NSS
Neutrosophic Sets and Systems, Vol. 41, 2021
University of New Mexico

The Importance of Indeterminate and Unknown Factors in Nourishing Crime: A Case Study of South Africa Using Neutrosophy

Mohd. Saif Wajid[1], Mohd Anas Wajid[2]

[1] School of Engineering and Sciences, Tecnológico de Monterrey, Monterrey, Mexico, 64849; a00831364@itesm.mx
[2] Department of Computer Science, Aligarh Muslim University, Aligarh, 202002; anaswajid.bbk@gmail.com

Abstract: There is no doubt regarding the notion that crime is deteriorating the socio-economic structure of society. Crime poses a serious threat to human values and existence. Therefore this menace should be stopped as early as possible otherwise it would lead to unavoidable circumstances. Whenever policies are formed there are some certain factors that are always taken into consideration to stop the crime. These measures were effective but with the passage of time there seems to be a constant situation and crime seems to be at its peak. This situation has forced us to think that there may be other factors that are leading to criminal behaviour in humans. These factors may be uncertain, unknown or indeterminate. Though previous researches in this regard have taken into consideration all the known factors, the present work takes into account both known and unknown factors together with the relationship among them. Taking into account all the factors which nourish crime either directly or indirectly, here we try to model the situation mathematically using Neutrosophic Cognitive Map since it provides us with a methodology of representing known and unknown factors together. The work is carried out using graphical methods and concepts together with linear algebra. The present work takes into account the crimes which are occurring in South Africa and models this situation taking into considerations all the certain and uncertain factors. The study reveals that relative poverty & inadequate housing, limited social and cognitive abilities, exclusion from school, family violence, culture conflict, colonialism, unemployment, income inequality, violent expressions of masculinity and use of violence to 'resolve' are directly related to crime in the country. The other factors such as Adherence to social norms, the multi-racial character of the society, Racial discrimination, apartheid policy, political transition, restructuring of the criminal justice system, gathering of people, intimate partner violence & femicide and use of 'tik' (crystal meth/ methamphetamine) which were not supposed to have a direct influence on crime in the country by previous researches are also having a significant effect on crime. The present work contributes effectively in identifying the factors leading to criminal behaviour among people. This would in turn help policymakers to take necessary steps at ground level to curb the crime in the country. The work also shows the modelling of the situation using Fuzzy Cognitive Maps just to represent the effectiveness of Neutrosophic Cognitive Maps over them.

Keywords: Crime Analysis, Unsupervised Data, Fuzzy Logic, Fuzzy Cognitive Maps, Neutrosophy, Neutrosophic Cognitive Maps

1. Introduction

Crime has remained a serious challenge in the history of South Africa. The recent statistics by the police department have shown an increase in the number of crimes [18]. There are several instances where it has been noticed that criminal behaviour in humans is motivated by certain factors. The need to identify these factors more accurately, the present work is carried out using recent data

from South Africa. Various crime instances have been noticed in the recent past in the country. This has motivated researchers to study criminal behaviour among people. Though most of the studies are concerned with only known factors none has focused on indeterminate and unknown factors. This study takes into account both the factors and shows how indeterminate factors play important roles in determining criminal behaviour among people. The crime in South Africa has started increasing from the mid-1980s to the early 1990s [19]. The studies at that time foretold that the crime was expected to reduce in between 1995-1996 which happened as expected but later in 1996 it again started at a large scale. Recently released report by Mid-Year Population Estimates (MYPE) 2019 shows that the population of South Africa is 56.78 million [26]. The population is not only comprised of native citizens but there exists a lot of multi-racial population. The Union contains four principal groups: Europeans, almost equally divided between British and Afrikaaner (2,643,187, according to the 1951 census); Africans or Bantus or "natives" (8,535,341); Colored, like those of mixed racial descent are known, (1,102,323); Asians, most of whom are Indians, (365,524). The multi-racial nature of society has led to various problems in the country. The crime in the country is at its peak at each and every corner. Below we show the crime statistics from the South African Police department which show how many numbers of crimes are committed annually with respect to the nature of the crime.

Type of Crimes	2013/14	2014/15	2015/16	2016/17	2017/18
Motor Vehicle Theft	57 415	67 104	57 783	47 586	56 526
Housebreaking/Burglary	940 954	874 606	844 982	776 933	832 122
Home Robbery	268 639	208 401	187 830	151 279	156 089
Theft of livestock, poultry and other animals	253 373	164 710	148 785	161 063	159 421
Theft of crops planted by the household	47 977	16 843	39 155	15 003	11 493
Trends in murder	26 529	18 012	14 930	16 201	16 809
Theft out of motor vehicle	208 978	196 236	192 736	139 432	130 350
Deliberate damage, burning or destruction of dwellings	58 452	60 624	40 892	46 915	50 426
Motor vehicle vandalism	54 633	74 824	67 715	31 907	40 155
Theft of bicycle	54 119	60 375	37 227	21 051	29 264
Theft of personal property	1 012 537	921 773	842 478	708 357	693 219
Robbery	373 148	348 349	283 544	294 874	280 526
Sexual Offences	62 074	44 464	29 473	73 842	28 596
Assault	431 043	431 914	331 913	318 077	355 739
Consumer Fraud	86 012	90 249	160 076	85 848	137 274

Table 1 Crime statistics of South Africa

Source: South African Police Services http://www.statssa.gov.za

The above table shows how crime is increasing in the country annually. The crime includes not only heinous crimes like murder, sexual assault but also includes the crime at a small level. These criminal behaviours among the people of South Africa are motivated due to several factors. However, while going through the previous researches in this regard the diversity in a population is regarded as one of the key reason for crime as explained by the experts [2]. Not only diversity but there are certainly other factors that are put forward by various researchers. These factors are regarded as certain factors throughout this study. These factors which are leading to most of the crimes in South Africa are Relative Poverty & inadequate housing [1], Limited social and cognitive abilities[1], Exclusion from school[1], Family violence [1], culture conflict [2], colonialism [9], unemployment [1], income inequality [10-12], violent expressions of masculinity [13-16], use of violence to 'resolve' conflict [10] and access to firearms [10] [17]. There exists a lot of literature that almost deals with all these factors. These certain or determinate factors have always been taken into consideration for making policies to tackle the situation of crime in South Africa. But despite considering all these factors and formulating strategies to curb crime in this country; crime appears to be the major problem at present. This situation has motivated us to inquire about the situation of this country to know what the other causes are leading to crime in this country. Through the reports by various agencies together with the opinion of the experts we came to know that there are uncertain and indeterminate factors that are increasing crime in this country more than certain factors. These factors are lack of adherence to social norms [27-28], the multi-racial character of the society [2], Racial discrimination [2], apartheid policy [2], political transition [3], restructuring of the criminal justice system [3], gathering of people at various occasions [3], perpetrating intimate partner violence (IPV) & femicide [4-6] and most importantly the use of 'tik' (crystal meth/ methamphetamine) [7-8] by people in South Africa. The data which is collected for analyzing any situation is always unsupervised [28-29] and this unsupervised data is in no way free from uncertainty and indeterminacy. The present work attempts to prove mathematically how these indeterminate and uncertain factors are related to crime in South Africa. Since the mathematical field of neutrosophy [21] [23] deals with the uncertainty among concepts; we try to model the situation of crime in South Africa using neutrosophy. Though various factors are taken into consideration in earlier researches to identify the criminal behaviour among the masses, as per knowledge none has taken into consideration the unknown and indeterminate factors. The present work in this regard seems to be more effective in knowing the behaviours by considering all known and unknown factors. There is recent research work by researchers in the field of crime in South Africa. The authors in [38] have explored whether the crime rate has been affected due to the weather conditions in the country or not. Authors in [39] have performed a multi-level model analysis to check whether criminal behaviour among the masses of South Africa is the result of internal migration or immigration. Authors in [40] have come up totally with different viewpoints. Their

study seeks to argue that the extent of corruption in South African public service as being equal to a crime against human rights and dignity. Authors in [41] have studied the impact of social media on crimes in the country. The increasing xenophobic hate crime in South Africa is on its verge. The authors in [42] have studied the reasons for such crime in South Africa. The study related to property crime in South Africa is conducted in [43].

The rest of the paper is divided as follows; section 2 gives the concepts and preliminaries required to carry out this work, section 3 presents the methodology, section 4 models the situation of crime in South Africa using Neutrosophy, section 5 shows calculation and interprets the results obtained and section 6 concludes the paper.

2. Concepts and Preliminaries

The situation of crime could also be modelled using fuzzy logic and fuzzy cognitive maps [24] but it has several limitations [22] [34]. The fuzzy logic is based on membership functions and crisp sets. It addresses the causal relationship between the concepts. The existence of membership and non-existence of membership among various concepts is measured by Fuzzy theory but it says nothing about the indeterminate concepts. As it is a well-known fact that when we deal with unsupervised data indeterminacy and uncertainty is always present; hence it needs to be addressed while dealing with unsupervised data. Since fuzzy logic is limited to the certainty of concepts here in this study we have employed neutrosophic sets and theories for dealing with unsupervised data.

Neutrosophy [21] [23] is a field of study that is not limited to certainties but it's an emerging field that incorporates all the indeterminacy and uncertainties. A number of problems are solved using this theory all around the globe with surprising results. The recent developments in this novel field could be seen in [35] where authors have proposed a multi-criteria decision-making model for evaluating sustainable hydrogen production. In [36] authors again proposed a multi-criteria decision-making model for evaluation of the medical care system by taking various case studies to prove the feasibility of the proposed model. To describe the real cognitive information authors in [37] have proposed type-2 Neutrosophic Number TOPSIS. They have demonstrated the effectiveness of the proposed technique by taking into account several case studies. This has led us to apply this theory in analyzing the crime situation in South Africa. To apply this theory we need to understand some of the concepts and preliminaries as follows:

Definition 1. Let $N = \{(T, I, F): T, I, F \in (0,1)\}$ be a neutrosophic set. Let $m: P \to N$ is a mapping of a group of propositional formulas into N, i.e., each sentence $p \in P$is associated to a value in N, as it is exposed in the Equation 1, meaning that p is T% true, I% indeterminate and F% false.

$$m(p) = (T, I, F) \qquad (1)$$

Hence, it can be concluded that fuzzy logic when generalized based on some concepts of neutrosophy; it becomes neutrosophic logic according to [21]

Definition 2. A Neutrosophic matrix is a matrix $M = [a_{ij}]_{ij}$ where $i = 1,2,3, \ldots\ldots, m$ and $j = 1,2,3, \ldots\ldots, n$such that each $a_{ij} \in K(I)$ where $K(I)$ is a neutrosophic ring. Now let us understand this neutrosophic matrix by an example. Suppose each element of matrix is represented by $a + bI$ where a and b are real numbers and I is a factor of indeterminacy.
For Example:

$$\begin{pmatrix} -1 & I & 5I \\ I & 4 & 7 \end{pmatrix} \begin{pmatrix} I & 9I & 6 \\ 0 & I & 0 \\ -4 & 7 & 5 \end{pmatrix} = \begin{pmatrix} -21I & 27I & -6+25I \\ -28+I & 49+13I & 35+6I \end{pmatrix}$$

Definition 3. A neutrosophic graph is a graph in which there exists an indeterminate node or an indeterminate edge. Now taking reference from the Definition 2 above we can conclude that when $a_{ij} = 0$ it means there is no connection between nodes i and j, $a_{ij} = 1$ means there is a connection between nodes i and j and $a_{ij} = I$ means that connection is indeterminate (unknown).
Definition 4. Cognitive maps are cause-effect networks, with nodes representing concepts articulated by individuals, and directional linkages capturing causal dependencies [25].
Definition 5. A directed graph whose nodes are represented as concepts and edges among concepts represents relationship which can be determinate &indeterminate edges; this graph is referred to as Neutrosophic Cognitive Map [20]

3. Methodology

The proposed methodology tries to introduce indeterminacy in Fuzzy Cognitive Maps (FCMs) [24]. This mapping would be referred as Neutrosophic Cognitive Maps (NCMs). This concept is well illustrated by W. B. Vasantha Kandasamy [20]. This concept of NCMs would be applied in modeling the situation in South Africa to study the influence of different determinate and indeterminate factors that have worsen the situation crime. To do this now let us understands NCMs. NCM is a neutrosophic graph. This is a directed graph in which dotted edge represents indeterminacy. The node of the graph is referred to various concepts. When $K_1, K_2, \ldots\ldots, K_n$ are n nodes of neutrosophic graph. These nodes of graph are connected using edges having weight '0' or '1' or 'I' where 'I' shows indeterminacy, '1' indicates that the node is at ON state and when it has value '0' it indicates the OFF state of the node. These NCMs are most of the time referred to as simple NCMs. The matrix corresponding to neutrosophic graph is called Neutrosophic adjacency matrix. Later this matrix is evaluated using laws of mathematics and the results obtained by this will be interpreted which would show the importance of the present work. To show the effectiveness of Neutrosophic Cognitive Maps over Fuzzy Cognitive Maps in analyzing the situation of crime in South Africa let us model the situation using FCM.

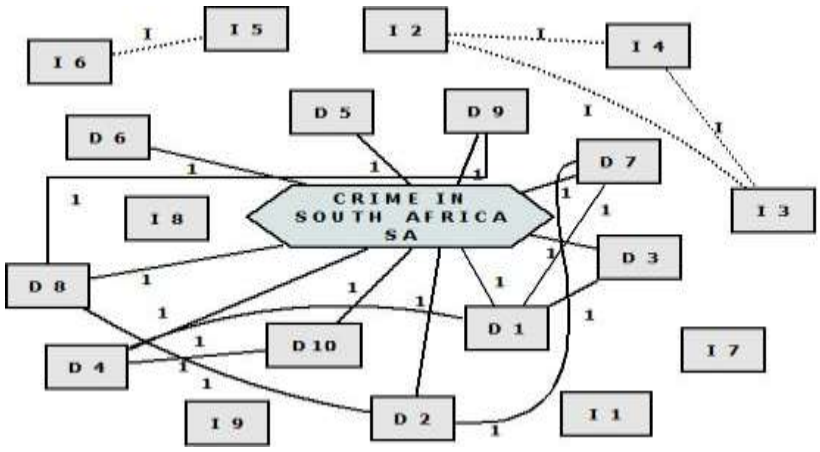

Figure 1 Fuzzy Cognitive Map based on determinate factors affecting crime in South Africa

The above graph is called is called Fuzzy cognitive map for studying the situation of crime in South Africa. The edges having weight '1' denotes determinate edges which show how determinate factors are nourishing crime in South Africa. Since Fuzzy does not take into consideration the indeterminate relationship therefore the indeterminate factors are not connected to the node representing crimes in South Africa. We also show how these indeterminate concepts are related to each other which are represented using dotted line with symbol 'I' denotes indeterminate edges. Now we formulate the adjacency matrix based on above graph.

	SA	**D1**	**I1**	**D2**	**I2**	**D3**	**I3**	**D4**	**I4**	**D5**	**I5**	**D6**	**I6**	**D7**	**I7**	**D8**	**I8**	**D9**	**I9**	**D10**
SA	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
D1	1	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0
I1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D2	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
I2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
I4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D7	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

D8	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
I8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
I9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D10	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Table 2 Fuzzy Adjacency Matrix based on neutrosophic cognitive map in figure 1

The fuzzy adjacency matrix is now evaluated to know the effect of factors on the crime is South Africa. Now for this we take vector SA as on state i.e.

The state vector $\mathrm{SA}_1 = (1\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0)$ is given as input effect of SA_1on the combined system is $\mathrm{SA}_1\mathrm{F(E)}$. The symbol $\rightarrow$ denotes that the resultant vector is updated and threshold. The following calculation is carried out till we obtain a constant state vector or it is also referred as limit cycle.

$SA_1F(E) = (0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1) \rightarrow$

$(1\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1) = SA_2$

$SA_2F(E) = (9\ \ 4\ \ 0\ \ 3\ \ 0\ \ 2\ \ 0\ \ 2\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 3\ \ 0\ \ 3\ \ 0\ \ 2\ \ 0\ \ 2) \rightarrow$

$(1\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0\ \ 1) = SA_3$

We notice that $\mathrm{SA}_2 = \mathrm{SA}_3$ so further iterations are not required. SA_8 is a fixed point or limit cycle. The significance of this limit cycle is the most since it shows a hidden pattern which is used in drawing inferences. The current results obtained above shows that when crime in South Africa is in on state all the factors such as relative poverty & inadequate housing, limited social and cognitive abilities, exclusion from school, family violence, culture conflict, colonialism, unemployment, income inequality, violent expressions of masculinity and use of violence to 'resolve' conflict are in on state. This signifies that all these factors have direct influence on crime in the country. But the factors which are put forward by the experts are other studies like Adherence to social norms, multi-racial character of the society, Racial discrimination, apartheid policy, political transition, restructuring of the criminal justice system, gathering of people, intimate partner violence (IPV) & femicide and use of 'tik' (crystal meth/ methamphetamine) are absent in this regard. So it could be clearly inferred that the FCMs take no importance of uncertain factors which could have direct influence on the concepts. Now further we try to model the situation using Neutrosophy [31-33].

4. Application of Neutrosophy in modeling situation of Crime in South Africa

To model the current situation of crime in South Africa we have considered some certain factor from previous researches and some of the factors are considered using expert's opinion. We have also utilized reports from various official departments to ascertain the current scenario in this country. These factors not only include certain factors but also capture some of the uncertain and indeterminate factors. Lists of the factors which are considered whether known or indeterminate are as follows:

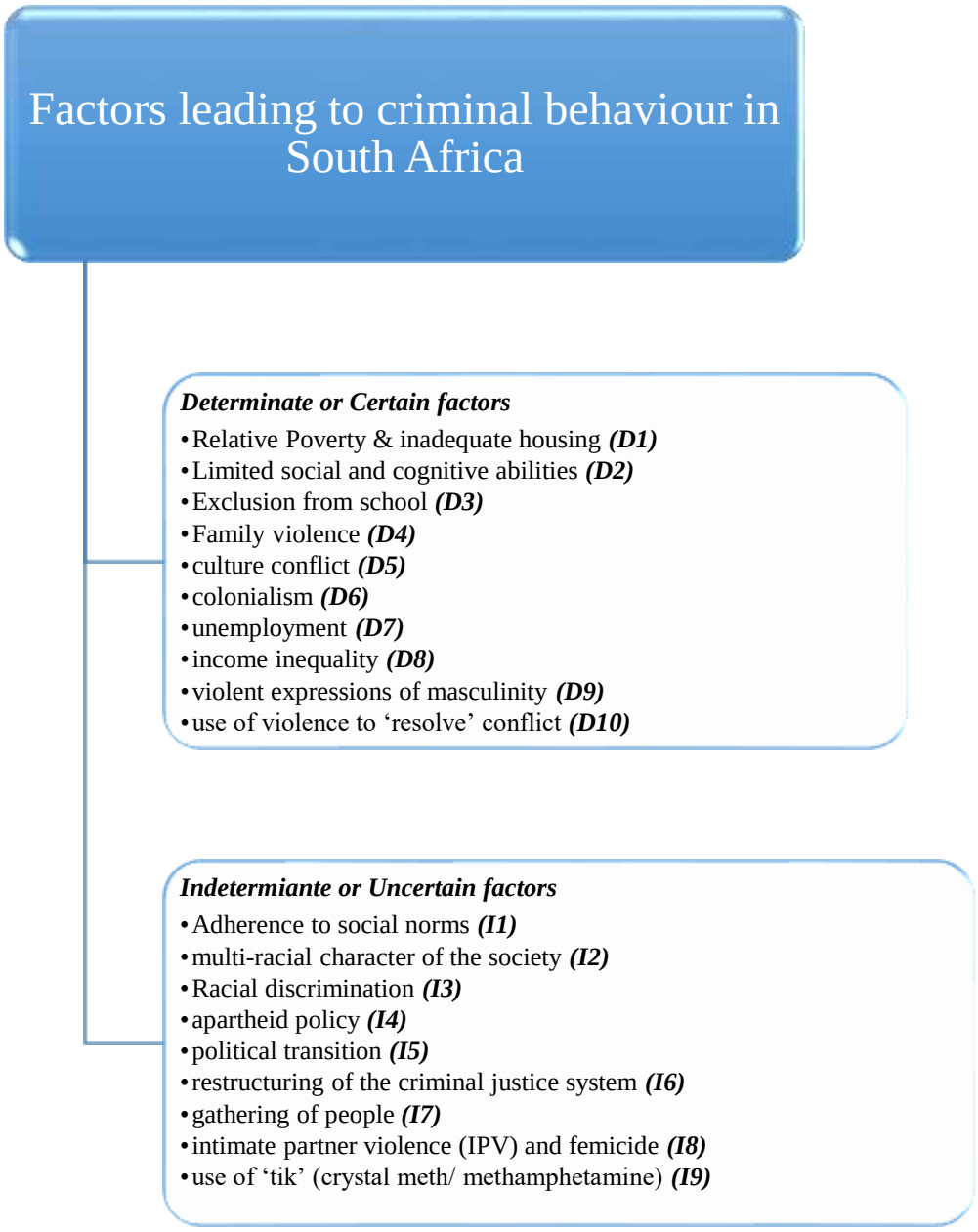

Figure 2 Summary of factors leading to crime in South Africa based on previous researches and experts opinion

Now we model the situation with the help of neutrosophic cognitive maps since it represents better models while analyzing the situation [30]. We try to show how these indeterminate and uncertain factors do influence the determinate and certain factors. The previous researches in this regard show that determinate factor such as Relative Poverty & inadequate housing and Exclusion from school led to the difficulty in Adherence to social norms and gathering of people at several places which are indeterminate factors [1] [3] [27-28]. Culture conflict among the people of society directly influences Adherence to social norms and racial discrimination [2] [27-28]. Unemployment is thought to be the main factors that led to crime in South Africa [1] and this unemployment results in some indeterminate factors which are also increasing crimes in the country. These factors are Adherence to social norms and gathering of people [27-28] [3]. The expression of masculinity is referred to as one of the key cause of crime in the country in many studies [13-16]. This violent expression of masculinity results in intimate partner violence (IPV) and femicide which itself is a crime [4-6]. Use of violence to 'resolve' conflict is also related to intimate partner violence (IPV) and femicide and use of 'tik' (crystal meth/ methamphetamine) [7-8] [10]. Many historical studies suggest that factors such as colonialism and apartheid have left a legacy of violence [2] [9]. This directly relates to political transition and restructuring of criminal justice system [3]. This shows how factors which always taken in considerations in various studies are linked which indeterminate and uncertain factors which most of the time are neglected. There some indeterminate factors which are interlinked like multi-racial character of the society and racial discrimination have association with apartheid policy of the country [2]. Taking all these factors and relationship among them we now model the situation of crime in South Africa using neutrosophic cognitive maps which is prominent concept of neutrosophy.

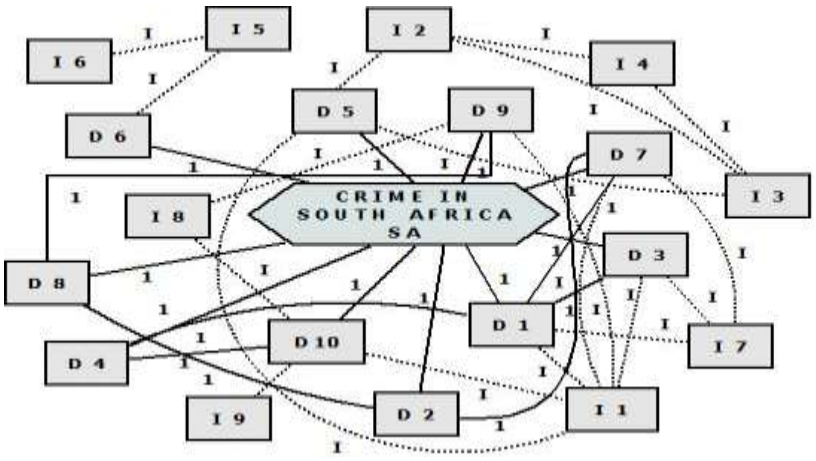

Figure 3 Neutrosophic Cognitive Map based on determinate and indeterminate factors affecting crime in South Africa

The above graph is called is called neutrosophic cognitive map for studying the situation of crime in South Africa. The edges having weight '1' denotes determinate edges and those edges which are shown with symbol 'I' denotes indeterminate edges.

5. Results

Now with the help of above cognitive map we form the neutrosophic adjacency matrix. This matrix is formulated taking in account the factors which are represented as nodes in cognitive maps and the relationship among the factors.

	SA	**D1**	**I1**	**D2**	**I2**	**D3**	**I3**	**D4**	**I4**	**D5**	**I5**	**D6**	**I6**	**D7**	**I7**	**D8**	**I8**	**D9**	**I9**	**D10**
SA	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
D1	1	0	I	0	0	1	0	1	0	0	0	0	0	1	I	0	0	0	0	0
I1	0	I	0	0	0	I	0	0	0	I	0	0	0	I	0	0	0	I	0	I
D2	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
I2	0	0	0	0	0	0	I	0	I	I	0	0	0	0	0	0	0	0	0	0
D3	1	1	I	0	0	0	0	0	0	0	0	0	0	0	I	0	0	0	0	0
I3	0	0	0	0	I	0	0	0	I	I	0	0	0	0	0	0	0	0	0	0
D4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
I4	0	0	0	0	I	0	I	0	0	0	0	0	0	0	0	0	0	0	0	0
D5	1	0	I	0	I	0	I	0	0	0	0	0	0	0	0	0	0	0	0	0
I5	0	0	0	0	0	0	0	0	0	0	0	I	I	0	0	0	0	0	0	0
D6	1	0	0	0	0	0	0	0	0	0	I	0	0	0	0	0	0	0	0	0
I6	0	0	0	0	0	0	0	0	0	0	I	0	0	0	0	0	0	0	0	0
D7	1	1	I	1	0	I	0	0	0	0	0	0	0	0	I	0	0	0	0	0
I7	0	I	0	0	0	0	0	0	0	0	0	0	0	I	0	0	0	0	0	0
D8	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
I8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	I	0	I
D9	1	0	I	0	0	0	0	0	0	0	0	0	0	0	0	1	I	0	0	0
I9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	I
D10	1	0	I	0	0	0	0	1	0	0	0	0	0	0	0	0	I	0	I	0

Figure 4 Neutrosophic Adjacency Matrix based on neutrosophic cognitive map in figure 3

The neutrosophic adjacency matrix is now evaluated to know the effect of factors on the crime is South Africa. Now for this we take vector SA as on state i.e.

The state vector $SA_1 = (1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0)$ is given as input effect of SA_1 on the combined system is $SA_1N(E)$. The symbol $\rightarrow$ denotes that the resultant vector is updated and threshold. The following calculation is carried out till we obtain a constant state vector or it is also referred as limit cycle.

$SA_1N(E) = (0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1) \rightarrow (1\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1)$

$= SA_2$

$SA_2N(E) = (10\ 3\ 6I\ 2\ I\ I + 1\ I\ 2\ 0\ 0\ I\ 0\ 0\ 2\ 3I\ 2\ 2I\ 1\ I\ 1) \rightarrow (1\ 1\ I\ 1\ I\ 1\ I\ 1\ 0\ 0\ I\ 0\ 0\ 1\ I\ 1\ I\ 1\ I\ 1)$

$= SA_3$

$SA_3N(E) = (8\ 2I^2 + 4\ 5I\ 3\ I^2\ I^2 + I + 2\ I^2\ 3\ 2I^2\ 3I^2 + 1\ 0\ I^2 + 1\ I^2\ 2I^2 + 3\ 3I\ 3\ 2I\ 2I^2 + 2\ I\ 2I\ 2I^2 + 2) \rightarrow$

$(1\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ 0\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1) = SA_4$

$SA_4N(E) = (10\ 2I^2 + 4\ 6I\ 3\ 2I^2 + I\ I^2 + I + 2\ 2I^2 + I\ 3\ 2I^2\ 3I^2 + 1\ I^2 + I\ 1\ 0\ 2I^2 + 3\ 3I\ 3\ 2I\ 2I^2 + 2\ I\ 3I^2 + 2) \rightarrow (1\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ 0\ 1\ I\ 1\ I\ 1\ I\ 1) = SA_5$

$SA_5N(E) = (10\ 2I^2 + 4\ 6I\ 3\ 2I^2 + I\ I^2 + I + 2\ 2I^2 + I\ 3\ 2I^2\ 3I^2 + 1\ I\ I^2 + 1\ I^2\ 2I^2 + 3\ 3I\ 3\ 2I\ 2I^2 + 2\ I\ 3I^2 + 2) \rightarrow (1\ 1\ I\ 1\ I\ 1\ 1\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1) = SA_6$

$SA_6N(E) = (10\ 2I^2 + 4\ 6I\ 3\ I^2 + 2I\ I^2 + I + 2\ 2I^2 + I\ 3\ I^2 + I\ 2I^2 + I + 1\ I^2 + I\ I^2 + 1\ I^2\ 2I^2 + 3\ 3I\ 3\ 2I\ 2I^2 + 2\ I\ 3I^2 + 2) \rightarrow (1\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1) = SA_7$

$SA_7N(E) = (10\ 2I^2 + 4\ 6I\ 3\ 2I^2 + I\ I^2 + I + 2\ 2I^2 + I\ 3\ 2I^2\ 3I^2 + 1\ I^2 + I\ I^2 + 1\ I^2\ 2I^2 + 3\ 3I\ 3\ 2I\ 2I^2 + 2\ I\ 3I^2 + 2) \rightarrow (1\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1) = SA_8$

We notice that $SA_7 = SA_8$ so further iterations are not required. SA_8 is a fixed point or limit cycle. The significance of this limit cycle is the most since it shows a hidden pattern which is used in drawing inferences. These inferences show the joint effect of interacting knowledge. The current results obtained using NCMs is $(1\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1\ I\ 1)$ which shows that when crime in South Africa is in on state all the factors such as relative poverty & inadequate housing, limited social and cognitive abilities, exclusion from school, family violence, culture conflict, colonialism, unemployment, income inequality, violent expressions of masculinity and use of violence to 'resolve' conflict are in on state. This signifies that all these factors have direct influence on crime in the country. The factors such as Adherence to social norms, multi-racial character of the society, Racial discrimination, apartheid policy, political transition, restructuring of the criminal justice system, gathering of people, intimate partner violence (IPV) & femicide and use of 'tik' (crystal meth/ methamphetamine) which were not supposed to have direct influence on crime in the country by previous researches are also having significant effect on crime as we have not obtained *'0'* in the limit cycle at their position but we have obtained *'I'* which shows these are having relationship with crime in the country. The previous result obtained using FCM is $(1\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1)$ that clearly shows that all indeterminate and uncertain factors are absent which signifies that the study conducted using FCM is unable to represent any real life situation. This proves that NCMs are better to model real life situation than FCMs also representing the importance of indeterminate and uncertain events in analyzing any real life situation.

6. Conclusion

The present work is aimed at mathematically analyzing the situation of crime in South Africa. The paper contributes in a sense that it takes into account all causes (factors) whether certain (known) or uncertain (indeterminate and unknown), responsible for nourishing crime in the country. Though the previous researches have focused only on known factors, the present work emphasizes both the factors which may not be considered in previous studies. Considering and representing all the factors mathematically we tried to develop a mathematical model using neutrosophic cognitive maps so that the situation could be analyzed at ground level. The model further evaluated using some mathematical laws of calculation like graphs and linear algebra. Later the results are interpreted which shows how indeterminate and uncertain factors are giving rise to criminal behaviour in the population of South Africa. Below is the finding of our work that shows what are the certain factors nourishing crime and what are the indeterminate/uncertain factors nourishing crime:

Known and certain factors nourishing crime:

- relative poverty & inadequate housing,
- limited social and cognitive abilities,
- exclusion from school,
- family violence,
- culture conflict,
- colonialism,
- unemployment,
- income inequality,
- violent expressions of masculinity and
- use of violence to 'resolve' conflict

Unknown and uncertain factors nourishing crime:

- Adherence to social norms,
- multi-racial character of the society,
- Racial discrimination,
- apartheid policy,
- political transition,
- restructuring of the criminal justice system,
- gathering of people,
- intimate partner violence (IPV) & femicide and
- use of 'tik' (crystal meth/ methamphetamine)

This study is expected to help policymakers in taking corrective measures to curb crime in the country. The current work takes a very limited number of factors in consideration and all the work is performed manually. Future work in this regard would be modelling the situation mathematically

considering a large number of factors and employing machine learning algorithms so that it may become easy to model the situation and interpret the results.

REFERENCE

1. Waller, Irvin, and Daniel Sansfaçon. Investing wisely in crime prevention: International experiences. No. 1. US Department of Justice, Office of Justice Programs, Bureau of Justice Assistance, (2000).
2. Williamson, Robert C. "Crime in South Africa: Some aspects of causes and treatment." The Journal of Criminal Law, Criminology, and Police Science 48, no. 2 (1957): 185-192.
3. Schönteich, Martin, and Antoinette Louw. "Crime in South Africa: A country and cities profile." (2001).
4. Dawes, Andrew, Zuyhar Kafaar, Zosa de Sas Kropiwnicki, Riashnee Pather, and Linda Richter. "Partner violence, attitudes to child discipline & use of corporal punishment: A South African national survey." (2004).
5. Jewkes, Rachel, Jonathan Levin, and Loveday Penn-Kekana. "Risk factors for domestic violence: findings from a South African cross-sectional study." Social science & medicine 55, no. 9 (2002): 1603-1617.
6. Mathews, Shanaaz, Naeemah Abrahams, Rachel Jewkes, Lorna J. Martin, and Carl Lombard. "Alcohol use and its role in female homicides in the Western Cape, South Africa." Journal of studies on alcohol and drugs 70, no. 3 (2009): 321-327.
7. Bhana, Arvin. "Substance Use and Abuse in South Africa: Insights from Brain and Behavioural Sciences." (2012): 651-651.
8. Lamb, Guy, and Giselle Warton. "WHY IS CRIME IN SOUTH AFRICA SO VIOLENT?." Updated Rapid Evidence Assessment on Violent Crime in South Africa. Cape Town: Safety and Violence Initiative (2016).
9. Bruce, David, A. Dissel, and M. Menziwa. "The violent nature of crime in South Africa: a concept paper for the Justice, Crime Prevention and Security Cluster." Braam-fontein: Centre for the Study of Violence and Reconciliation (CSVR) (2007).
10. Seedat, Mohamed, Ashley Van Niekerk, Rachel Jewkes, Shahnaaz Suffla, and Kopano Ratele. "Violence and injuries in South Africa: prioritising an agenda for prevention." The Lancet 374, no. 9694 (2009): 1011-1022.
11. De Kock, Chris, Anine Kriegler, and Mark Shaw. "A citizen's guide to SAPS crime statistics: 1994 to 2015." Centre of Criminology, University of Cape Town (2015).
12. Brown, Kay V. "The determinants of crime in South Africa." South African Journal of Economics 69, no. 2 (2001): 269-298.
13. Jewkes, Rachel, Yandisa Sikweyiya, Robert Morrell, and Kristin Dunkle. "Gender inequitable masculinity and sexual entitlement in rape perpetration South Africa: findings of a cross-sectional study." PloS one 6, no. 12 (2011): e29590.

14. Abrahams, Naeemah, Rachel Jewkes, Margaret Hoffman, and Ria Laubsher. "Sexual violence against intimate partners in Cape Town: prevalence and risk factors reported by men." Bulletin of the world health organization 82 (2004): 330-337.
15. Abrahams, Naeemah, Rachel Jewkes, Ria Laubscher, and Margaret Hoffman. "Intimate partner violence: prevalence and risk factors for men in Cape Town, South Africa." Violence and victims 21, no. 2 (2006): 247-264.
16. Machisa, Mercilene, Rachel Jewkes, Colleen Morna, and Kubi Rama. "The war at home: Gender based violence indicators project." In Gauteng research report. Gender Links & South African Medical Research Council, (2011).
17. Plüddemann, Andreas, Charles Parry, Hilton Donson, and Anesh Sukhai. "Alcohol use and trauma in Cape Town, Durban and Port Elizabeth, South Africa: 1999-2001." Injury control and safety promotion 11, no. 4 (2004): 265-267.
18. Statistics South Africa, Republic of South Africa, http://www.statssa.gov.za, (2020).
19. Schönteich, Martin, and Antoinette Louw. "Crime in South Africa: A country and cities profile." (2001).
20. Kandasamy, WB Vasantha, and Florentin Smarandache. Fuzzy cognitive maps and neutrosophic cognitive maps. Infinite Study, (2003).
21. Smarandache, Florentin. "First International Conference on Neutrosophy, Neutrosophic Logic, Set, Probability and Statistics." Florentin Smarandache (2001): 4.
22. Zafar, Aasim, and Mohd Anas Wajid. Neutrosophic cognitive maps for situation analysis. Infinite Study, (2020).
23. Smarandache, Florentin. "A unifying field in Logics: Neutrosophic Logic." In Philosophy, pp. 1-141. American Research Press, (1999).
24. Kosko, Bart. "Fuzzy cognitive maps." International journal of man-machine studies 24, no. 1 (1986): 65-75.
25. Srinivas and Shekar, "What are the Cognitive Maps", (1997). https://web.itu.edu.tr/topcuil/ya/MDM02xCognitiveMaps.pdf
26. Mid-year population estimates (MYPE), Statistical Release, "Department of Statistics South Africa", 2019. https://www.statssa.gov.za/publications/P0302/P03022019.pdf
27. Palmary, Ingrid. Social crime prevention in South Africa's major cities. CSVR, (2001).
28. World Health Organization. "Changing cultural and social norms that support violence." (2009).
29. Pew, Richard W. "Measurement: Heading Toward the Next Century." Situation awareness analysis and measurement (2000): 33.
30. Jousselme, Anne-Laure, and Patrick Maupin. "Neutrosophy in situation analysis." In Proceedings of Fusion, pp. 400-406. (2004).
31. Smarandache, Florentin. "A unifying field in Logics: Neutrosophic Logic." In Philosophy, pp. 1-141. American Research Press, (1999).
32. Smarandache, F, Collected Papers III, Editura Abaddaba, Oradea, (2000). http://www.gallup.unm.edu/~smarandache/CP3.pdf

33. Smarandache, Florentin. Proceedings of the First International Conference on Neutrosophy, Neutrosophic Logic, Neutrosophic Set, Neutrosophic Porbability and Statistics: Www. Gallup. Unm. Edu/~ Smarandache/NeutrosophicProceedings. Pdf. Infinite Study, (2003).
34. Smarandache, Florentin. "Definiton of neutrosophic logic-a generalization of the intuitionistic fuzzy logic." In EUSFLAT Conf., pp. 141-146. (2003).
35. Abdel-Basset, Mohamed, Abduallah Gamal, Ripon K. Chakrabortty, and Michael J. Ryan. "Evaluation of sustainable hydrogen production options using an advanced hybrid MCDM approach: A case study." International Journal of Hydrogen Energy (2020).
36. Abdel-Basset, Mohamed, Mohamed El-Hoseny, Abduallah Gamal, and Florentin Smarandache. "A novel model for evaluation Hospital medical care systems based on plithogenic sets." Artificial intelligence in medicine 100 (2019): 101710.
37. Abdel-Basset, Mohamed, M. Saleh, Abduallah Gamal, and Florentin Smarandache. "An approach of TOPSIS technique for developing supplier selection with group decision making under type-2 neutrosophic number." Applied Soft Computing 77 (2019): 438-452.
38. Chersich, Matthew F., Callum Patrick Swift, Ian Edelstein, Greg Breetzke, Fiona Scorgie, Francois Schutte, and Caradee Y. Wright. "Violence in hot weather: Will climate change exacerbate rates of violence in South Africa?." SAMJ: South African Medical Journal 109, no. 7 (2019): 447-449.
39. Kollamparambil, Umakrishnan. "Immigration, internal migration and crime in South Africa: A multi-level model analysis." Development Policy Review 37, no. 5 (2019): 672-691.
40. Sebake, Bernard Karabo. "Crime against humanity: social perception of public service corruption in South Africa." African Journal of Development Studies (formerly AFFRIKA Journal of Politics, Economics and Society) 10, no. 3 (2020): 167-188.
41. Asongu, Simplice, Jacinta Nwachukwu, Stella-Maris Orim, and Chris Pyke. "Crime and social media." Information Technology & People (2019).
42. Gordon, Steven Lawrence. "Understanding xenophobic hate crime in South Africa." Journal of Public Affairs 20, no. 3 (2020): e2076.
43. Mulamba, Kabeya Clement. "A Spatial Analysis of Property Crime Rates in South Africa." South African Journal of Economics (2020).

Received: Jan 1, 2021. Accepted: March 2, 2021.