

Respected reviewers

Firstly, I would like to thank you for your reviews, which have helped us significantly improve and expand our manuscript.

Secondly, I would like to inform you that one author had already dropped out of the research due to his privacy and family obligations.

Now there are three authors in the paper in the following order: Slađana Pantelić, Branislav Vulević, and Saša Milić.

Thank you for your time and effort.

Sincerely,

Branislav Vulević

Reviewer 4

Review Report Form

Open Review

- ☐ I would not like to sign my review report
☒ I would like to sign my review report

Quality of English Language

- ☐ I am not qualified to assess the quality of English in this paper
☐ English very difficult to understand/incomprehensible
☐ Extensive editing of English language required
☒ Moderate editing of English language
☐ Minor editing of English language required
☐ English language fine. No issues detected

	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	☐	☐	☒	☐
Are all the cited references relevant to the research?	☐	☐	☒	☐
Is the research design appropriate?	☐	☐	☒	☐
Are the methods adequately described?	☐	☐	☒	☐
Are the results clearly presented?	☐	☐	☒	☐
Are the conclusions supported by the results?	☐	☐	☒	☐

Comments and Suggestions for Authors

Type of manuscript: Article

Title: Fuzzy-decision Algorithm for Health Impact Assessment in 5G Environment

Journal: Applied Sciences

The authors present a relatively brief but interesting update on their previous fuzzy logic-based risk assessment methodology published in *Nuclear Technology and Radiation Protection* in 2019, now specifically treating risks to health of 5G, and reflecting recent changes in guidelines.

General comments

I would recommend the authors to seek English language editing prior to submission to a journal. Although the quality of English is reasonably high, there are some limitations to the current manuscript including, for example, confusing omissions/mistreatments of definite and indefinite articles throughout, which makes reading a little tiring, and several omitted words or muddled sentences, which obscure the intended meaning of the authors. Even in the first line (!) of the abstract there are mistakes that make understanding difficult: “The mass use of mobile phones and other wireless communication devices **causes apprehensive** of the negative impact of non-ionizing radiation on human health.” (my bold)

[Answer:](#)

The entire paper has been improved, and the grammatical errors have been corrected.

Section by section:

1 Introduction

The Introduction section is rather vaguely written. It is unclear throughout whether the authors are specifically interested in health risks, in biological effects, or perhaps some other impacts on humans. The aims should be specified more clearly with appropriate language. A whole paragraph is devoted to explaining what the paper will be about. I would recommend removing this whole paragraph and instead replacing with background relating to assessment of health risks relating to the exposures of interest here i.e. 5G.

There is no background presented regarding methodologies used for assessing health risks from EMF, either specifically for 5G or generally for all other EMF. This is lacking and should be provided. It is particularly necessary as it is not clear what “gap” the paper is addressing. If there are uncertainties or knowledge deficits in current EMF-risk assessment methodologies, what do these look like, how do they affect regulation, what are the implications for risk assessors, regulators or other scientists and engineers working in this field, and indeed what are the wider implications to human health and society?

The authors express the aims of the paper in an confused manner which requires rewriting. They state the goals as the goals of the fuzzy model and algorithm. They should instead express what the goals of the *research* are. The goals listed are threefold: (i) assessment of EMF-related health impacts; (ii) indication of “unexplored adverse health effects”; and (iii) reduction of subjectivity in assessing EMF impact on health. With regards to (i), this should be expressed in much specificity. What kinds of health effects are being assessed, are they authors only interested in developing the algorithm for 5G? (it is not mentioned here), are they talking about exposures from phones, masts, microcells, etc.? With regards to (ii) it is hard to understand what is meant by “indication of unexplored adverse health effects”. What is “indication” in this context? What is meant by unexplored—does it mean something completely novel? Or is this referring to non-thermal effects?

[Answer 1](#)

The introduction has been improved.

Answer 2

The following paragraphs have been added to the introduction:

Two key aspects have driven the research presented in the paper. The first relates to citizens' concerns about many IoT wireless devices and their impact on health. The second aspect concerns professionals. They are often exposed to strong electromagnetic fields during the repair and maintenance of equipment.

Their objectives are to promote and disseminate knowledge about the health effects of non-ionizing radiation, to develop and revise guidelines for exposure limits and safety measures, and to collaborate with other organizations and stakeholders to ensure the implementation of its recommendations.

A fuzzy decision-making process is a type of decision-making technique that is used to solve complex and vague problems. This technique uses fuzzy logic allowing the representation of vague and imprecise information. The aim of this paper is to discuss the fuzzy decision-making process, its advantages, and practical applications.

2. Overview of open questions, guidelines, recommendations, and standards

Again the language is rather weak. The first sentence: "In the last three decades, large increase in non-ionizing radiation sources is noticeable." Apart from grammatical issues, I would ask the authors to consider what this sentence is really telling the reader. The authors should be far more specific and point out that there has been a proliferation of wireless telecommunications technologies that has led to both increased potential for exposure to RF-EMF (and the frequencies we are considering here should be listed) and an increased concern over potential for impact on human health? These statements should be referenced properly, with citations taken from reliable peer-reviewed sources. Another sentence: "With the advent of new technologies in everyday life, people are continuously surrounded by lower levels of RF radiation that are unable to cause thermal effects." This cannot be presented without a citation. What is the source of this information. To which populations is this relevant? Are people really exposed to less RF, even if they are using more and more devices? There are some good exposure studies on this, and they should be cited properly in support of such sweeping statements. And again: "So far, countless studies have been conducted, but no study has provided a satisfactory methodology." Countless studies?! Really? And no study has provided a satisfactory methodology intended to achieve what exactly??

Section 2.1

The ICNIRP guidelines officially are designed to protect humans exposed to radiofrequency electromagnetic fields (RF) in the range 100 kHz to 300 GHz, and they do this through identifying minimal exposure levels required to produce harm. From this they apply reduction factors that result in exposure restrictions which incorporate large margins of safety (depending on whether for public or workers). This is not the summary presented by the authors, who state that "In terms of limitations, the guidelines indicate permitted RF levels that should not be exceeded to ensure health protection". The authors recommended to carefully review their writing about the guidelines to reflect what they are actually designed to do.

In general, it is unclear to the reader why they are reading about these differences between the various ICNIRP guidelines. The authors need to explain more clearly why this information is presented i.e. what purpose does it serve?

[Answer](#)

The following paragraph has been added:

The advent of 5G technology has been a significant advancement in telecommunications. It offers faster internet speeds, increased bandwidth, and lower latency. However, as 5G networks continue to expand, there are increasing concerns about the potential health risks associated with this technology. 5G technology relies on higher frequency radio waves than previous generations of wireless technology, which means that more energy is needed to transmit signals. This increased energy creates more electromagnetic radiation, and the proximity of the 5G antennas, which are expected to be placed much closer together, creates a higher risk of exposure to electromagnetic radiation.

Section 2.2

“Hazards” in the subtitle is the wrong term. I believe that the authors intended to write “health effects from non-thermal effects”. The RF-EMF is the hazard in this case.

“Millimeter wave and THz applications do not significantly affect the average exposure of the humans”. Exposure to what? Why are we learning about exposure here? I thought this section was about effects.

“it must be noted that a paradigm shift is slowly taking place, from apriori non-acceptance to a new understanding and acceptance of scientific explanations and results of clinical studies.. Obviously, another decade should pass so that conclusions can be drawn more reliably about the potential health hazards of high-frequency EMFs” This does read like a scientific manuscript. The authors are making all kinds of judgements here without citing any justification.

It is highly unclear reading this section what the authors wish the reader to learn. That there are non-thermal effects? The authors need to explain: what the non-thermal effects are; what health outcomes and biological changes have been putatively linked to such effects; what the uncertainties are in this field. At present the section does not do any of these things in sufficient detail, or at a sufficient level of rigour.

[Answer 1](#)

The subtitle has been changed.

3. Pathway for designing methodology

“The existence of many scientific studies, which have not been taken into account (justified or unjustified) in defining guidelines, recommendations, and standards, introduces great confusion in choosing a measurement methodology.” It seems to me that *this* is the justification for the current work. It belongs in the introduction to set the scene for the reader, to explain why a new methodology has merit. The authors should use this statement as a starting point for defining the precise shortcomings of the current regulatory system and then to outline their specific aims addressing these issues.

“Biological effects (non-thermal effects)” Not all biological effects are non-thermal effects. This is confusing. Thermal effects are also “biological”.

What is the “pathway principle”? Is it the same as the pathway (i.e. figure 2) or is it some conceptual underpinning of the pathway? The authors should either revise their terminology or explain properly how the principle is linked to the pathway itself.

Figure 2 is declared to represent the “pathway for methodology designing”, by which I assume the authors mean “methodology design”. But this is at odds with the statements previously, where the pathway is explained as a means of *choosing* a methodology for assessing RF impact on health. It is also not clear again here why the authors are avoiding using the term 5G, even though that is what is in the title. Is this a pathway (and a paper) explicitly about 5G RF-EMF or RF-EMF more generally? The authors should revise either the manuscript or the title accordingly.

“The benefit of the presented pathway principle is that a new parameter or procedure can be added anywhere in it without disturbing its sequence”. The authors cannot express value judgements about benefits of the pathway before explaining what it is? The section is jumbled and hard to follow. I suggest they explain the intention of building the pathway, the potential end-users that might use it, and the way they would apply it. This should be presented in context with relevant citations of the literature.

The Figure and the pathway are both wholly inadequately explained. What is a “comprehensive analysis”? Who conducts it? Why do they do it? What does it entail? What is the end goal?

How are the authors so sure that the pathway will be flexible enough to look at 6G when the details of that standard are as yet unconfirmed?

In summary, the whole of this section—which should be the meat of the paper—is inadequate. The reader is left without any idea of what the pathway is, what it represents, who should use it and in what circumstances, or how its use will improve decision making regarding method design.

[Answer](#)

The previous reference [5] has been replaced by a new one:

[5] Balmori A. Evidence for a health risk by RF on humans living around mobile phone base stations: From radiofrequency sickness to cancer. *Environmental Research* **2022**, 214,113851.

This reference provides a comprehensive survey with results that confirm the views expressed in the paper.

4. Internet of things (IoT) and 5G Network - Knowledge and Doubt

The introductory paragraph suggests that the authors do not know what the IoT is. What does booking hotels have to do with IoT? This whole paragraph requires rewriting based on published material.

Again there is background information in this section about why 5G has been developed, what some people hope it will achieve and enable. This should all be in the introduction, not in the middle of the paper. It makes no sense here and feels like an afterthought.

Figure 3 doesn't seem to have any attribution and it should have. Figures 4, 5 and 6 are almost wholly out of place here – they don't seem to relate to the text in a useful way and the authors would be recommended to either remove them or provide context for them in the written text.

“The newest 6G telecommunication mobile system should be a cellular data network overcoming all shortcomings of 5G and 4G mobile networks and supporting future AI devices and architectures.” I see no reason to include such a vague statement. If the authors wish to discuss 6G, then they should cite

relevant studies appropriately (I don't know of anything reliable in existence). A discussion of the “shortcomings” of 4G, 5G or any other G has no place in this paper.

Answer 1:

The following sentences and paragraphs have been added:

Millimeter wave technology is a critical component of 5G networks that promises to revolutionize the telecommunications industry.

Another challenge associated with millimeter wave technology is interference. The millimeter wave frequency range is highly congested, and multiple devices operating in the same frequency range can interfere with each other, resulting in signal degradation.

The following solutions successfully overcome the limitation of 5G millimeter waves technology:

1. **Beamforming:** Beamforming is a technique used to direct the transmission and reception of signals in a specific direction. It enables the millimeter wave signals to be directed towards the user, reducing the path loss and improving signal strength.
2. **Massive MIMO:** Massive MIMO (Multiple Input Multiple Output) is another technique that can overcome the limitations of millimeter wave technology. It involves the use of multiple antennas at the base station and the user's device, allowing multiple signals to be transmitted and received simultaneously, resulting in improved signal strength and reduced interference.
3. **Hybrid Beamforming:** Hybrid beamforming is a combination of beamforming and massive MIMO, allowing the antenna array to steer the beam in a specific direction while still maintaining the benefits of MIMO.

Answer 2:

Two figures have been changed and improved:

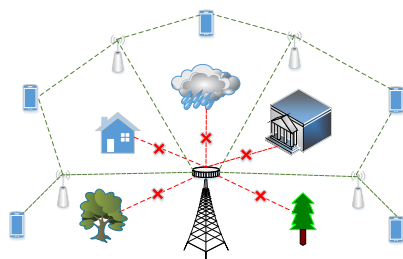


Figure 4. Limitations of 5G millimeter waves: All obstacles (rain, plants, and buildings) can attenuate the 5G signal [20].

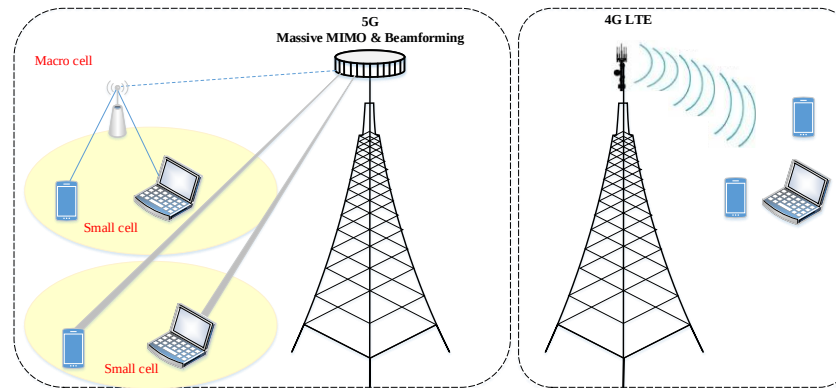


Figure 5. Beamforming techniques for avoiding obstacles using a bunch of low-power pole transceivers and wall transceivers.

Answer 3:

Three references have been added:

- [20] Sudhamani, C.; Roslee, M.; Tiang, J.J.; Rehman, A.U. A Survey on 5G Coverage Improvement Techniques: Issues and Future Challenges. *Sensors* 2023, 23, 2356.
- [21] International Commission on Non-Ionizing Radiation Protection (ICNIRP). Principles for Non-Ionizing Radiation Protection. (2020). Principles for Non-Ionizing Radiation Protection. *Health Physics* 2020, 118, 477–482.
- [22] Belpomme, D.; Hardell, L.; Belyaev, I.; Burgio, E.; Carpenter, D.O. (2018). Thermal and non-thermal health effects of low intensity non-ionizing radiation: An international perspective. *Environmental Pollution* 2018, 242, 643-658.

5. Fuzzy algorithm for 5G impact assessing

This is again the meat of the paper, and yet it is presented almost last, after a jumbled and confusing set of four introductory sections.

Section 5.1 opens with some rather textbook-like introduction to fuzzy logic. This should be in the introduction, not in the methods. Some of the information is extraneous. The reader wants to know about how fuzzy logic is applied to the task in hand, not in general terms. It is not a textbook, after all. This section could be split between the introduction and being deleted.

Section 5.2 explains some of the application of the fuzzy method to EMF, but only in vague and completely uninterpretable terms. This needs a complete rewrite. What is the aim of the fuzzy logic application? How is it applied? Detail that is required is wholly lacking. The lack of inclusion of exposure time for >30GHz “because there are no guidelines for adverse biological (non-thermal effects)” makes me question the value of the fuzzy approach. I was expecting that it was precisely to deal with uncertainties like that the fuzzy logic approach would be useful! The results that are presented e.g. in Figures 9 and 10 look

interesting, but they are completed unexplained either in terms of method or interpretation. The authors are requested to add a proper Methods and Results section that explain *what* was done and what was *found*.

Answer:

The entire chapter #5 has been improved and expanded with subchapters 5.1, 5.3 and 5.4:

5.1. Fuzzy logic

Introduction Fuzzy logic is a mathematical approach in which an object falls into a membership degree between completely true and false. Fuzzy logic has a wide range of applications, including control systems, decision-making, and pattern recognition. Fuzzy logic allows control systems to handle imprecise or uncertain data, which is particularly useful in situations where traditional control systems would be ineffective. One of the most common applications of fuzzy logic is in decision-making algorithms. Fuzzy logic can be used to model the decision-making process in a wide range of fields, including finance, engineering, and medicine. In multidisciplinary fields, fuzzy logic can be used to model the decision-making process that goes into designing complex systems. Fuzzy logic equations and fuzzy sets, make use of linguistic variables to express uncertain or vague reasoning. They are expressed by membership functions that assign a degree of membership to a fuzzy set. Some commonly used fuzzy logic equations include:

1. Mamdani's fuzzy inference method is used to map input variables to output variables using a set of fuzzy rules. The output is obtained by taking the weighted average of the rule outputs.
2. Takagi-Sugeno's fuzzy inference method represents the output as a linear combination of the inputs. Its ability to handle complex systems with both continuous and discrete inputs makes it a popular choice for applications ranging from control systems to data analysis.
3. Fuzzy clustering is used to group items based on similarity using a fuzzy membership function.
4. Fuzzy decision trees are used to represent decision-making processes based on fuzzy rules.
5. Fuzzy neural networks are used to learn patterns and relationships in data using fuzzy logic.

Measurement methodologies used for developing decision-making algorithms are affected by different uncertainties. Many of them could be processed using Fuzzy logic systems type-1 (FLS-T1) that have clear and precise membership functions. Application of FLS-T1 may be insufficient in the following cases: different expert opinions, the impact of the unknown EMF sources, spatial allocation of measurement points, the proximity influence of objects and obstacles, weather conditions, etc. In such cases, fuzzy logic systems type-2 (FLS-T2) are used. FLS-T2 is characterized by a fuzzy membership function, whose values also belong to the interval $[0,1]$. These functions are three-dimensional and include a footprint of uncertainty. These are three-dimensional functions that include footprints of uncertainty.

5.3. Fuzzy Logic Systems Type 2 and Type 3

Fuzzy logic systems type 1 can handle uncertainties with some limitations related to higher levels of uncertainty and complexity. To address these limitations, fuzzy logic systems type 2 (FLS-T2) have been developed [27-29]. FLS-T2 are widely used in control and decision-making algorithms and expert systems. FLS-T2 is more complex than FLS-T1. In FLS-T2, the membership functions are themselves fuzzy sets, and each membership function is defined by its upper and lower membership functions. Mamdani and Sugeno are the two main inference methods in FLS-T2.

The Mamdani inference method is widely used and involves a set of if-then rules. These rules consider the membership degree of inputs and compute the membership degree of the output. The Mamdani inference method uses a defuzzification process to convert the resulting fuzzy set back into a crisp output value. This inference method is suitable for applications with a high uncertainty degree.

The Sugeno inference method is another popular method for FLS-2. It uses a linear combination of input values to compute the output. This approach is faster and more accurate than the Mamdani method for certain applications, especially when the rule-base is small. Sugeno inference is more suitable when the system output mainly depends on the input values.

When selecting between Mamdani and Sugeno inference methods, the main factors to consider are the degree of dependency between inputs and outputs, the size of the rule-base, and the speed and accuracy of the system response.

One significant advantage of FLS-T2 is that it can handle higher levels of uncertainty and complexity compared to FLS-T1. The other one is that it can incorporate more expert knowledge, making the system more intuitive and easier to operate. However, a big disadvantage of FLS-T2 is that it requires more computational resources and complex calculations.

Fuzzy logic systems type 3 (FLS-T3) are a relatively new area of research in the field of fuzzy logic. These systems extend the classical type-1 and interval type-2 fuzzy sets to deal with more complex and uncertain environments. Until now, FLS-T3 only have a theoretical application, and the authors believe that the proposed algorithm would not be significantly improved by implementing them.

5.4. Fuzzy modeling

Fuzzy modeling has been widely applied to approximate nonlinear models by aggregating linear models with both numeric and linguistic inputs and nonlinear weighting functions [30-34]. Fuzzy modeling is a technique that uses fuzzy sets to model uncertain, imprecise, and/or vague information. Fuzzy modeling involves the following basic steps:

1. Fuzzification:
The first step in fuzzy modeling is to convert the inputs into fuzzy sets. This is done by assigning degrees of membership to each input based on their values.
2. Rule base creation:
The rule base is a set of if-then rules that represent the relationship between the inputs and the outputs. The rules are created based on expert knowledge or by using data-driven techniques such as clustering.
3. Inference:
Inference involves combining the rules to generate the output. This is done by using fuzzy logic operations such as and, or, and not.
4. Defuzzification:
The final step in fuzzy modeling is to convert the fuzzy output into a crisp value. This is done by using techniques such as the centroid method or the maximum method.

In a fuzzy modeling process, the first step is to define the problem and identify the variables that are relevant to the decision. Next, these variables are described using fuzzy sets, which assign degrees of membership to each variable. After defining the fuzzy sets, the experts make a set of "if-then" rules to the variables in order to arrive at a decision. Finally, the decision is made by aggregating the results of the rules using a defuzzification process, which converts the fuzzy output into a crisp, numerical value.

[The entire chapter „Results and Discussion“ has been improved and expanded.](#)

The following paragraphs and results (Fig.11, Fig.12 and Fig.13) have been added:

All data and frequency ranges, as well as corresponding membership functions and fuzzy intervals of observed parameters, in the fuzzy model, were also taken based on recommendations from ICNIRP guidelines. the presented algorithm that has been practically realized by software tool [35].

Fuzzy rules are simple statements that specify a relationship between a system's inputs and output. They consist of an antecedent (if-portion) and a consequent (then-portion) connected by the implication operator.

FLS Type 2 is composed of the following components (Fig.8): fuzzifier, fuzzy rules, inference engine, defuzzifier, and type-reducer [28]. The interval type 2 introduces uncertainty in both membership degrees and membership functions. It provides a more accurate representation of the complexities in decision-making processes where the level of uncertainty is high. Figure 11 shows a fuzzy model based on FLS-T2 (with same if-then rules) with the aim of validating the developed algorithm. The results of fuzzy modeling are shown in Fig.12 and Fig.13.

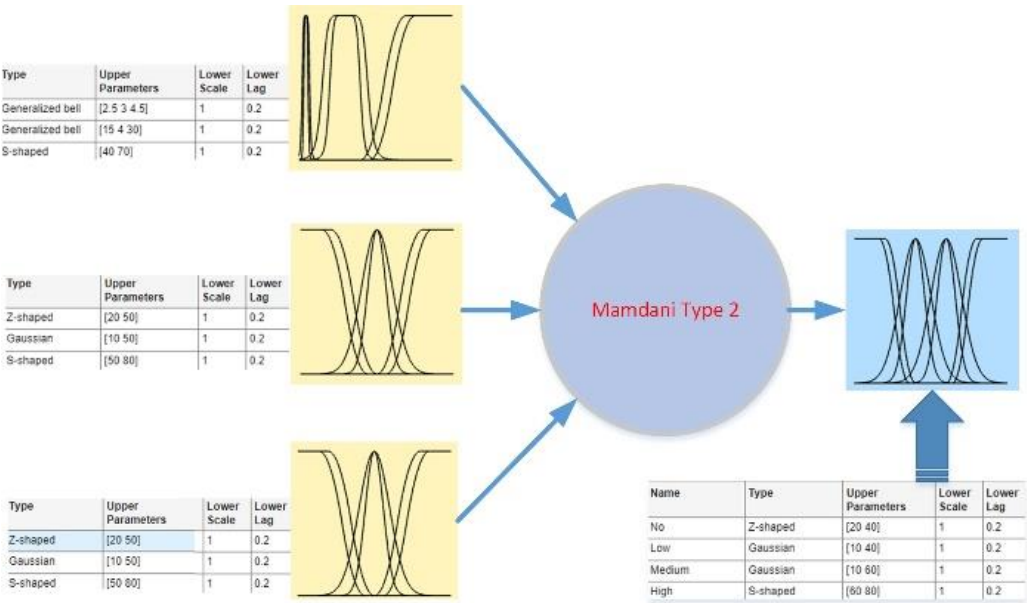


Figure 11. If-then rules in Fuzzy Logic System Type 2

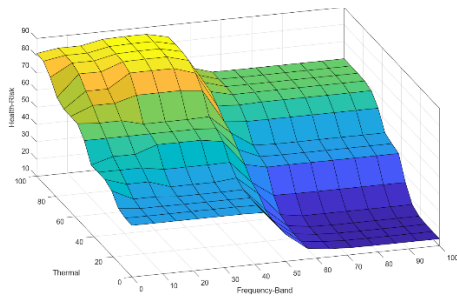


Figure 12. Thermal effects are dominant in the sub-millimeter range (Mamdani FLS-T2).

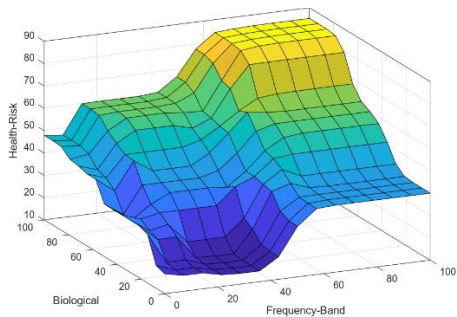


Figure 13. Non-thermal effects are dominant in the millimeter range (Mamdani FLS-T2).

The following references have been added:

- [27] Karnik, N.N.; Mendel, J.M. Introduction to type-2 fuzzy logic systems. In Proceedings of the 1998 IEEE International Conference on Fuzzy Systems, Anchorage, AK, USA, 04-09 May 1998.
- [28] Mendel, J.M.; John, R.; Liu, F. Interval Type-2 Fuzzy Logic Systems Made Simple. . *IEEE Transactions on Fuzzy Systems* **2008**, *14*, 808–821.
- [29] Mendel, J.M. General Type-2 Fuzzy Logic Systems Made Simple: A Tutorial. *IEEE Transactions on Fuzzy Systems* **2014**, *22*, 1162–1182.
- [35] MathWorks. **Fuzzy Logic Designer**. Available online: <https://www.mathworks.com/help/fuzzy/fuzzylogicdesigner-app.html> (accessed on 30 April 2023).

6.2. Discussion

The use of FLS-T2, i.e., the use of membership functions whose values are also fuzzy numbers, slightly improves the accuracy of fuzzy modeling. The practical application of FLS-T2, with multiple inputs and outputs, is a complex mathematical problem. For this reason, the authors used FLS-T1 to develop a practically applicable algorithm. One of the practical advantages of the presented algorithm is its simple implementation in measuring devices. These devices could assess the impact of the measured radiation in the field in real time.

The Conclusion and Future Work has been improved and expanded.

The following paragraphs have been added:

In implementing a hands-on fuzzy decision-making algorithm, an important role is played by the process that involves the expert's role in analyzing knowledge bases and ICNIRP guidelines to define fuzzy numbers, choose inference methods, and create fuzzy rules. This is a three-step cyclical and iterative process affecting the final fuzzy model.

The main contribution of this work is a practically applicable methodology for quickly determining the impact of electromagnetic radiation on human health. This methodology should provide a good foundation for developing software solutions for portable devices that would give a rapid assessment of the impact of measured radiation based on in-situ measurements.

The authors will focus future research on improving the fuzzy decision-making algorithm by considering, in addition to ICNIRP guidelines, the results of medical studies analyzing the effects of wireless IoT devices in the urban environment.