Indian Journal of Science and Technology Vol. 3 No. 7 (July 2010) ISSN: 0974- 6846

Fuzzy logic based model for predicting volcanic activity

Nilesh Dashore[1], Gopal Upadhyaya[2] and Kapil Vyas[3]

[1] *Dept. of Physics, B.M. College of Technology, Indore-452012;* [2] *School of Studies in Physics, Vikram University, Ujjain, India;* [3] *Dept. of Computer Science B.M. College of Technology, Indore 452012, India*
nk_dashore@yahoo.co.in; gopalujjain@yahoo.co.in; Vyas_bmct@rediffmail.com

Abstract

This paper describes a fuzzy logic based system to predict volcanic eruption. Meaningful prediction requires careful monitoring of a volcano's vital signs. Seismometers can be used to pinpoint earthquakes which track the rise of magma and its movement along fissures. Measurements of the tilt of the entire mountain provide additional information about the 'breathing' of the volcano as magma moves inside it. Instruments that sniff SO^2, CO^2 and other gases also can signal changes in the volcano. At some volcanoes the seismic information seems most reliable; at others the tilt tells the story. But the best predictions come from the combination of all of these methods into a volcano monitoring and prediction system.

Keywords: Fuzzy logic control system.

Introduction

Short- term prediction of volcanic eruptions involves monitoring when magma is approaching the surface and monitoring for precursor events that often signal a forthcoming eruption. Seismic activity is a result of a sudden release of energy in the earth crust that creates seismic waves. Earthquake is measured with a seismometer. Since seismic waves are generated by both earthquakes and explosions, and since S-waves cannot pass through liquids, arrays of seismographs can be placed around a volcano and small explosions can be set off to generate seismic waves. If a magma body exists beneath the volcano, then there will be zone where no S-waves arrive that can be detected. Monitoring the movement of the S-wave we can delineate the position and movement of magma body (Murck *et al*. 1997). As magma moves in to a volcano, the structure may inflate. Surface deformation pattern can provide important insights in to the structure, plumbing and state of restless volcanoes. Most eruptions are preceded by measurable ground deformation caused by pressurization of a magma reservoir or by upward intrusion of magma. Deformation pattern before, during and after eruptions provide a basis for understanding how volcanoes behave and ultimately forecast their activity (Zhong Lu *et al*., 2003). Rocks contain minerals such as magnetite that are magnetic. Such magnetic minerals generate a magnetic field. However, above a temperature called the Curie Temperature, these magnetic minerals show no magnetism. Thus, if a magma body enters a volcano, the body itself will show no magnetism, and if it heats the surrounding rocks to temperatures greater than the Curie Temperature (about 500°C for magnetite) the magnetic field over the volcano will be reduced. Thus, by measuring changes in the magnetic field, the movement of magma can sometimes be tracked (Patrick Abbott, 1996). Rocks have resistance to the flow of electrical current which is highly dependent on temperature and water content. As magma moves into a volcano, the electrical resistivity will decrease. Making measurements of the electrical resistivity by placing electrodes into the ground, may allow tracking of the movement of magma (Anderson *et al*.,1986). Heat is everywhere flowing out of the surface of the Earth. As magma approaches the surface or as the temperature of groundwater increases, the amount of surface heat flow will increase. Although these changes may be small they be measured using infrared remote sensing. The composition of gases emitted from volcanic vents and fumaroles often changes just prior to an eruption. In general, increases in the proportions of hydrogen chloride (HCl) and sulfur dioxide (SO_2) are seen to increase relative to the proportion of water vapor (Murck *et al*.,1997).

In general, no single event can be used to predict a volcanic eruption, and thus many events are usually monitored so that taken in total, an eruption can often be predicted. Still, each volcano behaves somewhat differently, and until patterns are recognized for an individual volcano, predictions vary in their reliability. Furthermore, sometimes a volcano can erupt with no precursor events at all. The most widely used method is studying the geographical area of the volcano. Taking seismic readings, measuring poison gasses, and using satellites. However following methods are applied for monitoring volcano activity: 1. Seismicity, 2. Gas emissions, 3. Ground deformation, 4. Thermal monitoring, 5. Hydrology, 6. Remote Sensing and 7. Mass movements & mass failures.

Fuzzy logic control process:- Control process consist of the following steps:

1. Defining the input variables- We use four variables to predict volcanic eruption-

(i) *Seismicity*: The Richter Scale measures the energy of an earthquake by determining the size of the greatest

Indian Journal of Science and Technology Vol. 3 No. 7 (July 2010) ISSN: 0974- 6846

Table1. Richter scale and its energy equivalent

Richter Approximate Magnitude	Approximate TNT for Seismic Energy Yield	Joule equivalent
0.0		63 kJ
0.5	0.07 kg (0.16 oz)	.35 MJ
1.0	0.43 kg (0.95 lb)	2.0 MJ
1.5	2.42 kg (5.34 lb)	11.2 MJ
2.0	30 lb	63 MJ
2.5	168 lb	354 MJ
3.0	952 lb	2.0 GJ
3.5	2.67 metric tons	11.2 GJ
4.0	15 metric tons	63 GJ
4.5	84.2 metric tons	354 GJ
5.0	476 metric tons	2.0 TJ
5.5	2.6 kilotons	11.2 TJ
6.0	15 kilotons	63 TJ
6.5	84 kilotons	354 TJ
6.7	168 kilotons	707 TJ
6.9	333 kilotons	1.4 PJ
7.0	476 kilotons	2.0 PJ
7.1	666 kilotons	2.8 PJ
7.5	2.67 megatons	11.2 PJ
7.8	7.5 megatons	31.6 PJ
8.0	15 megatons	63 PJ
8.5	84.2 megatons	354 PJ
8.8	238 megatons	1.0 EJ
9.0	476 megatons	2.0 EJ
9.2	947 megatons	3.98 EJ
9.3	1.3 gigatons	5.6 EJ
9.5	2.67 gigatons	11.22 EJ
10.0	15 gigatons	63 EJ

(Baralower, Timothy et al.1998)

vibrations recorded on a seismogram. A difference in magnitude of 1.0 is equivalent to a factor of 31.6 (= $(10^{1.0})^{(3\ /\ 2)}$) in the energy released; a difference in magnitude of 2.0 is equivalent to a factor of 1000 (= $(10^{2.0})^{(3\ /\ 2)}$) in the energy released. Most energy from an earthquake is not transmitted to and through the surface; instead, it dissipates into the crust and other subsurface structures. Table1 shows the relation between the magnitude of the earthquake and its energy equivalent.

Table 2. Earthquakes magnitude and Nos.

Date	Earthquakes magnitude	Nos.
22/03/1980	4.0	1
23/03/1980	3.0 and above	5
	4.0	1
24/03/1980	3.0 and above	10
	4.0 and above	04
25/03/2010	4.0 and above	25
26/03/1980	3.5 and above	100th
	4.0 and above	07
27/03/1980	Emission start	

For our model purpose we consider Mount St. Helens strato volcano located in Washington State. Earthquakes at Mount. St. Helens were monitored by the University of Washington in co-operation with the US Geological survey. Table 2 shows the observed data.

(ii) *Ground deformation*:- As magma moves into a volcano, the structure may inflate. This will cause deformation of the ground which can be monitored. Instruments like tilt meters measure changes in the angle of the Earth's surface which are measured in microradians. Other instruments track changes in distance between several points on the ground to monitor deformation. For our model purpose we consider Westdahl volcano, Alaska (erupted on 29-11-91). We document and model deformation patterns at Westdahl volcano, Alaska, using InSAR images acquired from 1991 to 2000, Table 3 shows the observed data.

Table 3. INSAR study of Westdahl volcano, Alaska

Duration	Altitude of ambiguity (h_a)
07-09-91 to 25-10-91	50 m
10-09-91 to 28-10-91	205m
21-11-91 to 30-11-91	455m

Eruption started on 29-11-91

(iii) *Gas emissions*;- As magma nears the surface and its pressure decreases, gases escape. Sulfur dioxide is one of the main components of volcanic gases, and increasing amounts of it herald the arrival of more and more magma near the surface. For example, on May 13, 1991, 500 tons of sulfur dioxide were released from Mount Pinatubo in the Philippines. On May 28--just two weeks later--sulfur dioxide emissions had increased to 5,000 tons, ten times the earlier amount. Mount Pinatubo erupted on June 12, 1991. Correlation Spectrometer (COSPEC) is used for measuring sulphur dioxide emission rates from various volcanoes around the world. They were originally designed for measuring industrial pollutants; the COSPEC measures the amount of ultraviolet light absorbed by sulphur dioxide molecules within a volcanic plume. The instrument is calibrated by comparing all measurements to a known SO_2 standard mounted in the instrument. Although the COSPEC can be used from the ground in a vehicle or tripod (like that below) to scan a plume, the highest quality measurements are obtained by mounting a COSPEC.

(iv) *Thermal sensing*- Both magma movement and changes in gas release and hydrothermal activity can lead to thermal emissivity changes at the volcano's surface. The presence of new significant thermal signatures or 'hot spots' may indicate new heating of the ground before an eruption, represent an eruption in progress or the presence of a very recent volcanic deposit, including lava flows or pyroclastic flows. For our model purpose we consider Mount St. Helens in Sept and Oct, 2004, before and after the onset of recent eruptive activity (Table 4 & 5).

2.Fuzzyfication- Comprises the process of transforming crisp values into grades of membership for linguistic terms of fuzzy sets. The membership function is used to associate a grade to each linguistic term. The fuzzification is the first step in fuzzy logic processing involves a domain transformation where the crisp inputs are transformed into fuzzy inputs (Nilesh & Gopal, 2009). To transform crisp inputs into fuzzy inputs, membership function must first be determined for each point. For our model purpose we defined following

Indian Journal of Science and Technology Vol. 3 No. 7 (July 2010) ISSN: 0974- 6846

membership functions for each input and output variables.

(i) Seismicity- Three types of linguistic variables are used as the inputs of seismicity (on the basis of no.of earthquakes and their magnitude). Fig.1 shows the three variables.

(ii) Ground deformation -Three types of linguistic variables are used as the inputs of ground deformation (on the basis of Altitude of Ambiguity (ha)). Fig.2 shows the three variables.

(iii) Gas emission - Three types of linguistic variables are used as the inputs of Gas emission (on the basis of magnitude (tons) of emission). Fig.3 shows the three variables.

(*iv) Thermal sensing*- Three types of linguistic variables are used as the inputs of Gas emission.(on the basis of temperature in °c). Fig.4 shows the three variables.

(v) Volcano eruption- Three types of linguistic variables are used as the output of volcano eruption.(0 represent low possibility and 1 represents high. Fig.5 shows the three variables.

3.Fuzzy inference rules - In this step the knowledge pertaining to the given control problem is formulated in terms of a set of fuzzy inference rules (Mohammad Abdul Azim & Abbas Jamlipour, 2006). An output of 0 represents low possibility of volcano eruption: whereas, 1 represents high. On the basis of input variables, output varies between 0 and 1. Output depends on input and inference rules. Some of the rules for our model are given in Chart 1.

4.Defuzzification- In our MATLAB flc module, the centre of gravity method is used to get a crisp output. This method calculates the weighted average of a fuzzy set (John Yen & Reza Langari, 2007). The result of applying COA defuzzification to a fuzzy conclusion "Y is A" can be expressed by the formula:

$$y = \frac{\sum \mu_A(y_i) \times y_i}{\sum \mu_A(y_i)}$$

If y is discrete and by the formula

$$y = \frac{\int \mu_A(y_i) \times y_i \, dy}{\int \mu_A(y_i) \, dy}$$

If y is continuous

Simulation result

We applied our suggested model to predict volcano

Fig.1.Three types of linguistic variables used as the inputs of seismicity

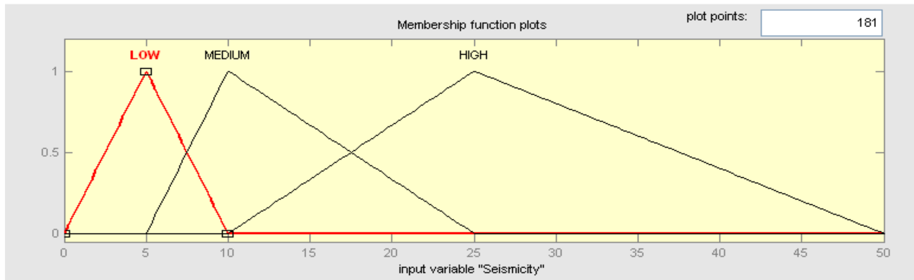


Fig.2.Three types of linguistic variables used as the inputs of deformation

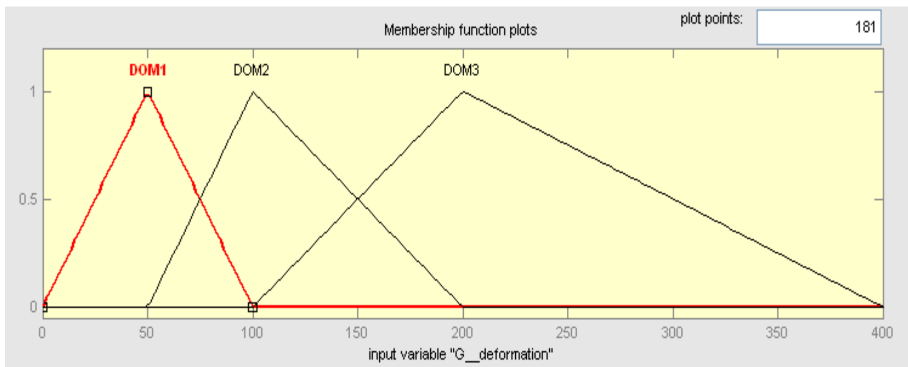


Fig.3.Three types of linguistic variables used as the inputs of gas emission on the basis of magnitude (tons)

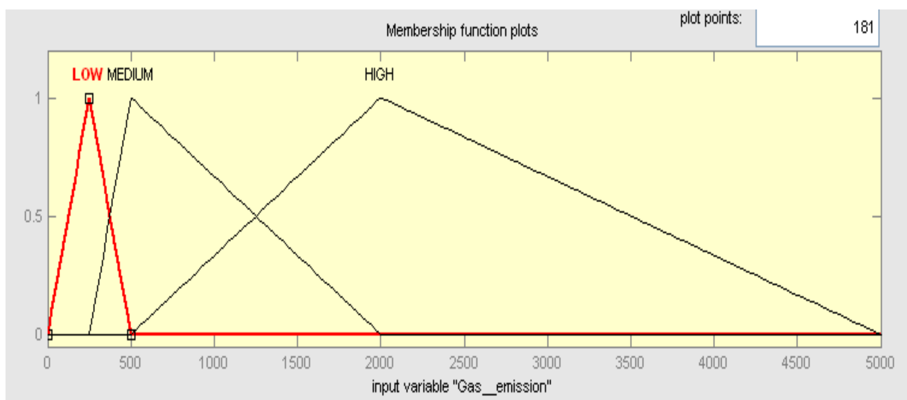
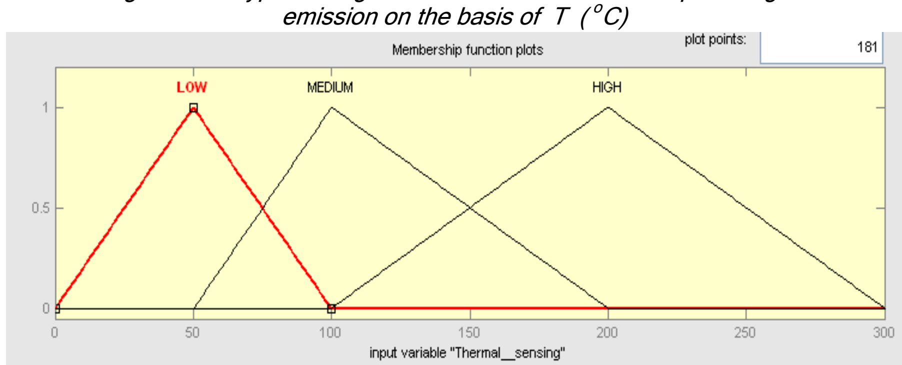


Fig.4. Three types of linguistic variables used as the inputs of gas emission on the basis of T (°C)



Indian Journal of Science and Technology Vol. 3 No. 7 (July 2010) ISSN: 0974- 6846

Table 4. Chronology of Mount St. Helens eruptive activity

Date (2004)	Mt. St. Helen's activity
23 SEP	Seismic swarm begins
24 SEP	Seismic activity continues
30 SEP	Uplift south of old dome
01 OCT	First phreatic eruption
02 OCT	Steam emission, Seismic tremor
04 OCT	large-scale dome uplift
11 OCT	First appearance of magmatic material
12 OCT	Steaming, lava extruding at the surface
14 OCT	Steaming, lava extruding at the surface

Fig.5.Three types of linguistic variables used as the outputs of volcano eruption

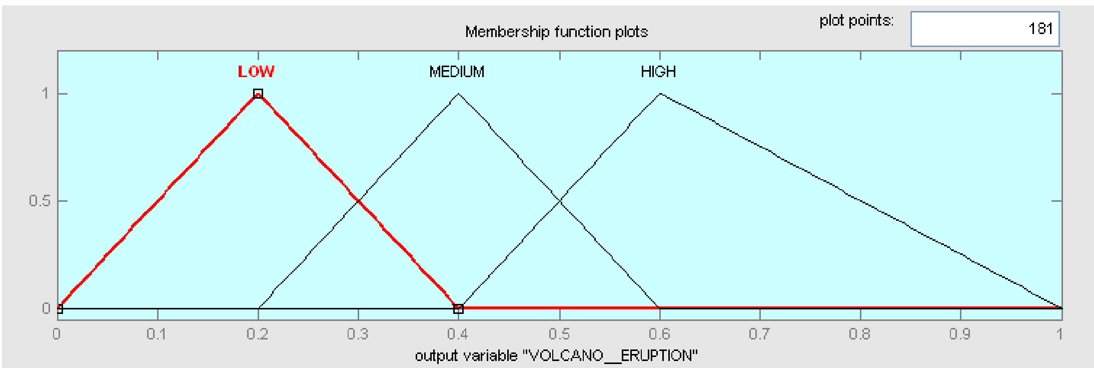


Table 5. Temperature data gathered by LIDAR

Date	*T Max.*
Sep 24	51^{0}c
Sep 30	54^{0}c
Oct 12	181^{0}c
Oct 14	330^{0}c

Chart 1.Inference rules deciding the value of input and output variables

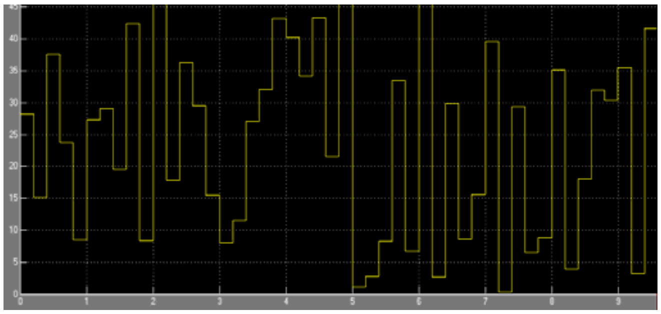
1. If (Seismicity is LOW) and (G__deformation is DOM1) and (Gas__emission is LOW) and (Thermal__sensing is LOW) then (VOLCANO__ERUPTION is LOW) (1)
2. If (Seismicity is MEDIUM) and (G__deformation is DOM2) and (Gas__emission is MEDIUM) and (Thermal__sensing is MEDIUM) then (VOLCANO__ERUPTION is MEDIUM) (
3. If (Seismicity is HIGH) and (G__deformation is DOM3) and (Gas__emission is HIGH) and (Thermal__sensing is HIGH) then (VOLCANO__ERUPTION is HIGH) (1)
4. If (Seismicity is HIGH) and (G__deformation is DOM2) and (Gas__emission is MEDIUM) and (Thermal__sensing is MEDIUM) then (VOLCANO__ERUPTION is HIGH) (1)
5. If (Seismicity is HIGH) and (G__deformation is DOM3) and (Gas__emission is LOW) and (Thermal__sensing is HIGH) then (VOLCANO__ERUPTION is HIGH) (1)
6. If (Seismicity is MEDIUM) and (G__deformation is DOM3) and (Gas__emission is LOW) and (Thermal__sensing is MEDIUM) then (VOLCANO__ERUPTION is MEDIUM) (1)
7. If (Seismicity is MEDIUM) and (G__deformation is DOM3) and (Gas__emission is LOW) and (Thermal__sensing is LOW) then (VOLCANO__ERUPTION is MEDIUM) (1)
8. If (Seismicity is HIGH) and (G__deformation is DOM3) and (Gas__emission is LOW) and (Thermal__sensing is HIGH) then (VOLCANO__ERUPTION is MEDIUM) (1)
9. If (Seismicity is LOW) and (G__deformation is DOM1) and (Gas__emission is LOW) and (Thermal__sensing is HIGH) then (VOLCANO__ERUPTION is LOW) (1)
10. If (Seismicity is LOW) and (G__deformation is DOM1) and (Gas__emission is MEDIUM) and (Thermal__sensing is MEDIUM) then (VOLCANO__ERUPTION is LOW) (1)

Table 6. Possibility of volcano eruption

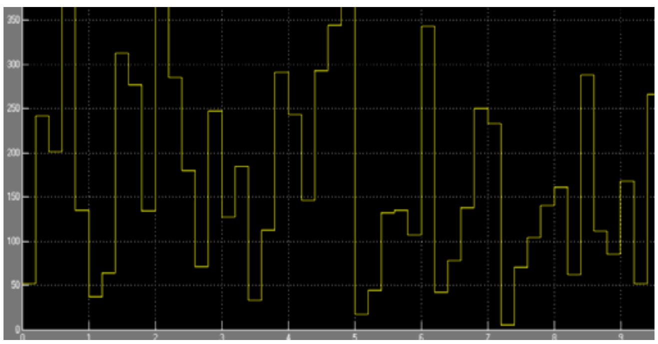
Seismicity (no. of earthquakes)	*Ground deformation (ha(meter))*	*Gas emission (tons)*	*Thermal sensing (T^0C)*	*Volcano eruption (varies 0-1)*
30	81	191	96	0.5
35	162	203	121	0.59
40	233	1200	174	0.68
8	127	857	96	0.4

Indian Journal of Science and Technology Vol. 3 No. 7 (July 2010) ISSN: 0974- 6846

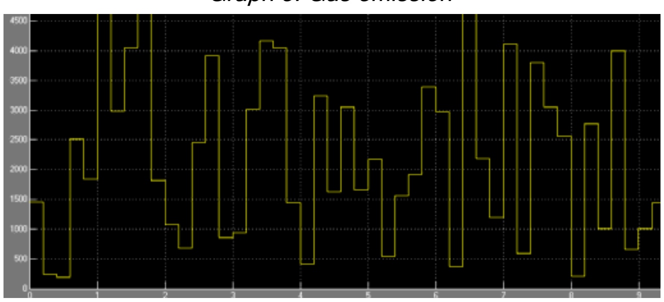
Graph1. Seismometer reading



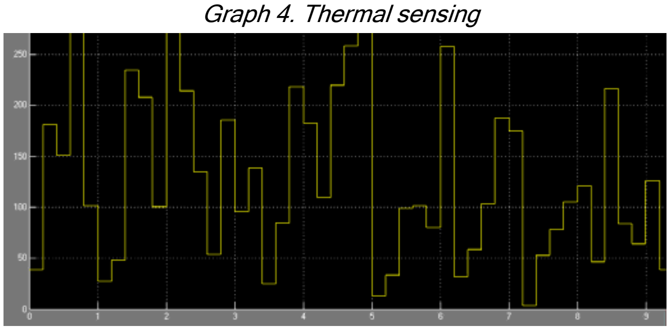
Graph 2. Ground deformation



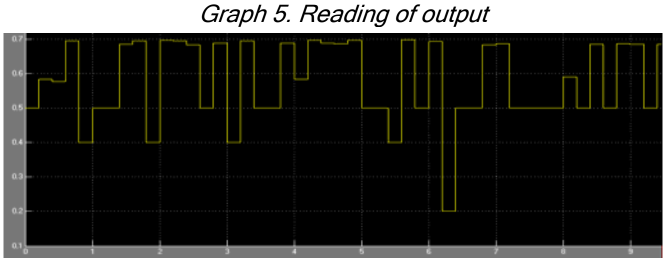
Graph 3. Gas emission



Graph 4. Thermal sensing



Graph 5. Reading of output



eruption (Table 6) and observed satisfactory simulation results. Simulation graphs show the reading of input variables (Graph 1-5).

Conclusion

We employed fuzzy logic system to predict volcanic activity. Volcanic eruptions can to date not be predicted by stochastic methods, but only by catching early symptoms before an imminent eruption. Each volcano is unique. The pattern of events that signifies an eruption at one volcano may not occur before an eruption at a different volcano and the same volcano may change its eruptive behaviour at any time. We present a model based on seismicity, ground deformation ,gas emission & thermal sensing. Volcano eruption possibility based on these input variables. Following Matlab^{R} diagram (Graph 5) shows that volcano eruption possibility varies between 0 and 1.

References

1. Anderson JG, Bodin P, Brune JN, Prince J, Singh SK, Quaas R and Onate M (1986) Strong ground motion from the Michoacan, Maxico earthquake. *Science*. 233, 1043-1049.
2. Bralower, Timothy J, Charles K. Paull and Mark Leckie R (1998) The cretaceous- Tertiary boundary cocktail: Chicxulub impact triggers margin collapse and extensive sediment gravity flows. *Geology*. 26, 331-334. doi: 10.1130/0091-7613(1998)026; ISSN 0091-7613.
3. John Yen and Reza Langari (2007) Fuzzy Logic Intelligence, control, and Information. Pearson Education, Texas. 68-70.
4. Mohammad Abdul Azim and Abbas Jamlipour (2006) Optimized forwarding for wireless sensor networks by fuzzy inference system. The Univ. of Sydney, NSW 2006, Australia.
5. Murck, Barbara W, Brian J. Skinner and Stephen C. Porter (1997) Dangerous Earth, an introduction to geologic hazards. Oxford University Press. pp: 299
6. Nilesh Dashore and Gopal Upadhyay (2009) Fuzzy logic based monitoring system for detecting radon concentration. *Indian J. Sci.Technol*. 2 (5), 29-30. Domain site: http://www.indjst.org.
7. Patrick L. Abbott (1996) Natural Disaster. Wm.c. Brown Publishing Co. pp:438.
8. Zhong Lu, Timothy Masterlark, Daniel Dzurisin , Russell Rykhus and Charles Wicks (2003) Magma Supply dynamics at Westdahl volcano, Alaska, modeled from satellite radar interferometry. *J. Geophysical Res*., 108 (B 7), 2354, ETG 9-1. 2003doi:10.1029/2002JB002311.