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User cum expert judgement model for accessibility using fuzzy approach

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Well-designed websites play a pivotal role in technological innovation by improving accessibility, user interaction and digital inclusivity. It is crucial to evaluate website accessibility as it meets the diverse needs of its users and adheres to legal and ethical standards. Significant research has been conducted that relies on user evaluation by apprehending user experiences or expert evaluation by capturing technical barriers. The current study proposes a fuzzy-based novel modeling approach that increases the strengths of both evaluation approaches. The datasets of twenty websites from two different domains of healthcare and incubation have been evaluated against the conformance of Web Accessibility Content Guidelines 2.1 (WCAG 2.1). The evaluation has been done by including low-vision impaired users and experts. The fuzzy-based approach has been used to aggregate the insights collected from users and experts. In order to compile the results, both domain websites have been evaluated with respect to parameters and ranking. At the end, both domains have been compared as per their accessibility index. The evaluation results indicate that the healthcare websites are more accessible, as these could achieve a very good level of accessibility, whereas the incubation websites failed to achieve the same level of accessibility. However, the makers of these websites must need to address certain critical issues to achieve an excellent level of accessibility. In order to validate, another sample as another case study with the same datasets of healthcare and incubation domain websites has been taken. As per the statistical analysis, the difference in accessibility indexes of both samples is insignificant at an interval of $\alpha = 0.05$. FUEJMA may be beneficial for the aggregation of diverse responses from the users as well as from the experts that results in contributing more inclusive digital environments and providing accessibility evaluation with more accuracy and context-sensitivity.

Keywords Fuzzy-based User cum Expert Judgement Model for Accessibility (FUEJMA), Questionnaire for Apparent Accessibility Evaluation (QAAE), Fuzzy aggregation, Fuzzy trapezoidal, Incubation websites, Healthcare websites, Apparent Accessibility Index (AAI)

The significance of websites in the current technological environment cannot be overstated, as they are responsible for imparting information throughout the world[1]. To survive in the arena of competition, these websites must be universally accessible to all types of users[2]. Accessibility makes sure that all people, without regard to their abilities or disabilities, can with effectiveness access, use, as well as benefit by multiple systems, services, along with environments[3]. Presently, due to the increase in online data and functions, digital accessibility is legally vital and morally important[4]. It empowers many people with disabilities for participating fully in society, promoting equality as well as inclusivity. These people may have certain kinds of impairments, such as vision, hearing, speech, cognitive, intellectual, psychological and many more[5]. Despite all such impairments, each type of website must be accessible in terms of four accessibility aspects perceivable, operable, understandable and robust. These four aspects must be in accordance with Web Content Accessibility Guidelines (WCAG) introduced by World Wide Web Consortium (W3C).

WCAG is a collection of certain guidelines leading to aid the site makers in making their websites more accessible. For each single guideline, there is a testable success criteria defined under three levels of conformance: level A, level AA, level AAA. Level A is the lowest level of conformance which is below the acceptance level, level AA is the medium level of conformance and level AAA is the highest level of conformance which leads to the most satisfied level of accessibility. While evaluating the accessibility of websites, these guidelines are inspected

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against three conformance levels: level A, level AA, and level AAA[6]. Level A defines the minimum level of accessibility, level AA makes accessibility a bit hard to satisfy and level AAA describes the hardest degree of accessibility to achieve[6]. It is very challenging for web developers to satisfy the these guidelines provided by W3C during the construction of websites. There is current need to evaluate the websites properly as per the WCAG guidelines. Numerous researchers have worked in this field by implementing W3C guidelines for the evaluation of website accessibility[4,7–14].

Moreover, extensive evaluation methodologies have been adopted by several researchers for accessibility evaluation of different websites[8,15–22]. These methodologies are automated testing methodology, user testing methodology and expert testing methodology. However, no researcher conducted the evaluation by using these methodologies based on a fuzzy-based mathematical technique. Current paper aims to conduct an evaluation study of different websites by proposing a fuzzy-based user cum expert judgement model depending upon a mathematical technique of fuzzy aggregation. The structure of the paper is organized as follows: The review of past studies concerned with user and expert testing along with some research gaps as well as the contribution is presented in section "Related work". Next, section "Criteria and methodologies" describes the evaluation criteria and methodologies of proposed work. Further, section "Proposed model" provides an overlook of different phases of proposed model. After that, the detailed results and interpretations are analyzed in section "Results and interpretations". Moreover, section "Discussion" describes an overall summary including certain accessibility violations. The validation of proposed model is illustrated in section "Validation of proposed model". Finally, section "Conclusion and future scope" is concluded with some major interpretations as well as recommendations for future work.

Related work

The most common approaches used to evaluate the website accessibility are the evaluation by real impaired users and/or experts in the subject matter. Both approaches are very important to measure the quality of accessibility evaluation of different websites[21,23]. In the last few years, numerous researchers have worked to inspect the accessibility of websites in different domains by using the approach of user testing and expert testing[5,21,24]. This review of literature provides an overlook of past studies carried out for various websites accessibility evaluation with the help of users and experts.

The research on website accessibility has advanced as evidenced by the studies referenced. Lazar et al.[25] conducted a study by using the method of user testing to determine the accessibility concerns. In order to perform user testing approach, a count of 100 blind users were involved and a large number of serious accessibility issues were found during the evaluation. Moreover, Brajnik et al.[21] carried out a study for accessibility evaluation with the help of nineteen experts and fifty-seven normal users. The results indicated that the accessibility results were more efficient and accurate with experts rather than non experts. Another exploratory study[26] was carried out for website accessibility with the involvement of blind users. Five disabled users participated in a Brazilian investigation carried out by the authors[27]. In addition, Roy et al.[28] inspected the accessibility of three academic websites by performing the method of user testing. Moreover, One more experiment was conducted[29] by making participation of eleven impaired users. Although, Islam et al.[30] conducted an evaluation of six e-government websites in Bangladesh. Thirty-two experts were participated in evaluation. A lot of major difficulties encountered and need to be resolved as per the users requirements.

Furthermore, Goncalves et al.[31] evaluated Portuguese e-commerce sites by taking help of some sighted and blind users. Although, the authors investigated the websites accessibility with the involvement of six impaired and six non-impaired users[32]. Sala et al.[33] carried out an investigation to evaluate the accessibility of e-services with the help of ten low-vision-impaired users. The results outcomes revealed major accessibility blunders and recommended some useful suggestions to improve the accessibility of e-services. Additionally, Adepoju et al.[8] evaluated the accessibility of four mobile network operator websites in Nigeria by implementing user testing approach. Further, a comprehensive review of all the different kinds of user testing was provided in a study[34].

Parajuli and Eika[35] conducted a comparative study for the purpose of evaluating the accessibility of Norwegian University websites. Sixteen users with vision impairments took part in the accessibility evaluation and significant problems concerned with the websites accessibility were disclosed. Nevertheless, Brown et al.[36] conducted a case study on a university website and a pilot project on user testing. Both normal and disabled users discussed about using assistive technologies. The output indicated if the test function was completed successfully or unsuccessfully by the users. Moreover, a special purpose crawler was executed by Bures et al.[37] for accessibility evaluation of small TV apps by participating two different groups of users. Oncins[38] carried out an online user-based inspection to evaluate the websites accessibility. Both normal as well as impaired users were included in the inspection. The results showed that the users faced numerous substantial difficulties during browsing and accessing the content of the websites.

Furthermore, Ismail and Kuppusami[39] proposed an Accessibility Classification Model depending upon multi-features metrics. The purpose of the proposed model was to inspect the technological aspects, structure and content of thirty six websites to classify them in terms of accessibility for impaired users. The websites were categorized using machine learning approaches as per the web accessibility standards. Four classes such as highly accessible, accessible, less accessible and not accessible were used for the classification of websites. According to the classification model's results, out of thirty six websites, eight sites were highly accessible, nine were accessible, ten sites were less accessible and nine were not accessible. In a recent study, the researcher[40] conducted a study to evaluate the accessibility of six Saudi universities by proposing two frameworks . The purpose of first framework was to compare the effectiveness of web accessibility evaluation tools by recognizing the accessibility issues against the conformance of WCAG 2.0 guidelines. The another framework was proposed for evaluating the websites as per the guidelines specified for WCAG 2.0. A brief review of earlier research on the models and frameworks proposed for accessibility evaluation is given in Table 1.

Authors	Year	Proposed model/ framework
Jinat and Cecilia[41]	2025	A model to evaluate webpage accessibility
Samir[42]	2024	AI-enabled system to enhance web accessibility
Samir[43]	2024	Inclusive framework for automated accessibility evaluation
Agrawal et al.[44]	2023	A system to find the best website using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Analytic Hierarchy Process (AHP), and Fuzzy AHP method
Ismail and Kuppusami[45]	2023	A variable magnitude approach to compute various accessibility issues
Dias et al.[46]	2022	Proposed web accessibility audit and evaluation system
Palamar and Naumenko[47]	2022	Frameworks for building and maintaining educational institution websites
M. Campoverde-Molina et al.[3]	2021	Process model for continuous evaluation of web accessibility
Alsaeedi A.[40]	2021	Evaluation framework to compare automated tools Evaluation framework to compare webpage accessibility
Miranda D. G. et al.[48]	2020	Framework to integrate accessibility requirements in an agile context
Nacheva et al.[49]	2020	Model for auditing and evaluating web accessibility
Acosta-Vargas et al.[50]	2018	Framework to evaluate the accessibility of hospital websites
Ismail and Kuppusami[39]	2018	Model based on SCT accessibility evaluation
Rodríguez G. et al.[51]	2017	Framework to improve web accessibility of open course ware sites
Pelzetter J.[52]	2017	Framework for tools to improve the accessibility of websites

Table 1. Recent frameworks and models proposed for website accessibility evaluation.

Research gaps

Based on a critical review of earlier research, some study limitations have been highlighted in the current investigations as follows:

- Only a few studies have been carried out for website accessibility evaluation with the combined assistance of real impaired users and experts together.
- As far as we are aware, no any website in the domain of incubation has been evaluated for accessibility.
- There exist insufficient models to refine the results of website accessibility evaluation.
- The existing models are laborious and time consuming to make decisions on website accessibility evaluation.
- No research has been applied Fuzzy-based mathematical technique for website accessibility evaluation.
- No research has been determined the relative degrees of interactions among evaluation criteria for website accessibility.

Main contributions to the study

The current study has sought to address the aforesaid research gaps in the field of web accessibility by putting forth a unique model to evaluate the accessibility of websites. From the standpoint of both researchers and web developers, the study's main contributions are as follows:

From the standpoint of researchers

- A unique model named as FUEJMA (Fuzzy-based User cum Expert Judgement Model for Accessibility) is proposed. This model is based on weighing technique of Fuzzy-DEMATEL developed by. This technique has been used by numerous researchers in diverse ambiences. Although, no researcher has applied this technique for website accessibility evaluation.
- The proposed model performs better than state-of-the-art models in terms of user cum expert testing by computing the degrees of importance of evaluation criteria as well as the relative degrees of interactions among each evaluation criteria.
- A dataset of top ten incubation websites is evaluated to apply the proposed model which has not yet evaluated by any researcher for accessibility. Hence, the current study will contribute by conducting accessibility study in the domain of incubation websites.
- The current study makes use of combined assistance of actual impaired users and experts as the prior studies are limited for this combined methodology of accessibility testing.

From the standpoint of web developers

- FUEJMA may be helpful for the web developers to have a better understanding about the status of their websites accessibility so that it can be improved as per all the user's requirements.
- Proposed model may also be beneficial to web developers as the testing by combined assistance of both users and experts may lead to more accurate and refined results in a very less time.

Criteria and methodologies

After finding research limitations from existing literature, the current section provides an overlook on the evaluation criteria as well as methodologies opted to evaluate the websites accessibility in the domain of healthcare and incubation.

Evaluation criteria

As per the accessibility guidelines launched by WAI, the evaluation criteria has been proposed for website accessibility evaluation. The detailed description of evaluation criteria has been explained in the next subsections.

Aspects for website accessibility

For the accessibility evaluation of healthcare and incubation domain websites, four accessibility aspects has been taken into consideration. These four aspects are perceivable, operable, understandable and robust which has been inspected against the Web Content Accessibility Guidelines (WCAG) specified by World Wide Web Consortium (W3C). Table 2 elaborates the four accessibility aspects in detail.

The following section divides these four accessibility aspects into further parameters and sub-parameters.

Evaluation criteria for for accessibility index and other indexes

In order to evaluate Apparent Accessibility Index (AAI), the evaluation criteria has been proposed against WCAG 2.1 conformance. The AAI has been divided into four accessibility aspects: Perceivable (P), Operable (O), Understandable (U) and Robust (R). These four aspects have been broken down into further parameters and sub-parameters. The first accessibility aspect P has been consisted of four parameters P1, P2, P3 and P4. The parameter P1 has been further partitioned into two sub-parameters P11 and P12, the parameters P2 and P3 have been scattered into a single sub-parameter P21 and P31 respectively whereas the last perceivability parameter P4 has been forked into two sub-parameters P41 and P42. Moreover, the second accessibility aspect O has been distributed into four parameters O1, O2, O3 and O4. The parameter O1 has been retreated into two sub-parameters O11 and O12, the second parameter O2 has been diverged into two sub-parameters O21 and O22, the third parameter O3 has been parted into two sub-parameters O31 and O32, whereas, the parameter O4 has been fragmented into a single sub-parameter O41. In the same manner, the third accessibility aspect has been diverged into three parameters U1, U2 and U3. The parameter U1 has been decomposed into two sub-parameters U11 and U12, the next parameter U2 has been broken down into a single sub-parameter U21 while the last parameter has been partitioned into three sub-parameters U31, U32 and U33. Furthermore, the last aspect of accessibility R has been scattered into a single parameter R1, which has also been forked into a single sub-parameter R11. The AAI has been evaluated by aggregating the calculated values measure and significance by employing Fuzzy Aggregation Method. Figure 1 depicts the hierarchical form of the proposed evaluation criteria for website accessibility. The detailed description of the hierarchical chart is shown in Table 3. In order to implement Fuzzy Aggregation Technique, the templates have been designed in Microsoft Excel have been used. The worst and excellent levels of accessibility have been calculated with optimum values for measure in the range of '0' to '1', where '0' is the optimum value of worst accessibility level and '1' is the optimum value of excellent accessibility level.

Methodologies used for accessibility evaluation

Dataset collection

Datasets have been collected from two domains: one from healthcare and another one from incubation. Google search engine has been used to explore several websites in both domains. After exploring the websites, top ten websites in both the domains of healthcare and incubation has been selected using Alexa Analytics Tool. An individual ID has been assigned to each website as per the Alexa ranking. Tables 4 and 5 depict the two different datasets of both domain websites with their Alexa rank selected for their accessibility evaluation.

Sampling selection

Sample for evaluation has been selected by means of user testing and expert testing. Both types of testing has been done in a controlled environment. User testing has been performed with the help of ten low-vision impaired users whereas expert testing has been conducted by involving five low-vision impaired experts. The sample size was bounded due to limited availability of low-vision impaired participants. Current work motivates to perform accessibility evaluation by selecting the sample of low-vision impaired users as more than 1.1 billion people at global level and more than 70 million people in India have been found with vision impairments.

Accessibility aspect	Description
Perceivable	The web interface and its content should be accessible to each person[53]
Operable	All controls, buttons, navigation and other components of the user interface must be usable to all users[53]
Understandable	All users must be able to understand and utilize the information as well as the interface[53]
Robust	The interpretation of web content must be robust enough regardless of assistive technology[53]

Table 2. Four aspects for accessibility evaluation.

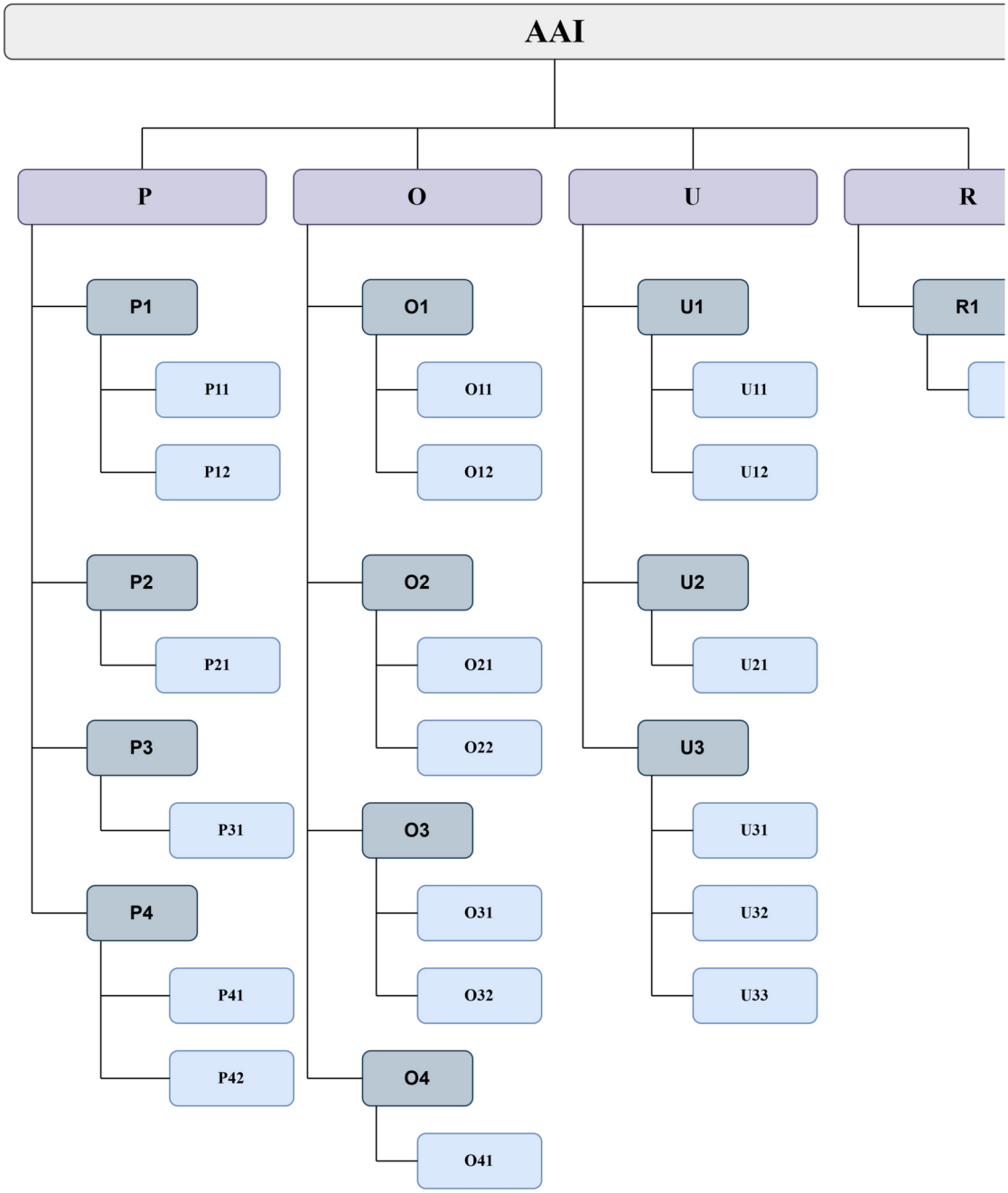

Fig. 1. Hierarchy chart of accessibility index.

User testing environment

User testing evaluation has been carried out in research lab, department of Computer Science, Guru Nanak Dev University, Amritsar, Punjab. The evaluators were the ten low-vision impaired users including the master students and research scholars from the department of Computer Science as well as from the department of Computer Engineering and Technology, Guru Nanak Dev University, Amritsar, Punjab. The sample size was limited to the participants from these two departments due to their proximity, ease of access and reachability. Each user was allotted with a separate desktop system in a controlled environment to perform the testing. The desktop setup was configured with Intel core i3 9th generation, @3.60GHz processor, 4GB RAM, 1TB hard disk and Windows 10. Google Chrome was used to explore the healthcare and incubation websites for accessibility evaluation. User testing was conducted under the guidance of two senior research scholars where each senior research scholar was holding the charge of a group of five users. Then, the users were instructed to explore and test each website one by one. They were asked to perform the tasks such as homepage navigation, forms submission, accessing multimedia and site content, and use of assistive technologies, etc. The total duration of the whole experiment was sixty days of which thirty days were devoted for testing a single domain websites.

Annotation	Accessibility criteria	Classification	Elucidation
AAI	Apparent Accessibility Index	Root	To compute the accessibility index by aggregating all aspects
P	Perceivability	Aspect	The web interface and its content must be fully accessible to all users
P1	Substitute for text content	Parameter	To check if there exists any substitute for the visual and audio content
P11	Visual Perceival	Sub-Parameter	To check if the visual content is easy to perceive
P12	Audio Perceival	Sub-Parameter	To check if the audio content is easy to perceive
P2	Adjustable	Parameter	To check if there are different ways to present the content without any loss
P21	Display alignment	Sub-Parameter	To check if the content holds any restriction on its view and operation
P3	Time-restricted media	Parameter	To check for the existence of substitutes for the media content
P31	Legends	Sub-Parameter	To check if the legends are provided for each multimedia content
P4	Identification	Parameter	To check if it is easy to see and hear the site content
P41	Rescalability	Sub-Parameter	To check if the content is easy to resize without any loss
P42	Scrolling	Sub-Parameter	To check if scrolling is required to access the site content
O	Operability	Aspect	The interface and its components must be fully usable for all users
O1	Sufficient Time	Parameter	To check if there is sufficient time to access the site content
O11	Timing restrictions	Sub-Parameter	To check whether the timing is essential or not for any activity
O12	Break, cease, conceal	Sub-Parameter	To check if there is a provision to break, cease and conceal an automatic activity
O2	Traversable	Parameter	To check the navigation and location of site content
O21	Traversal	Sub-Parameter	To check if the site is easy to move
O22	Heading with depiction	Sub-Parameter	To check if each web page is presented with a descriptive heading
O3	Input methods	Parameter	To check if the user can easily operate through keyboard inputs
O31	Controls and buttons	Sub-Parameter	To check if the controls and buttons are easy to use
O32	Learning Performance	Sub-Parameter	To check if the site content is easy to learn for the users
O4	Keyboard reachability	Parameter	To check if all activities can be performed from a keyboard
O41	Keyboard operations	Sub-Parameter	To check if all site operations are operable through a keyboard
U	Understandability	Aspect	There must be a complete understanding and utilization of information for each user
U1	Input Support	Parameter	To check if the input support is provided during the site surfing
U11	Assistance	Sub-Parameter	To check if assistance is provided for the current activity
U12	Content design	Sub-Parameter	To check if the site provides clear labelling for each content
U2	Accountable	Parameter	To check if the web pages appear and operate as per the user's requirements
U21	Persistent interface	Sub-Parameter	To check the persistence of the interface
U3	Precise	Parameter	To check if the site content is easy to read and understandable
U31	User Interface Material	Sub-Parameter	To check if the content of the user interface is readable
U32	Abbreviations Clarity	Sub-Parameter	To check if the abbreviations are easy to expand
U33	Word accentuation	Sub-Parameter	To check if there is a mechanism to pronounce the words
R	Robustness	Aspect	Web content must be robust enough despite the use of assistive technology
R1	Suitable	Parameter	To check if the site content is suitable for the users of assistive technologies
R11	Compliant	Sub-Parameter	To check if the site is compliant with assistive technologies

Table 3. Proposed design criteria for website accessibility evaluation.

Site ID	Site name	Site address	Rank
HSR1	Aarogya	https://www.aarogya.com	386,331
HSR2	MyUpchar Digital Hospital	https://www.myupchar.com	116,546
HSR3	Dr. Batras: The Homeopathy Way	https://www.drbatras.com	107,760
HSR4	NetMeds	https://www.netmeds.com	31,139
HSR5	Only My Health	https://www.onlymyhealth.com	24,492
HSR6	MedIndia	https://www.medindia.net	20,687
HSR7	Tata 1Mg	https://www.1mg.com	10,015
HSR8	Practo	https://www.practo.com	7654
HSR9	Baby Center	https://www.babycenter.com	1624
HSR10	National Institutes of Health	https://www.nih.gov	191

Table 4. Incubation websites with Alexa Rank.

Site ID	Site name	Site address	Rank
ISR1	Jabalpur Incubation centre	https://www.jicjabalpur.org	5,819,869
ISR2	Atal Incubation Centre, Gujarat University	https://www.aicgusec.org	3,924,949
ISR3	Incubation Centre, IIT, Patna	https://www.iciitp.com	1,917,303
ISR4	IIITD (Innovation and Incubation Centre, Delhi)	https://www.iiitdic.in	1,139,404
ISR5	SINE, Society for Innovation and Entrepreneurship	https://www.sineiitb.org	852,753
ISR6	IIT Kanpur (Startup Incubation and Innovation Centre)	https://www.siicincubator.com	622,008
ISR7	NSRCEL: Nadathur S. Raghavan Centre for Entrepreneurial Learning, IIM	https://www.nsrcel.org	311,656
ISR8	Technopark Technology Business Incubator (T-TBI)	https://www.technopark.org	162,263
ISR9	Atal Incubation, IIIT, Hyderabad	https://www.aic.iiit.ac.in	91,060
ISR10	istart Rajasthan	https://www.istart.rajasthan.gov.in	1556

Table 5. Incubation websites with Alexa Rank.

Fuzzy linguistic terms	Fuzzy trapezoidal numbers
Strongly disagree	(0, 0, 0, 0.25)
Disagree	(0, 0, 0.25, 0.5)
Can't say	(0, 0.25, 0.5, 0.75)
Agree	(0.25, 0.5, 0.75, 1)
Strongly agree	(0.5, 0.75, 1, 1)

Table 6. Fuzzy scale for measure.

Fuzzy linguistic terms	Fuzzy trapezoidal numbers
Not significant	(0, 0, 0, 0.325)
Least significant	(0, 0, 0.325, 0.65)
Moderate	(0, 0.325, 0.65, 1)
Significant	(0.325, 0.65, 1, 1)
Most significant	(0.65, 1, 1, 1)

Table 7. Fuzzy scale for weightage.

Expert testing environment

Expert testing evaluation was carried out with the help of five low-vision impaired experts. These experts were the web developers and programmers from the department of Computer Science, Computer Engineering and Technology and Centre for IT Solutions. The experts were provided with the hard copies of the questionnaires to fill the responses.

Questionnaires design, distribution and collection

In order to evaluate the website accessibility aspects, two types of questionnaires have been designed under consideration of the conformance of WCAG 2.1. The first questionnaire named as Questionnaire 1 for Apparent Accessibility Evaluation (Q1AAE) emphasizes the user testing with agreement/disagreement of users regarding the accessibility of websites and the second questionnaire named as Questionnaire 2 for Apparent Accessibility Evaluation (Q2AAE) deals with expert testing which focuses on the weightage or significance of each question asked to the user. After spending three days of experimentation, the users were asked to fill the questionnaire as the evaluation of one website was complete. As the collection of filled-in questionnaires was done, the users' responses were then evaluated and integrated for each question by implementing fuzzy aggregation algorithm as discussed in the next section.

Fuzzy aggregation method

The fuzzy aggregation method has been used to determine the aggregated values of the responses of different respondents to each question. Two types of values are aggregated after performing user and expert testing. The first aggregated value is the measure and another one is the weightage. The aggregated values of agreement/disagreement have been considered as a measure of the questions while the aggregated values of significance have been taken as the weightage of the questions. To describe the respondent judgement by fuzzy aggregation method, the approach of fuzzy linguistic variables is utilized and these variables are transformed into crisp values i.e. fuzzy trapezoidal numbers. Tables 6 and 7 represent the fuzzy scales used for the transformation of linguistic values into crisp values for measure and weightage respectively.

The formal procedure of the fuzzy aggregation method is as follows:

- **Step 1:** Initialize the process with a finite collection of n fuzzy trapezoidal numbers R.
- **Step 2:** Sort the collection of fuzzy trapezoidal numbers in their increasing order R . Let r_i denotes the ith fuzzy trapezoidal number, where i = 1, 2, …, n from R'.
- **Step 3:** Divide the collection into two halves.
- **Step 3(a):** If m is even, then the first half ranges from r_1 to $r_{\frac{n}{2}}$ and the second half ranges from $r_{(\frac{n}{2}+1)}$ to r_n.
- **Step 3(b):** If m is odd, then the first half ranges from r_1 to $r_{\frac{n+1}{2}}$ and the second half ranges from $r_{\frac{n+3}{2}}$ to r_n.
- **Step 4:** Compute D_1 from the first half by determining absolute differences from $r_{\frac{n}{2}}$ to each response as follows:

$$D_1 = \sum_{i=1}^{\frac{n+1}{2}} [abs(a_{\frac{n}{2}} - a_i) + abs(b_{\frac{n}{2}} - b_i) + abs(c_{\frac{n}{2}} - c_i) + abs(d_{\frac{n}{2}} - d_i)]$$

- **Step 5:** Compute D_2 from the second half by determining absolute differences from $r_{\frac{n+3}{2}}$ to each response as follows:

$$D_2 = \sum_{i=\frac{n}{2}+1}^{n} [abs(a_{\frac{n+3}{2}} - a_i) + abs(b_{\frac{n+3}{2}} - b_i) + abs(c_{\frac{n+3}{2}} - c_i) + abs(d_{\frac{n+3}{2}} - d_i)]$$

- **Step 6:** Compute the representative R^* of R'_i, where i = 1, 2, …, n.
- **Step 6(a):** If ($D1 = D2$), then, compute R^* as per the value of m as follows:

$$R^* = \frac{R_{\frac{n}{2}} + R_{\frac{n+3}{2}}}{2}, \quad when\ n\ is\ even$$
$$R^* = \frac{(R_{\frac{n}{2}} - 1) + R_{\frac{n+3}{2}}}{2}, \quad when\ n\ is\ odd$$

- **Step 6(b):** If ($D_1 \neq D_2$), then, compute the value of R^* as follows:

$$R^* = R_{\frac{n}{2}} + \frac{D_1}{D_1 + D_2}[R_{\frac{n+3}{2}} - R_{\frac{n}{2}}]$$

- **Step 7:** Repeat Step 8 for i = 1, 2, …, n.
- **Step 8:** Compute δ_i from $D(R^*, R_i)$ as follows:

$$\delta_i = abs(a' - a_i) + abs(b' - b_i) + abs(c' - c_i) + abs(d' - d_i)$$

where (a', b', c', d') be the trapezoidal fuzzy numbers of R^*.

- **Step 8(a):** if (at least one $\delta_i = 0$), then, $R = R^*$
- **Step 8(b):** If ($\delta_i > 0$, for all i), compute w_i and *R* as follows:

$$w_i = \frac{\frac{1}{\delta_i}}{\sum(\frac{1}{\delta_i})} \quad and \quad R = \sum_{i=1}^{n}(R_i * W_i)$$

Here, w_i denotes the aggregation weight of the ith user and R denotes the final result.

Proposed index range

In order to perform the job of website ranking, an index range is proposed in the current study. Table 8 depicts the proposed index range specified to find the ranking of each website. The proposed index range consists of seven scale values varies from '0' to '1', each of which corresponds to a different level of accessibility. The lowest index value '0' means the 'worst', '0.2' means 'very bad', '0.4' means 'bad', '0.5' means 'average', '0.6' means 'good', 0.8'very good' and '1' means 'excellent' level of accessibility. The websites are assigned the rank as per the index value attained by the website.

Creation of apparent accessibility index (AAI)

After implementing fuzzy aggregation algorithm, the Apparent Accessibility Index (AAI) has been created. The index has been quantified by aggregating all the values of measure and weightage into a single integrated value to form the Apparent Accessibility Index (AAI). Following steps has been executed to create the Apparent Accessibility Index (AAI):

Index range	Accessibility level
1	Excellent
0.8	Very good
0.6	Good
0.5	Average
0.4	Bad
0.2	Very bad
0	Worst

Table 8. Proposed index range for accessibility.

- **Step 1:** Find all the measure values of each question i.e. M_i and W_i, where M_i is the frequency of aggregated satisfaction level taken as a measure of the question and W_i is the frequency of the aggregated importance level taken as a weightage of the question. Here i = 1, 2, …, n.
- **Step 2:** Find the summation of all the weightage values of each question i.e. $\sum W_i$.
- **Step 3:** Find the summation of the product of both measure and weightage for all values i.e. $\sum M_i W_i$, where i = 1, 2, …, n.
- **Step 4:** Finally, the Apparent Accessibility Index (AAI) can be computed as the fraction of $\sum M_i W_i$ and $\sum W_i$ as follows:

$$AAI = \frac{\sum M_i W_i}{\sum W_i}$$

Furthermore, each of ten websites are evaluated for accessibility in terms of Perceivable Index (PI), Operable Index (OI), Understandable Index (UI) and Robust Index (RI) by following the same method as above. PI is computed by evaluating the values of measure and weightage under perceivable parameter only. Similarly, OI, UI and RI are computed by evaluating the values of measure and weightage under operable, understandable and robust parameters respectively. The next section portrays all these methodologies in the form of a compiled model for the evaluation of website accessibility.

Proposed model

Current study proposes a new model named as Fuzzy-based User cum Expert Judgement Model for Accessibility (FUEJMA). The aim of proposed model is the determination of Apparent Accessibility Index (AAI) after the application of Fuzzy Aggregation Technique as proposed by Tsabadze[54]. FUEJMA is comprised of seven core phases: 'initial phase', 'dataset collection and sample selection phase', 'user testing phase', 'expert testing phase', 'fuzzy transformation and aggregation phase', 'indexing phase', and 'ranking phase' as depicted in Fig. 2.

Initial phase

The initial phase of the model starts by choosing the website accessibility evaluation criteria. The detailed explanation of evaluation criteria is given in section "Evaluation criteria". Following that, the two types of questionnaires are designed by conforming the guidelines of WCAG 2.1. The first one is the Questionnaire 1 for Apparent Accessibility Evaluation (Q1AAE) and other one is the Questionnaire 2 for Apparent Accessibility Evaluation (Q2AAE). The questionnaire Q1AAE is designed for user evaluation while the questionnaire Q2AAE is designed for expert evaluation as explained in section "Questionnaires design, distribution and collection". Then, the hierarchy chart is constructed for the Apparent Accessibility Index by dividing the aspects of accessibility into parameters which are further sub-divided into sub-parameters as elaborated in the section "Evaluation criteria for for accessibility index and other indexes".

Dataset collection and sample selection phase

The second phase is concerned with the process of dataset collection and preparation of samples for accessibility evaluation. The dataset is collected from two domains: one from healthcare and another one from incubation. Section "Dataset collection" gives the detailed description about dataset collection. After collecting datasets, the research sample is prepared by including ten low-vision impaired users as well as five accessibility experts with same impairment specified in section "Sampling selection".

User testing phase

User evaluation is the third phase of FUEJMA. In this phase, the evaluation is done with the help of low-vision impaired users. The environment is set up for the user evaluation as in section "User testing environment". Each user was given with the task of accessing all the twenty websites: ten from healthcare and other ten from the domain of incubation. All the websites were accessed by each user individually. After completing the evaluation of each website, the questionnaire Q1AAE was distributed to the users and collected back after getting response from each user. The duration of evaluation was sixty days as it took thirty days for one domain websites evaluation while remaining thirty days to evaluate second domain websites. The next phase deals with accessibility evaluation with some experts.

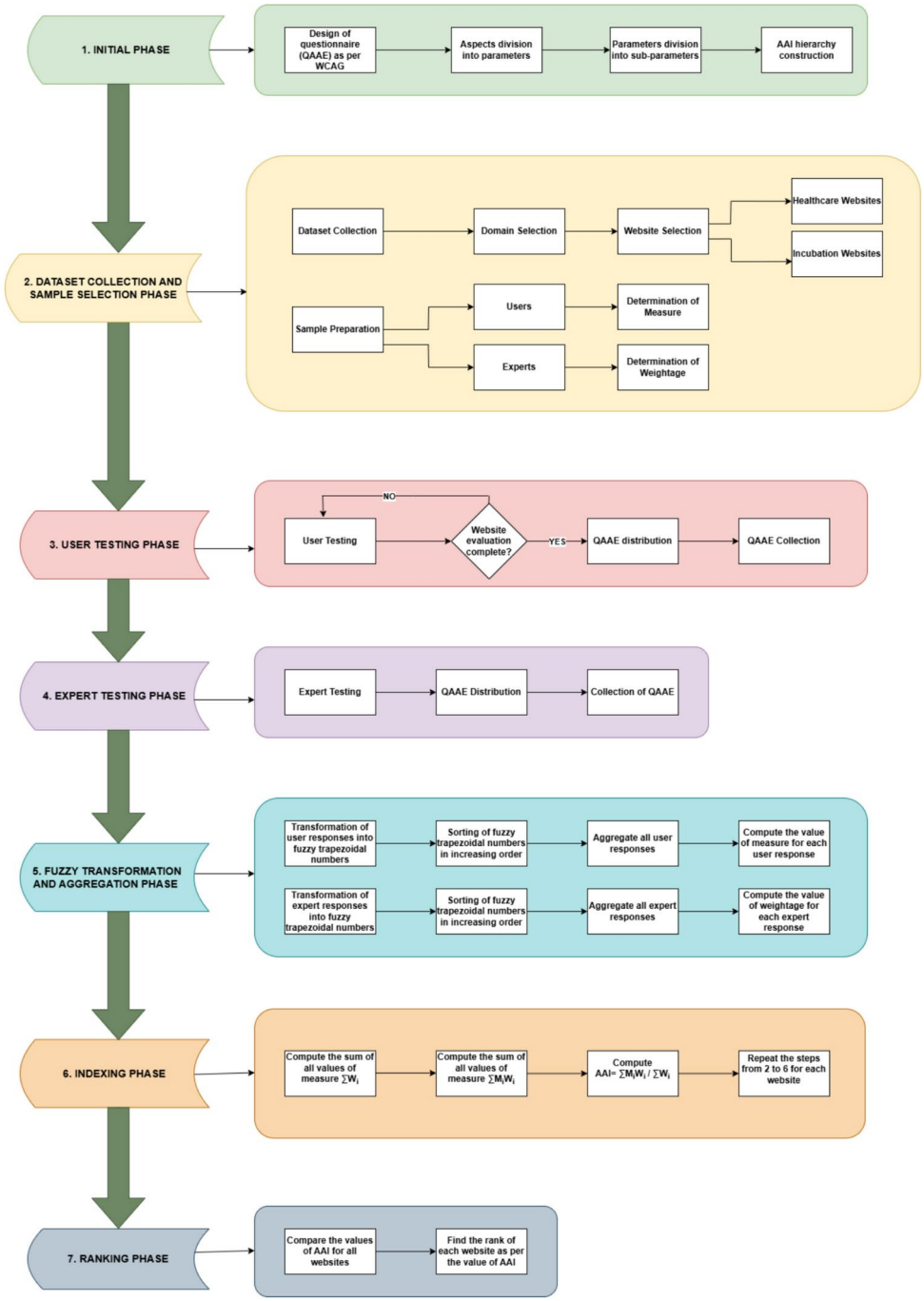

Fig. 2. FUEJMA phases.

Expert testing phase

The next phase is the evaluation with professional experts. This testing was carried out in department of Computer Science, Guru Nanak Dev University, Amritsar, Punjab. The accessibility inspectors were the web developers and programmers from the department of Computer Science, Guru Nanak Dev University, Amritsar, Punjab. These experts were also impaired with low-vision. The questionnaire Q2AAE was distributed to each expert individually and collected back after getting insights from each expert. The next step was to transform these experts' insights into fuzzy trapezoidal numbers as discussed in next subsection.

Fuzzy transformation and aggregation phase

This phase is implemented using fuzzy-based aggregation technique proposed by Tsabadze[54]. During this phase, all the insights collected from users as well as experts were converted into crisp values i.e. fuzzy trapezoidal numbers. These crisp values were then arranged in ascending order to aggregate all users and experts insights. Fuzzy aggregation algorithm was used to aggregate the collection of these insights. The first aggregated value

is computed as the measure of each user response to each question. The second aggregated value of experts' responses is determined as the weightage or significance of each question asked from the user. Overall representative was used to compute the aggregated value of all insights of different users as well as experts. Next, all the computed values of measure and weightage are aggregated to evaluate the Apparent Accessibility Index as in next subsection.

Indexing phase

This is the sixth phase of FUEJMA which deals with the creation of four accessibility aspects: perceivability, operability, understandability and robustness. By integrating the index values of the four aspects, an overall Apparent Accessibility Index (AAI) is evaluated. Moreover, all the websites from both domains are compared for AAI as per the proposed index range described in section "Proposed index range". The range of index values lies between 0 and 1 referring different levels of accessibility. The value '1' tends to 'excellent', '0.8' points to 'very good', '0.6' leads to 'good', '0.5' as 'average', '0.4' refers to 'bad', '0.2' indicates 'very bad' and '0' means 'worst' level of accessibility. Table 8 represents the proposed index range for accessibility.

Ranking phase

The model exits after the process of fuzzification by providing ranks in diverse contexts. Firstly, the parameters ranking is done in terms of each website, secondly, the websites ranking with respect to the four parameters indexing: Perceivable Index (PI), Operable Index (OI), Understandable Index (UI) and Robust Index (RI). At the end, final ranking is done by comparing all the index values of each website. Higher the index value is, higher the website rank will be whereas lower website rank tends to lower index value. Next section presents a comprehensive analysis of the result findings.

Results and interpretations

After executing fuzzy aggregation technique and constructing AAI, the results analysis of both domain websites accessibility has been performed. To analyze the results, the index values of all twenty websites have been computed. For example, the index value i.e. AAI for the websites HSR1 and ISR1 is shown in Tables 9 and 10 respectively.

The index value for HSR1 is computed as:

$$AAI = \frac{\sum M_i W_i}{\sum W_i} = \frac{3.672455853}{11.28094796} = 0.325545$$

In the same manner, the index values for all other healthcare sites have been computed.

Similarly, the index value for ISR1 is computed as:

i	Parameter	M_i	W_i	$M_i W_i$
1	P11	0.1875	0.74375	0.139453125
2	P12	0.25	0.7435	0.1859375
3	P21	0.1875	0.825307223	0.154745104
4	P31	0.330882353	0.678352659	0.224454924
5	P41	0.375	0.74375	0.27890625
6	P42	0.625	0.74375	0.46484375
7	O11	0.225	0.135794662	0.030553799
8	O12	0.1875	0.74375	0.139453125
9	O21	0.625	0.9125	0.5703125
10	O22	0.1875	0.74375	0.139453125
11	O31	0.1875	0.24375	0.045703125
12	O32	0.1875	0.08125	0.015234375
13	O41	0.1875	0.397596154	0.074549279
14	U11	0.0625	0.24375	0.015234375
15	U12	0.482142857	0.24375	0.117522321
16	U21	0.8125	0.163640796	0.132958146
17	U31	0.625	0.74375	0.46484375
18	U32	0.525	0.74375	0.39046875
19	U33	0.0625	0.492756469	0.030797279
20	R11	0.0625	0.9125	0.05703125
		$\sum M_i$	$\sum W_i$	$\sum M_i W_i$
		6.37552521	11.28094796	3.672455853

Table 9. Evaluation of AAI for HSR1.

i	Parameter	M_i	W_i	M_iWi
1	P11	0.8125	0.9125	0.74140625
2	P12	0.8125	0.9125	0.74140625
3	P21	0.8125	0.9125	0.74140625
4	P31	0.8125	0.828125	0.672851563
5	P41	0.8125	0.9125	0.74140625
6	P42	0.8125	0.9125	0.74140625
7	O11	0.8125	0.49375	0.401171875
8	O12	0.8125	0.9125	0.74140625
9	O21	0.8125	0.49375	0.401171875
10	O22	0.8125	0.9125	0.74140625
11	O31	0.8125	0.49375	0.401171875
12	O32	0.8125	0.74375	0.604296875
13	O41	0.8125	0.439238722	0.356881461
14	U11	0.8125	0.74375	0.604296875
15	U12	0.8125	0.9125	0.74140625
16	U21	0.8125	0.24375	0.198046875
17	U31	0.8125	0.24375	0.198046875
18	U32	0.8125	0.9125	0.74140625
19	U33	0.625	0.74375	0.46484375
20	R11	0.8125	0.24375	0.198046875
		$\sum M_i$	$\sum W_i$	$\sum M_iW_i$
		16.0625	13.92361372	11.17348302

Table 10. Evaluation of AAI for ISR1.

$$AAI = \frac{\sum M_i W_i}{\sum W_i} = \frac{11.17348302}{13.92361372} = 0.802484$$

Likewise, the index values for the remaining incubation sites have been computed. Moreover, for each site accessibility, other four indexes PI, OI, UI and RI have also been evaluated from Tables 9 and 10 as follows:

$$PI = \frac{\sum_{i=1}^{6} M_i W_i}{\sum_{i=1}^{6} W_i}$$

$$OI = \frac{\sum_{i=7}^{13} M_i W_i}{\sum_{i=7}^{13} W_i}$$

$$UI = \frac{\sum_{i=14}^{19} M_i W_i}{\sum_{i=14}^{19} W_i}$$

$$RI = \frac{\sum_{i=20}^{20} M_i W_i}{\sum_{i=20}^{20} W_i}$$

Accessibility evaluation of healthcare websites with respect to accessibility parameters

Four accessibility aspects have been considered for the accessibility evaluation of top ten healthcare websites. These four aspects are Perceivable, Operable, Understandable and Robust.

Evaluation in terms of perceivability

Perceivability of all ten websites have been inspected against four parameters P1, P2, P3 and P4 as computed in Table 11. The parameter P1 has been found with the highest index value for the website HSR1 while the website HSR10 has been recognized with the lowest index value among the ten websites. In addition, the parameter P2 has been found to have the highest index value for the website HSR1 whereas the website HSR4 has been achieved the lowest index value for parameter P2. Moreover, in the case of parameter P3, the website HSR1 has been found with the highest index value while the website HSR7 has been achieved the lowest index value. Furthermore, for parameter P4, the website HSR1 has been hold the highest index value whereas the website HSR10 has been found to have the lowest index value for the website HSR10. While evaluating websites from the perceivable aspect of accessibility, it has been observed that P2 is the least violated parameter followed by P3, P1 and P4 whereas P1 and P2 are the most violated parameters of accessibility followed by P3 and P4. The graphical depiction of perceivable index has been shown in Fig. 3.

	HSR1	HSR2	HSR3	HSR4	HSR5	HSR6	HSR7	HSR8	HSR9	HSR10
P1	0.671875	0.375	0.21875	0.22678571	0.2225404	0.1576086	0.2276785	0.1332547	0.125	0.0625
P2	0.8125	0.1875	0.1875	0.0625	0.1875	0.1875	0.2040094	0.2678571	0.2040094	0.3125
P3	0.71875	0.3625	0.3308823	0.4375	0.2375	0.2451923	0.234375	0.2410714	0.2527173	0.2625
P4	0.59375	0.546875	0.5	0.4330357	0.4388586	0.2667464	0.2630624	0.275	0.2279411	0.25

Table 11. Index values in terms of perceivability.

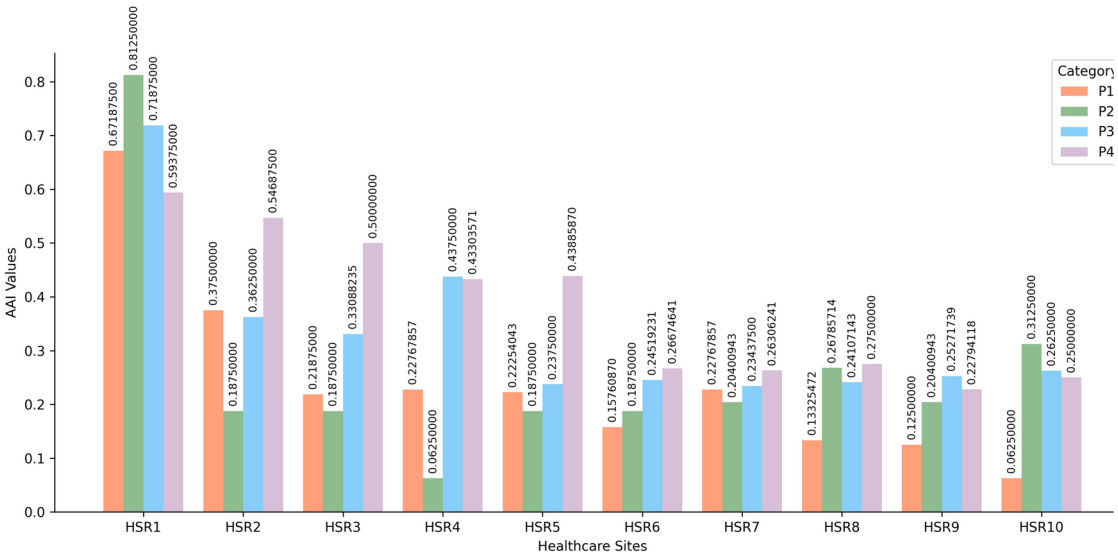

Fig. 3. Perceivability index evaluation of healthcare websites.

	HSR1	HSR2	HSR3	HSR4	HSR5	HSR6	HSR7	HSR8	HSR9	HSR10
O1	0.375	0.2567103	0.1932897	0.1971495	0.1999065	0.0843479	0.0939878	0.0843479	0.0625	0.0625
O2	0.5155660	0.3535377	0.3719339	0.3719339	0.3535377	0.3535377	0.3535377	0.3535377	0.3535377	0.3535377
O3	0.8125	0.0625	0.1875	0.15625	0.09375	0.0625	0.0625	0.0625	0.0625	0.0625
O4	0.71875	0.1875	0.1875	0.0625	0.1875	0.1875	0.0625	0.0625	0.0625	0.0625

Table 12. Index values in terms of operability.

Evaluation in terms of operability

The operability of websites has been evaluated by determining the index values of four parameters O1, O2, O3 and O4 as shown in Table 12. For the first parameter O1, the website HSR1 has been achieved the highest index value whereas the websites HSR9 and HSR10 have been found with the lowest index values. Additionally, in the case of parameter O2, the website HSR1 has been found to have the highest index value while the lowest index values have been achieved by seven websites HSR2, HSR5, HSR6, HSR7, HSR8, HSR9 and HSR10. Furthermore, for third parameter O3, the website HSR1 has been found with the highest index value whereas the five websites HSR4, HSR7, HSR8, HSR9 and HSR10 has been found to have the lowest index value. Although, in the case of parameter O4, two websites HSR1 and HSR2 have been found to have the highest index values whereas the two websites HSR5 and HSR7 have been found with the lowest index values. As per the index values computed, it has been analyzed that O4 is the least violated parameter and O1 is the most violated parameter. Figure 4 depicts the comparative analysis of operable index.

Evaluation in terms of understandability

Table 13 presents the index values computed for accessibility aspect of understandability. Three parameters U1, U2 and U3 have been used to compute the highest and lowest index values for this aspect. The analysis of U1 index values shows that HSR1 has been achieved the highest index range while the website HSR10 has been found with the lowest index value. As per the analysis of U2, it has been observed that a count of six websites have been found to have the highest index value whereas the website HSR9 has been found with the lowest index value. Moreover, in the case of parameter U3, the website HSR1 has been recognized by having the highest index value while a total of eight websites HSR3, HSR4, HSR5, HSR6, HSR7, HSR8, HSR9 and HSR10 have been found to have the lowest index values. In comparison to the analysis of these index values of understandable aspect, it

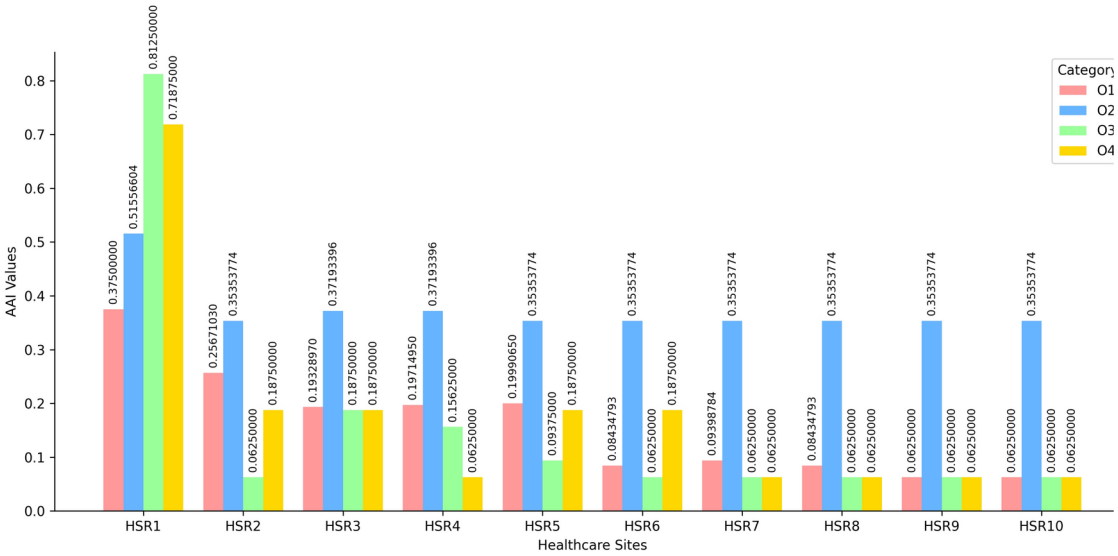

Fig. 4. Operability index evaluation of healthcare websites.

	HSR1	HSR2	HSR3	HSR4	HSR5	HSR6	HSR7	HSR8	HSR9	HSR10
U1	0.40625	0.3229166	0.2723214	0.26543765	0.2901785	0.2948369	0.36125	0.3020833	0.21875	0.1431451
U2	0.8125	0.71875	0.8125	0.71875	0.8125	0.8125	0.8125	0.8125	0.5227272	0.535
U3	0.625	0.4850304	0.4474722	0.2268174	0.3723556	0.2972391	0.2972391	0.2972391	0.1916065	0.2000295

Table 13. Index values in terms of understandability.

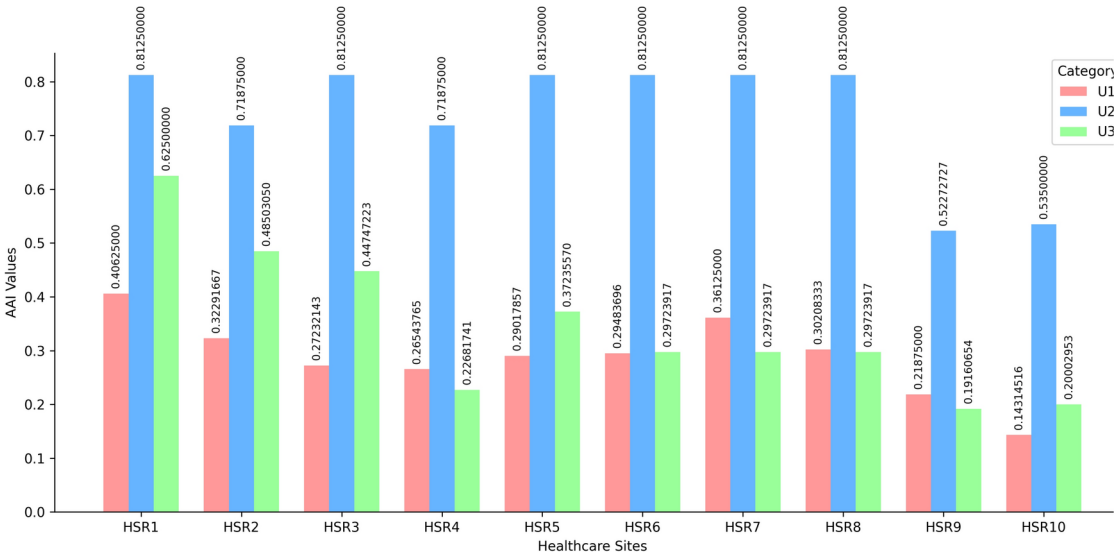

Fig. 5. Understandability index evaluation of healthcare websites.

has been revealed that U2 and U3 are the least violated parameters whereas U1 is the most violated parameter. the comparative chart of the index values for understandable aspect has been displayed in Fig. 5.

Evaluation in terms of robustness parameter

Table 14 represents the highest and lowest index values for the accessibility aspect of robustness. There is only one parameter for the computation of the highest and lowest index values. The parameter R1 is least violated only for the website ISR1, followed by the website ISR5, and most violated in the case of all other websites. The comparative chart of robust index values of all sites is displayed in Fig. 6.

	HSR1	HSR2	HSR3	HSR4	HSR5	HSR6	HSR7	HSR8	HSR9	HSR10
R1	0.8125	0.1041666	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625

Table 14. Index values in terms of robustness.

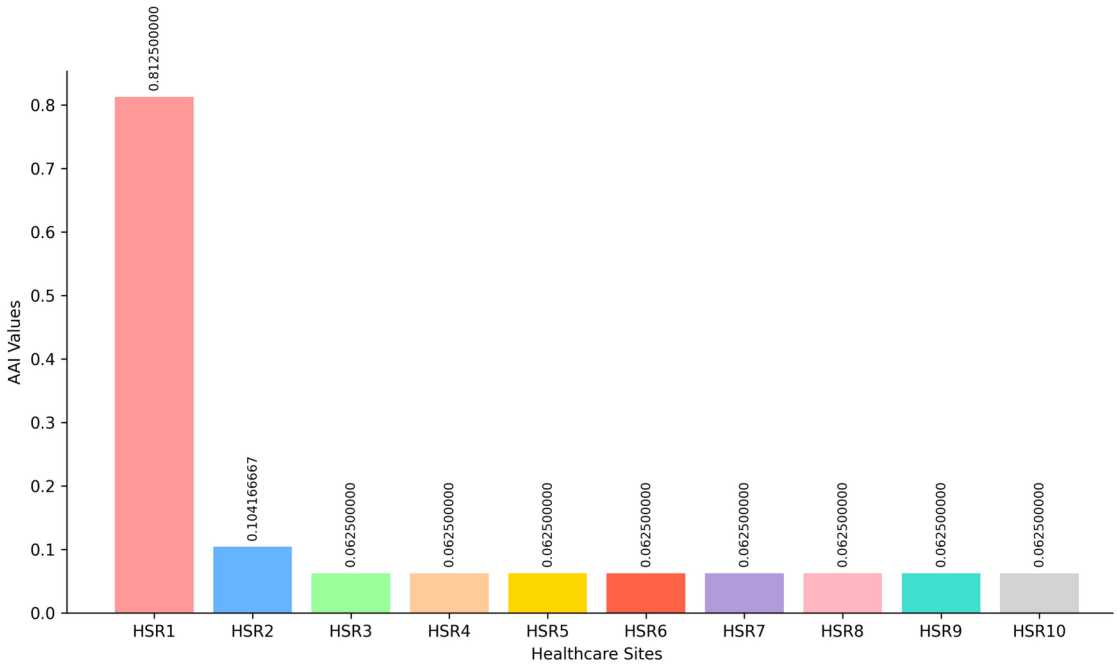

Fig. 6. Robustness index evaluation of healthcare websites.

	HSR1	HSR2	HSR3	HSR4	HSR5	HSR6	HSR7	HSR8	HSR9	HSR10
P	0.6789408	0.3956400	0.3233870	0.2972258	0.2901950	0.2126306	0.2360832	0.2214668	0.1930939	0.2011360
O	0.5140502	0.3162344	0.3115830	0.2942551	0.2754861	0.2411762	0.2285255	0.2259234	0.2200259	0.2200259
U	0.5961339	0.4695313	0.4377235	0.2645645	0.3845029	0.3288370	0.3411409	0.3301795	0.2172268	0.2103220
R	0.8125	0.1041666	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625

Table 15. Overall AAI with respect to POUR.

Accessibility index with respect to POUR

Finally, Table 15 shows the overall AAI computed by means of POUR. Each of ten websites has been inspected against the index values computed for accessibility aspects. All four aspects perceivability, operability, understandability and robustness have been recognized as least violated aspects of accessibility for the website HSR1 as these hold the highest index values for HSR1. However, in the case of lowest index values, the perceivability has been found the most violated aspect for HSR9, the operability has been found to be most violated for two websites HSR9 and HSR10, the understandability has been found with the major violations for HSR10 and robustness has been found to be the most violated aspect for the website HSR9. The comparison of all POUR index values has been shown in Fig. 7.

Highest and lowest POUR index

The highest and lowest POUR index values have been presented in this subsection. Table 16 shows the four aspects Perceivability, Operability, Understandability and Robustness with highest and lowest index value. It is clear that the accessibility aspect of Understandability has been found to have the highest index value as it holds the highest index value for six websites HSR2, HSR3, HSR5, HSR6, HSR7 and HSR8. Although, the Operable aspect of accessibility has been hold the lowest index value as it has been found with lowest index value for five websites HSR1, HSR2, HSR3, HSR5 and HSR7.

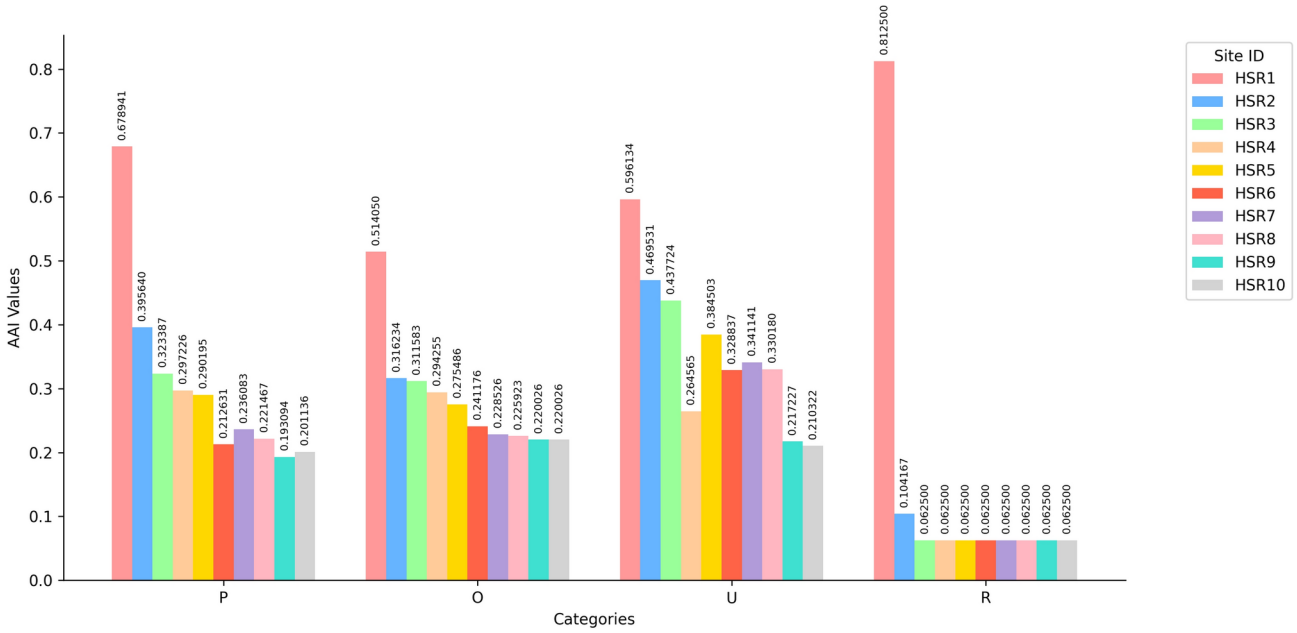

Fig. 7. Overall POUR index evaluation of healthcare websites.

	HSR1	HSR2	HSR3	HSR4	HSR5	HSR6	HSR7	HSR8	HSR9	HSR10
Aspect with the highest index	R	U	U	P	U	U	U	U	O	O
Aspect with the lowest index	O	O	O	U	O	P	O	P	P	R

Table 16. Sites with the highest and lowest POUR index.

Websites	P	O	U	R
HSR1	Rank1	Rank1	Rank1	Rank1
HSR2	Rank2	Rank2	Rank2	Rank2
HSR3	Rank3	Rank3	Rank3	Rank3
HSR4	Rank4	Rank4	Rank5	Rank3
HSR5	Rank5	Rank5	Rank7	Rank3
HSR6	Rank7	Rank6	Rank8	Rank3
HSR7	Rank8	Rank7	Rank6	Rank3
HSR8	Rank6	Rank8	Rank4	Rank3
HSR9	Rank10	Rank9	Rank9	Rank3
HSR10	Rank9	Rank10	Rank10	Rank3

Table 17. Website ranking w.r.t. POUR Index value.

Evaluation results in terms of ranking

Website rank using AAI

Websites have been ranked depending upon the POUR index values computed as in Table 17. It has been analyzed that the website HSR1 has been found to achieve rank 1 for all four aspects of accessibility and and hence, it has been found to be the least violated website among all websites. In addition, the websites HSR2 and HSR3 have been found to have rank 2 and rank 3 respectively for all accessibility aspects. Furthermore, Perceivability has been found to be most violated aspect in the case of site HSR9 by holding the rank 10 whereas other two aspects Operability and Understandability have been found to be the most violated by having rank 10 for the same website HSR10. Moreover, the Robustness has been found to achieve only three ranks: rank 1 for HSR1, rank 2 for HSR2 and rank 3 for all other sites HSR3, HSR4, HSR5, HSR6, HSR7, HSR8, HSR9 and HSR10. The highest rank 1 indicates the least number of accessibility violations while the lowest rank 10 points to the major count of accessibility issues encountered for the website. It can be seen from the Table 17 that the site HSR1 is the least violated website whereas the site HSR10 is the most violated website among all ten websites.

Site ID	Website URL	AAI value	Accessibility status
HSR1	https://www.aarogya.com	0.622801679	Rank 1
HSR2	https://www.myupchar.com	0.36636355	Rank 2
HSR3	https://www.drbatras.com	0.325544969	Rank 3
HSR4	https://www.netmeds.com	0.269762568	Rank 5
HSR5	https://www.onlymyhealth.com	0.2895269	Rank 4
HSR6	https://www.medindia.net	0.235838229	Rank 7
HSR7	https://www.1mg.com	0.24436517	Rank 6
HSR8	https://www.practo.com	0.235253853	Rank 8
HSR9	https://www.babycenter.com	0.195938686	Rank 10
HSR10	https://www.nih.gov	0.197520867	Rank 9

Table 18. Ranking of healthcare websites as per overall AAI.

Site ID	Website URL	AAI value	Accessibility status
ISR1	https://www.jicjabalpur.org	0.802484416	Rank 1
ISR2	https://www.aicgusec.org	0.629856238	Rank 3
ISR3	https://www.iciitp.com	0.712271227	Rank 2
ISR4	https://www.iiitdic.in	0.612929551	Rank 4
ISR5	https://www.sineiitb.org	0.416460948	Rank 6
ISR6	https://www.siicincubator.com	0.524412763	Rank 5
ISR7	https://www.nsrcel.org	0.279148475	Rank 10
ISR8	https://www.technopark.org	0.400926388	Rank 8
ISR9	https://www.aic.iiit.ac.in	0.356130891	Rank 9
ISR10	https://www.istart.rajasthan.gov.in	0.405141937	Rank 7

Table 19. Ranking of incubation websites as per overall AAI.

Overall website ranking

Tables 18 and 19 displays the final ranking of healthcare and incubation websites respectively as per the accessibility index values. The index range has been determined between 0 and 1, and, then, the websites have been compared with their index values and ranked as per the range specified in Table 8. It has been analyzed from Table 18 that the site HSR1 is the least violated website among all websites as it holds the rank 1 with a very good level of accessibility. On the other hand, the site HSR9 has been achieved rank 10 with a very bad level of accessibility and has been found to be the most violated website among all websites. Although, the site HSR6 has been found to be at an average level of accessibility. Moreover, it is clearly visible from Table 19 that no website could achieve either an excellent or the worst level of accessibility. Figure 8 presents an overlook of the comparison of all websites ranking in the domain of healthcare.

Overall, which domain websites are more accessible: healthcare or incubation? During the analysis of both domain websites, it has been observed that healthcare websites have performed better as compared to incubation websites. The healthcare websites have been achieved a very good level of accessibility while the incubation domain websites were unable to achieve a very good level of accessibility. Hence, the healthcare websites are more accessible with a very good level as compared to incubation websites.

Similarly, the results have been computed and analyzed for the incubation websites and the ranking of incubation domain websites has been shown in Table 19. It depicts the final ranking of incubation websites as per the overall accessibility index. During the analysis, it has been observed that the site ISR1 has been found to achieve the rank 1 with a good level of accessibility by having the largest index value among other websites whereas the site ISR7 has scored a very bad level of accessibility by having the rank 10. However, no site could reach an excellent, average or the worst level of accessibility. Figure 9 shows the comparative depiction of all incubation websites' ranking. It can be analyzed that the rank 1 website ISR1 is found to have the least number of accessibility violations whereas the rank 9 website ISR7 is found to have the largest number of accessibility violations.

Figure 10 depicts the AAI comparison of both healthcare and incubation websites. In the case of healthcare websites, site HSR9 achieves the lowest index value and site HSR1 is found to have the highest index value, whereas site ISR7 is recognized with the lowest index value and site ISR1 gets the highest index value in the domain of incubation.

After compiling evaluation results, some critical violations related to accessibility have been discussed in the next subsection.

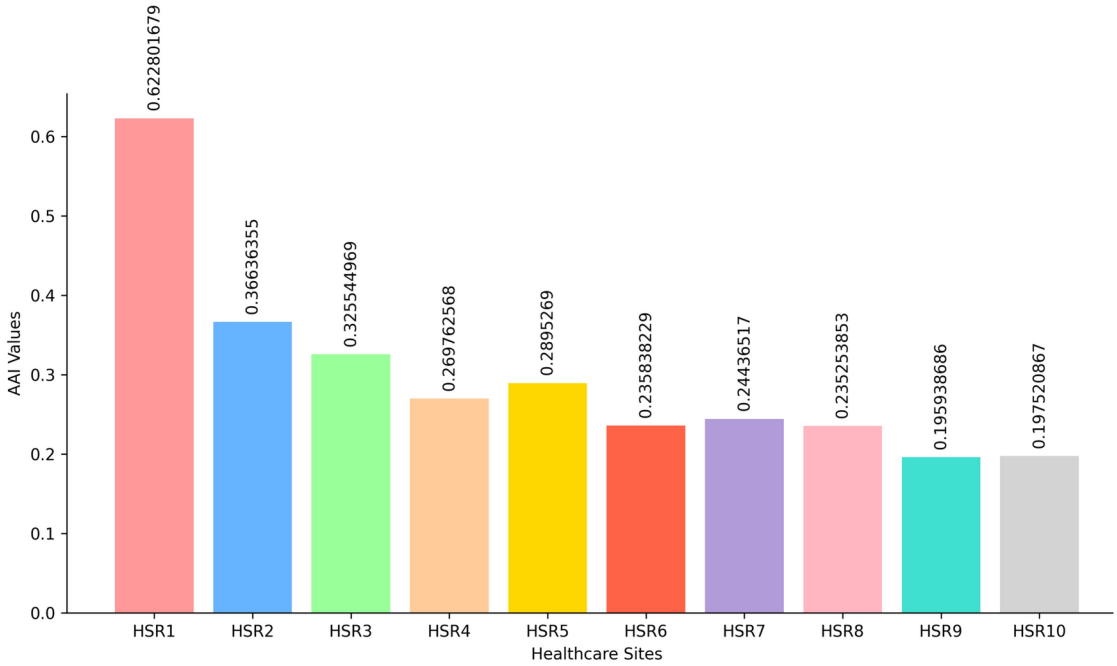

Fig. 8. AAI of healthcare websites.

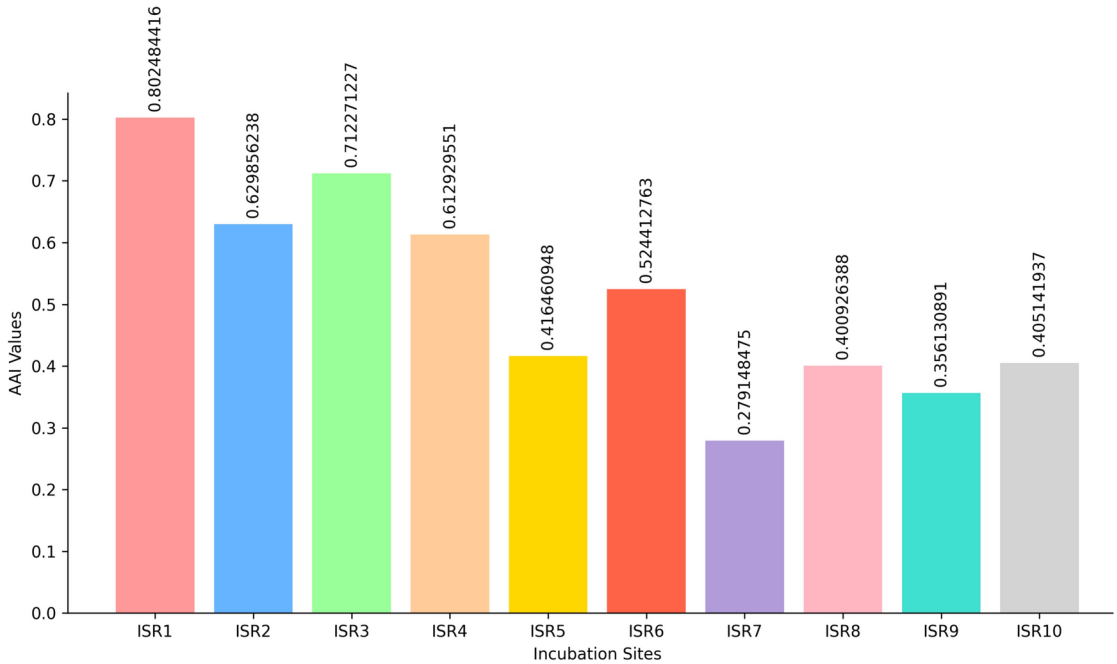

Fig. 9. AAI of incubation websites.

Website accessibility violations

Some critical issues violating accessibility guidelines have been encountered during the evaluation. These violations have been detected as per the user responses collected through the questionnaires. Overall description of these accessibility violations is depicted in Tables 20 and 21. The coverage of these violations by different websites is indicated by a symbol of Checkmark.

These violations have played a major role in making the websites more difficult to access by low-vision impaired users and are discussed in detail as follows:

- **Visual layout:** The problem of visual alignment occurs in the case of five healthcare websites HSR2, HSR3,HSR4, HSR8 and HSR9 whereas six websites ISR3, ISR4, ISR5, ISR6, ISR7 and ISR9 in the domain of

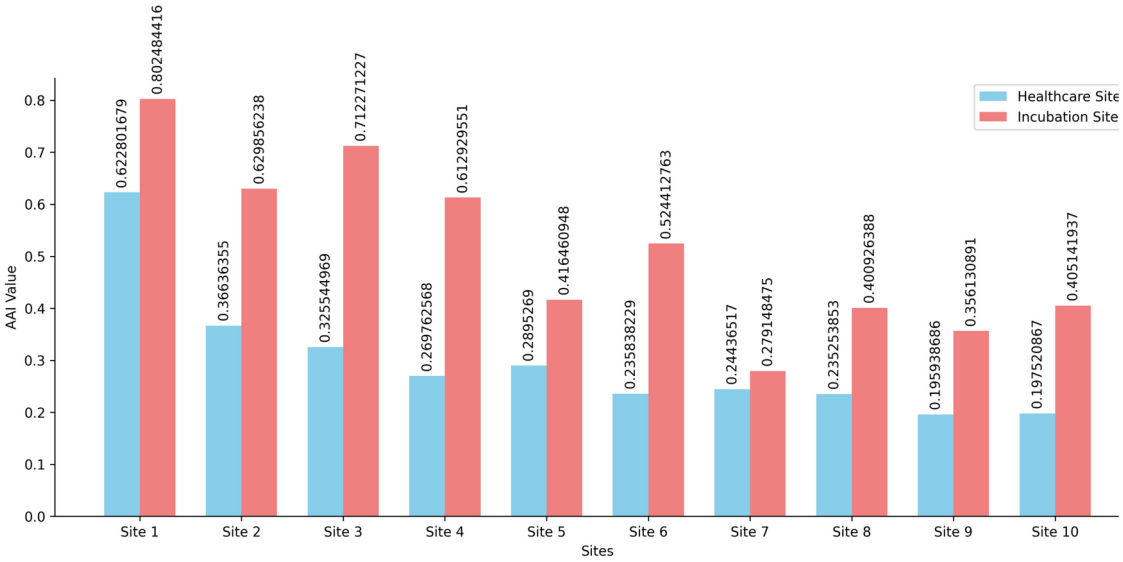

Fig. 10. AAI comparison of both domain websites.

	HSR1	HSR2	HSR3	HSR4	HSR5	HSR6	HSR7	HSR8	HSR9	HSR10
Visual layout		✓	✓	✓				✓	✓	
Limited access content	✓		✓		✓	✓	✓	✓	✓	✓
Variable sizing							✓	✓	✓	✓
Dragging		✓						✓	✓	✓
Traversal	✓		✓				✓	✓	✓	✓
Top-line illustration			✓				✓		✓	✓
Interaction tools				✓	✓	✓			✓	
Learning efficacy				✓	✓	✓			✓	
Keyboard support					✓	✓				✓
Data input facilitation						✓	✓		✓	
Aiding service						✓	✓	✓	✓	✓
Persistence	✓		✓		✓	✓			✓	
Interaction interface							✓		✓	✓
Ease of reading		✓		✓			✓	✓	✓	✓
Transparency							✓	✓	✓	✓
Specificity		✓		✓		✓		✓	✓	✓
Assistive tools		✓	✓	✓	✓	✓		✓	✓	✓

Table 20. List of accessibility violations encountered during the evaluation of healthcare websites.

incubation were found with serious issues related to visual layout. The users found difficulty in viewing the content with portrait and landscape layout.

- **Limited access content:** A total of eight healthcare sites HSR1, HSR3, HSR5, HSR6, HSR7, HSR8, HSR9 and HSR10 as well as seven incubation sites ISR1, ISR5, ISR6, ISR7, ISR8, ISR9 and ISR10 were found with the issues of accessing the media content. No alternative for the media content was provided by the websites.
- **Variable sizing:** The variations in content size created problems for users in the case of four healthcare websites HSR7, HSR8, HSR9 and HSR10. Similarly, the content was lost while resizing six incubation websites ISR2, ISR4, ISR5, ISR6, ISR7 and ISR9.
- **Dragging:** Additionally, the dragging issue was found with found with four healthcare sites HSR2, HSR8, HSR9 and HSR10 and also in four incubation sites ISR2, ISR4, ISR7 and ISR8. It was not possible to access the site content without horizontal and vertical scrolling.
- **Traversal:** Users faced obstacles in traversing from one web page to another with six healthcare sites HSR1, HSR3, HSR7, HSR8, HSR9 and HSR10 including seven incubation sites ISR1, ISR3, ISR6, ISR7, ISR8, ISR9 and also ISR10.

	ISR1	ISR2	ISR3	ISR4	ISR5	ISR6	ISR7	ISR8	ISR9	ISR10
Visual layout			✓	✓	✓	✓	✓		✓	
Limited access content	✓				✓	✓	✓	✓	✓	✓
Variable sizing		✓		✓	✓	✓	✓		✓	
Dragging		✓		✓			✓	✓		
Traversal	✓		✓			✓	✓	✓	✓	✓
Top-line illustration	✓		✓			✓	✓	✓	✓	✓
Interaction tools					✓		✓		✓	
Learning efficacy				✓	✓	✓			✓	✓
Keyboard support					✓	✓		✓	✓	✓
Data input facilitation							✓	✓	✓	✓
Aiding service							✓	✓		✓
Persistence	✓		✓		✓	✓		✓	✓	
Interaction interface		✓					✓	✓	✓	✓
Ease of reading		✓		✓			✓	✓		✓
Transparency		✓		✓	✓		✓	✓	✓	✓
Specificity		✓		✓	✓		✓	✓		
Assistive tools		✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 21. List of accessibility violations encountered during the evaluation of incubation websites.

- **Top-line illustration:** Although, a count of four healthcare websites HSR3, HSR7, HSR9 and HSR10 as well as seven incubation websites ISR1, ISR3, ISR6, ISR7, ISR8, ISR9 and ISR10 lacked in the illustration for each heading as no description was provided for the same.
- **Interaction tools:** Furthermore, the users found difficulty in interacting with tools like controls and buttons in the case of four healthcare sites HSR4, HSR5, HSR6 and HSR9, however, three incubation sites ISR5, ISR7 and ISR9 were difficult to use.
- **Learning efficacy:** Moreover, four healthcare sites HSR4, HSR5, HSR6 and HSR9 as well as five incubation sites ISR4, ISR5, ISR6, ISR9 and ISR10 were not accessible for new users as these websites were difficult to learn and operate.
- **Keyboard support:** The users were found uncomfortable in operating three healthcare sites HSR5, HSR6 and HSR10 including five incubation sites ISR5, ISR6, ISR8, ISR9 and ISR10 through a keyboard.
- **Data input facilitation:** Further, three healthcare websites HSR6, HSR7 and HSR9, whereas, four incubation websites ISR7, ISR8, ISR9 and ISR10 were found unsatisfactory as these sites were failed to provide input facilitation.
- **Website aiding service:** Moreover, a few accessibility issues related with website aiding service were encountered while accessing the websites HSR6, HSR7, HSR8, HSR9 and HSR10 as well as ISR7, ISR8 and ISR10.
- **Persistence:** The users were found with the problem of non-persistent interfaces while accessing five healthcare sites HSR1, HSR3, HSR5, HSR6 and HSR9 while six websites ISR1, ISR3, ISR5, ISR6, ISR8 and ISR9 in the domain of incubation.
- **User interface:** In addition, three healthcare websites HSR7, HSR9 and HSR10, whereas, five incubation websites ISR2, ISR7, ISR8, ISR9 and ISR10 were unable to provide the accessible interfaces to users.
- **Ease of reading:** Although, six healthcare websites HSR2, HSR4, HSR7, HSR8, HSR9 and HSR10 while five incubation websites ISR2, ISR4, ISR7, ISR8 and ISR10 were lacked in pronouncing mechanism as well as in abbreviations clarity.
- **Transparency:** Additionally, an issue of transparency was also disclosed for four healthcare sites HSR7, HSR8, HSR9 and HSR10 as well as for seven incubation websites ISR2, ISR4, ISR5, ISR7, ISR8, ISR9 and ISR10.
- **Specificity:** Six healthcare sites HSR2, HSR4, HSR6, HSR8, HSR9, HSR10 and also, five incubation websites ISR2, ISR4, ISR5, ISR7 and ISR8 were found to have the accessibility issues related to specificity.
- **Assistive tools:** Furthermore, all the sites except HSR1, HSR7 and ISR1 were non-compliant with assistive technologies as the site content is not accessible for the users of assistive technologies.

The above-mentioned violations need to be addressed by the developers of these websites to ensure universal access to all kinds of users despite their impairments as well as to improve the level of accessibility of their websites. The next section illustrates the validation of FUEJMA by preparing another sample of ten different impaired users.

Discussion

With the enormous and rapid growth of e-services, the web accessibility has become an indispensable topic in the world of web. Providing accessible e-services to all users is quite challenging for web developers. Past studies made use of several methodologies to evaluate the accessibility of different websites from various domains[4,5,7–10,12–14,20,21]. Some researchers presented versatile models and frameworks for accessibility evaluation of websites[3,40,45–47,50]. However, no study has been conducted to evaluate the accessibility of healthcare and

incubation websites by applying a mathematical model based on fuzzy aggregation technique. To address this gap, a dual approached model named as Fuzzy-based User cum Expert Judgement Model for Accessibility (FUEJMA) has been proposed in current study. By using the proposed model, an Apparent Accessibility Index (AAI) has been evaluated with respect to all four accessibility aspects. As per the result findings, understandability has been found the least violated whereas the Operability has been found to be the most violated aspect of accessibility. Finally, the two types of ranking has been done: Website ranking using AAI and the overall website ranking as per the computed values of AAI. It has been observed that the site HSR9 is the most violated site while the site HSR1 is the least violated site among all healthcare websites. However, in the case of incubation websites, the site ISR1 is found to be the least violated and ISR7 is found to be the most violated site. After that, the websites have been compared domain wise in accordance with the computed AAI values. The result findings have been revealed that healthcare websites achieved a very good level of accessibility in comparison to incubation websites.

Moreover, in order to validate the model, the same datasets are evaluated by taking different sample. Following that, the t-test is applied to check the confidence interval which is found insignificant at difference of $\alpha = 0.05$ as per the statistical analysis. Although, FUEJMA vanquished the existing models as it offers the dual approach of user as well as expert testing method. The proposed model may be helpful for site makers to check the accessibility level of their websites with the help of computed values of AAI. Current study is limited to the evaluation of websites which can be extended to the mobile apps evaluation. Moreover, the size of research sample is also constrained and it is recommended to incorporate large sample to conduct the evaluation.

Validation of proposed model

To perform the validation of proposed model, another sample with different impaired users and experts is prepared as another case study. The four accessibility aspects are re-evaluated by using the same questionnaires Q1AAE and Q2AAE for users and experts respectively. Same procedure is followed to aggregate the users and experts insights by applying fuzzy-based aggregation technique. After computing the index values of both domain websites with second research sample, both case studies are compared by these index values.

AAI comparison of both case studies

After making comparison of both case studies, it is clear that the index value is almost same or nearly equal to the value computed with the first research sample. In order to compare the variations in AAI values of both case studies, the t-test has been applied. As per the results of t-test, insignificant difference of AAI values has been found at confidence level $\alpha = 0.05$. Table 22 and Fig. 11 represent the AAI comparative analysis of both case studies in tabular and graphical form respectively.

It has been evident that each index value of the second sample is either same or very similar to the index value computed from the first sample. The t-test has been used to compare the variations in the values of AAI obtained from both models. According to statistical analysis, the samples are not significant at a confidence interval of this difference at $\alpha = 0.05$. The comparative analysis of AAI for both case studies is depicted in Table 23 and Fig. 12.

Conclusion and future scope

Website accessibility has been become an emerging topic among researchers and developers in current scenario. Universal access to web and its content is the primary right of each user despite having any kind of disability. Extensive research has been done in the area of Web accessibility evaluation by involving either end users or professional experts. However, no researcher has ever employed fuzzy-based mathematical technique to aggregate the insights from both the end users and experts for the website accessibility evaluation. Current study aimed to propose a fuzzy-based novel modeling approach for evaluating the accessibility of datasets of twenty websites from two different domains: ten from healthcare domain and remaining ten from the domain of incubation. As per the result findings, healthcare websites achieved a very good level of accessibility as compared to incubation websites. Further, the validation of proposed model has been done by evaluating another sample as another case study with same datasets. The statistical analysis found an insignificant variation of accessibility index at confidence level $\alpha = 0.05$. Moreover, FUEJMA may be helpful for the web developers for more refined, accurate and context-sensitive accessibility evaluation by integrating the insights from user and expert testing based on fuzzy aggregation technique.

Site ID	AAI of case study 1	AAI of case study 2
HSR1	0.622801679	0.629855652
HSR2	0.36636355	0.37856389
HSR3	0.325544969	0.310025522
HSR4	0.269762568	0.289754585
HSR5	0.2895269	0.2802586
HSR6	0.235838229	0.236555869
HSR7	0.24436517	0.235956933
HSR8	0.235253853	0.232854654
HSR9	0.195938686	0.194852121
HSR10	0.197520867	0.195862356

Table 22. Index values of both case studies in the case of healthcare websites.

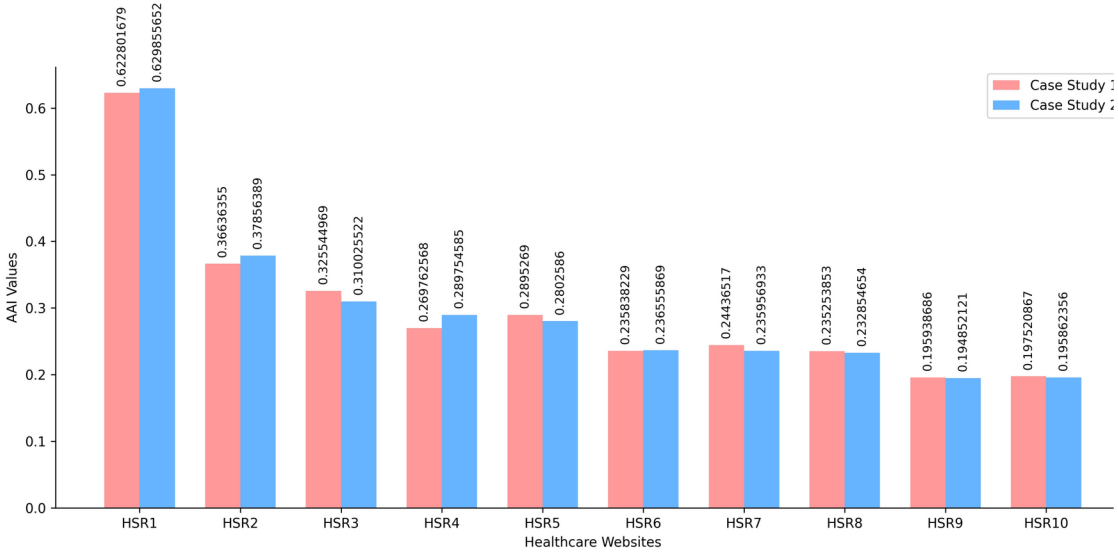

Fig. 11. AAI of healthcare websites.

Site ID	AAI of case study 1	AAI of case study 2
ISR1	0.802484416	0.800843207
ISR2	0.629856238	0.65487089
ISR3	0.712271227	0.739204722
ISR4	0.612929551	0.611633312
ISR5	0.416460948	0.442065344
ISR6	0.524412763	0.574163723
ISR7	0.279148475	0.235989933
ISR8	0.400926388	0.447719027
ISR9	0.356130891	0.372026131
ISR10	0.405141937	0.405068952

Table 23. Index values of both case studies in the case of incubation websites.

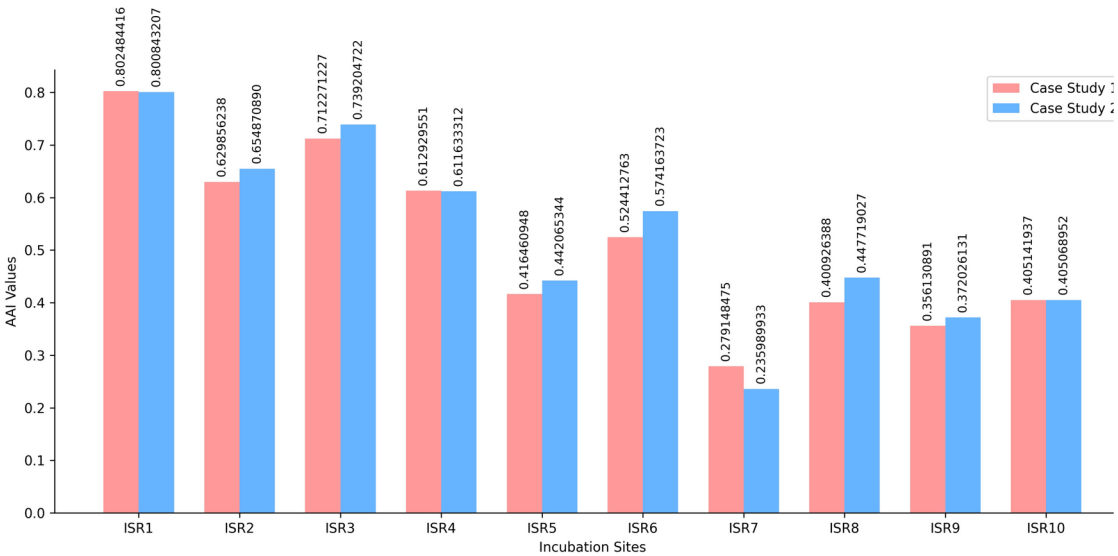

Fig. 12. AAI of incubation websites.

Furthermore, current study meets with some shortcomings like other research studies. The primary limitation of current study is that the user testing is restricted to a single impairment of low-vision only due to unavailability of other impaired users. The model's effectiveness is illustrated by applying it to twenty websites of two domains only. The comparative analysis of current study is confined solely on the observations and inferences derived by the researchers during user and expert testing against the conformance of WCAG 2.1. In future, the research study can be extended by including the latest versions of WCAG to design the questionnaires and evaluation criteria for accessibility. Moreover, there may be variability in the domains of websites, sample size, user impairments as well as more accessibility evaluation approaches for future scope of work. In addition, the future work can be also extended to the evaluation of mobile applications rather than websites. Moreover, the size of research sample is also constrained and it is recommended to incorporate large sample to conduct the evaluation. In addition, certain testing techniques like Cohen's Kappa, Fleiss's Kappa or Intraclass Correlation Coefficient (ICC) can be applied to validate the model for future work.

Data availability

Data will be made available on reasonable request of corresponding author.

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Author contributions

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Declarations

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Consent

We have taken the consents of all the participants before data collection process. Also, we have taken into considerations the privacy concerns of all participants. Moreover, we are not revealing the identities of the participants.

Ethical approval

This manuscript is not considered for publication anywhere else.

Additional information

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