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ARTIFICIAL NEURAL NETWORK-BASED ELECTROMAGNETIC INVERSE MODELING FOR WATER QUALITY MONITORING

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Abstract
Water quality monitoring is important for detecting harmful contaminants and ensuring safe water use. This paper focuses on an artificial neural network-based electromagnetic inverse modeling approach for monitoring water quality. Electromagnetic sensing helps identify changes in the electrical properties of water, while inverse modeling connects sensor responses with the physical and chemical characteristics of the tested material. In this study, the method is applied to water contaminated with fluoride. Laboratory-prepared samples are used to train and test the artificial neural network model. Once trained, the ANN model can estimate fluoride concentration in water with good accuracy and low computational effort. The approach is useful because it supports non-destructive, fast, and efficient monitoring of water quality. Therefore, electromagnetic inverse modeling combined with ANN can provide a practical solution for detecting water contamination and supporting environmental safety.

Keywords
Artificial Neural Network, Electromagnetic Inverse Modeling, Water Quality Monitoring, Fluoride Detection, Microwave Sensor, Non-Destructive Testing.

Introduction

Water contamination is a serious environmental and public health concern. The presence of harmful substances such as fluoride can affect the quality of drinking water and may cause health problems if present above safe limits. Traditional water testing methods are often time-consuming and require laboratory-based chemical analysis. Therefore, there is a need for faster, low-cost, and non-destructive techniques for monitoring water quality.

Electromagnetic sensing is an effective approach for studying the electrical properties of materials. When a microwave sensor interacts with water or any other material under test, the sensor response changes according to the material's physical and chemical condition. Electromagnetic forward modeling helps explain how the sensor interacts with layered dielectric media, while electromagnetic inverse modeling helps estimate the unknown properties of the tested material from the sensor response. In this context, artificial neural networks can be used to develop a relationship between electromagnetic sensor data and contaminant concentration.

ELECTROMAGNETIC FORWARD MODEL

Using electromagnetic forward modeling, we are able to see the method in which the microwave sensor interacts with the multilayer dielectric medium in the near field. This allows us to better understand the nature of the interaction. This thesis contains the building of a model that is both innovative and effective in order to compute the interaction of open- ended transmission line sensors with layered media. This is done in order to measure the interaction. It has been found that the newly produced model is similar to a model that is available for commercial use and uses a solver that is based on the finite element method (FEM) in terms of the computational efficiency that it possesses. The model that was built to monitor water salinity was found to have a high degree of concordance with the data that was acquired in the frequency range of 1GHz to 10GHz throughout the course of experimental testing. This was demonstrated by the fact that the model performed very well. In addition to being a significant contribution to the open source community, the model that was built has also been made accessible as a software package for the nondestructive examination of multilayer media. This is a significant accomplishment. The C++ programming language serves as the foundation for this whole software solution.

Electromagnetic Inverse Model:

Electromagnetic inverse modeling makes it possible to monitor the changes that take place in the material's physical and chemical characteristics. This is accomplished by creating a correlation between the response of the sensor and the electrical property of the material. For the purpose of this research thesis, we are going to design a model that will make use of an artificial neural network (ANN) in order to track the development of the material that is being tested (MUT). The electrical property of water that had been polluted with fluoride was determined using samples that were created in a laboratory. The model that was developed was put to the test by monitoring the quantity of fluoride that was present in water and by assessing the electrical property of water that had been contaminated with fluoride. For the purpose of testing the model, both of these methods were utilized. Based on the findings, it has been shown that an artificial neural network (ANN), once trained, is capable of delivering an accurate assessment of the fluoride level in clean water while utilizing a low amount of computer resources. The results are in agreement with what was previously known as a result of the study that has been carried out when the temperature is at room temperature.

Software Defined Radio based Non-Destructive Microwave Sensing System

This thesis presents a prototype that was built with software defined radio (SDR) technology for the purpose of constructing a non-destructive, real-time, microwave reflectivity-based sensing system from the ground up. The prototype was produced in order to accomplish this goal. Software defined radio is a type of programmable radio communication system that permits the modular construction of bespoke hardware architecture for use in embedded or System-on-Chip productized implementations. This type of radio communication framework is also known as SDR. This particular kind of technology is referred to as "software defined radio" in the industry. The open-source GNU radio platform was used to construct the system, and the B210 SDR board was utilized for both the hardware implementation and the SDR programming. The system was constructed using the GNU radio platform. Systems that are based on SDR are employed for a broad variety of material characterization applications. The findings that are acquired from these systems are compared to the results that are obtained from VNA-based systems that are available for commercial use. Using a single- frequency radio receiver (SDR) board that is programmed to send a single frequency at predetermined intervals and then receive the same frequency back after the sensor has reflected it, the system that has been constructed is able to lower the signal intensity to -70 dBm. This is accomplished by utilizing the SDR board. The design, which makes use of the constantly expanding SDR technology, makes use of a variety of applications for the aim of material characterisation. These applications are used to provide information about the material. Both the observations and the theoretical model that is provided in this thesis are congruent with one another. The findings are astonishingly comparable to those of vector network analyzers that are already available for commercial usage. On the other hand, in comparison to the earlier models, the new small system is not only more user-friendly but also more affordable. A reduced footprint is also a feature of it.

ELECTROMAGNETIC SENSOR

Theoretically speaking, extremely low frequency electromagnetic radiation, which is analogous to solar, ultraviolet, X, and γ radiations, is basically its own form of electromagnetic radiation. This is the case since it is equivalent to these other types of radiation. A term that refers to the whole area of the electromagnetic spectrum is called static ELF, which is an abbreviation that stands for extremely low frequency. The creation and transmission of electrical power, as well as the powering of a wide range of electronic equipment, all result in the natural occurrence of electromagnetic energy. This is a phenomena that happens when electromagnetic energy is present. Throughout the course of their examination, researchers discovered that there is a significant distinction between it and different types of radiation and electromagnetic fields. As a result of this, as will be seen in Figure 1.3, applications that make use of electromagnetic frequencies play a significant role in the transmission of signals for mobile phones, as well as for radio and television. There are sources that are capable of creating low-frequency static electric and magnetic fields. These sources can be either naturally occurring or create them intentionally. It is true that these electromagnetic natural fields have an influence on the surface of the planet, despite the fact that their pace of change is extremely slow. Electric fields and static fields are both produced by them. They are responsible for their invention. The environment is affected by it, and it has the capability to detect voltages of up to one hundred millivolts per meter. However, when the conditions are really severe, such as when there is a major storm or an earthquake, the voltage may be 10 times higher than what is recorded. Using the geomagnetic field sensing effect, it is possible to identify fields that have a range that is greater than or equal to fifty micro teslas (μT).

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Electromagnetic sources that have been engineered have the capacity to generate a diverse spectrum of frequencies, which includes ultra-low (ULF), extremely low (ELF), very low (VLF), low (LF), and high (HF). The frequency range that ranges from 0 to 50/60 hertz is produced by a multitude of electrical sources, including power plants, transmission lines, and distribution systems. These sources are responsible for the bulk of the production of this frequency range. ELFs, which are sometimes referred to as electric or electromagnetic fields of extremely low frequencies, are electromagnetic fields that are produced by people. These fields are produced by external sources. The creation of voltage equivalents of signals, energy, or noise falls within the purview of this domain, which features a variety of orders and peaks within its boundaries. The device has the ability to detect electromagnetic effects that vary from 0.09 microtesla to 1.5 microtesla (μT), and its voltage sensitivity spans from 10 to 100 millivolts per meter. Additionally, it has the capability to detect electromagnetic vibrations. The sources of sound and communications that are categorized as electromagnetic fields or static fields, respectively, are electromagnetic fields and static fields, both of which are classed as very low frequency fields. Magnetic fields and static fields are both classified as extremely low frequency fields. There are two possible sources of these fields: natural environments and man-made environments. The low frequencies that are identified in this region are those that lie within the intensity range of 20 dB to 40 dB. Some of the physiologically detrimental consequences that this field may produce include, among other things, the likelihood of risks that may cause the system that is being examined to become more unstable.

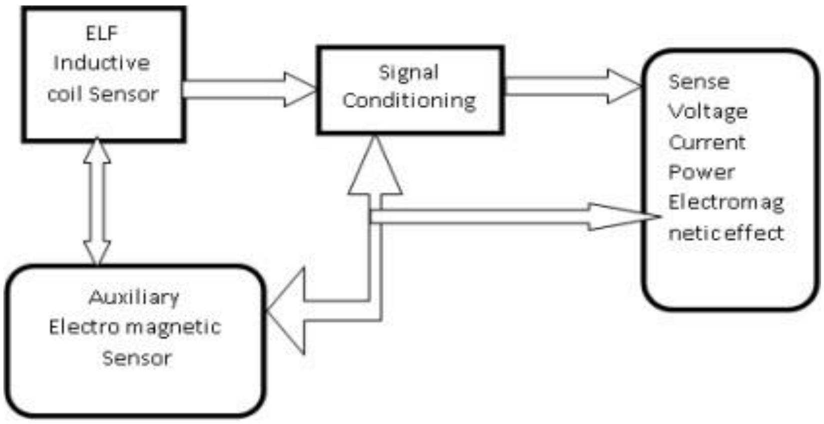

Figure.1.1 Block-by-Block Architecture of a Proposed Intelligent Electromagnetic Ultra Low Frequency Sensor

At a frequency range that runs from 0.3 Hz to 100 KHz, the electromagnetic or static forces that are responsible for the formation of these electromagnetic low frequencies (ELFs) have a frequency range. Developing an intelligent electromagnetic very low frequency sensor is not a straightforward undertaking, particularly when it comes to accurately and sensitively evaluating the impacts of signals. This is especially true when it comes to the evaluation of signals. A further factor that is taken into account is the origins of the ELF fields, namely whether they are natural or synthetic. Because of the invention of an intelligent electromagnetic ELF sensor, which is illustrated in Figure 1.3, it is easy to understand for the first time. These sensors are typically referred to by the term of an electromagnetic inductive coil sensor. This is the nomenclature that is most widely used. It was found and mentioned in the goals that its principal role is to detect the fields of the threshold at extremely low frequencies. This was the primary function that it serves. It is the purpose of this device to transmit the signal conditioning components with an increased effective sensitivity of these signals and other electromagnetic materials that are sensing components for all parameter values (such as voltage, current, power, sensitivity, electromagnetic effects, and so on) through magnetic or airborne mediums. This device's purpose is to accomplish this.

As a result of having access to data on static fields, researchers and designers have the chance to gain a deeper understanding of the effects that electromagnetic fields have, as well as the potential dangers that these fields poses. This category contains all of the signals, energies, and sounds that are included within the ELF frequency range.

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Throughout the course of this chapter, I was able to get a grasp of the significance and effect of electromagnetic fields (ELFs), which are utilized in a wide number of applications within the realms of medical and communication. Throughout the course of our investigation, we have carried out microanalysis on a broad variety of ELF range signals, energy, and noises. Bioassay, direct current, frequency modulation, magnetic resonance imaging (MRI), television signals, electromagnetic radiation, and electromagnetic low frequency (ELF) are some examples of these procedures.

In the second half of the report that I wrote for my research project, we spoke about each and every kind of sensor. Throughout the course of the previous forty to fifty years, we have covered every aspect and structure that has taken place, and we have done so in this chapter. Following an exhaustive review of over 150 scientific articles on the subject of microanalysis, we came to the realization that there was a knowledge gap that included all of the different types of sensors. To all of the researchers who have made major contributions to our understanding of the world via the amazing studies that they have undertaken, I would like to extend my heartfelt gratitude and best wishes. In the course of the past three decades, they have been able to achieve a degree of physical quality that has never been seen before. This has been accomplished through the utilization of cutting-edge microtechnology. There have been a variety of various methods in which the number of different kinds of physical sensors that are based on applications has been increased or discovered. In the present day, the phrase "intelligent sensors" is utilized to refer to both the individual sensors as well as the systems that make use of them. You can see in figure 1.3 that these sensors are more versatile in terms of the applications to which they may be used, that they have a better degree of precision, and that they are robust enough to resist a wider range of environmental conditions.

There are a broad variety of applications that may be carried out with this intelligent sensor system. Some of the most typical uses include being easy to handle, giving transparent sensing of all aspects, and carrying out data analysis. Around the distribution of the system's applications and physical nodes or devices, such as sensors, actuators, controllers, base transducers, and so on, it is possible to construct a suitable communication network of any type or behavior, whether it be periodic or otherwise. This may be accomplished in a number of different ways. Instead of offering a physical location in which the data might be kept, these bespoke devices have the capability of transferring data from one media to another based on the events that they see. The results and actions of the balanced nodes and layers of the communication networks have been supplied with this information. The following are some of the things that can be experienced as a result of this: data transfers, physical reaction and processing time, maximum medium directed distance, network and system speeds (including wired and wireless), scheduling, and the resolution of faults in communication.

ELF (Extremely Low Frequency) electromagnetic sensors and systems that combine EEG sensors are going to be explored and developed as part of this project. ELF stands for extremely low frequency. As a consequence of this, the sound energy may be modified and rectified, which makes it easier to regulate and modify an extra parameter that is accountable for this. This newly assigned parameter will be handled by hardware devices, components, and systems, in addition to digital signal processing systems that are both quick and trustworthy. This new parameter has been allocated. In spite of the fact that the electromagnetic sensor for ELF has been subjected to a number of alterations, there is no study that has demonstrated that it is capable of utilizing EEG as a control mechanism. When this is taken into consideration, the strategy will lead to the development of new ways of thinking in this particular field, as well as in fields that are close to it and in the direction on the whole.

Creating an electromagnetic field-limited (ELF) sensor that is equipped with two loop- inductive antennas for pitch and loudness is the objective of this project. Electroencephalogram (EEG) sensors will be utilized in the construction of this sensor in order to read information from our brains while simultaneously filtering out noisy information. Through the use of this indication energy, the recognized sound energy ought to be changed in a method that is both efficient and effective. This results in the development of new applications and methods for playing and controlling the instrument, each of which involves an extra degree of regulating control. As a consequence of this, new applications and methods are produced.

Definition and Specifications of the Electromagnetic sensor:

The primary purpose of this project is to develop a circuit that is capable of detecting and recording electrical activity in the brain, such as electroencephalogram (EEG), energy, and noise. This will be accomplished through the employment of electrodes. I will now construct an inductive coil with a core made of ferrite that operates at a very low frequency in order to solve the problem of replacing the electrodes and lowering the probability of failure in that connection. Immediately following the completion of the simulation program's testing and validation of the inductive coil sensor, this step will be carried out.

One of the most challenging difficulties is coming up with a design for the current detecting coil that is capable of detecting the very small signals that you want to detect while at the same time filtering out background noise that comes from other electrical and electromagnetic sources. In order to achieve the goal of preventing measurement-related problems that are brought about by human or mechanical mistake, it is necessary to establish a user amplifier circuit that is beyond the norm.

Fundamentals of Electromagnetic Field Theory:

There are many different fields that encompass frequencies ranging from 3 Hz to 3*104 Hz at (IEEE-1998), and the primary emphasis of my study is on these field combinations. There are time-variable and time-non-variable scales that are encompassed by these fields. These domains make use of both natural and artificial sources of knowledge in their research projects. Magnetic fields are capable of producing signals with very low frequencies, and they may also produce noise phenomena or input variables with varying intensities and magnitudes. Magnetic fields may generate signals with extremely low frequencies. There is a maximum frequency of three kilohertz that it is able to produce through its capabilities. There is an influence on the potential for major electrical risks and damages induced by electromagnetic low-frequency radiation.

The emission of radiation and the magnetic effects that are present in the air are both caused by the frequencies that are created or developed in magnetic fields. These frequencies are responsible for the electromagnetic fields. In such a circumstance, it is feasible that the strength of the electric field might be precisely determined if one makes the assumption that the flux is always visible and known. Additionally, it is plausible that this could be the case. One thing that should be brought to your attention is the fact that the magnetic field produces incredibly low frequencies for the two different kinds of units that are being discussed here.

1) Electric Static (Electro-static) Field

2) Magnetic Static (Magneto-static) Field

Electric Static (Electro-static) Fields

The letter "E" in equation 1.1 represents the extremely low frequencies field (ELF) that is created on the surface of the Earth by either natural or man-made sources, and the letter "F" represents the electrical force that is produced as a result of this field. Both of these fields affect the Earth's surface.

$$F = qE \quad \text{…………….(1.3)}$$

Equation 1.3 demonstrates that the electric charge (q) in ELF field sources, regardless of whether they are naturally occurring or man-made, is converted into an electric charge on the surface of the Earth, which in turn generates a multitude of signals and noises ranging from zero to three thousand hertz. This phenomenon occurs regardless of whether the ELF field sources are man-made or naturally occurring. These are the vector quantities that are formed or the magnetic attraction effects that are discovered in response to the directions and qualities of the electrical compactness.

It is necessary to take into account the permittivity of the material and the electromagnetic field (EMF) in order to ensure that the displacement vector ($D = \varepsilon E$) and the electrical flux density are acceptable. It is possible for electromagnetic and electric fields to detect the difference in charge (q) that exists between neighboring conductors or objects and the surface of the Earth. This difference may be detected by electromagnetic and electric fields. This electric potential may be produced between two materials via the usage of both naturally occurring and purposely manufactured electrical fields [4, 16]. The word "voltage" refers to the electric potential that can be formed between these two materials. The variations and changes that take place in the sources and the ambient operating conditions make reference and measurement procedures particularly necessary in this environment. Reference and measuring procedures are extremely crucial.

Fundamentals for the Magnetic Fields:

In accordance with the idea, these fields are generated by sources that are either naturally occurring or the result of purposeful creation. Alternatively, the letter 'B' stands for the magnetic density, while the letter 'H' stands for the static field. Both of these values are represented by the letters. The electrical charges of the unit carrier, which are represented by the letter 'q,' are often maintained at a constant value, and the effects that they cause are unit produced. When there is a change in the connection between the electrical charges and the time and distance under particular conditions, the flow of current is denoted by the letter 'I'. This flow of current occurs when there is a different relationship between the electrical charges. This is something that is constructed in order to build a connection between the contour of the section and the density area of the unit, while also taking into consideration the absolute porosity or permittivity of the medium, which was represented by the symbol 'ε' in the equations that came before it. Manufacturers, scientists, engineers, and researchers all work together in the field of electromagnetics to investigate the signals and noise that are produced by the porosity of materials. This porosity, which is sometimes referred to as apparent porosity, is often referred to as physical porosity. The study of the signals and noise is a result of the permeability ρ = vo, where vo is the porosity of free space represented by air or vacuum. In this context, the permeability ρ = vo leads to the research. According to equation 1.4, it has been noticed in this field that the magnetic density, which is denoted by the letter 'F' in the treatise, is sufficient for the density, and the rate charge of the signals in this field may be related to one another. This is something that has been observed

.

$$\mathbf{B} = \mu\mathbf{H} \qquad \text{..........(1.4)}$$

Under these conditions, the magnetic field generates the force in a direction that is perpendicular to both the charge velocity and the magnetic flux density B. This way, the force is created in a direction that is anticlockwise. This equation provides a formula for the force that is acting on a moving charge in a magnetic field that is supplied. The charging charge is traveling in the magnetic field.

The Extremely Low-Frequency (ELF) Fields and Their Effects on Living Beings: A Conceptual Understanding and theory:

The time-varying equations that Maxwell created are responsible for regulating and controlling the physical interactions that take place between electromagnetic fields and tissues within the body. This holds true in spite of the fact that not all physical components interact with one another in the same manner. Vector power, also known as gauge energy, is the principal source of propulsion for extremely low frequency fields that function at electromagnetic low frequency frequencies. When the intensity of electrical, magnetic, and electromagnetic force fields is being measured, the gauge energy is utilized to verify the vector power in a very minute manner. This makes the gauge energy a very useful tool. Sources that are developed by humans are accountable for the generation of electromagnetic power frequencies that vary from 10 Hz to 50 Hz or 60 Hz. These frequencies are responsible for the transmission of electromagnetic waves. The frequencies that are created by sources that originate from the natural world are ten to twelve times higher than the frequencies that are produced by energy that has been calibrated specifically for that purpose. The energy link that exists between them may either be strengthened or dissolved through the utilization of these frequencies, depending on the particular situation. The reaction in these areas is determined by the ramifications that have become obvious, regardless of whether they are direct or indirect. The semi-electro-thermal effects are caused by electromagnetic frequency (ELF) signals, energy, and disturbances that are not permitted in these locations. Measurement of heat losses is made possible as a result of these factors. There is a strict adherence to the electromagnetic coupling rules, which include the Mutual Induction Law, Faraday's Law, and Ohm's Law. Manufacturers propose the use of magnetic forces or electrical static outcomes when dealing with electromagnetic fields (ELFs), which typically operate in the frequency range of 03Hz to 300KHz when they are subjected to this field. When working with ELFs, manufacturers recommend the employment of these outcomes. During the time when this field was active, it was responsible for the production of a variety of distinct frequency ranges, including electromagnetic fields (ELF), radio frequency (RF), microwave frequency (MF), infrared field (I.F.), and ionization signals (I.S.). Depending on the presence of these fields, the signal-gauge boson energy electron

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voltage (eV) can be anywhere from 1.2*10-22 to 1.2*103 eV when it is measured. When subjected to a certain field, it is able to generate noise with a frequency range that runs from 0.3 Hz to 3*1022 Hz. This noise can affect the surrounding environment. These frequency sets are manufactured for extremely low frequencies with a wavelength of 106 meters; below that, they transition to ionization signals with a wavelength of 10 to 12 meters at the universal standard, which is used for all frequencies and has been approved by the United Nations; Figure 1.5 illustrates the results of this radiation production. These frequency sets are manufactured for extremely low frequencies.

The induction of concentration of both information and physical materials is a type of process that occurs in fields that have gauge boson voltage and the present. This type of process is known as the induction of concentration. Furthermore, the scientific investigation of the impact of magnetic fields on biological systems can benefit from this subject matter. A wide range of industries, including medical, as well as the transmission and distribution of energy, are among those that make extensive use of this technology. The direction vector of these currents is perpendicular to the intensity vector, which is perpendicular to the intensity vector. The intensity vector of the magnetic force field is perpendicular to the direction vector. Using this method, one is able to find the present state of things as well as the gauge boson voltage inside the fields' unit induction of material density and examined data that has been collected from storage. This is all possible because of the use of this strategy.

Additionally, the fundamental biological and reciprocal magnetic effects of this field are highly favorable. This field has a range of applications. Its widespread application may be attributed, in large part, to the fact that it is advantageous in vital medicinal applications, as well as in the generation, transmission, and distribution of energy. The vector dimensions that are attributed to these currents in respect to the direction of the magnetic field or electromagnetic fields designate them as unit followers. In other words, these currents are described as unit followers. The static gauge boson voltage (Ve) and the static field are both patterns of the current and field directions that are generally recognized. Figure 1.4 illustrates both of these patterns.

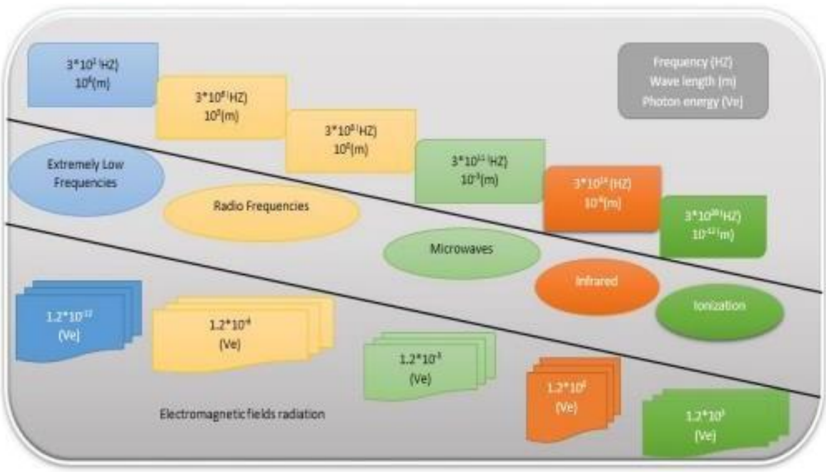

Figure 1.2 radiation from electromagnetic fields in terms of wavelengths (m), photon energy (eV), and frequencies (Hz)

Inducing electric current density in the tissue of interest that has been identified is the most fundamental and required method for creating precise interaction and strong interfaces formed by electrical exposure to magnetic fields. This is because it is the only means to achieve these goals. For good conductors that are suitably exposed to the time-varying electric fields, the accompanying electric currents will always be very correctly induced. This is because the electric fields will fluctuate over time. Because of their ability to carry electricity, excellent conductors are responsible for this. Because of this, it is possible to determine that the electric current density increases as a function of both the frequency variation that has been described and the volume and contents fluctuations that are brought about by changes in the shape and size of the body. For this reason, it is possible to determine that the electric current density increases. The well-defined multi-dimensional absolute spatial patterns that these electric currents display are a reflection of this specific distinction, which is one of the many ways in which these electric currents that are created by electric and magnetic fields are unique from one another. When a vertically directed electric field is applied to an upright perfect human body or assumed body, the induced field and current flow are also observed to be vertical with respect to the ideal reference. This is because the electric field is directed along the vertical direction. When the ideal reference is taken into consideration, this is the situation. If it ever takes place at all, the production of closed loops that are orthogonal to or perpendicular to the direction of a magnetic field that is completely normal is an incredibly unusual occurrence with very little likelihood of happening.

Conclusion

The study concludes that artificial neural network-based electromagnetic inverse modeling is a useful method for water quality monitoring. By connecting electromagnetic sensor responses with the electrical properties of contaminated water, the ANN model can estimate fluoride concentration efficiently. This approach is non-destructive, requires low computational resources, and can support faster water testing compared with conventional methods. The technique can be further improved by using larger datasets, different contaminants, and advanced sensor systems. Overall, ANN-based electromagnetic inverse modeling offers a promising direction for reliable and practical water quality assessment.

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