Modeling unsaturated soils moisture with Artificial Neural Network

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ABSTRACT: The landslides cause the loss of thousands of lives due to extreme rainfall events in the mountainous region of Brazil. The tropical climate is significantly rainy. Repeated extreme precipitation events can trigger landslides by decreasing the effective normal stress and thereby decreasing the cohesion and contact between soil particles. The measurement of rainfall by pluviometers is a foremost basic tool. However, many other parameters are involved in landslides and should be monitored. Soil moisture is an important parameter involving landslides. Historical long-term soil moisture data is fundamental for knowledge of the unsaturated soil conditions before an extreme rainfall event. Stresses in the slope are altered suddenly in the presence of excess of water. The relationship between rainfall and soil moisture was studied in a slope in the state of Rio de Janeiro. TDR probes and pluviometers with dataloggers were installed to measure soil moisture, temperature and precipitation. For the prediction system, an Artificial Neural Network (ANN) was developed to predict soil moisture, which was fed with the historical data of the field equipment for its convergence and knowledge base formation. The results of the ANN in the prediction of humidity using data soil was satisfactory

1 INTRODUCTION

It is relevant to understand the catastrophic phenomena associated with the intense or continuous rains that occur frequently in Brazil and in the world.

This work focuses on the possibility of applying a practical and low-cost computational solution, the Artificial Neural Networks (ANN), associated with simple field equipment, to predict soil moisture changes capable of provoking situations of geotechnical instability, which could lead to great tragedies.

Many tests were carried out in artificial networks, using as basis the data collected on a plot of land in the Municipality of Itaboraí, State of Rio de Janeiro, Brazil.

2 MATERIALS AND METHODS

2.1 *Laboratory tests*

To characterize the soil of the test fields, laboratory tests were performed. Undeformed specimens and deformed samples were collected and a plot of land located in Itaboraí Municipality.

The deformed samples were initially air-dried and de-rooted, and were used to perform particle size and soil physico-chemical analyzes.

The soil texture and the actual grain density were determined. The granulometric tests were performed at the Embrapa Solos Laboratory according to the ABNT-NBR 7181 (1984) standard. Basically, the granulometry of the soil is sand-clay and dry mass between 1,067 g/cm³ (from 0 to 15 cm deep) and 1,350 g/cm³ (from 15 to 36 cm deep).

Permeability tests were carried out following the principles of ABNT-NBR 13292 (1995) and ABNT-NBR 14545 (2000), respectively. By the tests, the following permeability values were obtained: 50,1 cm/h (from 0 to 20 cm deep), 18,5 cm/h (from 20 to 40 cm deep) and 4,9 cm/h (from 40 to 60 cm deep).

2.2 *Field testing*

Three field experiments were carried out in Itaboraí: evaluation of surface runoff and sediment production through hydro erosive plots; Soil moisture analysis by TDR probes with direct data acquisition (data logger); and determination of the hydraulic conductivity of the soils in the erosive plots with the use of Guelph permeameter.

The forest fragments found in Itaboraí are remnants of the Atlantic Forest, of secondary forests in different successional stages with floristic dominance of the Dense Montana Ombrophilous Forest, which is a perennial ecosystem. forest with variegated vegetation and closed canopy with high and well distributed pluviometric indices.

The average temperature of the air of the coldest month is higher than 18° C. The precipitation is higher than 750 mm per year, reaching 1800 mm.

The sets of rain gauges and data loggers (Campbell Scientific CR1000®) were installed in the experimental area. The precipitation was measured at intervals of 5 minutes, which allowed to evaluate its intensity, which was quantified by the maximum intensity of precipitation in 30 min (I30).

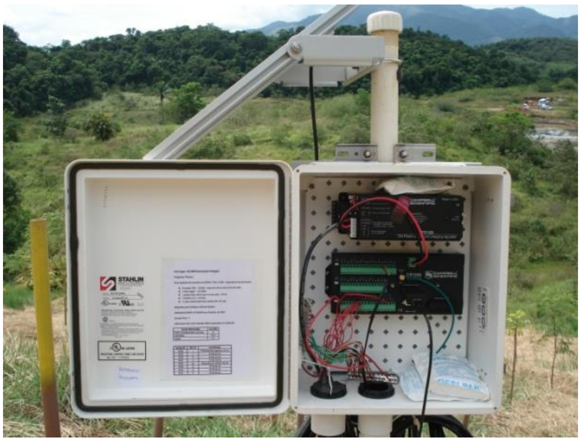

Figure 1. Data acquisition system CR 1000® at the field

The monitoring of soil moisture and temperature was performed through the installation of TDR type humidity detectors. The soil temperature was measured through a temperature sensor inserted in the base of the TDR probe. Sixteen TDR probes (Campbell Scientific CS650®) were installed at depths of 10 and 30 cm. The calibration of the TDR probe was performed in the field.

With the data of moisture content in the field and the characteristic curves of the soils, it was possible to correlate: moisture, suction and erosion.

2.3 *Artificial Neural Network (ANN)*

Artificial neural networks were first modeled by McCulloch and Pitts in 1943, and are based on the representation of a network of biological neurons. The human nervous system has 100 billions of nerve cells that are interconnected, constituting a true network of neurons. The nervous impulse passes from one neuron to another through the synapse. Synaptic transmission is correlated with the release of neurotransmitters, and is variable, and can be inhibited or excited, conferring adaptability to the system. The resulting electric response of this interaction is a measure of the synaptic force. In addition, the artificial neural network (ANN) is based on an analogy with the synaptic force between the output produced and transmitted by the axon.

In this work, a weightless neural network was programmed to predict soil moisture from data from TDR probes. The weightless neural network estimates the soil moisture at first, from five attributes:

- Precipitation data;
- Soil temperature;
- Rainfall index accumulated in 30 min;
- Drought time and;
- Time of day.

The attribute data were normalized to put the results between 0 and 1. Normalization is the harmonization of scales to increase the efficiency and speed of response of the network.

3 RESULTS AND DISCUSSION

The data log records and formats a table with twenty seven attributes, which were thoroughly tested until the best use of them for the forecasting system was found. It was noted the need to not use some attributes such as the battery voltage that keeps the TDR sensors connected and the VWC which is the volumetric content of water in the soil. Such a value is the same as permissiveness. Any of the values could be chosen, however, the scale of the Permissivity values is closer to the Temperature, which is one of the most important attributes for the system.

Another attribute generated from the existing ones was the dry period. Its importance for the accuracy of the network was perceived.

Time of Day was also an unusual attribute, as it would in principle be discarded because it was only a data log label, but it became very necessary to address the ambiguity of soil temperature in the night and day periods.

Results of the artificial neural network in the prediction of humidity with data of soil temperature, time of drought and time of day:

- Average hits: 96.625%;
- Standard deviation: 0.283;
- Trust: 98.762%;
- 36,486 hits in a total of 37,771 cases, representing 96.598% accuracy.

Table 1. Results of artificial neural network in the detection of soil moisture.

Permissiveness (intervals)	**Total samples**	**Total network responses**	**Percentage per class**	**Percentage of adjustment per class**
10.5 – 11.4	1555	1914	4,12	99,16
11.5 – 12.4	1193	1175	3,16	97,07
12.5 – 13.4	2309	2289	6,11	96,80
13.5 – 14.4	2027	1994	5,37	96,84
14.5 – 15.4	3624	3608	9,59	97,54

15.5 – 16.4	6568	6493	17,39	96,71
16.5 – 17.4	7102	7071	18,80	97,82
17.5 – 18.4	6225	6161	16,48	97,00
18.5 – 19.4	4260	4222	11,28	95,07
19.5 – 20.4	1889	1872	5,00	93,70
20.5 – 21.4	835	802	2,21	88,50
21.5 – 22.4	177	166	0,47	87,01
22.5 – 23.4	7	4	0,02	42,86

4 CONCLUSIONS

The understanding of the phenomena related to unsaturated soils still allows a world of discoveries, but it is notorious that great progress has been made, mainly by the technological development, associated to the importance that the scientific community has given to the subject.

The use of a computational method, such as ANN, for programming a soil moisture prediction system, is in line with this new reality that employs modern technology to more efficiently solve engineering problems.

The soil characterization, obtained by the tests mentioned in this article, had as its main delinear justification the contour conditions in which the tool effectively worked.

In this concrete case, for which, it was clear that it's sufficient to have an initial set of information (targets and boundary conditions) to be able to train the network, thus making it unnecessary to use expensive equipment to maintain monitoring.

In future studies, it is important to always make sure to supply the neural networks with information from databases referring to soils whose characteristics are well known.

It should be noted that the results obtained through ANNs will be as reliable as the data collected. The use of unreliable data makes the forecasting process merely mathematical and therefore has no practical utility. In this sense, it is recommended that special attention be given to the collection of data and training of the network.

5 REFERENCES

ABNT - Associação Brasileira de Normas Técnicas (Brazilian Association of Technical Standards). 1984. NBR 7181 Solo – Análise Granulométrica (Brazilian Standard 7181 Soil - Granulometric Analysis), Rio de Janeiro (in Portuguese).

ABNT - Associação Brasileira de Normas Técnicas (Brazilian Association of Technical Standards). 1995. NBR 13292 Determinação do Coeficiente de Permeabilidade de Solos Granulares à Carga Constante (Brazilian Standard 13292 Determination of the Coefficient of Permeability of Gramineous Soils at Constant Load), Rio de Janeiro (in Portuguese).

ABNT - Associação Brasileira de Normas Técnicas (Brazilian Association of Technical Standards). 1998. NBR 14114 Solos Argilosos Dispersivos – Identificação e Classificação por Meio do Ensaio do Furo de Agulha (Pin Hole Test) (Brazilian Standard 14114 Soil Argilous Dispersive Soils - Identification and Classification through the Pin Hole Test), Rio de Janeiro (in Portuguese).

ABNT - Associação Brasileira de Normas Técnicas (Brazilian Association of Technical Standards). 2000. NBR 14545 Determinação do Coeficiente de Permeabilidade de Solos Argilosos à Carga Variável (Brazilian Standard 14545 Determination of the Coefficient of Permeability of Arginous Soils to the Variable Load), Rio de Janeiro (in Portuguese).

Aleksander, I., De Gregorio, M., França, F.M.G., Lima, P.M.V. & Morton, H. 2009. A Brief Introduction to Weightless Neural Systems. *Proceedings of the European Symposium on Artificial Neural Networks - Advances in Computational Intelligence and Learning*. 1-7.

ASTM D5298. 2003. Standard Test method for Measurement of Soil Potential (Suction) Using Filter Paper. West Conshohocken, USA.

ABNT - Associação Brasileira de Normas Técnicas (Brazilian Association of Technical Standards). 1984. NBR 7181 Solo – Análise Granulométrica (Brazilian Standard 7181 Soil - Granulometric Analysis), Rio de Janeiro (in Portuguese).

Calôba, L.P., Alencar, G.A. & Assis, M. 2005. Hybrid Neural-Phenomenological Sub-Models and its Application to Earth-space Path Signal Attenuation Prediction. *Proceedings of the International Joint Conference on Neural Networks.*

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária (Brazilian Agricultural Research Corporation). 2006. Sistema Brasileiro de Classificação de Solos, Centro Nacional de Pesquisa de Solos (Brazilian Soil Classification System, National Soil Research Center), 306p., Rio de Janeiro (in Portuguese).

Fyfe, C. 2005. Artificial Neural Networks. *In Do Smart Adaptive Systems Exist?* 173: 57–79.

Mendel, J.M. & Mclaren, R.W. 1970. Reinforcement learning control and pattern recognition systems. *In Learning and Pattern Recognition Systems: Theory and Applications* 287-318.

van Genuchten, M.T. 1980. A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils. *Soil Science Society of American Journal* 44: 892-898.