure 1b). Hence, fuzzy set theory provides a soft threshold to assess an intermediate value $\mu_{\tilde{T}}(x)$ between tolerable amounts of using pesticides and intolerable amounts. A membership function $\mu_{\tilde{T}}$ defines a soft threshold, which enables a smooth and practical assessment of measurements x of sustainability indicator (SI).

UNCERTAINTY IN AGRICULTURAL SUSTAINABLE DEVELOPMENT

On construction of a mathematical theory on agricultural sustainability model, we must consider the type of uncertainty related to Sustainable Development (SD). Because SD of agriculture will be assessed using selected sustainability indicators (SI), this selection determines how much we know about SD, i.e. how much information is available; and how much we do not know about SD, i.e. how much information is missing. Certainty about SD requires complete and consistent information. To reduce the description of SD to a manageable level and to obtain feasible model, it is necessary to reduce the amount of information.

In this context we can quote the following: "Further, an increasing number of pest control is an issue of conflict because pests are our major competitors on earth. But from our experience gathered so far, it remains a fact that war against pests is neither necessary nor effective. Pesticides themselves beget more virulent pests, they do not control them. Pests are controlled when there is an ecological balance between diverse components of the farming system. One possible alternative could be application of non-toxic environmental friendly formulations and solutions to combat pests. Bio-pesticides, typically microbial biological pest control agents, are the appropriate substitutes for toxic chemical pesticides. Use of bio-pesticides as a component of Integrated Pest Management (IPM) program can considerably decrease the use of chemical pesticides. Ecological or organic farming is also considered as environmentally suitable, economically viable and socially adaptable through which agricultural sustainable development can be attained" (Jaydev Jana, The Statesman, Kolkata, India, 4th December, 2019).

Due to incomplete and inconsistent information, SD has no well-defined meaning. The type of uncertainty regarding an assessment of the contribution of SI to SD, therefore, essentially concerns the meaning of SD. In mathematical terms, this type of uncertainty is known as fuzzy uncertainty.

LINGUISTIC VARIABLES IN FUZZY MODEL

For any fuzzy model, membership functions play fundamental role for which we use such functions to operate "linguistic variables" [9, 10]. In fuzzy set theory, a linguistic variable $\tilde{T}$ may be characterized by: (i) name of $\tilde{T}$, (ii) base variable x of $\tilde{T}$, (iii) linguistic value $\tilde{T}_i$ of $\tilde{T}$ (i = 1, 2, ..., m) and (iv) membership function $\mu_{\tilde{T}}$ of $\tilde{T}_i$. Characteristics of a linguistic variable are shown in Figure 2.

Consider that the amount of pesticide used x, which is a measurement of the SI "Pesticide Use", defines U_{SI}; hence x is the base variable of $\tilde{T}$. If the contribution of "Pesticide Use" to SD is expressed in terms of “Tolerance” of base variable x, then the name of $\tilde{T}$ is “Tolerability”.Three linguistic values $\tilde{T}_i(\tilde{T}_1, \tilde{T}_2, \tilde{T}_3)$ define the contribution of x to SD in linguistic terms: $\tilde{T}_1$ = “Tolerable”, $\tilde{T}_1$ = “Moderately Tolerable” and $\tilde{T}_3$ = “Intolerable”.

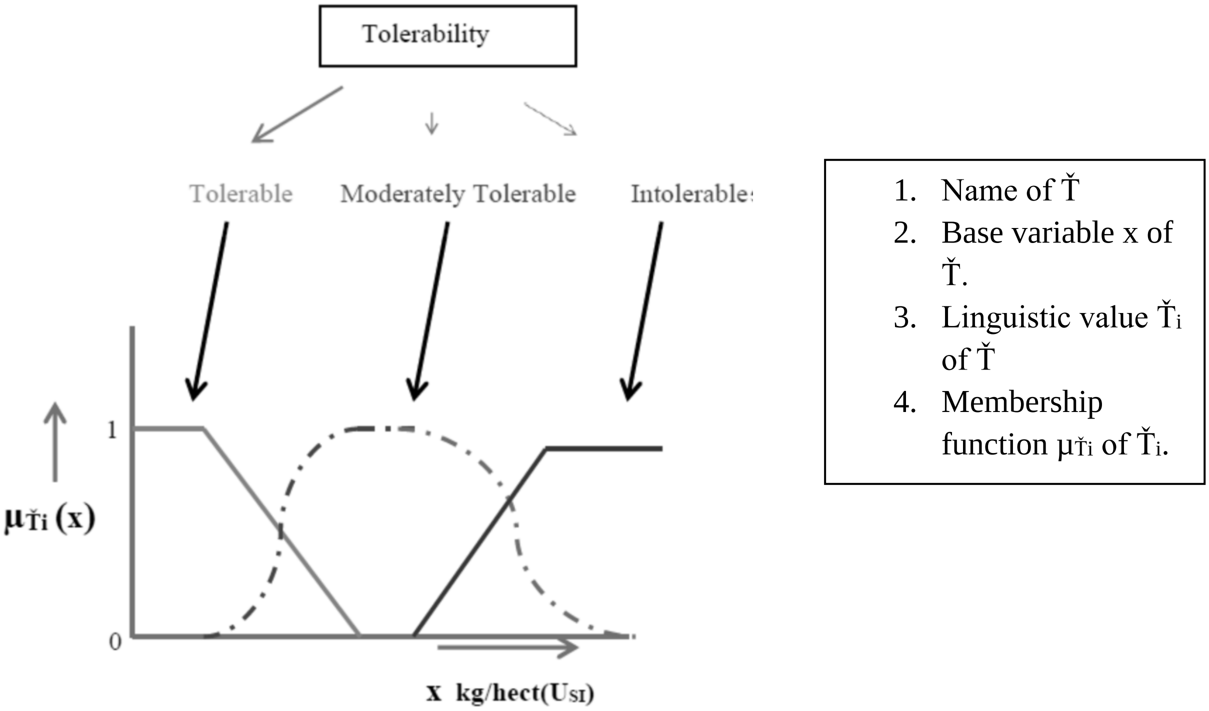

Figure 2. Linguistic variable $\tilde{T}$ is characterized by: (i) name of $\tilde{T}$, (ii) base variable x of $\tilde{T}$, (iii) linguistic value $\tilde{T}_i$ of $\tilde{T}$ and (iv) membership function $\mu_{\tilde{T}}$ of $\tilde{T}_i$.

A linguistic value is a fuzzy subset $\tilde{T}_i$ of the universal set U_{SI} ($\tilde{T}_i \subset U_{SI}$). A membership function $\mu_{\tilde{T}}$ defines to each linguistic value $\tilde{T}_i$ by determining to what degree $\mu_{\tilde{T}_i}(x)$ a base variable x is “Tolerable”, $\mu_{\tilde{T}_1}(x)$; “Moderately Tolerable”, $\mu_{\tilde{T}_2}(x)$; or “Intolerable”, $\mu_{\tilde{T}_3}(x)$.

In the sustainability framework, human expectations about SD are expressed as ecological, economical and social issues, for which SI provides numerical data. Use of linguistic variables in fuzzy models enable one to link expectations about SD, expressed in linguistic propositions, to numerical data, expressed in measurements of SI. Use of “Tolerance”, for example, enables one to link the proposition “Pesticide Use is Tolerable” to the amount of pesticide used (x kg per hectare).

FUZZY MODEL TO ASSESS AGRICULTURAL SUSTAINABLE DEVELOPMENT

SYMBOLS

Here are two techniques in the fuzzy model used to assess SD: one applying **fuzzy set aggregation** and another which applying **approximate reasoning**. Input in fuzzy model has n sustainability indicators SI_j (j = 1, 2, ..., n) and base variables x_j. In each SI_j there is a membership function μ_{ij} associated with a linguistic value $\tilde{T}_i$ by functioning x_j into the interval [0, 1]. Each x_j with μ_{ij} results in n degrees of membership $\mu_{ij}(x_j)$. Numerical assessment of SD, μ_{SD} is the output of the fuzzy model; i.e. the value of μ_{SD} lies in the interval [0, 1].

FUZZY SET AGGREGATION IN FUZZY MODEL

Steps in fuzzy aggregation

Aggregation operations for the assessment of SD is shown in Figure 3. Five steps are involved: 1st step defines model input, sustainability indicator SI_j and base variable x_j; 2nd step defines linguistic variable $\tilde{T}$ and linguistic value $\tilde{T}_i$; 3rd step constructs membership function μ_{ij}; 4th step computes degree of mem- bership $\mu_{ij}(x_j)$; and 5th step selects a fuzzy set aggregation for $\mu_{ij}(x_j)$ so as to assess model output μ_{SD}.

Computation in fuzzy aggregation

The computations of aggregation for the SD gives a meaningful numerical assessment μ_{SD} which requires careful selection of an aggregation.

Let us assume that 2nd step defines linguistic variable "Tolerability"($\tilde{T}$) and linguistic value "Tolerable"($\tilde{T}_1$). An inclusive (conservative) attitude toward SD means that μ_{SD} is the smallest degree of membership among $\mu_{11}(x_1)$, $\mu_{12}(x_2)$, ..., $\mu_{1n}(x_n)$. In fuzzy set theory, the standard fuzzy intersection makes computation of SD by applying the minimum operator:

$$\mu_{SD} = \min\{\mu_{11}(x_1),\ \mu_{12}(x_2), \ldots,\ \mu_{1n}(x_n)\},$$

where 'min' denotes the minimum operator. Consequently, if one degree of membership $\mu_{1j}(x_j)$ is 0, then assessment μ_{SD} is 0.

On the other hand, an exclusive (liberal) attitude toward SD means that μ_{SD} is the largest degree of membership among $\mu_{11}(x_1)$, $\mu_{12}(x_2)$, ..., $\mu_{1n}(x_n)$. In fuzzy set theory,the standard fuzzy union makes computation of SD by applying the maximum operator:

$$\mu_{SD} = \max\{\mu_{11}(x_1),\ \mu_{12}(x_2),\ \ldots,\ \mu_{1n}(x_n)\},$$

where 'max' denotes the maximum operator. Consequently, if one degree of membership $\mu_{1j}(x_j)$ is 1, then assessment μ_{SD} is 1.

In agricultural sustainability, ecological, economical and social (EES) are the main three pillars. Averaging operations allow a degree of compromise among the n degrees of membership $\mu_{11}(x_1)$, $\mu_{12}(x_2)$, ..., $\mu_{1n}(x_n)$ and determine a value for μ_{SD} between $\min\{\mu_{11}(x_1), \mu_{12}(x_2), \ldots, \mu_{1n}(x_n)\}$ and $\max\{\mu_{11}(x_1), \mu_{12}(x_2), \ldots, \mu_{1n}(x_n)\}$. Again in addition, the relative importance (weightage) of each sustainability indicator SI_j may be considered in proportion to its importance.

If ω_j denotes the relative importance (weightage) of SI_j, then a generalized formula of weighted averaging operation is

$$\mu_{SD} = \sum_{j=1}^{n} \omega_j \mu_{1j} x_j, \quad (1)$$

with $\sum_{j=1}^{n} \omega_j = 1$.

In the special case when the relative importance of each SI_j is equal, equation (1) reduces to

$$\mu_{SD} = \frac{1}{n}\sum_{j=1}^{n} \mu_{1j} x_j. \quad (2)$$

Using poisons (Pesticides) in agriculture, assume SD is to be assessed based on five SIs:

- SI_1 is "Effect on **Human health**" (x_1 kg/ hect),
- SI_2 is "Impact on **Environment**" (x_2 kg/ hect),
- SI_3 is "**Production quantity**" (x_3 kg/ hect),
- SI_4 is "**Food quality**" (x_4 kg/ hect),
- SI_5 is "Effect on **Animals and Birds**" (x_5 kg/ hect).

Further assume that associating x_j with μ_{1j} results in degrees of membership $\mu_{11}(x_1) = 0{,}3$; $\mu_{12}(x_2) = 0{,}4$, $\mu_{13}(x_3) = 0{,}6$, $\mu_{14}(x_4) = 0{,}2$ and $\mu_{15}(x_5) = 0{,}5$.

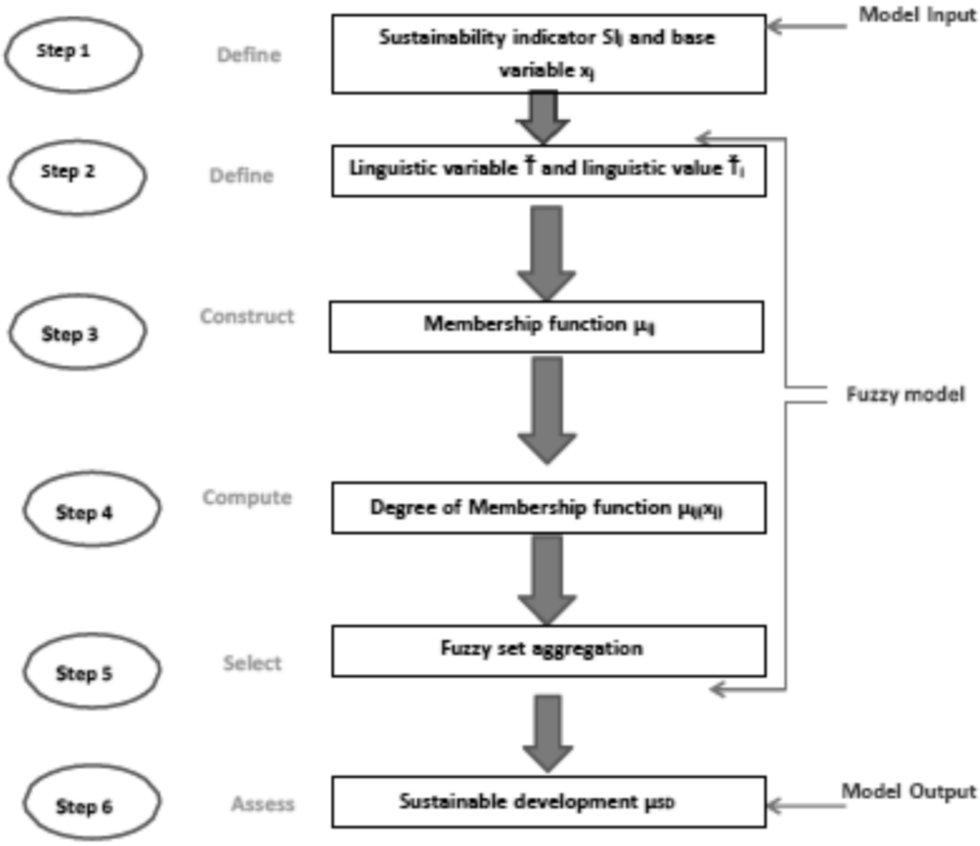

Figure 3. The scheme of a fuzzy model applying fuzzy set aggregation to assess the contribution of SI to SD.

Equation (1) determines the degree of membership μ_{SD} for some specific relativeness of weightage.

NORMALIZATION OF DATA

Normalization is generally used to a scale so that the value of the raw data falls in such a standard (smaller) range, such as from –1 to 1, or from 0 to 1, etc. Normalization is generally required when we are dealing with re-scaling of raw data on different scales especially when values are on larger scale. So normalization brings all the data on same scale. We use here so called 'Max-Min Normalization'(Min-Max scaling) technique so that normalized data of each basic indicator are on a scale between zero (lowest level of sustainability) and one (highest level of sustainability) for fuzzy computations. It may be done as follows.

Let c be the indicator value for the system whose sustainability we want to assess. The normalized value, x_c, is calculated as given in Figure 4.

Between a minimum value $\underline{c}$ and a maximum value $\overline{c}$ of each basic indicator c, we assign a target, which may be a single value or an interval on the real line of the form [t_c, T_c] representing a range of desireable values for the indicator.

SOME SUSTAINABLE INDICATORS AND FUZZY NUMBERS

Indicators of health influence and effect of pesticides on human health

Pesticides are incredibly harmful to human health. Pesticides have been proven to cause reproductive and development effects, cancer, kidney and liver damage, endocrine disruption etc. People are exposed to pesticides when they breathe air where pesticides have been sprayed,

$$x_c = \begin{cases} (c - \underline{c})/(t_c - \underline{c}), & \text{when } \underline{c} \le c < t_c \\ 1, & \text{when } t_c \le c \le T_c \\ (\overline{c} - c)/(\overline{c} - T_c), & \text{when } T_c < c \le \overline{c} \end{cases}$$

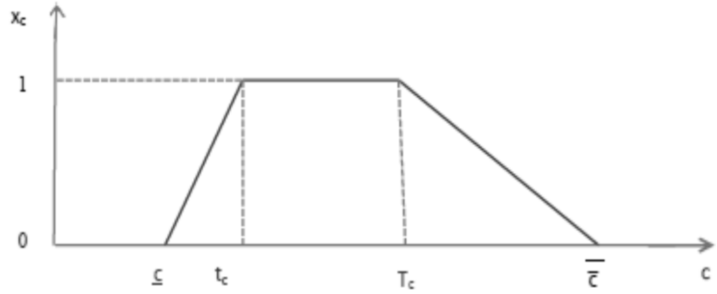

Figure 4. Normalized value of indicator c. It is clear that x_c is a trapezoidal function.

drink contaminated water or come into contact with areas where pesticides have been used, such as lawns, parks, lakes and more. Its adverse effects on health depends upon the degree of toxicity, amount of water intake each day and the individual’s health. Adverse effects on human health can also be caused by impurities in pesticides.

Children, whose bodies are still developing, are particularly vulnerable. They take inpesticides at home in daycare and at school in the playgrounds, as kids are more likely tocrawl on the ground and put their contaminated hands in their mouths. Research shows that children are even exposed to pesticides in utero. One of these pesticides, chlorpyrifos, has been found to cause irreversible brain damage in infants when they are exposed to theinsecticides during this period. Children ages 5-10 nationwide have significantly higher level of pesticide residues in their bodies than all other age categories.

People and families working on and living near industrial farms are some of the mostat risk populations of these health problems. Farm workers/ Farmers/ Agricultural workers often suffer from short-term effects such as blindness, coma, asthma and death as wellas long-term effects like infertility, birth defects and cancer.

Let us apply, regarding this criteria, fuzzy logic on effect of pesticides on human health indicator using following symbols and terminology.

Suppose H is a set of all fuzzy sets which we will use to describe as an human healthindicator related to the amount of a particular pesticide used in agriculture. Notation is as follows:

- H_1 is fuzzy number which indicates that the effect of that pesticide on Human health is “sustainable”. For sustainability we may assume that the value of base variable of the membership function may be assumed to be less than 0,4;
- $H_{1/2}$ is fuzzy number which indicates that the effect is not sustainable i.e.“moderately sustainable”. In this case the value of base variable of membership function may range between 0,4 and 0,6, and
- H_0 is fuzzy number which indicates that the situation is “unsustainable”. In this case the value of base variable of membership function must be greater than 0,6.

Therefore, set H contains H_1, $H_{1/2}$, H_0 and $H = \{H_1, H_{1/2}, H_0\}$. Sets $H_1, H_{1/2}, H_0$ indicate the state of sustainability of Human health in using pesticides in agriculture. Based on this indicator we must gain those sets using membership function in trapezoidal form displaying fuzzy numbers, Figure 5.

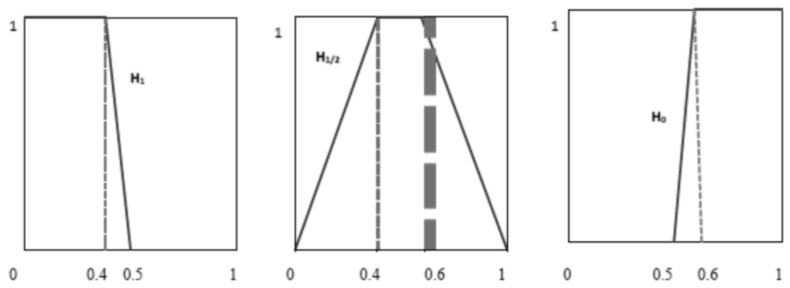

Figure 5. Membership functions of fuzzy sets H_1, $H_{1/2}$ and H_0.

Indicators of environment issues and environmental impact of pesticides

The arrival of humans in an area, to live or to conduct agriculture, necessarily has environmental impacts. The use of agricultural chemicals such as pesticides magnify thoseimpacts. Pesticides, in addition to their potential negative effects on human health, poseadverse effects also on the environment (soil, water and air contamination, toxic effects on non-target organism). In particular, inappropriate use of pesticides has been linked with : (i) adverse effect on non-target organism (e.g. reduction of beneficial species population), (ii) effect of soil fertility extensive use of pesticides, (iii) water contamination from mobile pesticides or from pesticide drift, (iv) air pollution from volatile pesticides, (v) injury on non-target plants from herbicide drift, (vi) injury to rotational crops from herbicide residues remained in the field, (vii) crop injury due to high application rates, wrong application timing or unfavourable environmental conditions at and after pesticideapplication. The extensive use of pesticides in agricultural production can degrade and damage the community of micro-organism living in the soil, particularly when these chemicals are overused or misused as chemical compounds built up in the soil. The full impact of pesticides on soil micro-organism is still not entirely understood;many studies have found deleterious effects of pesticides on soil micro-organisms and biochemical processes. The effect of pesticides on soil micro-organism is impacted by the persistence, concentration and toxicity of the applied pesticide, in addition to various environmental factors. In general, long-term pesticide application can disturb the biochemical process of nutrient cycling.

Pesticide impacts on aquatic systems are often studied using a hydrology transport model to study movement and fate of chemicals in rivers and streams. Pesticide residues also been found in rain and groundwater where as it is shown that pesticideconcentrations exceeded those allowable for drinking water in some samples of river water and groundwater. Water containing pesticides, when used for drinking purposes, canbe harmful, ranging from mild headache and skin allergy to cancer of internal organs.

Pesticide can contribute to air pollution. Pesticides that are applied to crops can volatilize and may be blown by winds intonearby areas, potentially posing a threat to wildlife. Pesticide use accounts for about 6 % of total tropospheric ozone levels.

Let us denote as E a set of all fuzzy sets that describe the impact of pesticide on environment, and:

- E_1 represents fuzzy set that points that the impact of pesticide on Environment is "sustainable". For sustainability the value of base variable of the membership function can be assumed to be less than 0,3;
- $E_{1/2}$ represents fuzzy set that points that the impact on environment is "tolerable" and in this case the value of base variable of the membership function may be in between 0,3 and 0,7;
- E_0 represents fuzzy sets that points that the impact on environment is "unsustainable" and in this case the value of base variable of the membership function should be larger than 0,7.

Obviously, E contains E_1, $E_{1/2}$ and E_0 i.e. $E = \{E_1, E_{1/2}, E_0\}$, where E_1, $E_{1/2}$, E_0 represents the state of impact of pesticide on environment. Membership functions of E_1, $E_{1/2}$ and E_0 are given in Figure 6.

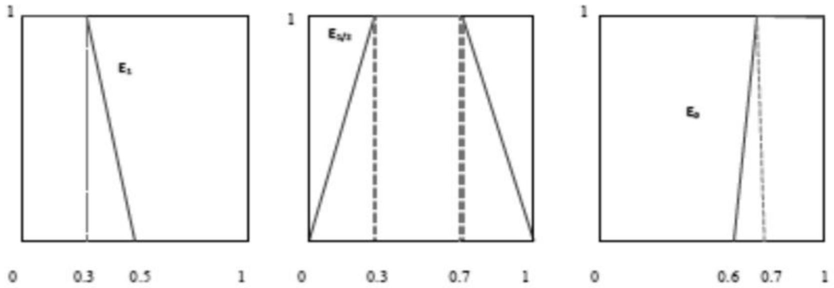

Figure 6. Membership functions of fuzzy sets E_1, $E_{1/2}$ and E_0.

Indicators of quantitative issues of pesticides on production quantity

The production of pesticides started in India in 1952 with the establishment of a plant for the production of Benzene Hexachloride (BHC) near Calcutta (now Kolkata), and India was the second largest manufacturer of pesticides in Asia after China and ranked twelfth in world [11]. There has been a steady growth in the production of technical grade pesticides in India, from 5 000 metric tons in 1958 to 102 240 metric tons in 1998. In 1996 to 1997 the demand for pesticides in terms of value was estimated to be around Rs. 22 billion (USD 0,5 billion), which was about 2 % of the global market [1].

The increased threat of higher crop losses to pests has to be counteracted by improved crop protection whatever method it will be (biologically, mechanically, chemically, IPM (Integrated Pest Management) and training of farmers). The use of pesticides has increased dramatically since the early 1960s; in the same period also, the average yield of wheat, rice and maize, the major sources for human nutrition, has more than doubled. Without pesticides, food production would drop and food prices would soar. With lower production and higher prices, farmers would be less competitive in global markets for major commodities. Where overall crop productivity is low, crop protection is largely limited to some weed control, and actual losses to pests may account for more than 50% of the attainable production [12].

From the time when synthetic pesticides were developed after second World War, there have been major increases in agricultural productivity accompanied by an increase in efficiency, with fewer farmers on fewer farms producing more food for more people. A major factor in the changing productivity patterns, either directly or indirectly, has been the use of pesticides. Ensuring the safety and quality of foods and the increase in crop loss was accompanied by a growth in the rate of pesticide use.

Let us suppose that:

- P_1 represents fuzzy set that points that the effect of using pesticide on production amount is “sustainable”. For sustainability we may assume that the value of base variable of the membership function may lie between 0,3 to 0,8;
- P_0 represents fuzzy set that points that the effect of using pesticide on production amount is “unsustainable”. For unsustainability we must have the value of base variable of the membership function must be greater than 0,8.

Obviously $P = \{P_1, P_0\}$. Corresponding membership functions are given in Figure 7.

Indicators of qualitative issues of pesticides on food quality

In the first world countries, it has been observed that diet chart containing fresh fruits and vegetables far outweigh potential risks from eating very low residues of pesticides in crops [13]. Increasing evidence (Dietary Guidelines, 2005) shows that eating fruits and vegetables regularly reduces the risk of many cancers, high blood pressure, heart disease, diabetes, stroke and other chronic diseases [1].

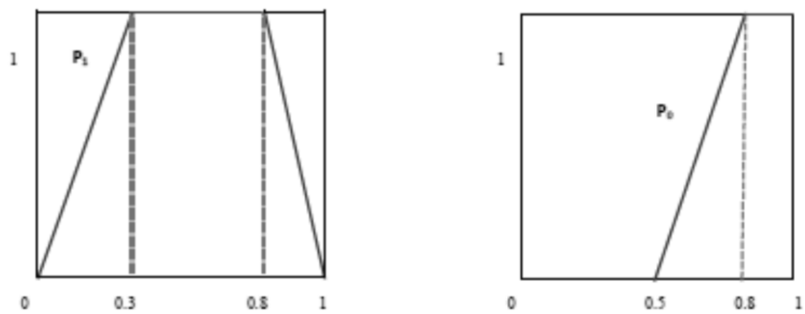

Figure 7. Membership functions of fuzzy sets P_1 and P_0.

The current model of agriculture is designed to maximize profit by increasing production yields and quality of agricultural products, while reducing costs for both producers and consumers. In this regard, the use of pesticides has paid an enormous importance allowing controlling insects or fungal infestations or growth of weeds, either to handle immediate infestations or to anticipate long lasting problems. Pesticides can also be used to help protect seeds, or prolong the life of crops after they have been harvested.

However despite their many merits and due to their inherent nature, pesticides are some of most toxic, environmentally stable and mobile substances in the environment. Their excessive use (misuse) especially in the developing countries, their volatility, long distance transports eventually results in widespread environmental contamination. In addition, many older, non-patented, more toxic, environmentally persistent and inexpensive chemicals are used extensively in developing nations, creating serious acute health problems and local and global environmental impacts [14]. As a consequence of their extensive applications, most of the applied pesticides find their way as 'residue' in the environment into the terrestrial and aquatic food chains, where they undergo concentration and exert potential, long term, adverse health effects. Nevertheless, the perception on the risks that pesticides in food pose to human health relative to other dietary risks varies between consumers and scientists. Pesticides itself slowly start dissipating after these are sprayed. The rate at which pesticides are moved or dissipated varies with the nature of pesticide molecule, type and portion of food material and environmental factors [15]. From an effective point of view, food safety monitoring programs must consider all these possible situations. Therefore, the result of the processing studies should be as follows:

- to provide information on the transfer of residues from the raw agricultural commodity to the processed products, in order to calculate reduction or concentration factors;
- to enable a more realistic estimate of the dietary intake of pesticide residues;
- to establish MRLs (Maximum Residue Limits) for residues in processed products where necessary, according to the requirements of national regulatory authorities or international standards.

Production of safe and healthy food is a key priority in the worldwide. Recommendations are also given on those research challenges facing the study of the effects of fermentation on pesticide residues, as well as the effects of residues on food quality and safely.

Let us express this statements in fuzzy sets. Let F be the set of all fuzzy sets which describe the effect of pesticides on the quality of food or crops.

- F_1 represent fuzzy set which shows that the impact of pesticide on the quality of food or crops is "sustainable". For sustainability we may assume that the value of base variable of the membership function may be less than 0,4;
- F_0 represents the fuzzy set which shows that the impact of pesticide on the quality of food or crops is "unsustainable". For unsustainability the value of base variable of the membership function then should be greater than 0,7.

Obviously $F = \{F_1, F_0\}$. Membership functions of F_1 and F_0 are given in Figure 8.

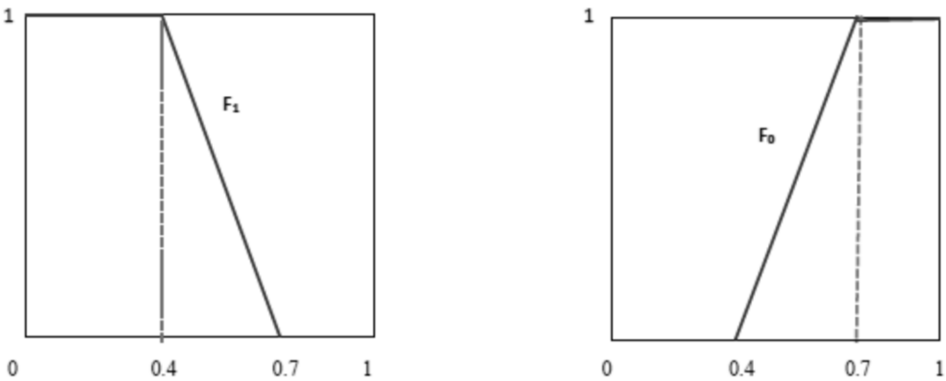

Figure 8. Membership functions of fuzzy sets F_1 and F_0.

Indicators of bio-diversities of pesticides on wildlife

Wildlife may come into contact with pesticides in many ways. They can be exposed if they touch treated areas, eat treated plants, or drink contaminated water. Hidden nestsor young may also be directly exposed to pesticides during an application. Pesticides thatdestroy habitat or food can also affect wildlife. Birds of prey were primarily affected; exceptions apparently are the result of lesser exposure because of different food habits. Many species of fish-eating birds are also affected.

We may be familiar with colony collapse disorder and the effect it has onbee populations. Pesticides are non-discriminatory chemicals, meaning they impact both good bugs and bad ones alike.

Atrazine, the most widely used pesticide in the United States, has been shown to causesexual abnormalities in frogs. Atrazine is not water soluble, meaning when it rains, it caneasily wash off crop fields and into surrounding watersheds without breaking down. Frogexposed to atrazine have exhibited multiple ovaries and testes or even frogs with both setsof gendered sex organs. This pesticide has been banned in Europe and has been linked to human cancers and reproductive disorders.

Birdsthat come into contact with toxic pesticides (like neonicotinoids) have shown a decrease in breeding success, physical malformations, an impaired ability to avoid predators or migrate, and in some cases, pesticides can lead to death.

Let us say that set W represents set of all fuzzy sets that describe the impact of pesticides on Animals and Birds (Wildlife), so:

- W_1 is fuzzy set that represents the impact of pesticides is "sustainable" and the value of base variable of the membership function may less than 0,4;
- $W_{1/2}$ is fuzzy set that represents the impact of pesticides is "tolerable" and the value of base variable of the membership function may be lie between 0,4 and 0,6;
- W_0 is fuzzy set that represent the impact of pesticides is "unsustainable" and the value of base variable of the membership function should be greater than 0,6.

Obviously $W = \{W_1, W_{1/2}, W_0\}$, and fuzzy sets of its membership functions are given in Figure 9.

APPROXIMATE REASONING IN FUZZY MODEL

Steps in approximate reasoning

The computations of approximate reasoning for the assessment of SD is given in Figure 10. Six steps are involved: 1st step defines model input, sustainability indicator SI_j and the base

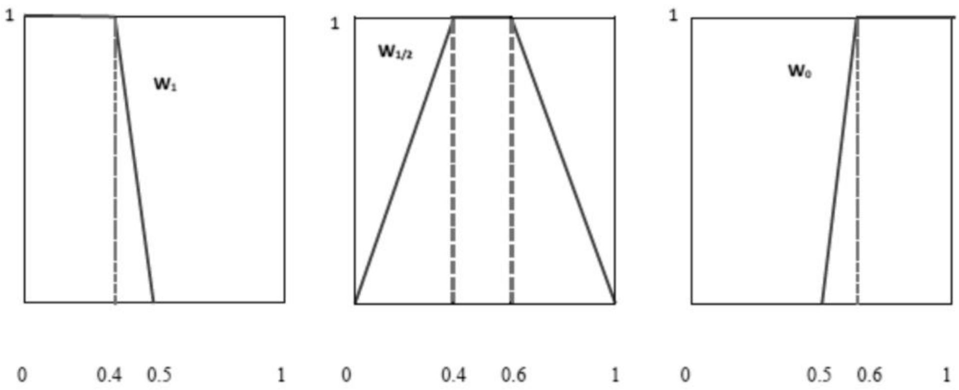

Figure 9. Membership functions of fuzzy sets W_1, $W_{1/2}$ and W_0.

variable x_j; 2nd step defines linguistic variable $\tilde{T}$ for input and m linguistic values $\tilde{T}_i$, and also defines linguistic variable $\tilde{O}$ for output and q linguistic values $\tilde{O}_p$ (p = 1, 2, ..., q) regarding assessment μ_{SD}; 3rd step constructs membership function μ_{ij} and $\mu_{\tilde{O}}$; 4th step computes degree of membership $\mu_{ij}(x_j)$; 5th step determines a fuzzy conclusion $\tilde{C}$; and 6th step draws a numerical assessment μ_{SD}.

In approximate reasoning, 4th step is known as fuzzification, 5th step as fuzzy inference and 6th step as defuzzification.

Fuzzy rule base

Approximate reasoning is the process of inferring a conclusion for a problem that cannot be observed directly (i.e. SD), but in the problem there are some things that can be observed directly (i.e. SI). In a fuzzy model applying approximatereasoning, the reasoning process is based on a series of r fuzzy rules R_k (k = 1, 2, ..., r),which together is referred to as the fuzzy rule base of the model. A fuzzy rule introduces us the contribution of SI_j to SD by using of linguistic IF-THEN fuzzy rule base propositions.

A proposition contains an antecedent (premise), the IF-part, and a consequent (conclusion), the THEN-part [16]. The premise can contain one and more facts “SI_j *is* $\tilde{T}_i$”. The conclusion contains a single fact “SD *is* $\tilde{O}_p$”, where linguistic value $\tilde{O}_p$ defines a fuzzy assessment regarding SD ($\tilde{O}_p \subset U_{SD}$). Thus fuzzy rule R_k is the conditional statement

IF “SI_j is $\tilde{T}_i$” THEN “SD is $\tilde{O}_p$”.

For instance, if SI_1 is “Pesticide impact on **Human health**”, $\tilde{T}_1$ is linguistic value “Tolerable”, SD is “Sustainable Development”, $\tilde{O}$ is linguistic variable, “Output” or “Achievement”, and $\tilde{O}_1$ is linguistic value “Very Good”, then fuzzy rule R_k reads:

IF *Pesticide impact on Human health is Tolerable*

THEN *Sustainable Development is Very Good.*

Recall assessing the SD of Pesticide Use in Agriculture: SI_1 is “Effect on Human health” (x_1 kg/hect), SI_2 is “Impact on Environment” (x_2 kg/hect), SI_3 is “Production quantity” (x_3 kg/hect), SI_4 is “Food quality” (x_4 kg/hect), and SI_5 is “Effect on Animals and Birds” (x_5 kg/hect). Further linguistic value (Tolerability) $\tilde{T}_1$ is “Tolerable”, and $\tilde{T}_2$ is “Intolerable”, and linguistic value (Output) $\tilde{O}_1$ is “Very Good”, $\tilde{O}_2$ is “Good”, $\tilde{O}_3$ is “Average”, $\tilde{O}_4$ is “Bad”, and $\tilde{O}_5$ is “Very Bad”.

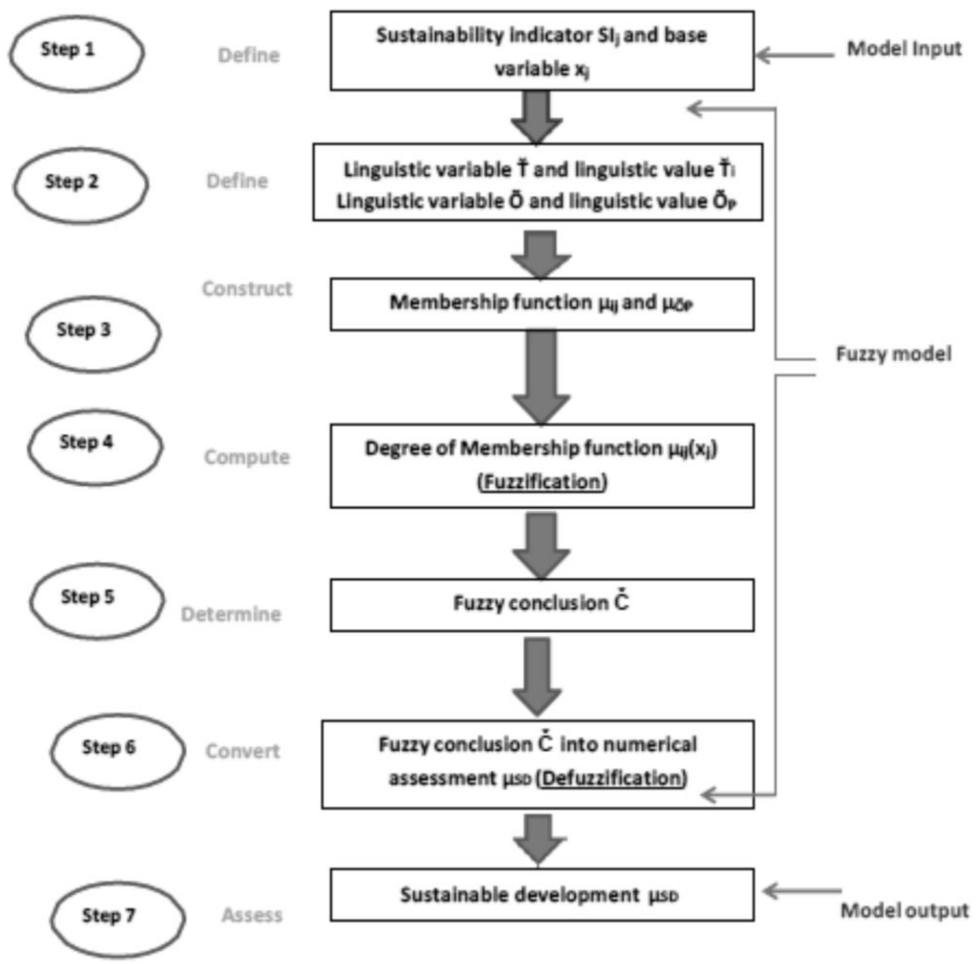

Figure 10. The scheme of a fuzzy model applying approximate reasoning to access the contribution of SI to SD.

A fuzzy rule base comprising five fuzzy rules could read

$\boldsymbol{R}_1$: IF SI_1 *is* $\tilde{T}_1$ AND SI_2 *is* $\tilde{T}_1$ AND SI_3 *is* $\tilde{T}_1$ THEN *SD is* $\tilde{O}_1$;
$\boldsymbol{R}_2$: IF SI_1 *is* $\tilde{T}_1$ AND SI_2 *is* $\tilde{T}_1$ AND SI_3 *is* $\tilde{T}_2$ THEN *SD is* $\tilde{O}_2$;
$\boldsymbol{R}_3$: IF SI_1 *is* $\tilde{T}_1$ AND SI_2 *is* $\tilde{T}_2$ AND SI_3 *is* $\tilde{T}_1$ THEN *SD is* $\tilde{O}_3$;
$\boldsymbol{R}_4$: IF SI_1 *is* $\tilde{T}_2$ AND SI_2 *is* $\tilde{T}_1$ AND SI_3 *is* $\tilde{T}_1$ THEN *SD is* $\tilde{O}_4$;
$\boldsymbol{R}_5$: IF SI_1 *is* $\tilde{T}_2$ AND SI_2 *is* $\tilde{T}_2$ AND SI_3 *is* $\tilde{T}_2$ THEN *SD is* $\tilde{O}_5$.

Rule R_1, for example, reads "IF Pesticide effect on Human health is Tolerable AND Pesticides impact on Environment is Tolerable AND Pesticides on Production quantity isTolerable THEN Sustainable Development (SD) is Very Good"; where 'AND' denotes a logical connective [17]. 4th Step (Fuzzification), 5th Step (Fuzzy inference), and 6th Step (Defuzzification) will be illustrated based on the stated fuzzy rule base.

FUZZIFICATION

Fuzzification of model input refers to computing the degree of membership $\mu_{ij}(x_j)$. In the example of assessing SD of using Pesticides in Agriculture, the fuzzification for the hypothetical values (taken earlier) in computaion of SI_1 results in$\mu_{11}(x_1)$= 0,3; of SI_2, $\mu_{12}(x_2)$ = 0,4; of SI_3, $\mu_{13}(x_3)$ = 0,6. Further, $\tilde{T}_2$ ("Intolerable") is the fuzzy complement of $\tilde{T}_1$ ("Tolerable"), so that $\mu_{2j}(x_j) = 1 - \mu_{1j}(x_j)$ [17]: $\mu_{21}(x_1)$ = 0,7, $\mu_{22}(x_2)$ = 0,6, $\mu_{23}(x_3)$ = 0,4, Figure 11.

FUZZY INFERENCE

Fuzzy inference is a two step process : the implication process and the aggregation process [18]. The implication process defines a fuzzy conclusion $\tilde{C}_k$ for each rule R_k. The aggregation process then defines an overall fuzzy conclusion $\tilde{C}$ for the entire fuzzy rule base. We use here **Mamdani** fuzzy controllers for fuzzy inference.

The implication process first defines a value τ_k for the antecedent (premise) of the proposition in fuzzy rule R_k. If the antecedent (premise) contains a single fact " SI_j is $\tilde{T}_i$", then τ_k is defined by the degree of membership $\mu_{ij}(x_j)$. If the antecedent (premise) contains more than one fact, however, then τ_k is defined by a logical connective [9, 10].

Let us consider here Mamdani fuzzy controller in our fuzzy inference system to assess the SD of using Pesticides in Agriculture. For fuzzy rule R_k, the logical connective "AND" defines a fuzzy intersection operator to compute τ_k based on degrees of membership. Applying the min-operator for fuzzy rule R_1, for example, results τ_1 = min{0,3; 0,4; 0,6} = 0,3, Figure 11.

The implication process then defines how τ_k implies a fuzzy conclusion $\tilde{C}_k$ based on the fact "SD is $\tilde{O}_p$". The operator defined to implement the implication process in fuzzy rule R_k modifies membership function $\mu_{\tilde{O}p}$ (construction of membership function μ_{ij} and $\mu_{\tilde{O}p}$) to the degree specified by τ_k. Applying the min-operator for fuzzy rule R_1, for example modifies the membership function $\mu_{\tilde{O}1}$ by truncation at τ_1 =0,3. The fuzzy conclusion $\tilde{C}_1$ is the area under the truncated membership function, Figure 11.

The aggregation process defines an overall fuzzy conclusion $\tilde{C}$ by selecting an operator to aggregate the $\tilde{C}_k$. In a fuzzy rule base, rules are connected by the logical connective "ELSE". In the example, the fuzzy rule then reads

R_1: IF SI_1 is $\tilde{T}_1$ AND SI_2 is $\tilde{T}_1$ AND SI_3 is $\tilde{T}_1$ THEN SD is $\tilde{O}_1$,
ELSE R_2: IF SI_1 is $\tilde{T}_1$ AND SI_2 is $\tilde{T}_1$ AND SI_3 is $\tilde{T}_2$ THEN SD is $\tilde{O}_2$,
ELSE R_3: IF SI_1 is $\tilde{T}_1$ AND SI_2 is $\tilde{T}_2$ AND SI_3 is $\tilde{T}_1$ THEN SD is $\tilde{O}_3$,
ELSE R_4: IF SI_1 is $\tilde{T}_2$ AND SI_2 is $\tilde{T}_1$ AND SI_3 is $\tilde{T}_1$ THEN SD is $\tilde{O}_4$,
ELSE R_5: IF SI_1 is $\tilde{T}_2$ AND SI_2 is $\tilde{T}_2$ AND SI_3 is $\tilde{T}_2$ THEN SD is $\tilde{O}_5$.

Each fuzzy rule stated expresses a situation regarding the contribution of three SI to SD. In approximate reasoning, rules R_1 to R_5 are true to a certain degree, as expressed by τ_1 to τ_5, which means that all rules contribute partly to the overall fuzzy conclusion $\tilde{C}$. The logical connective "ELSE" is defined, therefore, by the max-operator to enable a fuzzy union of $\tilde{C}k$ [18]. The fuzzy conclusion $\tilde{C}$ is the area under the curve, Figure 11.

DEFUZZIFICATION

Conversion of the fuzzy conclusion $\tilde{C}$ from an area under the curve to a numerical assessment μ_{SD} i.e. to a crisp value is known as Defuzzification. Various methods of defuzzification are available such as Maximum membership principle (Height method), Centre of gravity method (one of the Centroid methods), Weighted average method (for symmetric membership function), Mean-max method (Middle of maxima), etc. [16, 17, 19-21].

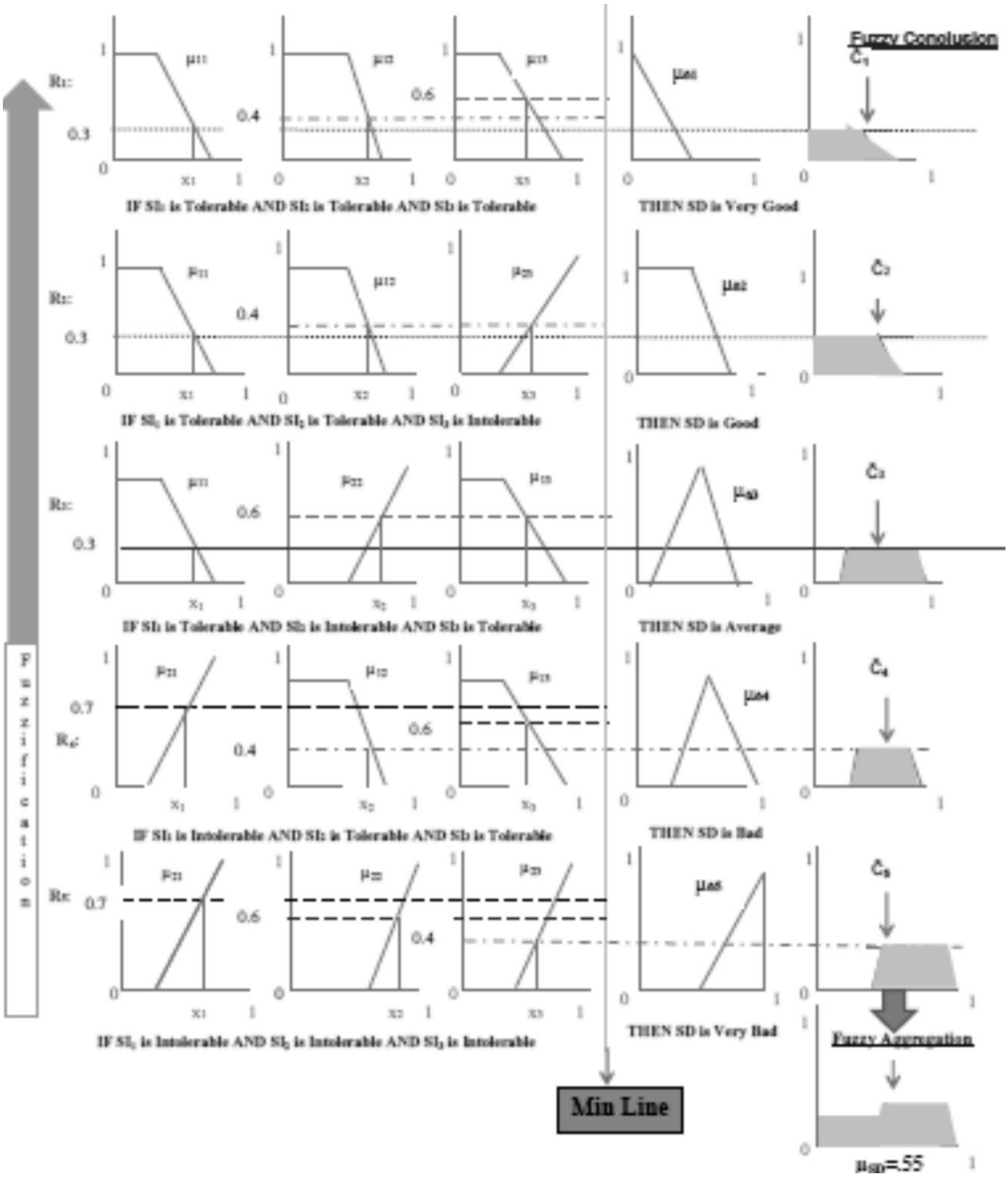

Figure 11. Approximate reasoning of a fuzzy model is represented graphically here to assess the SD amount of Pesticide Use. Five fuzzy IF-THEN rules are presented for three SI (i.e. Human health, Environment, Production quantity) to SD for the stated fuzzy rule base system. Approximate reasoning starts with fuzzification of model input x_1, x_2, x_3 (in kg/hect). Fuzzy inference is a two-step process containing the implication process and the aggregation process, determines an overall fuzzy conclusion $\tilde{C}$ based on fuzzy conclusions $\tilde{C}_1$ through $\tilde{C}_5$ for the five rules.

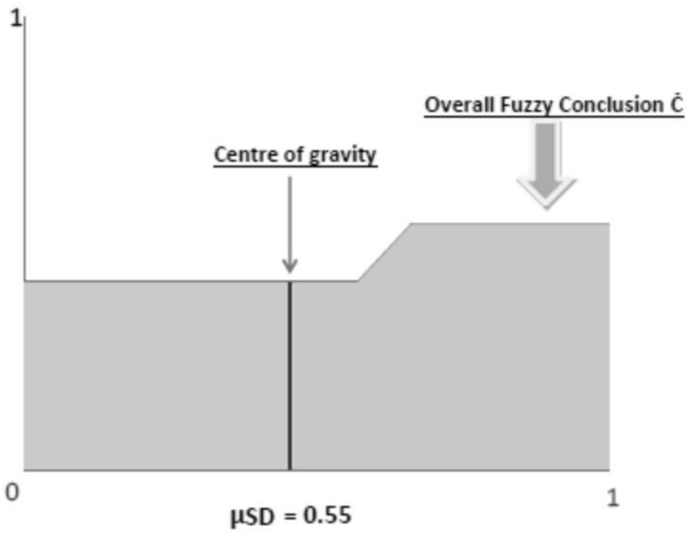

Figure 12. In the stated fuzzy model, defuzzification of the overall fuzzy conclusion C̃ applying approximate reasoning to assess SD of amount of Pesticide Use in Agriculture is graphically presented. The Centre of gravity method divides the area under the curve C̃ into two equal subareas and hence determines μ_{SD}.

CONCLUSIONS

In this article a preliminary study has been done to employ fuzzy logic to build a model for the use of pesticides leading towards sustainable development of agriculture. Here rules are defined for measuring the intensity of the sustainable development of agriculture using individual indicators, and any uncertainty in such process has been minimised. Using linguistic variables and rules, the model gives quantitative measures of human economical, ecological and social sustainability which are then combined into overall sustainability.

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