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Analyzing the Efficacy of Fuzzy logic in the Concentration of Cadmium in Soil and Potatoes (Case Study in Absard City of Damavand)

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ABSTRACT

Owing to complexity, uncertainty in natural phenomena and natural dynamism, Fuzzy logic puts the obscurities in mathematical formation and preparation for decision-making and reasoning. The present analysis represents the accuracy of Fuzzy interpretation (qualitative measurement of cadmium) in estimating the concentration of cadmium in soil and the potato product in 8 pieces of farmland in Absard, Damavand. Some physical and chemical features of soil, together with the amount of cadmium concentrated in soil and potatoes, were measured three times by Flame and Graphite Furnace Atomic Absorption Spectrometer and were analyzed through Mamdani Inference System by Toolbox of Matlab. The cadmium in potatoes and roadside farmlands was measured to be more than the standard amount; therefore, it illustrates high cadmium toxicity in the mentioned area. It is concluded that Fuzzy logic (the rule of if-then) has a more appropriate and accurate approach to evaluating the concentration of cadmium in soil and product regarding the attention that is paid to the impact of all the characteristics of soil and the complex relationship among the parameters and plant type.

Key words: Fuzzy logic, Concentration, Cadmium, Potato, Mamdani.

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1. INTRODUCTION

The real world is complex and generally, this complexity originates from lack of certainty; humans are able to realize the vagueness of complexities owing to cognitive ability. A large number of the real world problems are not solvable by using classic set theory. In this theory, one element either is a member of the set or is not; it is either zero or one. The counterpoint to classic set theory is fuzzy theory (1). Unlike the widespread application of fuzzy logic in engineering, this technique is not popular yet in research purpose of water and soil resources and other related subjects. Especially in some fields of this science, it is not documented yet. As a result, it seems necessary to learn about this technique and how to apply it in different branches of this science. The obscurities observed in natural meanings and phenomena had better be considered as an integral part of these fields of science. Fuzzy logic can be instrumental because of first having simple and

flexible meaning and then using ambiguous data and complex models (2). Some authors employed fuzzy logic in order to face environmental subjects. Researchers introduced the problem of uncertainty in ecological research by fuzzy logic approach, applying approximated reasoning to create a fuzzy knowledge-based model (3). Various sciences related to water and soil resources, such as watershed, Range management, and forestry, contain phenomena and subjects which are quantifiable, or quantitatively, they are hard to measure, time consuming, and costly; therefore, they are described qualitatively (2). In the past several decades, humans' activities have led to dramatic changes in nature. In addition, each change in a variable of hydrological, weather or other types of nature can lead to some changes in other variables. These alterations have had numerous consequences in the environment (2). Methodologies of multi-criteria analysis have proved to be efficient in the definition of integrative frameworks, but their application requires processing

imprecise, uncertain, qualitative or vague data. Fuzzy logic is one of the most common methodologies used to address uncertainty matters (4). Agricultural land is not only the essential land resource that supplies a variety of materials for human subsistence but also a complex system that combines natural ecology and social economy. A rapidly developing economy and the growing population accelerate the degradation of land and endanger food security-issues of common concern to all sectors of society (5). Most heavy metals infiltrate and accumulate in top soil. Accumulation of heavy metals in soil is incremental and, in the long term, the results produced are increased levels of contamination that may constitute a real threat to food safety for humans (6). In sciences related to the management of water and soil resources as well as natural resources and environmental issues, modeling phenomena is very important. Because modeling makes it possible to predict a phenomenon, provided it is possible to manage (2). This study presents an intelligence committee fuzzy logic (ICFL) model to estimate the concentration of total arsenic of the Sahand Dam basin, Iran. Respecting a high concentration of arsenic compared to world health organization (WHO) standard, Geology Department of Tabriz University and East Azerbaijan Regional Water Authority of hydrochemical parameters used as input parameters for fuzzy logic, Larsen fuzzy logic and Sugeno fuzzy logic to estimate arsenic concentrations. The ICFL model was adopted to combine the output of three single fuzzy models instead of selecting superior single model because these models have a similar fitting (7). There has been another analysis on the environmental degradation in Iran using fuzzy logic. Computations on fuzzy logic based on vague data related to natural resources in Iran reveal that under critical conditions (imposed war and oil shock), environmental degradation elevates (8). In determining environmental sustainability using fuzzy logic, three parameters of the quality of water, soil, and air are considered. The results obtained with the help of MATLAB software showed that if the soil quality is low and air and water quality is moderate, then the environmental sustainability will be average (9). The results obtained from the use of Mamdani fuzzy inference system and Artificial Neural Networks in Predicting Seasonal Rainfall, Case Study (10): of Khorasan Area, in which three regions of Khorasan Razavi Province, Northern Khorasan, and Southern Khorasan in a period of December to May were studied. The results reveal that fuzzy inference System and artificial neural networks are able to predict rainfalls with an acceptable accuracy; furthermore, artificial neural networks have been more successful with fewer errors (11). Results in evaluation of traditional and consolidated rice farms in Gilan Province, Iran, using life cycle assessment and fuzzy modeling showed that the performance metrics of the model based on Adaptive Neuro Fuzzy Inference System (ANFIS) can be used to predict the environmental burdens of rice production with high accuracy and minimal error. Then

evaluation and comparison was done using Life Cycle Assessment (LCA) methodology and ANFIS (12). A novel approach in water quality assessment based on fuzzy logic showed that the proposed index seems to produce accurate and reliable results and can therefore be used as a comprehensive tool for water quality assessment, especially for the analysis of drinkable water for human (13). The fuzzy comprehensive assessment of heavy metals and lead isotopic signature in surface sediments from a bay under serious anthropogenic influences, Daya Bay, China showed that the average metal concentrations for cadmium (Cd), lead (Pb), chromium (Cr), copper (Cu), zinc (Zn), mercury (Hg), and arsenic (As), which were clearly higher with respect to their corresponding background values (14). The study of atmospheric metal pollutants and environmental injustice through a methodological approach to environmental risk analysis using fuzzy logic and tree bark showed that the use of a complementary mathematical logic is necessary. The mentioned study describes a methodological approach to evaluate the environmental risk from air pollution integrating data on environmental pollutants from tree bark using fuzzy logic, based in the port city of Paranaguá in the state of Paraná in Brazil, and it was validated using income indicators. Therefore, this type of information provides a decision making tool for environmental risk analysis from air pollution and can be used in the definition of public policies (15). In a study titled Integrating spectral indices with environmental parameters for estimating heavy metal concentrations in rice using a dynamic fuzzy neural-network model, the results showed that the genetic dynamic fuzzy neural network genetic (GDFNN) for estimating Cu and Cd concentrations in rice performed well at prediction with a compact network structure using the training validation, and testing sets. This demonstrates that the GDFNN model is more suitable for predicting heavy metal concentrations in rice (16). In an application of testing fuzzy hypotheses in soil study on the bioavailability of cadmium, the results showed that using classical hypotheses testing may lead to contradictory decisions, and the proposed fuzzy hypotheses testing is a rational substitute for classical hypotheses testing when the environment is in a vague status (6). In a study titled "Status and fuzzy comprehensive assessment of combined heavy metal and organo-chlorine pesticide pollution in the Taihu Lake region of China," Statistical analyses showed the presence of combined pollution in the soil. At many sampling sites, heavy metal concentrations were above corresponding background values, indicating the effects of extraneous pollutants. (17); the mentioned study was carried out in Isfahan Province, Iran, to assess the environmental impact of greenhouse cucumber and tomato production using Life-cycle Assessment (LCA) methodology. The results indicated that greenhouse tomato production had a lower environmental impact than cucumber due to less total energy input and correspondingly lower environmental burdens in all impact

categories. Furthermore, ANFIS was capable of forecasting the environmental indices of greenhouse production with a high degree of accuracy and minimal error (18). According to indicator functions of fuzzy operation, normalized entropy and detachment stock are the best clustering with 7 classes. In a study of distribution of soil pollution by heavy metals with geostatistics and Fuzzy clustering in Dizajabad area, Zanzan Province (Iran), it was showed that most polluted classes A, B, E, and G are located at center and around the factory, while C, D, and F are covered northern, northeast, and southeast parts of the studying area. A major part of extra grade class was the location of factory and landfill compliance (19). In a case study about the development of environmental quality, indexes based on fuzzy logic show that the final value of the index is obtained as an achievement of a fuzzy inference procedure based on the zero-order method of Takagi and Sugeno. This methodology is applied to a simplified case study in order to illustrate its practical application, which is the design and assessment of a physical-chemical soil quality index at a particular site (20). The purpose of the study is to analyze the efficacy of fuzzy logic Method in the concentration of cadmium in soil and potatoes of Absard City of Damavand. It is to notice that the area under the study is influenced by environmental pollutants, such as using large amounts of superphosphate fertilizers by farmers, air pollution caused by commutation of vehicles on Tehran-Firuzhuh Highway, road surface run-off, which contains pollution caused by the friction of vehicles' brake pads. These are the major factors in this research and are paid attention to. Fertilizer and vehicles could affect the amount of cadmium in soils. Uses of fertilizer are the same in all farms but some of farmland are located far from the roads.

2. MATERIALS AND METHODS

2.1. The Study Area and Data

Due to the lack of certainty about the appropriate amount of cadmium absorption, to test the amount, fuzzy hypothesis testing was used instead of classical hypothesis testing, and the process of concentration in soil and potatoes was analyzed.

2.2. The Fuzzy Inference System

Fuzzy logic was first introduced in a dissertation called "fuzzy Sets-- Information and Control" in 1965, and it grew and became practical in 1970s (21). The greatest event of this decade was producing fuzzy logic controllers for real systems (1). One way to handle practical problems, particularly those connected with uncertainty and

imprecision about input values and theoretical relationships, is to apply the framework of Fuzzy logic, which is based on fuzzy Set theory (21).

2.2.1. Algorithm Types of Fuzzy Inference

2.2.1.1. The Mamdani Inference Algorithm

Inference Systems were suggested by researchers. These systems, due to having visual and interpretive nature of rules, could be used widely in decision backup systems; they also have high descriptive power and could be operated as "multiple input multiple output"(MIMO) and "multiple input single output" (MISO) (1).

2.2.1.2. The Takagi Sugeno Inference Algorithm

The Takagi Sugeno Inference system was provided by Takagi et al in order to develop a systematic approach to generate Fuzzy rules (22); this inference system is used more in control systems and fields in which mathematical calculations are needed. The output of the algorithm uses a first-order polynomial of input variables as the result of the rule, and the Defuzzification method in it is of weighted average (WA) and weighted sum (WS) types of Defuzzification method. Moreover, Sugeno Inference System is operated as MISO but not as MIMO (1). The Mamdani Inference System as a process of mapping a set of input data into a set of output data is described through fuzzy logic viewpoint. A Mamdani Inference System is a process which formulates human language reasoning by means of fuzzy logic (based on the fuzzy rule of if-then). The Mamdani Inference System is usually made up of four main parts of Fuzzification, fuzzy regulations, fuzzy inference engine, and Defuzzyfication. The general structure of the Mamdani Inference System is illustrated below (23).

2.3. Topography

Damavand Area, especially Absard, contains vast potato farmlands, which excel other crop lands, and this is commercially and economically of great value. Regarding its observable features, this area's soil color is khaki; in addition, its appropriate soil acidity (which is often alkaline), together with adequate water and the large area of farmland, has created proper conditions for planting potatoes. The increase of environmental pollutants, such as the air pollution caused by travelling by vehicles and using a great deal of chemical fertilizers due to the expansion of agriculture in this area, has led to heavy metals toxicity in the water and soil. Therefore, it was decided to analyze the soil of the potato farmlands and assess cadmium concentration, which tends to be high in tubers, especially potatoes (Table 1).

Table 1. Longitude and latitude of the harvested spot and the sample of harvested potatoes in The Year 2015

Spot	Longitude			latitude		
	Degree	Minute	Second	Degree	Minute	Second
1	52 °	06 ´	41.59"	35 °	41.59"	41.59"
2	52 °	07 ´	06.76 "	35 °	06.76 "	06.76 "
3	52 °	07 ´	36.36 "	35 °	36.36 "	36.36 "
4	52 °	06 ´	38.11 "	35 °	38.11 "	38.11 "
5	53 °	7 ´	38.11 "	36 °	38.11 "	38.11 "
6	54 °	8 ´	38.11 "	37 °	38.11 "	38.11 "
7	55 °	9 ´	38.11 "	38 °	38.11 "	38.11 "
8	56 °	10 ´	38.11 "	39 °	38.11 "	38.11 "

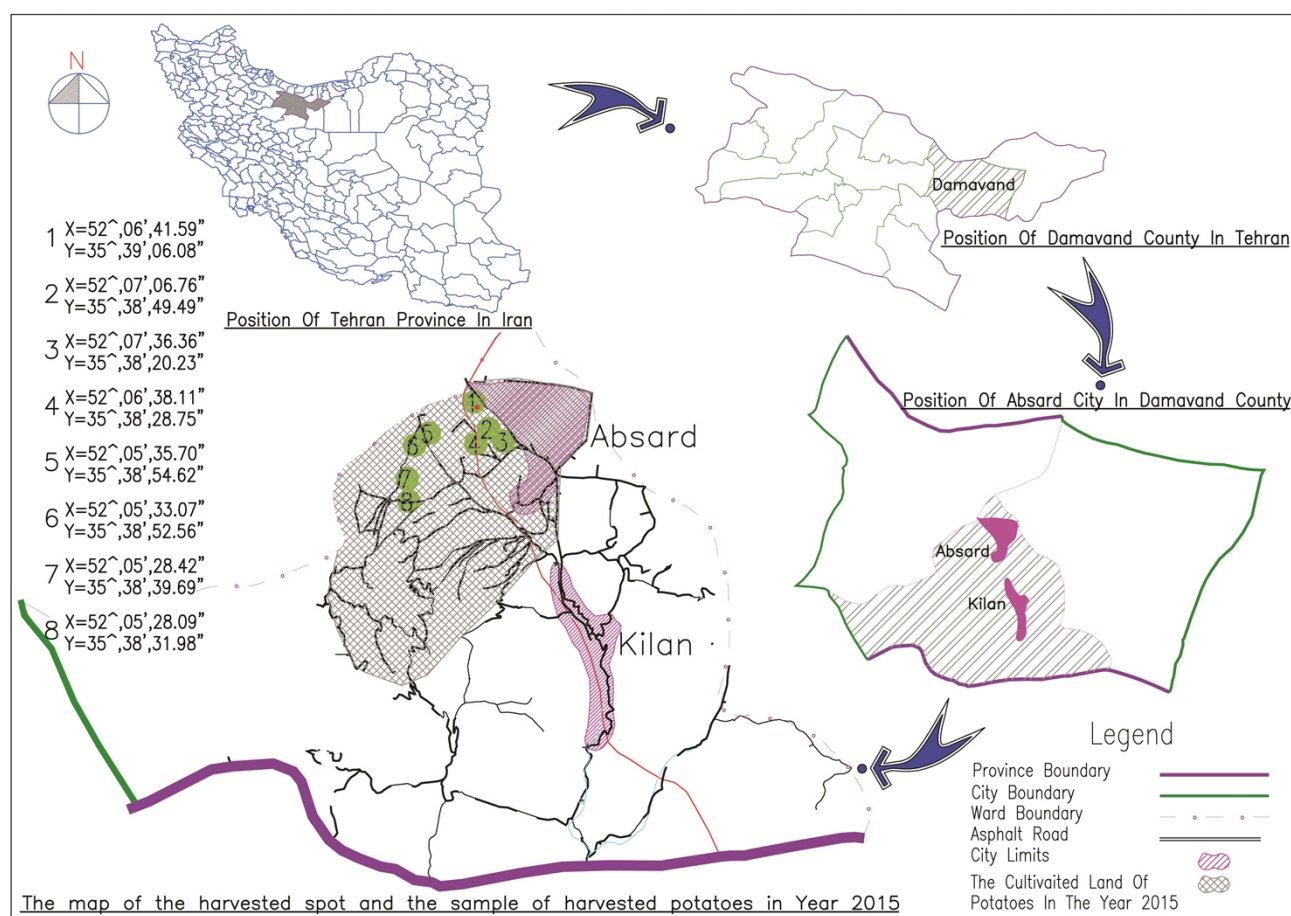


Figure 1. The map of the harvested spot and the sample of harvested potatoes in The Year 2015

2.4. Factors Affecting Soil Pollution

The used lands have a major and minor access: the major road of Firuzkuh and the minor intra-city road of Absard, which on its own is one reason of soil pollution of the farmlands located on the roadside due to the deposition of cadmium caused by travelling vehicles, especially on the busy road of Firuzkuh. Obviously, wind direction and slope of the road are aggravating factors of the condition. Other affecting factors, which inject heavy metals directly to the environment, are inappropriate use of superphosphate fertilizers by the farmers of the area and the road surface runoff.

2.5. Sampling

The soil and potatoes were sampled from the seed and crop at two phases and this happened at two times: spring and fall. 8 soil samples and 24 potato samples (3 samples from each farmland) were given to the laboratory.

2.6. Procedure

The potato samples and seeds of potato were analyzed twice by Graphite furnace flame spectrophotometer to measure the amount of cadmium (Table 2). In order to specify the amount of cadmium and measuring pH parameters, the electrical conductivity, phosphorus, nitrogen, and cadmium, the soil samples were analyzed twice using the mentioned machines.

Table 2. Specifications graphite furnace atomic absorption used in the experiment

Device name	Model	Manufacturing Country	Device software	Input gas
Graphite furnace atomic absorption spectrometry method	PG-990	Australia	Spectra AA	Acetylene – Air Or acetylene – N ₂ O

2.7. Data Analysis

Raw data obtained from laboratory, called data entry software, enter the fuzzy system. In this data analysis, fuzzy logic is used on the basis of Mamdani method, which is one of the fuzzy statistical methods of analysis. The table showing the soil profile depending on the type and farmland number and the data are modeled in the system. The used toolbox is Matlab. The Mamdani Inference System is based on the rules of if-then so that by using the mentioned rules, the relationship between some input or output variables could be understood. As a result, fuzzy logic could be used as a predictive model for occasions on which the input and output data have high uncertainty (2). Five stages are necessary in fuzzy inference process:

1. The Fuzzification of the input variables
2. The application of the operators of (and/or) in the introduction
3. Deduction from introduction to conclusion
4. The combination of the results of the regulations
5. Defuzzification (11).

It is worth to mention that in Mamdani Fuzzy Model, the model output of a set is fuzzy. Thus, to change it to a fuzzy number the model output needs to be Defuzzy (11). In this research, lab data of soil samples, which is about the amounts of pH, electrical conductivity (EC), cadmium in soil (CD soil), nitrogen (N), phosphor (P), and also the amount of cadmium in potato samples are placed in the system under the term input data. Inasmuch as the system contains the 5 aforementioned phases, firstly, the raw data are Fuzzified in the system. Next, with the help of operators (and, or), a conclusion, whose results produce output, is derived. The results of the rules blend with each other and finally, to obtain a specific model they are defuzzified (Figure 1). In fact, in this model, a group of factors and parameters exist and unlike classic method, the final consequence is a result of different environmental parameters' effects and the conditions of the phenomenon.

2.7.1. Raw Data of Samples

Laboratory achieved results from measuring cadmium in samples of soil, potatoes, seed potatoes, and measuring soil features are provided in Table 3 and Table 4. The amount of cadmium in the seed of potatoes was 0.224 mil.Kg⁻¹.

Table 3. The soil profile depending on the type and farmland number

Subject	Number 1	Number 2	Number 3	Number 4	Number 5	Number 6	Number 7	Number 8
soil pH	8.19	8.10	8.00	7.90	7.44	7.43	7.41	7.16
amount of cadmium	0.45	0.46	0.46	0.41	0.31	0.37	0.31	0.30
EC	4060	9160	7560	7864	5086	4568	3940	3652
amount of N	0.280	0.282	0.276	0.271	0.255	0.231	0.246	0.277
amount of P	98	79	67	59	64	92	68	50

Table 4. The amount of cadmium in the potatoes depending on the type and farmland number

Sample	Amount of Cadmium mg/kg
Potato number 1 (from intracity roadside farmlands)	0.831
	0.825
	0.840
Potato number 2 (from intracity roadside farmlands)	0.555
	0.560
	0.543
Potato number 3 (from intracity roadside farmlands)	0.363
	0.371
	0.359
Potato number 4 (from the second farmland located near the intracity roadside farmland)	0.169
	0.162
	0.162
Potato number 5 (from the farmland located in the area of cultivation with minor access)	0.04 >
	0.04 >
	0.04 >
Potato number 6 (from the farmland located in the area of cultivation with minor access)	0.04 >
	0.04 >
	0.04 >
Potato number 7 (from the farmland located in the area of cultivation with minor access)	0.03 >
	0.03 >
	0.03 >
Potato number 8 (from the farmland located in the area of cultivation with minor access)	0.03 >
	0.03 >
	0.03 >

2.7.2. The Fuzzification of Data

Lab results of samples are recorded in the system for the first fuzzification phase under the name input data (Table 5).

Next, the amount of each one of the variables is modeled and the modeled data are illustrated in Table 6.

Table 5. Each variable's data for modeling (input data)

Amount of cadmium in the potatoes	Amount of cadmium in seed of potatoes	P	N	EC	Amount of cadmium in the soil	pH
0.832	0.224	98	0.28	4060	0.45	8.19
0.55	0.224	79	0.282	9160	0.46	8.1
0.36	0.224	59	0.271	7864	0.41	7.9
0.16	0.224	64	0.255	5086	0.31	7.44
0.04	0.224	92	0.231	4568	0.37	7.43
0.03	0.224	68	0.264	3940	0.31	7.41
0.03	0.224	50	0.277	3652	0.3	7.16

Table 6. The results of modeling for each one of the variables and potatoes separately

pH	EC	CD soil	N	P	CD seed	Modeling
7.5	6500	0.4	0.25	72.2	-	0.41
7.5	8500	0.4	0.25	72.5	-	0.44
7.5	5270	0.4	0.25	72.5	-	0.3
7.5	5270	0.39	0.25	72.5	-	0.32
7.5	5270	0.35	0.25	72.5	-	0.26
7.5	5270	0.35	0.26	72.5	-	0.29
7.5	5270	0.35	0.23	72.5	-	0.25
7.5	5270	0.35	0.23	63	-	0.23
7.5	5270	0.35	0.23	80	-	0.33
7.5	5270	0.37	0.23	80	-	0.43
7.5	5270	0.42	0.23	80	-	0.23
7.5	5270	0.42	0.23	75	-	0.27
7.5	8510	0.42	0.23	75	-	0.37
8	8510	0.42	0.23	75	-	0.44
8	8510	0.38	0.23	75	-	0.34
8	8510	0.38	0.26	75	-	0.37
8	9000	0.44	0.27	92.4	-	0.52
7.23	4100	0.32	0.24	53.7	-	0.24

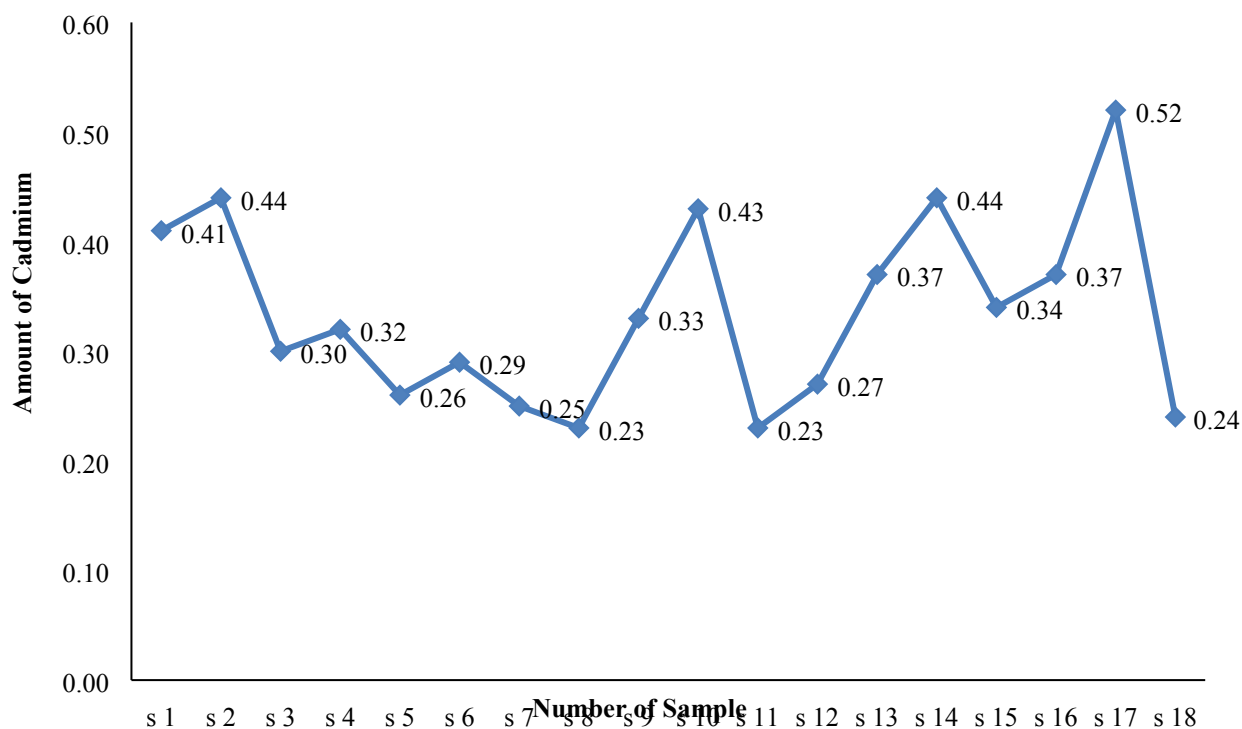


Figure 2. The modeling process diagram: cadmium in potatoes

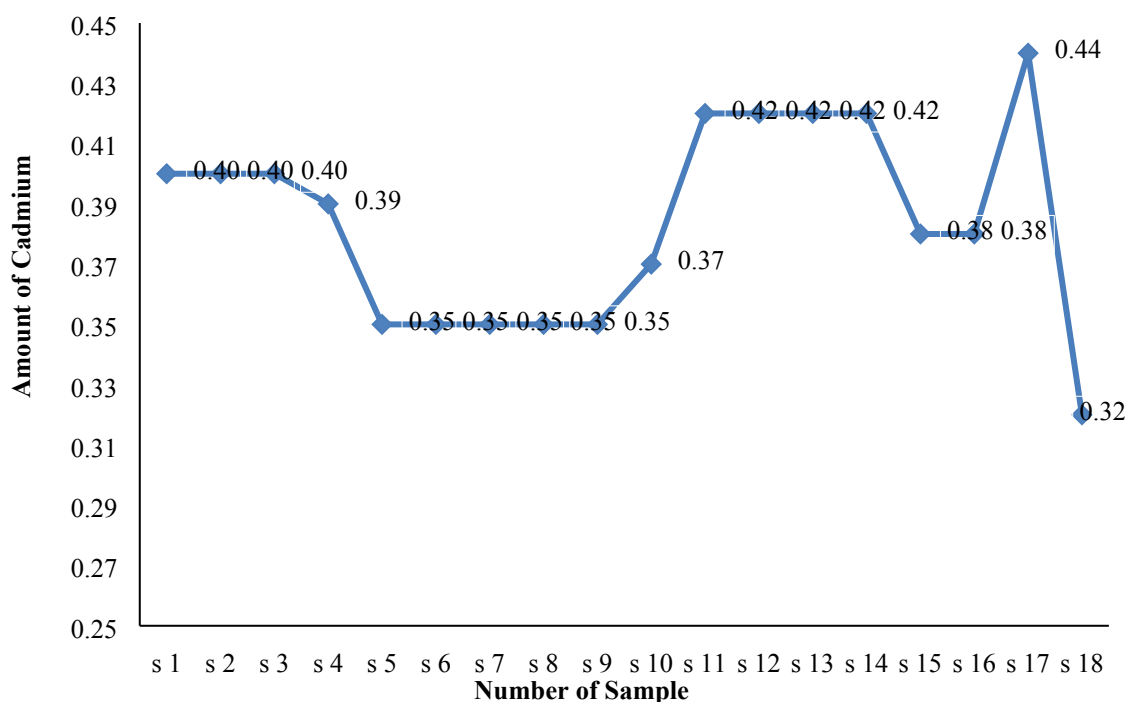


Figure 3. The modeling process diagram: cadmium in soil

3. RESULTS AND DISCUSSION

The increase of heavy metals in soil by chemical fertilizers (superphosphate), air pollution, and road surface run-off in the soil of farmlands near intercity roads (busy highway of Tehran-Firuzkuh), together with the regional climate, lead to more and more pollution of the soil in Damavand Area.

The intake of the elements in soil by plants, especially tuberous plants (like potatoes), brings about high concentration of heavy metals (like cadmium) in the plant compared to the standard amount and this in turn causes a drop in the quality of the crop and damages the lifecycle. Inasmuch as natural resources and natural events contain complex and vague chemical relationships and there is

uncertainty in the collected data of any related studies, this research was conducted based on fuzzy logic Analysis in the assessment of concentration process so that the relationship between the concentration process and Fuzzy logic could be analyzed based on fuzzy Method. Additionally, the amount of pollution of cadmium in the potatoes with respect to effective parameters of pH, EC, nitrogen, phosphorus, and the amount of cadmium in the soil was analyzed (based on fuzzy method). In this study, the Mamdani inference system was selected and the fuzzy logic toolbox of Matlab was used. The output data in the system showed that: If pH, P, N, and Cadmium in soil are high, and EC is also high, then the amount of CD in the potatoes is low. If pH, P, N, Cadmium in soil, and EC are low, then the amount of CD in the potatoes is high. If pH and P are moderate and EC, Cadmium in soil, and N are low, then the amount of CD in the potatoes is low. If pH and EC are moderate and Cadmium in soil, N, and P are low, then the amount of CD in the potatoes is low. If P is low and pH and EC are moderate and Cadmium in soil and N are high, then the amount of CD in the potatoes is low. If P, N, and Cadmium in soil are low and pH and EC are low, too, then the amount of CD in the potatoes is low. If P, N, and Cadmium in soil are high and pH and EC are high, then the amount of CD in the potatoes is low (Table 7, Table 8, Table 9).

Table 7. Output data bracketing

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	Average		Low		Moderate	
CD	0.23	0.243	0.243	0.257	0.257	0.27
P	53.7	66.6	66.6	79.5	79.5	92.4
N	0.23	0.243	0.243	0.257	0.257	0.27
Cadmium in soil	0.32	0.35	0.35	0.39	0.39	0.42
EC	4100	5723	5723	7367	7367	9000
pH	7.23	7.49	7.49	7.74	7.74	8

Table 8. The mean of output data

Average	Low	Moderate	High
CD	0.265	335.0	0.405
P	60.15	73.05	85.95
N	0.237	0.25	0.263
Cadmium in soil	0.34	0.37	0.40
EC	4917	6550	8183
pH	7.62	7.62	7.87

Table 9. Descriptive analysis of the relationship between soil parameters and cadmium in the potatoes

VARIABLE	P	N	Cadmium in soil	EC	pH	CD
1	High	High	High	High	High	High
2	Low	Low	Low	Low	Low	Low
3	Moderate	Low	Low	Low	Moderate	Low
4	Low	Low	Low	Moderate	Moderate	Low
5	Low	High	High	Moderate	Moderate	Low
6	Low	Low	Low	High	High	Low
7	High	High	High	Moderate	Moderate	Low

Among all the collected samples in various situations related to farmland 1 (on the roadside), the highest amount of cadmium in potato samples is between 0.37 to 0.44 (Figure 2) and the highest amount of cadmium in soil, between 0.39 to 0.42, belongs to the lands on the roadside (Figure 3). Fuzzy logic (the rule of if-then) is a more appropriate and accurate method to analyze the concentration of cadmium in the soil and crops regarding the impact of various factors such as PH, the amount of cadmium in the soil, the electrical conductivity, nitrogen, the phosphorus in the soil, and the type of the plant in reaction to each other or each one on its own. Similar studies about various plants with different methods prove this point. In a review of soil and soil environmental quality monitoring in China, it is showed that besides soil surveys, soil monitoring is essential to study the data and to examine the effects of contaminants in soils. However, the current soil quality monitoring system was insufficient to accurately determine the soil quality status of soils across China. Levels of pollution in urban soil, agricultural soil, and soil in mining and smelting areas were compared using the concentrations and pollution indexes (24). In many studies, the increase of heavy metals' concentration in soil has been recorded. The noticeable concentration of cadmium, copper, molybdenum, nickel, lead, palladium, and zinc have been observed in roadside soils in Melbourne and this high concentration of metals were related to the features of traffic, such as the age of the road, the traffic congestion, and the speed of the vehicle (25). In a study which is titled: Biodiversity of roadside plants and their response to air pollution in an Indo-Burma hotspot region: implications for urban ecosystem restoration, it is showed that the plant species growing at the Ramrikawn site (RKN-Med) showed significant decreases in stomatal size and stomatal index. Further, increased concentration of heavy metals (Fe, Cu, and Zn) was recorded at the RKN-Med site. Moreover, tolerant roadside plants find their suitability for plantation in ecologically sensitive regions, having implications for urban ecosystem restoration (26). In the analysis of metal pollution caused by fossil fuels in the soils found around Tehran-Damavand Road, statistics results reveal that as the distance from the main roadside increases, the lead concentration in the samples decreases. Moreover, as there is more raining (because of the washing of soil by rain), lead decreases in

soil and cadmium mostly concentrates in the surface of soil (27). The mentioned studies report metal pollution of soil in places near roadside areas in various cities, which have been conducted using different methods and include fuzzy and classic methods. This research is unique as it is the first time that the concentration of cadmium in soil and potatoes of Absard Area of Damavand is analyzed by fuzzy method, especially Mamdani fuzzy method. Analyzing the relationship between different parameters of soil in the process of cadmium concentration in potatoes is one of the distinctive features of this method in analyzing heavy metal concentration in plants, which elevates the accuracy of the research and leads to more realistic results.

4. CONCLUSION

To sum up the findings of this study, according to the results of the analysis of the relationships between the mentioned parameters in the concentration of cadmium in potatoes, the most amount of cadmium in the prepared set samples of potatoes in various situations is related to farmland 1 (on the roadside) with the numerical range of 0.37 to 0.44. The maximum allowed cadmium in crops is reported to be 0.1 mg.kg^{-1} ; therefore, with regard to the specified standard, the obtained amounts are more than the allowed limit. Furthermore, the highest amount of cadmium in the soil, with a high limit standing at 0.39 to 0.42, belongs to the lands on the roadside. This limit goes beyond the standard amount of 0.39 mg.kg^{-1} . Overall, the amounts of cadmium in the soil and the potatoes of the agricultural area are higher than the amounts specified by WHO standards which reveal cadmium pollution of the studied area.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration with all the authors. Dr.Shahrzad Khoramnejadian designed the research strategy and Maryam Valadkhani worked on the experimental section and contributed to the writing of the manuscript. Dr.Hadi Radnejad contributed to coordinating the data-analysis.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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