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LONG PAPER

Evaluating the accessibility of *E*-government websites in the United States: empirical evidence and insights

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Abstract
The proliferation of the internet and mobile technology has significantly reshaped how governments deliver services to their citizens. E-government initiatives enable citizens to conveniently access government services online while maintaining transparency and ensuring seamless communication and compatibility between different government systems. Due to the monopolistic nature of government services, it is extremely important that all individuals, regardless of their visual, cognitive, and hearing abilities, have fair and unhindered access to these vital services. Research suggests that a majority of e-government websites globally fail to meet the accessibility standards outlined in the Web Content Accessibility Guidelines (WCAG). This study investigates the compliance of US e-government websites to WCAG accessibility criteria. We evaluate the accessibility of 64 e-government websites from various departments against WCAG standards. Our findings emphasize the importance of integrating accessibility features during the website development process to achieve universal accessibility and ensure a user-friendly experience for all citizens. This emphasis on accessibility during development is critical to ensure that all users, including those with disabilities, can easily use and navigate these online platforms.

Keywords E-government · Accessibility · WCAG · US E-government

1 Introduction

The widespread adoption of the internet has fundamentally transformed how citizens access information and interact with government services [1]. This shift represents a significant global evolution in how the public sector structures and delivers services. E-government, also known as electronic or digital government, utilizes web-based applications to streamline government procedures and deliver services to citizens more efficiently [2–4]. The US General Accounting Office categorized E-government services into four primary models [1] including Government-to-Citizen (G2C), Government-to-Business (G2B), Government-to-Government (G2G) [5], and Government-to-Employee (G2E) [6].

E-government services have demonstrably reduced government operating costs [7] and expedited bureaucratic processes [1, 8, 9]. These advancements contribute to enhanced responsiveness of government agencies. Additionally, E-government websites aim to provide equal access to information and services for all citizens [1, 10]. Therefore, accessibility is a key factor in evaluating the quality of E-government websites [10–12].

The Web Content Accessibility Guidelines (WCAG) provide a standardized framework to assess how well individuals with disabilities can navigate and interact with online platforms [13, 14]. The WCAG framework is informed by four key principles known as POUR (Perceivable, Operable, Understandable, and Robust) [15, 16]. These principles ensure that web content is *Perceivable* (users can perceive the information using one or more of their senses), *Operable* (users can navigate and interact with the content using a keyboard, voice commands, or other assistive technologies), *Understandable* (users can understand the information and the functionality of the content), and *Robust* (the content remains accessible even when used with different assistive technologies or when combined with future technologies). Implementing these accessibility standards fosters trust and wider adoption of E-government services by ensuring inclusivity for all citizens. Research suggests that a significant number of E-government websites globally fail to meet accessibility

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best practices [1, 17–21]. This highlights the need for improvement in E-government website accessibility to ensure all citizens can access and utilize these essential services.

Previous studies have primarily employed WCAG 1.0 [17], 2.0 [19, 20], and 2.1 [1, 10, 22] guidelines to assess E-government website accessibility. However, the latest iteration, WCAG 2.2, introduced in 2023 by the World Wide Web Consortium (W3C), offers a comprehensive set of accessibility criteria while maintaining backward compatibility with WCAG 2.1 [23]. Notably, the adoption of WCAG 2.2 for evaluating E-government website accessibility remains under-investigated in current research. This gap in knowledge presents an opportunity to contribute to the field.

Therefore, this study aims to examine E-government website accessibility in the US context using the latest WCAG 2.2 standards. By employing this most recent framework, the research seeks to provide a more comprehensive and up-to-date assessment of accessibility compliance within US E-government websites. The main contributions of this study are outlined as follows:

- We employed a rigorous methodology and established accessibility evaluation tools to provide empirical evidence regarding the accessibility status of US E-government websites. This data can inform future research and policy decisions;
- The underlying analysis of website accessibility issues leads to the development of targeted recommendations for practitioners. These recommendations provide actionable guidance for improving the accessibility of US E-government websites, ultimately benefiting users with disabilities;
- WCAG primarily relies on the POUR principles. This study analyzed the accessibility issues through the lens of POUR principles, thus providing valuable insights into the overall WCAG compliance of US E-government websites. This knowledge can guide policymakers and developers in ensuring adherence to these critical accessibility standards;
- We employed a comprehensive accessibility evaluation to establish a ranking system for US E-government websites. This ranking system reveals significant variations in accessibility levels, highlighting websites that require immediate attention and those demonstrating a stronger commitment to accessibility;
- We conducted a comparative analysis of accessibility issues in US E-government websites against research findings from other countries. This comparative approach offers valuable insights into the relative accessibility performance of US E-government websites on a global scale.

The remainder of this article is structured as follows. Section 2 explores the underlying concepts of website accessibility and outlines the relevant guidelines and established research on E-government website evaluations. We also provide a comprehensive comparison of our study with prior works on accessibility evaluation of E-government websites of other countries. Section 3 details the methodological approach employed in the study, including data collection methods, the chosen evaluation tools, and the website evaluation procedure itself. The results of the accessibility evaluation conducted on the E-government websites are presented in Sect. 4. Section 5 offers a thorough analysis of the evaluation findings and provides practical recommendations for practitioners based on the observed accessibility issues. Section 6 discusses the potential limitations of the study and outlines future research directions. Finally, Sect. 7 summarizes the key findings and emphasizes the significance of accessibility in E-government websites.

2 Related work

Prior research has explored various aspects of accessibility, including mobile applications [24–29], web content accessibility guidelines (WCAG) [30–32], large language models (LLMs) [33, 34], and accessibility in educational settings [35–38]. These studies highlight ongoing challenges in implementing accessible design and automation in diverse domains. However, there remains a need for comprehensive evaluations of E-government websites to ensure they meet accessibility standards and effectively serve diverse user populations. This section discusses website accessibility guidelines and the evaluation of E-government website accessibility across various countries.

2.1 Website accessibility and guidelines

Web accessibility has been a critical consideration since the early days of the web [39]. However, a universally accepted definition remains elusive [40]. According to Yesilada et al. [41], the Web Accessibility Initiative (WAI), a subgroup of the World Wide Web Consortium (W3C) [42], offers a widely adopted definition of web accessibility. It states,"Web accessibility means that people with disabilities can use the Web. More specifically, Web accessibility means that people with disabilities can perceive, understand, navigate, and interact with the Web, and that they can contribute to the Web"[41]. While this definition prioritizes users with disabilities, the International Organization for Standardization (ISO) offers a broader perspective. ISO defines accessibility as the usability of a product, service, or environment by a wider range of people with varying capabilities [43]. This demonstrates that website accessibility extends beyond

benefits for people with disabilities. It also enhances the overall usability of the website for a wider audience [44–47].

Recognizing this need, WAI published the first iteration of its Web Content Accessibility Guidelines (WCAG), known as WCAG 1.0 [48] in 1999. This set of guidelines empowers developers and designers to create websites that are accessible to a broad range of users with disabilities. Building on WCAG 1.0, the WAI introduced WCAG 2.0 in 2008 [49]. This version offers a more comprehensive set of accessibility guidelines while maintaining backward compatibility. Further advancements came in 2018 with WCAG 2.1 [50], which extended WCAG 2.0 and provided recommendations for enhanced website accessibility for users with low vision, cognitive disabilities, and those using mobile devices [51].

2.2 Accessibility evaluation of *E*-government websites

A growing body of research has investigated the accessibility of E-government websites across a range of countries [21, 52, 53]. These studies have identified accessibility issues that can hinder the ability of these websites to serve users with disabilities [2, 54–56]. For instance, studies employing automated evaluation tools like WAVE and Bobby found accessibility problems across websites in Romania [21], Saudi Arabia and Oman [52], Nigeria [57], Dubai [58], China [53], Turkey [59], and Malaysia [60]. Common accessibility issues identified include the lack of text alternatives for non-text elements [17, 22, 52, 53, 61], empty links [22, 62], and incompatibility with various user agents [17]. Additionally, static content not updating dynamically presents another challenge [17, 59]. Furthermore, research by Akgül [63] indicates that a significant portion (75%) of websites from a sample of 61 Turkish E-government websites exhibited accessibility problems related to ARIA compliance. Sanchez-Gordon et al. [22] found a lack of alternative text and empty links to be the most prevalent accessibility issues in Ecuadorian E-government websites. Reinforcing this concern, Csontos and Heckl [62] examined 25 Hungarian government websites for WCAG conformance. This study found that“Empty Link” (84%) was the most prevalent violation, followed by“Redundant Link”(84%) as the most common warning, and“Redundant title text” (56%) as the most frequently encountered developer warning. Dominic et al. [64] evaluated E-government websites from five Asian countries, including Singapore, Korea, Japan, Hong Kong, and Malaysia. Their findings suggest that accessibility remains a challenge across these Asian websites.

Baowaly and Bhuiyan [65] examined the accessibility of ten government websites in Bangladesh. Their evaluation using AChecker found that all websites failed to meet the criteria for conformance levels A, AA, and AAA. However, five websites achieved conformance at levels AA and AAA while failing to meet the minimum requirements for level A. Similarly, the evaluation of ten Libyan government websites by Karim and Inal revealed that only two websites passed the minimum Level A criteria, six websites achieved Level AA, and seven websites achieved AAA conformance, respectively [18]. Abu Doush and Almeraj [20] assessed the accessibility of 17 most-used E-government services in Kuwait against WCAG 2.0 Level A criteria. The evaluation revealed that 76% (13 out of 17) of the services failed, with“non-text content”and“labels or instructions”being the most frequent accessibility problems. A recent study by Paul [1] assessed the WCAG 2.1 accessibility of 65 Indian E-government websites. The findings revealed that most websites exhibited accessibility issues, primarily at level A, and only a small number (7) achieved the highest conformance level AAA.

Table 1 summarizes recent studies on E-government website accessibility evaluation. This is particularly noteworthy because none of these studies focus on websites within the United States. Additionally, all studies have a limited sample size and lack detailed information about the evaluation methodology. Furthermore, the studies primarily assessed websites against WCAG versions 1.0, 2.0, or 2.1, not considering the recently introduced WCAG 2.2 guidelines. To address these gaps, we employed WCAG 2.2 to evaluate a comprehensive set of E-government websites for accessibility. Furthermore, we provide a more granular analysis of the accessibility issues pertaining to POUR principles, providing a deeper understanding of the specific accessibility challenges faced by users with disabilities when interacting with the websites.

3 Methodology

This section outlines the data collection procedure and methodology employed to evaluate the accessibility of US E-government websites.

3.1 Website selection

A sample of 64 E-government websites was selected for this study. These websites represent a variety of government sectors, including general public service, health, defense, economic affairs, recreation, culture, religion, environmental protection, and public order and safety. The website sample consists of entities from both the federal government and state governments within the United States. This collection is intended to be a representative sample of US E-government websites. Details regarding these websites are presented in Table 2.

Table 1 The comparison table for the countries

Authors	Year	Country	Accessibility Guideline	Sample Size	Findings
Al Mourad and Kamoun [58]	2013	United Arab Emirates	WCAG 1.0	21	Absence of text equivalents and failure of static equivalents are more frequent errors
Lujan-Mora et al. [66]	2014	12 South American Countries	WCAG 2.0	33	Parliament of Argentina and Venezuela to have the most significant accessibility barriers, while the Parliament of Brazil and the Government of Guyana demonstrated the highest levels of accessibility compliance
Yakup and Vatansever [8]	2016	Turkey	WCAG 1.0. WCAG 2.0	30	Evaluation revealed pervasive inaccessibility across Turkish E-government websites, with none demonstrably adhering to minimum web accessibility standards
Adepoju and Shehu [67]	2016	Nigeria	WCAG 2.0	36	Evaluation revealed no E-government websites achieving full conformance with the WCAG 2.0 standard
Rita Ismailova [9]	2017	Kyrgyzstan, Azerbaijan, Kazakhstan, and Turkey	WCAG 2.0	55	No websites achieved WCAG 2.0 Level AAA conformance, with significant violations in core accessibility guidelines like Level A 1.1.1 and Level AAA 1.4.6
Noe Elisa [56]	2017	Tanzania	WCAG 2.0	79	Results showed abundance of broken links, and poor website loading speed and time
Muhammad Bilai et al. [68]	2019	China & Pakistan	WCAG 2.0	60	Results show poor loading time, inaccessible page size, and broken links
Doush and AlMeraj [20]	2019	Kuwait	WCAG 2.0	17	Results revealed widespread non-compliance with WCAG success criteria, encompassing issues like non-text alternatives, descriptive link text, focus management, and clear labeling of instructions
Balázs and István [62]	2020	Hungary	WCAG 2.0	25	Authors identified empty links, linked images missing alternative text, missing form labels, empty buttons, and missing alternative text for spaces as the five most prevalent accessibility errors
Ahmed et al. [69]	2020	Bangladesh	WCAG 2.0	20	Evaluation revealed an average of 24 errors, 114 alerts, 24 HTML5/ARIA problems, and 27 color contrast errors across the websites
AL-Sakran and Alsudairi [70]	2021	Saudi Arabia	WCAG 2.1	22	Redundant links and skipped heading levels were the most frequent accessibility errors identified in E-government websites

Table 1 (continued)

Authors	Year	Country	Accessibility Guideline	Sample Size	Findings
Pabitra Dangol [71]	2023	Nepal	WCAG 2.1	25	Evaluation revealed concerning low WCAG 2.1 conformance, with only 4%, 24%, and 4% of websites meeting levels A, AA, and AAA, respectively
Our study	2025	United States	WCAG 2.2	64	Findings reveal significant violations of the perceivable POUR principle, particularly WCAG guidelines 1.1.1 and 1.3.1

3.2 Automated Accessibility Evaluation Tools

Several automated accessibility evaluation tools have been used in previous studies, such as SortSite, TAW, EvalAccess, eXaminator, AChecker, and WAVE, to analyze E-government websites [1, 10, 22, 62]. Most of these tools assess website accessibility against WCAG 1.0, 2.0, and 2.1 standards. However, WCAG 2.2 is the current accessibility standard published by the WAI in 2023 [72]. WCAG 2.2 builds upon the POUR principles to define three levels of conformance, which are A, AA, and AAA. Table 3 presents the different conformance levels of WCAG 2.2 guidelines and corresponding POUR principles.

This study employs a multi-tool approach for evaluating E-government website accessibility. This decision is based on the comparison conducted by Vigo et al. [73]. The authors found that relying on a single automated tool for accessibility evaluation was flawed because none of the tools obtained the best scores across all dimensions. Therefore, a robust accessibility evaluation should leverage the combined results of multiple tools to ensure a comprehensive and reliable assessment. Hence, we used various tools, including AChecker [74], Total Validator [75], and WAVE [76]. These tools are discussed in subsequent sections.

3.2.1 Accessibility checker (AChecker)

AChecker [77, 78] is a web-based accessibility evaluation tool. It assesses HTML pages against various accessibility standards, including BITV 1.0, Section 508 of the Rehabilitation Act, and the WCAG guidelines. The evaluation results are categorized into conformance levels A, AA, and AAA. The tool identifies three types of errors, including "Known","Likely", and"Potential". Known errors represent clear accessibility issues. Likely and Potential errors require human judgment to confirm their presence and determine appropriate solutions. AChecker presents identified errors by referencing the relevant WCAG Success Criteria, which helps developers understand the nature of the issues and potential solutions. In this study, we used AChecker to assess conformance with WCAG 2.1 guidelines at levels A, AA, and AAA, identifying violations and potential errors.

3.2.2 Web accessibility evaluation tool (WAVE)

WAVE [79, 80] offers a visual interface to highlight potential accessibility issues in a webpage. Yellow markers are directly placed on the webpage to indicate potential errors. Additionally, a sidebar on the right side presents a summary of identified accessibility problems. Explanations for the identified issues are displayed on the left side of the sidebar. WAVE also generates a detailed report summarizing the number of errors and potential errors, along with some explanatory information.

3.2.3 Total validator

Total Validator [81, 82] is a software designed to assess the accessibility and validity of web pages. It assesses web pages against web accessibility standards like WCAG 1.0, 2.0, 2.1, and the latest 2.2. The tool identifies potential accessibility issues such as missing image alt text, insufficient color contrast, or keyboard navigation problems. It may also categorize these issues by severity to prioritize fixes. Additionally, Total Validator can validate website code, including HTML and CSS. In our study, we employed Total Validator for HTML and CSS validation. The tool can evaluate code against over twenty HTML standards and covers more than 60 W3C specifications.

3.3 Evaluation procedure

We focused the accessibility evaluation on the homepages of the E-government websites. This decision aligns with previous research by Vigo et al. [73], which suggests the homepage can be indicative of the overall accessibility of other pages within the same website. A four-step evaluation process was employed to ensure a comprehensive assessment.

We began with conducting an automated conformance check using AChecker. This tool assessed the webpages against WCAG guidelines, identifying potential accessibility

Table 2 US E-Government websites selected for evaluation

No.	Government name	Website URL	Government type	ID
1	The National Park Service	https://www.nps.gov/index.htm	General Public Services	1
2	The National Aeronautics and Space Administration	https://www.nasa.gov/	General Public Services	2
3	The World Factbook - CIA	https://www.cia.gov/the-world-factbook/	General Public Services	3
4	National Gallery of Art	https://www.nga.gov/	Recreation, Culture, and Religion	4
5	The Texas Department of Motor Vehicles	https://www.txdmv.gov/	General Public Services	5
6	California State Parks	https://www.parks.ca.gov/	General Public Services	6
7	Texas Parks and Wildlife	https://tpwd.texas.gov/	Economic Affairs	7
8	Texas Health and Human Services	https://www.hhs.texas.gov/services/health	Health	8
9	Food Assistance	https://www.usa.gov/food-help	Social Protection	9
10	Travel State Gov	https://travel.state.gov/content/travel.html	Recreation, Culture, and Religion	10
11	U.S. Food and Drug Administration	https://www.fda.gov/	Health	11
12	Centers for Disease Control and Prevention	https://www.cdc.gov/	Health	12
13	U.S. Environmental Protection Agency	https://www.epa.gov/	Environmental Protection	13
14	Federal Communications Commission	https://www.fcc.gov/	Economic Affairs	14
15	The United States Social Security Administration	https://www.ssa.gov/	General Public Services	15
16	US Department of Labor	https://www.dol.gov/	Economic Affairs	16
17	Department of Transportation	https://www.transportation.gov/	General Public Services	17
18	U.S. Fish and Wildlife Service	https://www.fws.gov/	Environmental Protection	18
19	U.S. Securities and Exchange Commission	https://www.investor.gov/	Economic Affairs	19
20	Homeland Security	https://www.dhs.gov/	Defence	20
21	The Alcohol and Tobacco Tax and Trade Bureau	https://www.ttb.gov/	Economic Affairs	21
22	The Usability Government Website	https://www.usability.gov/	Social Protection	22
23	The Texas Department of Public Safety	https://www.dps.texas.gov/	Public Order and Safety	23
24	Texas Workforce Commission	https://www.twc.texas.gov/	Social Protection	24
25	The Recreation Government Website	https://www.recreation.gov/	Recreation, Culture, and Religion	25
26	Federal Emergency Management Agency	https://www.fema.gov/	Public Order and Safety	26
27	National Library of Medicine - National Institutes of Health	https://www.nlm.nih.gov/	Health	27
28	Texas Department of State Health Services Mobile	https://dshs.texas.gov/	Health	28
29	Substance Abuse and Mental Health Services Administration	https://www.samhsa.gov/	Health	29
30	National Institute on Aging	https://www.nia.nih.gov/	Health	30
31	Department of the Treasury	https://home.treasury.gov/	Economic Affairs	31
32	Vaccines website	https://www.vaccines.gov/	Health	32
33	The home of the U.S. Government's open data	https://www.data.gov/	Social Protection	33
34	U.S. General Services Administration	https://www.gsa.gov/	General Public Services	34
35	Internal Revenue Service	https://www.irs.gov/	Economic Affairs	35
36	U.S. Congress legislation	https://www.congress.gov/	General Public Services	36
37	U.S. House of Representatives	https://www.house.gov/	General Public Services	37
38	United States Senate	https://www.senate.gov/	General Public Services	38
39	Office of International Affairs	https://www.doi.gov/intl	General Public Services	39
40	U.S. Department of Agriculture	https://www.usda.gov/	Recreation, Culture, and Religion	40
41	Bureau of Ocean Energy Management	https://www.boem.gov/	Economic Affairs	41
42	National Weather Service	https://www.weather.gov/	Public Order and Safety	42
43	U.S. Wind Turbine Database	https://eerscmap.usgs.gov/uswtdb/	Economic Affairs	43
44	U.S. Energy Information Administration	https://www.eia.gov/	Economic Affairs	44
45	U.S. Department of State	https://www.state.gov/	General Public Services	45
46	Benefits website of the U.S. government	https://www.benefits.gov/	General Public Services	46
47	Texas Attorney General	https://www.texasattorneygeneral.gov/	General Public Services	47
48	Official City of Plano, TX	https://www.plano.gov/	General Public Services	48

Table 2 (continued)

No.	Government name	Website URL	Government type	ID
49	The Federal Government's official employment site	https://www.usajobs.gov/	Economic Affairs	49
50	United States Botanic Garden	https://www.usbg.gov/	Recreation, Culture, and Religion	50
51	Bureau of Transportation Statistics	https://www.bts.gov/	Public Order and Safety	51
52	Centers for Medicare and Medicaid Services	https://www.cms.gov/	Health	52
53	Department of Homeland Security Seal	https://www.uscis.gov/	Defence	53
54	U.S. Department of Education	https://www.ed.gov/	Education	54
55	Freedom of Information Act	https://www.foia.gov/	Social Protection	55
56	Health Insurance Marketplace	https://www.healthcare.gov/	Health	56
57	National Endowment for the Arts	https://www.arts.gov/	Recreation, Culture, and Religion	57
58	Obama White House Archives	https://obamawhitehouse.archives.gov/	General Public Services	58
59	National Security Agency/Central Security Service	https://www.nsa.gov/	Defence	59
60	The official website of State of Texas	https://www.texas.gov/	General Public Services	60
61	Library of Congress	https://www.loc.gov/	General Public Services	61
62	Federal Trade Commission	https://www.ftc.gov/	Economic Affairs	62
63	Department of Energy	https://www.energy.gov/	Economic Affairs	63
64	Cybersecurity and Infrastructure Security Agency	https://www.cisa.gov/cybersecurity	Defence	64

errors and their corresponding conformance levels (A, AA, or AAA). Subsequently, the WCAG success criteria associated with the identified errors were analyzed. This analysis mapped these criteria to the POUR principles to provide context for website developers in addressing accessibility concerns.

Following the initial automated conformance check, we employed WAVE and Total Validator to identify potential accessibility issues on the web pages. Utilizing multiple tools for accessibility evaluation is a recognized best practice [8, 73]. Different tools have varying strengths and weaknesses, and employing a combination helps to overcome these limitations and provide a more thorough assessment. This multi-tool approach ensured a broader range of accessibility problems were captured in the evaluation.

4 Results

This section presents the accessibility evaluation results of 64 E-government websites. The evaluation focuses on web accessibility conformance, followed by an analysis of HTML and CSS code validity.

4.1 Web accessibility

Tables 4 and 5 reveal the distribution of accessibility errors identified using AChecker across the WCAG conformance levels for the 64 US E-government websites. We identified that only a small portion of websites, approximately 16% (11 out of 64), achieved perfect scores with zero errors at any WCAG level.

For Level A accessibility, the average number of errors per website was 11. However, the number of errors varied considerably, with a single website exhibiting the highest number at 101 (see Table 4). Similarly, the average number of Level AA errors per website was 28, with a maximum of 191 errors identified on a single website (see Table 5). Importantly, no accessibility errors were detected at the Level AAA conformance level for any of the websites.

To assess overall accessibility performance, we implemented a website ranking system based on the total number of errors across all WCAG levels. Websites with zero errors received the highest rank. This evaluation revealed that 19 websites achieved a perfect score with zero Level A errors, and 11 websites achieved a perfect score with zero Level AA errors. We also identified that the majority of errors belonged to the Perceivable and Operable POUR principles. Website ID 36 had the highest number of accessibility errors overall, consequently receiving the lowest ranking.

4.1.1 AChecker results

Table 6 outlines the most frequent accessibility issues identified by AChecker at the Level A conformance level. The most common error, with n=82 instances, was empty label text, which violates WCAG guideline 3.3.2. Another prevalent issue was the absence of text in anchor elements, with n=73 errors identified across 64 websites, violating WCAG guideline 2.4.4. Additionally, the lack of alternative text for image elements was a significant accessibility issue, with n=64 instances violating WCAG guideline 1.1.1. Similarly, missing alternative text for images used as anchors resulted in n=57 errors, also in violation of WCAG guideline 1.1.1.

Table 3 WCAG 2.2 Conformance Levels and POUR Principles

Conformance level	POUR principles	Description
A (Minimum)	-Perceivable: Information and user interface components must be presented in ways users can perceive -Operable: User interface components and navigation must be operable	This level ensures basic accessibility, allowing users to perceive and interact with the content. However, it might not address all accessibility needs
AA (Recommended)	-Perceivable (all A criteria) -Operable (all A criteria) -Understandable: Information and the operation of the user interface must be understandable	This level builds on A, ensuring content is not only perceivable and operable but also understandable for users with a wider range of disabilities. It is considered the recommended target for most websites
AAA (Optional)	-Perceivable: All A & AA criteria -Operable: All A & AA criteria -Understandable: All A & AA criteria -Robust: Content must be robust enough that it can be reliably interpreted by a wide variety of user agents, including assistive technologies	This level represents the most stringent conformance level, addressing all POUR principles in detail. It ensures maximum accessibility for users with various disabilities and assistive technologies. However, meeting AAA may not always be practical for all content types

Form elements presented notable accessibility challenges as well, with n=40 and n=44 instances of missing labels for text input and checkbox input elements, respectively, violating WCAG guideline 1.3.1.

Our evaluation also identified several accessibility issues at the Level AA conformance level, as shown in Table 7. The most frequent errors were due to the use of italics, with n=123 instances violating WCAG guideline 1.4.4. Insufficient color contrast between text and its background was another common issue, with n=73 errors violating WCAG guideline 1.4.3. Recurring problems also included empty anchor tags, violating WCAG guideline 2.4.4. Similar to Level A, the lack of proper alternative text descriptions for images was prevalent, violating WCAG guideline 1.1.1.

To gain a more granular understanding of the AChecker results, we quantified the distribution of accessibility issues across the three error types identified by the tool as shown in Table 8. The analysis revealed that only 11 websites from a total of 64 websites passed the accessibility check by the tool. The majority of issues were categorized as"Potential" errors spanning conformance levels A, AA, and AAA, followed by "Likely"conformance errors at level AAA. The highest number of "Known"errors were reported in Website ID 36. These results revealed a trend where a higher level of conformance to accessibility standards coincided with a greater number of accessibility errors identified.

4.1.2 WAVE results

Our evaluation using WAVE identified a range of accessibility issues across the analyzed websites presented in Table 9. The most frequent error was empty buttons, accounting for 19.46% of the identified accessibility barriers. This is followed closely by empty links, present in 17.07% of the errors. Missing form labels and broken ARIA references were also prevalent accessibility issues, each constituting 15.87% of the errors. Another common issue was the lack of alternative text descriptions, impacting 11.96% of the analyzed websites. In contrast, errors related to missing alternative text in space images, missing form labels for specific elements, and broken skip links were less frequent, with only one instance each.

Table 10 provides a comprehensive summary of accessibility issues identified in E-government websites using the WAVE tool. The severity of these issues varied significantly across different websites. Critical errors, representing the most severe problems, ranged from 0 to 21 per site. The majority of the websites had n≤2 critical errors, with the highest number of errors recorded for Website ID 35 (n=21), followed by Website ID 21 (n=19).

Alerts, which signify potential accessibility barriers, were more frequent, ranging from 2 to 200 per website. Notably, none of the websites passed the Alert test. Website ID 44 had

Table 4 Average known Level A errors according to WCAG 2.0-POUR principles per website

ID	Ranking	Perceivable	Operable	Under-standable	Robust	Error %	Performance %
1	1	0	0	0	0	0.00%	High
2	1	0	0	0	0	0.00%	High
3	20	0	0	1	0	0.99%	High
4	63	27	1	10	1	38.61%	Medium
5	59	8	8	0	1	16.83%	High
6	1	0	0	0	0	0.00%	High
7	56	10	2	3	0	14.85%	High
8	20	0	0	0	1	0.99%	High
9	1	0	0	0	0	0.00%	High
10	45	5	1	1	0	6.93%	High
11	1	0	0	0	0	0.00%	High
12	31	2	0	1	0	2.97%	High
13	45	0	7	0	0	6.93%	High
14	41	3	0	2	1	5.94%	High
15	56	15	0	0	0	14.85%	High
16	56	15	0	10	1	38.61%	Medium
17	28	0	0	1	1	1.98%	High
18	20	0	0	0	1	0.99%	High
19	1	0	0	0	0	0.00%	High
20	60	0	22	0	0	21.78%	Medium
21	40	3	1	1	0	4.95%	High
22	36	3	0	1	0	3.96%	High
23	1	0	0	0	0	0.00%	High
24	36	1	0	2	1	3.96%	High
25	1	0	0	0	0	0.00%	High
26	1	0	0	0	0	0.00%	High
27	41	4	0	2	0	5.94%	High
28	1	0	0	0	0	0.00%	High
29	45	4	0	3	0	6.93%	High
30	31	0	3	0	0	2.97%	High
31	20	0	0	0	1	0.99%	High
32	20	0	0	0	1	0.99%	High
33	53	9	0	0	1	9.90%	High
34	1	0	0	0	0	0.00%	High
35	45	0	6	0	1	6.93%	High
36	64	75	3	23	0	100.00%	Low
37	41	3	0	2	1	5.94%	High
38	62	16	0	14	0	29.70%	High
39	20	0	0	0	1	0.99%	High
40	36	4	0	0	0	3.96%	High
41	1	0	0	0	0	0.00%	High
42	50	6	0	2	0	7.92%	High
43	1	0	0	0	0	0.00%	High
44	60	9	4	8	1	21.78%	High
45	55	5	6	1	0	11.88%	High
46	1	0	0	0	0	0.00%	High
47	1	0	0	0	0	0.00%	High
48	1	0	0	0	0	0.00%	High
49	1	0	0	0	0	0.00%	High
50	28	1	1	0	0	1.98%	High

Table 4 (continued)

ID	Ranking	Perceivable	Operable	Under-standable	Robust	Error %	Performance %
51	36	0	4	0	0	3.96%	High
52	31	2	0	1	0	2.97%	High
53	45	6	1	0	0	6.93%	High
54	31	2	1	0	0	2.97%	High
55	1	0	0	0	0	0.00%	High
56	52	3	3	3	0	8.91%	High
57	31	2	0	1	0	2.97%	High
58	20	0	1	0	0	0.99%	High
59	41	4	0	2	0	5.94%	High
60	20	0	0	0	1	0.99%	High
61	53	10	0	0	0	9.90%	High
62	50	4	3	1	0	7.92%	High
63	1	0	0	0	0	0.00%	High
64	28	0	2	0	0	1.98%	High

the highest number of alerts reported by WAVE (n=200), followed by Website ID 36 with 181 alerts. Additionally, WAVE suggested features to enhance the accessibility of the websites. Every website received feature suggestions, with the highest number (n=475) suggested for Website ID 36. In contrast, many websites suggested features n≤10, including Website IDs 2, 10, 32, 33, 41, 43, 46, 47, 50, 51, and 58.

WAVE also assessed the underlying website code structure and the use of modern coding practices (HTML5 & ARIA). These categories exhibited variations, with some websites having no errors and others having hundreds. For instance, the highest number of structural element errors was recorded for Website ID 29 (n=425), while the minimum number of errors was recorded for Website ID 45 (n=11). Additionally, WAVE identified errors related to proper HTML and ARIA implementation, which could hinder assistive technologies from interpreting content correctly. Website ID 8 had the highest number of HTML and ARIA errors, with a total count of 4,511, which were the highest recorded errors for any website.

The number of contrast errors also varied across websites. Approximately 30% of the websites displayed no contrast errors (n=0). The highest contrast errors were recorded for Website ID 58 (n=105) and Website ID 38 (n=80).

4.2 Total validator results

Table 11 details the frequency of accessibility issues reported by the Total Validator tool. The results indicate a predominance of conformance Level A issues. Website ID 35 exhibits the highest number of Level A errors (n=273), followed by Website ID 56 (n=111). Additionally, the tool identifies Level AA errors in several websites, with the highest number (n=70) found in Website ID 36. Interestingly, 16 websites have no reported Level AA errors. Level AAA errors are detected in seven websites (IDs: 12, 33, 35, 38, 44, 61, and 62).

4.2.1 HTML and CSS validation

We also validated the code quality of the websites to identify potential HTML and CSS errors using Total Validator. The results in Table 11 revealed a predominance of HTML errors over CSS errors within the websites examined. The highest number of HTML errors (n=193) was found in Website ID 35, which conversely had a relatively low count of CSS errors (n=14). Website ID 45 followed with n=154 HTML errors and n=69 CSS errors. Website ID 14 ranked third with 123 HTML errors and only n=7 CSS errors. Notably, Website ID 12 achieved perfect validation with zero errors reported for both HTML and CSS. Additionally, Website IDs 13, 15, 25, and 46 exhibited exceptional HTML validation with just a single error each. However, it is important to note that except for Website ID 15, these websites had a significant number of CSS errors (e.g., n=37 for Website ID 25). Conversely, Website IDs 32 and 42 achieved perfect CSS validation with zero errors reported.

In contrast, the distribution of CSS errors displayed greater variation. Website ID 10 exhibited the highest number of CSS errors (n=93), followed by Website ID 19 with n=80 errors. Interestingly, Websites ID 27 and 60 had only a single CSS error each.

Table 5 Average known Level AA errors according to WCAG 2.0-POUR principles per website

ID	Ranking	Perceivable	Operable	Under-standable	Robust	Error %	Performance %
1	33	4	1	0	0	4.27%	High
2	1	0	0	0	0	0.00%	High
3	12	0	0	1	0	0.85%	High
4	59	13	6	5	1	21.37%	High
5	52	10	3	0	4	14.53%	High
6	33	3	2	0	0	4.27%	High
7	50	10	2	3	0	12.82%	High
8	12	0	0	0	1	0.85%	High
9	1	0	0	0	0	0.00%	High
10	38	5	1	1	0	5.98%	High
11	1	0	0	0	0	0.00%	High
12	37	5	0	1	0	5.13%	High
13	38	0	7	0	0	5.98%	High
14	27	2	0	1	1	3.42%	High
15	55	20	0	0	0	17.09%	High
16	43	7	1	0	1	7.69%	High
17	19	0	0	1	1	1.71%	High
18	24	1	1	0	1	2.56%	High
19	12	1	0	0	0	0.85%	High
20	60	6	22	0	0	23.93%	High
21	50	13	1	1	0	12.82%	High
22	27	3	0	1	0	3.42%	High
23	1	0	0	0	0	0.00%	High
24	24	1	0	1	1	2.56%	High
25	1	0	0	0	0	0.00%	High
26	12	0	1	0	0	0.85%	High
27	48	6	5	2	0	11.11%	High
28	12	0	1	0	0	0.85%	High
29	38	4	0	3	0	5.98%	High
30	24	0	3	0	0	2.56%	High
31	12	0	0	0	1	0.85%	High
32	33	4	0	0	1	4.27%	High
33	58	19	4	0	1	20.51%	High
34	1	0	0	0	0	0.00%	High
35	57	15	6	0	1	18.80%	High
36	64	91	3	23	0	100.00%	Low
37	27	2	0	1	1	3.42%	High
38	62	16	3	14	0	28.21%	High
39	12	0	0	0	1	0.85%	High
40	27	4	0	0	0	3.42%	High
41	1	0	0	0	0	0.00%	High
42	41	6	0	2	0	6.84%	High
43	19	0	2	0	0	1.71%	High
44	60	16	7	4	1	23.93%	High
45	53	10	7	1	0	15.38%	High
46	1	0	0	0	0	0.00%	High
47	19	0	2	0	0	1.71%	High
48	1	0	0	0	0	0.00%	High
49	1	0	0	0	0	0.00%	High
50	19	1	1	0	0	1.71%	High

Table 5 (continued)

ID	Ranking	Perceivable	Operable	Under-standable	Robust	Error %	Performance %
51	43	5	4	0	0	7.69%	High
52	49	13	0	1	0	11.97%	High
53	53	11	7	0	0	15.38%	High
54	27	3	1	0	0	3.42%	High
55	43	7	2	0	0	7.69%	High
56	47	5	3	3	0	9.40%	High
57	27	2	0	1	1	3.42%	High
58	46	9	1	0	0	8.55%	High
59	56	18	1	2	0	17.95%	High
60	19	0	1	0	1	1.71%	High
61	63	81	0	0	0	69.23%	Low
62	41	4	3	1	0	6.84%	High
63	1	0	0	0	0	0.00%	High
64	33	3	2	0	0	4.27%	High

Table 6 A list of the most common known accessibility problems according to the AChecker tool, Level A

Category	Guideline	Success criteria	No. of errors	No. of errors(33-64)	Total errors(Final)
Perceivable	1.1.1	img element missing alt attribute	42	22	64
Perceivable	1.1.1	Image used as anchor is missing valid Alt text	25	32	57
Perceivable	1.3.1	input element, type of“text”has no text in label	16	24	40
Perceivable	1.3.1	input element, type of“text”, missing an associated label	18	26	44
Perceivable	1.3.1	input element, type of“checkbox”, has no text in label	0	19	19
Perceivable	1.3.1	input element, type of“radio”, has no text in label	0	4	4
Perceivable	1.3.1	Form missing fieldset and legend to group multiple radio buttons	0	5	5
Perceivable	1.3.1	select element missing an associated label	0	24	24
Perceivable	1.3.1	Label text is empty for select element	0	1	1
Operable	2.1.1	onmousedown event missing onkeydown event	1	0	1
Operable	2.1.1	script not keyboard accessible - onmouseout missing onblur	0	1	1
Operable	2.1.1	onmouseover event handler missing onfocus event handler	0	1	1
Operable	2.4.2	Document missing title element	1	0	1
Operable	2.4.2	title element is empty	3	1	4
Operable	2.4.4	Anchor contains no text	34	39	73
Understandable	3.1.1	Document language not identified	3	3	6
Understandable	3.1.1	Document has invalid language code	1	3	4
Understandable	3.3.2	Label text is empty	29	53	82
Understandable	3.3.2	input element has more than one associated label	1	0	1
Robust	4.1.1	id attribute is not unique	9	6	15

5 Discussion

This study investigates the accessibility of E-government websites, which serve as critical gateways for citizens to access government services. The importance of these websites has been amplified in recent times, particularly during the COVID-19 pandemic, where online service delivery has become increasingly prevalent. Ensuring accessibility for these websites is paramount to guarantee that all citizens, regardless of ability, can effectively utilize these essential government resources. Our findings expand the understanding of accessibility challenges in E-government websites by evaluating a sample of 64 US government websites from various ministries against WCAG 2.2 guidelines.

Table 7 A list of the most common known accessibility problems according to the AChecker tool, Level AA

Category	Guideline	Success criteria	No. of errors	No. of errors(33-64)	Total errors(Final)
Perceivable	1.1.1	img element missing alt attribute	10	13	23
Perceivable	1.1.1	Image used as anchor is missing valid Alt text	22	30	52
Perceivable	1.3.1	input element, type of"text", has no text in label	15	21	36
Perceivable	1.3.1	input element, type of "text", missing an associated label	17	18	35
Perceivable	1.3.1	input element, type of"checkbox", has no text in label	0	9	9
Perceivable	1.3.1	Input element, type of "radio", has no text in label	0	4	4
Perceivable	1.3.1	Form missing fieldset and legend to group multiple radio buttons	0	5	5
Perceivable	1.3.2	The contrast between the colour of text and its background for The element is not sufficient to meet WCAG2.0 Level AA	10	63	73
Perceivable	1.3.2	The contrast between the colour of visited link text and its background For the element is not sufficient to meet WCAG2.0 Level AA	0	3	3
Perceivable	1.3.2	The contrast between the colour of active link text and Its background is not sufficient to meet WCAG2.0 Level AA	0	15	15
Perceivable	1.3.2	The contrast between the colour of selected link text and its background is not sufficient to meet WCAG2.0 Level AA	0	2	2
Perceivable	1.4.4	i (italic) element used	28	95	123
Perceivable	1.4.4	b (bold) element used	6	24	30
Operable	2.1.1	onmousedown event missing onkeydown event	1	0	1
Operable	2.1.1	Script not keyboard accessible - onmouseout missing onblur	0	1	1
Operable	2.1.1	Onmouseover event handler missing onfocus event handler	0	1	1
Operable	2.4.2	Document missing title element	1	2	3
Operable	2.4.2	title element is empty	3	1	4
Operable	2.4.4	Anchor contains no text	36	37	73
Operable	2.4.6	Header nesting	21	9	30
Understandable	3.1.1	Document language not identified	2	2	4
Understandable	3.1.1	Document has invalid language code	2	1	3
Understandable	3.3.2	Label text is empty	18	12	30
Understandable	3.3.2	input element has more than one associated label	1	0	1
Robust	4.1.1	id attribute is not unique	9	5	14

Our analysis of US E-government website accessibility revealed a possible association between increasing conformance levels and a higher detection rate of accessibility errors. This finding suggests that while these websites may achieve a basic level of accessibility compliance, they might not be fully optimized for users with disabilities.

We found varying levels of compliance with WCAG 2.2 standards in US E-government websites. While some websites achieved successful validation for specific criteria, a significant number exhibited accessibility issues. Tools identified errors related to missing document titles, lack of alternative text for images, and presence of empty links and buttons. These errors can hinder usability for users with disabilities, particularly those relying on assistive technologies.

We also identified several accessibility barriers that could significantly impact users with disabilities. Violations of WCAG 2.2 POUR principles were found. The most prevalent issues fell under the Perceivable principle, potentially creating barriers for users in perceiving information. Most common issues include missing alternative text descriptions for images, insufficient color contrast between text and background elements, or unclear website layouts that make content organization difficult to grasp.

Operable principle violations were also identified which can potentially impact user interaction with the websites. These involved the absence of keyboard navigation functionality for users who rely on it, a lack of clear focus indicators for interactive elements, and overly complex forms without proper instructions for completion.

Furthermore, the analysis identified violations of the Understandable principle. This could manifest as missing document titles, the use of ambiguous language that is not easily understood, and the presence of jargon without proper definitions, all of which can create difficulties for users in comprehending the information presented on the websites.

Table 8 Occurrence of type of errors detected by AChecker in US E-government websites

Achecker	Result	Known			Likely			Potential		
ID		A	AA	AAA	A	AA	AAA	A	AA	AAA
1	F	0	5	5	0	284	101	260	284	289
2	P	0	0	0	0	0	0	35	37	39
3	F	1	1	1	16	16	67	212	229	234
4	F	37	25	25	1	1	126	268	302	307
5	F	17	15	15	2	2	277	406	448	453
6	F	0	5	5	0	0	120	372	391	410
7	F	15	15	15	0	0	269	490	524	529
8	F	1	1	1	0	0	1343	1409	1428	1434
9	P	0	0	0	0	0	1	96	99	104
10	F	7	7	7	0	0	38	278	314	320
11	P	0	0	0	0	0	115	206	261	267
12	F	3	6	6	5	5	219	355	363	373
13	F	7	7	7	0	0	114	290	318	323
14	F	6	4	4	0	0	191	304	347	357
15	F	15	20	20	1	1	73	166	181	186
16	F	15	10	10	1	1	171	166	310	316
17	F	2	0	2	0	0	113	244	298	304
18	F	1	3	3	0	1	178	342	361	388
19	F	0	1	1	0	0	119	273	306	312
20	F	22	28	22	0	0	0	580	624	580
21	F	5	15	15	4	4	376	655	679	685
22	F	4	4	4	0	0	36	162	174	183
23	P	0	0	0	0	0	97	185	222	159
24	F	4	3	3	0	0	218	43	472	478
25	P	0	0	0	0	0	309	396	438	443
26	F	0	1	1	0	0	183	420	431	436
27	F	6	13	13	8	8	100	288	326	332
28	F	0	1	1	0	0	183	420	431	436
29	F	7	7	7	0	0	1126	1404	1482	1487
30	F	3	3	3	0	0	77	292	320	325
31	F	1	1	1	5	5	349	603	674	680
32	F	1	5	5	1	1	31	108	121	126
33	F	10	24	24	1	1	48	165	184	183
34	P	0	0	0	0	0	0	107	109	111
35	F	7	22	22	0	0	265	456	504	509
36	F	101	117	117	2	2	177	754	842	847
37	F	6	4	4	64	64	325	836	853	794
38	F	31	33	36	3	3	118	245	278	284
39	F	1	1	1	0	0	65	183	201	208
40	F	4	4	4	0	0	95	249	277	280
41	P	0	0	0	3	3	142	244	270	276
42	F	8	8	8	243	243	241	880	902	662
43	F	0	2	2	0	0	41	106	118	123
44	F	22	28	28	3	3	261	398	489	494
45	F	12	18	18	2	2	225	406	443	448
46	P	0	0	0	0	0	0	29	32	37
47	F	0	2	2	0	0	73	153	187	192
48	P	0	0	0	0	11	33	239	242	248
49	P	0	0	0	0	0	83	160	214	220

Table 8 (continued)

Achecker	Result	Known			Likely			Potential		
ID		A	AA	AAA	A	AA	AAA	A	AA	AAA
50	F	2	2	2	0	0	85	231	298	314
51	F	4	9	9	1	1	143	255	285	291
52	F	3	14	14	0	0	72	165	195	201
53	F	7	18	18	2	2	99	259	275	283
54	F	3	4	4	0	0	101	205	224	236
55	F	0	9	9	0	0	28	105	117	123
56	F	9	11	11	1	1	236	319	349	356
57	F	3	3	3	0	0	59	212	246	251
58	F	1	10	10	0	0	246	432	450	456
59	F	6	21	21	0	0	99	246	272	281
60	F	1	2	2	0	0	26	107	121	126
61	F	10	81	191	1	1	171	650	717	722
62	F	8	8	8	1	1	342	436	467	476
63	P	0	0	0	0	0	100	184	199	204
64	F	2	5	5	0	0	86	353	373	379

Table 9 WAVE tool error analysis

Error type	No. Errors(1-32)	No. Errors(33-64)	Total	Error %
Empty form label	13	12	25	7.49%
Missing form label	30	23	53	15.87%
Multiple form labels	4	2	6	1.80%
Broken ARIA reference	30	23	53	15.87%
Linked image missing alternative text	4	3	7	2.10%
Spacer image mising alternative text	1	0	1	0.30%
Image map missing alternative text	3	3	6	1.80%
Missing form label	1	0	1	0.30%
Missing alternative text	23	17	40	11.98%
Language mising or invalid	6	3	9	2.69%
Empty Button	45	19	64	19.16%
Empty link	34	23	57	17.07%
Empty heading	6	5	11	3.29%
Broken skip link	1	0	1	0.30%

The Robust principle was also violated with recorded issues with duplicate ID attributes within web pages. Such issues can lead to errors in how assistive technologies interpret the website structure, ultimately hindering user experience for those who rely on these assistive technologies.

Observed consistency of errors across webpages within a website suggests potential use of website templates. This highlights the importance of prioritizing accessibility during the initial development stages and implementing accessibility best practices throughout website creation. Additionally, the prevalence of errors related to missing alternative text and ARIA elements emphasizes the need for developers to be aware of these crucial accessibility features and integrate them into website design.

The findings suggest a need for increased focus on accessibility in E-government website development. Implementing WCAG 2.2 guidelines can significantly improve the user experience for individuals with disabilities.

5.1 Considerations for accessibility improvement in *E*-government websites

The findings of this study offer valuable insights for E-government website developers, designers, and policymakers. The analysis revealed that a significant number of websites exhibited accessibility issues based on WCAG 2.2 standards. These issues create barriers for users with disabilities, hindering their ability to access information and utilize government services effectively. The results suggest that

Table 10 Frequency of accessibility errors detected by WAVE

	WAVE					
Website ID	Errors	Alerts	Features	Struc. elements	HTML5 &ARIA	Contrast errors
1	2	5	29	31	98	3
2	1	9	3	20	4	1
3	6	24	11	20	43	0
4	8	22	12	36	21	2
5	0	38	16	68	49	4
6	0	31	38	46	13	7
7	2	49	33	60	87	1
8	3	6	10	293	4511	7
9	0	4	19	192	709	1
10	9	11	4	70	7	2
11	1	42	17	63	15	0
12	0	14	53	34	63	10
13	0	5	20	38	59	0
14	4	110	11	53	220	10
15	0	5	22	23	0	1
16	0	12	15	49	72	6
17	0	7	24	81	69	0
18	0	20	27	21	3	1
19	0	18	20	52	61	0
20	0	103	63	53	40	20
21	19	49	39	55	92	3
22	1	18	17	9	1	0
23	0	15	17	54	9	1
24	0	35	41	55	27	19
25	1	62	24	79	337	5
26	0	36	147	118	232	12
27	0	20	29	35	25	2
28	0	8	22	59	22	6
29	9	105	40	425	799	12
30	0	4	19	38	22	2
31	2	26	22	109	38	11
32	0	2	8	20	15	0
33	5	5	8	25	15	53
34	2	8	19	46	66	0
35	21	72	67	114	118	0
36	11	181	475	85	401	3
37	3	18	24	209	600	12
38	16	17	13	60	1	80
39	0	16	12	18	9	2
40	4	11	21	36	55	5
41	0	3	18	43	122	0
42	6	23	19	15	0	13
43	0	4	8	11	2	23
44	11	200	11	132	63	22
45	3	25	27	64	96	3
46	1	6	19	38	74	0
47	1	5	7	38	5	0
48	5	16	9	167	439	6
49	1	38	5	70	113	0

Table 10 (continued)

	WAVE					
Website ID	Errors	Alerts	Features	Struc. elements	HTML5 &ARIA	Contrast errors
50	8	10	15	77	16	23
51	5	6	18	57	49	4
52	0	37	13	37	99	0
53	6	35	23	38	98	0
54	3	65	17	32	0	0
55	0	25	11	50	520	0
56	4	41	44	59	132	5
57	2	31	32	44	107	3
58	4	2	21	63	37	105
59	2	38	9	42	65	7
60	1	11	7	28	63	0
61	0	91	135	83	96	1
62	0	36	9	22	27	0
63	9	14	11	97	14	4
64	0	66	41	23	7	2

accessibility features are not consistently prioritized during the design and development phases of E-government websites. To address this gap, several considerations are recommended, as discussed in the following.

Integration of accessibility features. E-government websites should integrate essential accessibility features from the outset of development. This includes providing equivalent text for non-text content such as images, incorporating descriptive labels, and assigning unique IDs to web pages.

Label all form elements. Ensuring accessibility in E-government website forms requires consistent labeling of all input elements such as text, checkbox, and radio elements. These labels should provide clear and concise descriptions of the information users are expected to enter. Established web development practices dictate this association. The implementation can be achieved by strategically nesting labels within the form structure or through alternative methods supported by the chosen development framework.

Visual Considerations. Font selection and color contrast are crucial for ensuring readability for users with visual impairments. Utilizing appropriate fonts with sufficient size and maintaining a clear contrast between text and background colors are essential and recommended practices.

Usability Testing. Regular website audits and usability testing should be considered. Users with disabilities should be incorporated into the testing process. This allows for the identification and rectification of accessibility barriers that may not be apparent through automated testing tools.

Semantic Use of HTML. We recommend that developers consider semantic HTML elements to structure content meaningfully. This foundation enables assistive technologies to interpret the content and relationships between elements effectively.

ARIA for enhanced accessibility. ARIA can enhance the user experience for individuals with disabilities by clarifying the functionality of interactive elements or describing complex content layouts. Therefore, we recommend that developers utilize ARIA attributes strategically to provide additional information on assistive technologies.

Valid code ensures accessibility. Well-structured HTML and CSS code ensures proper interpretation by assistive technologies and screen readers for people with varying abilities and also improves website performance. The developers should consider maintaining the HTML and CSS code structure by identifying potential coding errors or inconsistencies that could hinder the accessibility of the website. We recommend that the developers implement CSS effectively to style content without compromising accessibility and ensure sufficient color contrast between text and background. The developers should avoid relying solely on color to convey information. Moreover, developers should regularly validate HTML and CSS code using automated tools to identify and rectify potential accessibility barriers stemming from coding errors or non-optimal practices.

Prioritize WCAG 2.2 compliance. WCAG 2.2 is the latest accessibility guideline set by the W3C, which outlines various checkpoints for achieving accessible web content. Developers are recommended to evaluate E-government websites against WCAG 2.2 and address WCAG conformance issues through code corrections and design modifications, which significantly improve accessibility for diverse user groups.

Integration throughout development. Accessibility considerations should be integrated throughout the entire development lifecycle of E-government websites, not just as an afterthought during the final testing stages. Developers and

Table 11 Frequency of accessibility errors detected by Total Validator

ID	Total validator			HTML Val.	CSS Val.	ID	Total validator			HTML Val.	CSS Val.
	A	AA	AAA				A	AA	AAA		
1	67	7	0	34	13	33	13	0	1	14	11
2	4	1	0	4	46	34	13	10	0	20	49
3	14	4	0	38	5	35	273	9	0	193	14
4	33	3	0	11	7	36	61	70	1	29	18
5	31	6	0	24	11	37	10	3	0	8	30
6	5	0	0	5	18	38	34	0	2	6	16
7	18	4	0	55	7	39	9	0	0	8	5
8	37	1	0	5	16	40	10	2	0	39	5
9	4	15	0	3	8	41	4	4	0	14	11
10	20	1	0	45	93	42	17	3	0	46	0
11	5	0	0	4	14	43	3	0	0	5	2
12	71	0	5	0	0	44	20	1	1	44	13
13	7	5	0	1	19	45	22	23	0	154	69
14	8	0	0	123	7	46	1	1	0	1	11
15	3	0	0	1	2	47	5	4	0	2	13
16	27	6	0	51	23	48	7	0	0	37	8
17	1	2	0	34	13	49	41	0	0	15	41
18	8	5	0	24	7	50	10	3	0	17	21
19	5	1	0	3	80	51	10	0	0	25	10
20	69	1	0	49	74	52	19	2	0	14	38
21	22	1	0	73	23	53	40	1	0	5	3
22	6	2	0	22	8	54	7	0	0	5	26
23	8	5	0	5	5	55	20	0	0	7	4
24	25	2	0	38	5	56	111	2	0	58	11
25	1	1	0	1	37	57	49	1	0	29	11
26	18	3	0	16	39	58	10	3	0	10	23
27	12	1	0	3	1	59	23	1	0	58	64
28	18	3	0	13	2	60	30	1	0	39	1
29	3	3	0	16	65	61	50	2	1	69	61
30	17	2	0	58	22	62	6	2	1	38	50
31	40	0	0	47	15	63	30	3	0	18	6
32	0	0	0	6	0	64	27	2	0	47	28

designers should be trained on WCAG 2.2 guidelines and best practices for accessible web development. Accessibility audits should be conducted at various development phases to identify and address accessibility issues in the early stages and prevent difficulty in usage for people with disabilities.

By implementing these recommendations and adhering to WCAG 2.2 guidelines, E-government websites can become more inclusive and accessible for all citizens, regardless of their abilities. This fosters a more equitable online environment where everyone can effectively interact with government services.

6 Limitations & future work

This study employed automated testing tools, including Achecker, WAVE, and Total Validator, to assess website accessibility. Although valuable insights are provided by these tools, their performance varies and may affect the results. To mitigate this potential bias, we utilized three well-known tools with documented reliability and accuracy in accessibility error detection. This multi-tool

approach aims to reduce the impact of any single tool's limitations on the overall findings.

Additionally, the sample size can influence the generalizability of results. To address this, we analyzed a substantial sample of 64 E-government websites encompassing various government sectors. This broader sampling frame strengthens the generalizability of the findings to the broader population of E-government websites.

Accessibility concerns and user experiences may differ significantly across website categories compared to E-government websites. The focus of this study is on E-government websites, which can limit the generalizability of the findings to other website types. Future research can explore accessibility challenges in a broader range of website domains.

Furthermore, the analysis focused on US E-government websites. Accessibility regulations, cultural considerations, and website design trends can vary across different countries. This limits the direct applicability of the findings to E-government websites in other geographical regions. Future studies can benefit from including websites from a wider range of countries to provide a more comprehensive understanding of global E-government website accessibility.

7 Conclusion

This study evaluated the accessibility of US E-government websites using established automated tools against WCAG 2.2, a widely recognized standard for web content accessibility. The analysis concentrated on Level A and Level AA conformance levels, representing the minimum and recommended accessibility benchmarks. The evaluation revealed a concerning prevalence of accessibility issues across the websites evaluated. These issues spanned the core principles like perceivable content, operable user interface, and understandable content, potentially hindering the user experience of individuals with disabilities. Our observations suggest a potential correlation between higher conformance levels and a greater number of accessibility errors identified on US E-government websites. This might indicate that while US E-government websites achieve a baseline level of accessibility, they may not be fully compliant with accessibility standards. Therefore, we infer that accessibility considerations may not have been adequately prioritized during the design and development phases of these websites.

Limited accessibility can significantly impede the ability of users with disabilities to interact with and utilize E-government services. Addressing these accessibility shortcomings is crucial for ensuring inclusive access to E-government services for all citizens

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Declarations

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