How digitally advanced is your digital public health system? A narrative review of indicators published as grey literature

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Abstract

Background: Revealing the full potential of digital public health (DiPH) systems requires a wide-ranging tool to assess their maturity and readiness for emerging technologies. Although a variety of indices exist to address digital health systems, questions arise regarding the integration of indicators on information-communication-technology maturity and readiness, digital (health) literacy, and interest in DiPH tools by the society and workforce, as well as the legal maturity and readiness of digitalized health systems. Existing tools frequently target one of these domains while overlooking the others. Additionally, no review has been conducted to holistically investigate available national DiPH system maturity and readiness indicators using a multidisciplinary lens.

Objective: Applying a narrative review, we aimed to map the landscape of DiPH system maturity and readiness indicators published in the grey literature.

Methods: As original indicators were not published in scientific databases, we applied pre-defined search strings to DuckDuckGo.com and Google.com for 11 countries from all continents classified as having reached level 4 of 5 in the latest Global Digital Health Monitor evaluation. Additionally, 19 international organizations (such as the World Health Organization, World Bank, or International Telecommunication Union) were searched for maturity and readiness indicators concerning DiPH.

Results: Of the 1484 identified references, 137 were included and named 15806 indicators (2129 after assessment for eligibility and duplication screening). We deemed 286 indicators from 90 references relevant for DiPH system maturity and readiness assessments. Most of these (133) had a legal background, and the fewest (37) were related to social domains. Although most indicators focused on clinical and healthcare-related topics, we identified indicators for various DiPH settings and issues, including data protection, literacy, infrastructure, empowering vulnerable groups, health promotion, public health surveillance, and workforce preparedness.

Conclusions: Our work is the first to comprehensively analyze the gray literature on maturity and readiness assessments from multidisciplinary perspectives. By this, we contributed towards a more holistic understanding of DiPH and justify why such a perspective is essential when conducting evaluations of digital healthcare systems to effectively leverage digital technologies to optimize public health goals and functions. Although new methods for systematically researching grey literature are needed, our study holds the potential to develop more comprehensive tools for DiPH system maturity and readiness assessments. Further examination is required to analyze the suitability and applicability of all identified indicators for diverse healthcare settings. By working towards a uniform evaluation of DiPH system maturity and readiness, we foster informed decision-making among healthcare planners and practitioners to improve resource distribution and continue to drive innovation in healthcare delivery.

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Abstract

Background: Revealing the full potential of digital public health (DiPH) systems requires a wide-ranging tool to assess their maturity and readiness for emerging technologies. Although a variety of indices exist to address digital health systems, questions arise regarding the integration of indicators on information-communication-technology maturity and readiness, digital (health) literacy, and interest in DiPH tools by the society and workforce, as well as the legal maturity and readiness of digitalized health systems. Existing tools frequently target one of these domains while overlooking the others. Additionally, no review has been conducted to holistically investigate available national DiPH system maturity and readiness indicators using a multidisciplinary lens.

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Keywords: digital public health; health system; indicator; interdisciplinary; information-communication-technology; maturity assessment; readiness assessment; narrative review; grey literature; digital health

Introduction

Background

The digital transformation of systems throughout society, particularly within health systems, has substantial implications for public health [1, 2]. Practitioners and researchers agree that the digital transformation of healthcare systems can potentially shift health services from curative to preventive services that promote equity and optimal health outcomes within communities [3, 4]. This shift, facilitated by the digital transformation of public health systems, is an opportunity to address long-standing public health challenges like rising healthcare costs, aging populations, and human resource shortages [5, 6]. Public health systems include not only the traditional healthcare delivery system but also governmental public health agencies, academia, and additional sectors that are engaged in health activities such as social care or schools. As such, they broaden the clinical understanding of health systems [7]. However, national governments, non-governmental organizations, and intergovernmental organizations, including the World Health Organization (WHO), have created comprehensive strategies to facilitate the digital transformation of health systems [8, 9], unlike more holistic public health systems. These strategies aim to reorganize health services and operations to deeply integrate digital technologies at every level of healthcare [10]. While these strategies have broadly explored the digital transformation of health systems, there is increasing recognition of the opportunities and challenges of this process, specifically in terms of public health services and functions. The recognition has led to the emergence of digital public health (DiPH) as a critical focus area [10-12].

Built on public health, which is the “science and art of preventing disease, prolonging life and promoting, protecting and improving health through the organized efforts of society” [13], DiPH is not considered a new discipline but considers digital transformation as “an asset [the public health] community has to [fulfill] its aims and mission” [4]. It leverages digital technologies to achieve public health system goals of quality, accessibility, efficiency, and healthcare equity with a population health impact [4, 14]. DiPH tools are, as a result of this, public goods, accessible to and/or beneficial to different social groups without charges, including health-specific hardware and software applications for recording, monitoring, evaluating, and intervening to optimize specific health parameters at a population, community, and global health level [15]. Specific challenges must be considered to effectively facilitate the digital transformation of public health and achieve public health goals. First, DiPH is inherently interdisciplinary, involving many stakeholders within and outside the health sector who must navigate ethical, legal, financial, regulatory, and infrastructure issues at scale to effectively leverage digital transformation to ensure public health goals [16].

Moreover, widespread digital transformation within public health systems leads to inherent technological and healthcare complexities that must be reconciled with the complex interplay of intra- and inter-jurisdictional socio-political, economic, and technical contexts that influence public health outcomes. Incorporating digital transformation strategies as a priority on the agendas of national governments and international organizations creates opportunities and challenges that will reshape the rules of engagement and the ways of working and interacting for organizations and institutions in the health sector [1]. However, DiPH goes beyond the application of tools for public health functions. It addresses the growing role of digital technologies as an environment for enacting health promotion and protection and the role of DiPH in managing the public health risks of the widespread uptake of digital technologies [17, 18]

Current status of digital maturity and readiness measurement approaches

To effectively consolidate digital transformation strategies for DiPH, we must understand how digital

technologies are used within public health systems to deliver high-quality services and the capacity of such systems to adapt and integrate new information and communications technologies (ICT). For these assessments, digital maturity or readiness can be evaluated. Both concepts are often used interchangeably in the literature. However, it is important to distinguish between both concepts. Digital maturity assesses the status quo of digital systems. It describes the current degree to which digital tools are used and how information technology (IT) systems are connected in the health system as enablers to allow high-quality healthcare [19-21]. Digital readiness evaluations, on the other hand, analyze the preparedness of systems for anticipated change brought by ICT developments to implement and leverage emerging digital technologies effectively [22]. Consequently, readiness is a multifactorial concept that includes domains such as social and organizational culture, policies, and human resources instead of focusing exclusively on investments in IT equipment or infrastructure [23]. Such assessments can inform the development of roadmaps for continuous innovation and sustainable integration of digital public health interventions to achieve public health goals (see Figure 1) [19, 24].

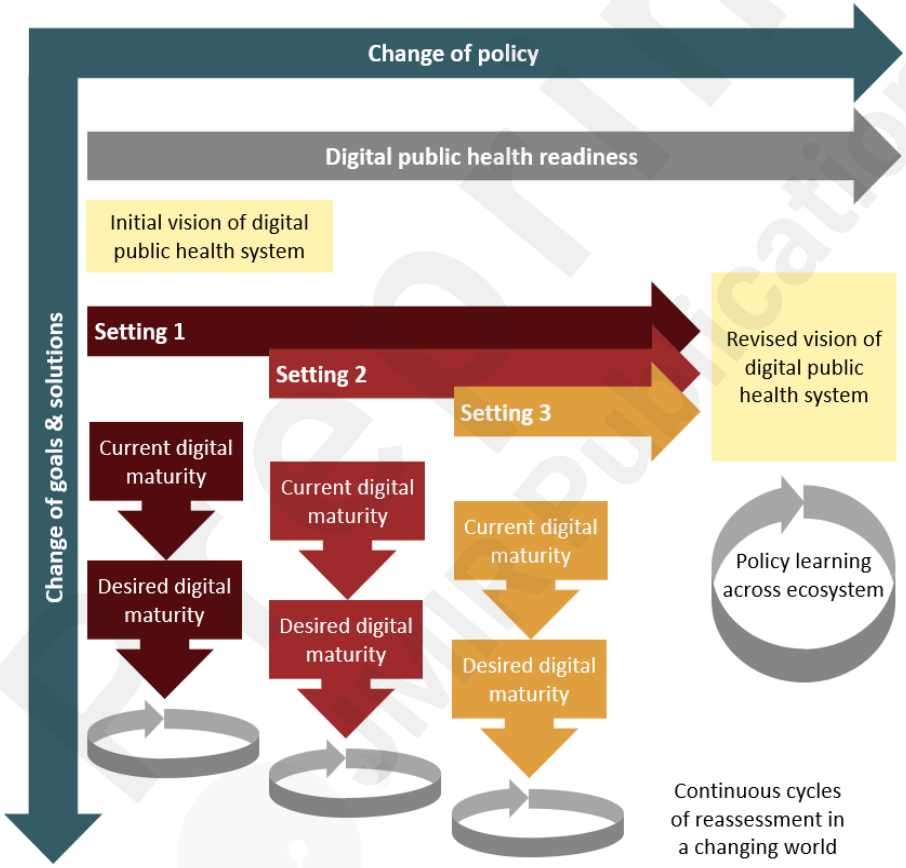

Figure 1. Reconceptualizing the digital maturity of public health systems. Adapted from Cresswell et al. (2019) and Yusif et al. (2017) [19, 22]

Existing indicators explore health systems' capacity for digital technologies in terms of leadership, workforce capacity, infrastructure, legislation, policy and compliance, standards and interoperability, and the existence of national strategies and investments in these technologies [25-27]. While they have been developed at least partially to evaluate the digital transformation of health systems, these indices do not effectively capture the far-reaching nature of DiPH, extending beyond clinical health services to consider social systems and other similar domains that significantly impact public health [15]. Where available within public health, these indices have only focused on the digital maturity of public health agencies and not public health systems within jurisdictions as DiPH requires [28]. Although these indices may embrace similar domains as existing tools, including focusing on having a digital transformation strategy, building employee capacity, and adapting processes and

infrastructure for digital transformation, their organizational focus may not necessarily translate to a system perspective relevant to DiPH [29]. Establishing indicators for DiPH systems maturity and readiness can help foster clear jurisdictional objectives for the digital transformation process, create benchmarks for evaluating progress across public health systems, ensure that digital transformation goals are realistic, and ensure continued engagement of local and national players in facilitating public health goals through this process [19].

Study aim and objective

It is necessary to conceptualize, operationalize, and define indicators to measure digital public health systems maturity and readiness (DiPHSMR). Measuring DiPHSMR though available well-defined indicators will support policymakers and researchers in measuring the progress of digital transformation and facilitate the identification of shortcomings within public health systems [20, 21]. Thereby, our study aims to select published and validated indicators for measuring DiPHSMR through a multidisciplinary approach according to their importance for such assessments. With this approach, we strive to complement the results of our previous Delphi study and integrate them into the current canon of DiPHSMR analysis [15].

Methods

Search strategy

We conducted a narrative review of gray literature on indicators for DiPHSMR. Our search strategy was collaboratively developed with librarians specialized in health, economics, political sciences, information and communications technologies, and public health. The strategy focused entirely on the gray literature, given our collective conclusion that indicators of interest were more likely to be published as organizational reports or in repositories like the indicator metadata registry list by the Global Health Observatory [30] rather than as peer-reviewed articles, which would be indexed in more traditional databases. Mahood et al. [31] similarly describe the importance of including gray literature for reviews on such practical topics. Our search strategy explored concepts highlighted in a previous Delphi study the authors conducted, identifying potential indicators for measuring national digital public health maturity [15]. The search terms were related to the four DiPH overarching domains:

1. The ICT requirements for nationwide rollout and usability of DiPH tools (ICT)
2. The legal framework and political support for regulating DiPH tools (Legal)
3. The general public’s and workforce’s willingness and capability to use DiPH tools (Social)
4. The degree of DiPH tool and service implementation in the health system (Application)

Literature search

We used 15 maturity-measurement tools from the Delphi study [15] that were previously identified and had included at least one developed indicator to decide on a suitable platform for the literature search. We aimed to identify these references by using pre-defined search terms and search strings (see Table 1). The complete search, including terms, date, and results, is documented in Multimedia Appendix 1 (pages 5-6). We piloted the search strategy among three search engines (DuckDuckGo.com, Google.com, and Scholar.Google.com) and three scientific databases (PubMed, Web of Science, and Ieee Xplore). However, only DuckDuckGo.com and Google.com listed all of the targeted references and were included as platforms for our search. The scientific databases did not contain any of the references as primary literature. While we identified some scientific articles that mentioned the maturity tools in the scientific databases or Google Scholar, these were merely secondary references and not the primary resource for the indicators. As we aimed to identify raw indicators directly from their providing bodies, we decided to include only DuckDuckGo and, where

needed due to geographical restrictions of DuckDuckGo, Google in our search. Unlike Google, DuckDuckGo does not collect its users' personal data and, therefore, claims to display the same results to every user, increasing the chance of reproducibility of our search results [32]. For all searches conducted with Google, a second author reran the searches and compared the first ten results for each term with the author who had performed the initial examination to assess the neutrality of the result display. This was given for all cases. The search was conducted from September to December 2023.

For the Google search, we turned off the personal results function, set the language of displayed results to English, German, Portuguese, or Spanish (as at least one author in the team can understand these languages fluently), and changed the geographical result location according to the specific country the search was conducted for. For DuckDuckGo, we only changed the geographical result location as the other options were unavailable during our search. As neither DuckDuckGo nor Google allow sophisticated search strings, we facilitated the search strategy and applied it to both search engines (see Table 1), following Godin et al. [33].

Table 1. Search Terms for DuckDuckGo

Digital Health and Public Health	Policy and data protection	Information - Communication - Infrastructure	Willingness and capability to use digital tools
- "digital health" index - health index - "public health" index - "mobile health" index - "electronic health" index - "healthcare access" index	- government index - cybersecurity index	- digital index - security digital index - ICT index - network index - connectivity index - - internet index	- "digital literacy" index - "digital health literacy" index - "health literacy" index

We applied the search strategy to the two biggest countries of each continent (from a population perspective) that had reached at least level 4 of the total five levels in the 2023 update of the Global Digital Health Monitor (GDHM) [34]. The GDHM is currently the most interdisciplinary and holistic tool to assess national digital health maturity and, therefore, the most suited orientation tool for our purposes. It tracks and evaluates the nationwide use of digital health globally and classifies countries based on 23 indicators into one of 5 phases of development (where the fifth phase is the most advanced) through seven domains (although data is not always provided for each domain per country): 1. Legislation, policy, and compliance, 2. Infrastructure, 3. Leadership and governance, 4. Strategy and investment, 5. Workforce, 6. Standards and interoperability, and 7. Services and application.

We assumed that the higher the GDHM score, the more relevant digital health and DiPH would be for a country. We further assumed that this would increase the chances that search algorithms would show DiPH-related topics and that we would be more likely to identify DiPHSMR indicators. For the Australian continent, we only included Australia. Neither Tanzania nor Ethiopia were available for Africa as search locations in DuckDuckGo. Consequently, Google was used to search for these two countries. Table 2 gives an overview of the selected countries.

Table 2. Overview of selected countries used for the search

Country	Global Digital Health Monitor Dimension								Population
	Overall	D1	D2	D3	D4	D5	D6	D7	
Canada	5	5	5	5	-	-	-	-	39 Million

USA	5	5	5	5	-	-	-	-	340 Million
Brazil	4	4	5	5	4	4	5	5	216 Million
Argentina	4	5	3	4	5	4	2	2	46 Million
United Kingdom	5	4	5	5	-	-	-	-	68 Million
Germany	5	5	5	5	-	-	-	-	83 Million
Ethiopia	4	3	4	4	3	5	3	3	128 Million
Tanzania	4	4	4	5	4	4	5	4	67 Million
India	4	4	3	3	-	-	-	-	1,428 Million
China	5	4	4	5	-	-	-	-	1,425 Million
Australia	5	5	5	5	-	-	-	-	26 Million

Source: Chukwu et al. (2023) [34]

To support our findings from the country search, we followed the approach by Godin et al. [33] and searched the websites of relevant international organizations [35-53]. These organizations were broadly recognized for engaging in at least one of the four domains we aimed to address in the project and had previously published indicators or indices on at least one of our defined DiPH domains. Each organization was hand-searched for indicators or indices not already identified through the initial country search. The identified website and the search date were documented for the country and the organization searches. Finally, we concluded a hand search among the reference lists of included publications to identify further indicators.

Screening process and eligibility criteria

Each search term was run by one author per country, leading to 11 searches per search term. Every author searched for one to four countries. The organization search was run by two authors individually. The investigations were run from 26 September to 15 December 2023. For the country searches, we screened only the first page of Google results (60 results) and the first three pages (80 results) for DuckDuckGo. We extracted all references that stated the terms index, indices, indicators, or indicators that had not already been extracted. Table 3 displays the screening inclusion and exclusion criteria.

Table 3. Inclusion and exclusion criteria of references

Inclusion criteria	Exclusion criteria
- Reference is available in English, Portuguese, Spanish, or German - Reference addresses at least one of the digital public health system maturity domains according to the Delphi study by Maaß et al. (2023) - Reference lists at least one concrete indicator applicable for measuring one domain of digital public health system maturity	- Reference uses the search term as a synonym for a glossary or registry - Search term is a company's, social media account's, or stock fund's name - Search term refers to a mathematical or informatics code - Reference does not mention specific indicators - Reference does not fit the topic according to the Delphi study [15]

Initially, all identified references were collected in a Microsoft Excel 2019 sheet. Each author independently decided on an initial inclusion- or exclusion of the publications based on our pre-defined criteria. Following the four-eye principle, another author screened all extracted references again for eligibility.

Data extraction

For each given indicator, provided by included references, we extracted the following information in a Microsoft Excel 2019 file:

- The reference title and link
- The name of the providing organization or author(s)
- The description and definition of the indicator
- The data source of the indicator

Due to the large number of included references, all indicators were extracted only by one author each. For data quality assurance, the indicators of a random 5% sample of the included references were extracted by another author to check for discrepancies. As this was not the case, we are confident that no selection bias impacted our approach.

Due to the vast number of indicators, we assessed for eligibility before cleaning for duplications. Two authors followed this approach, and conflicts were discussed between them. We pre-defined the following inclusion criteria based on the Delphi study [15], the Digital Integration Index [54], and the #SmartHealthSystems Index [55]: If an indicator was also mentioned in the Delphi study [15], it was automatically included. All other indicators:

- needed to be applicable for assessing the national system level instead of the individual people or institutions (such as hospitals),
- needed to be relevant for at least one thematic cluster in digital public health system maturity assessment,
- needed to be answered either through official national reports or expert opinions on Likert Scales,
- needed to be transparent in terms of their methodology and a trustworthy data source,
- must be consistent (so that the indicator can also be applied for future assessments),
- must use up-to-date data to display the current maturity of a national system,
- must use data sources that are freely and openly accessible.

The remaining indicators were then assessed by three authors for duplications and were combined if needed. A duplicate was defined as an indicator with the same terminology, definition, and data source. We then merged indicators that measured the same construct. Two authors independently clustered the remaining indicators across the four overarching DiPH domains and categorized them into smaller clusters based on targeted topics. Conflicts were resolved by discussion between both authors. Kohen’s Cappa was calculated to measure the strength of agreement between merging decisions [56].

For the final inclusion decision, all authors independently assessed the importance of the remaining indicators based on the pre-defined inclusion criteria and their expertise in DiPH. Every team member provided their decision on a four-point Likert Scale from 1 (not important) to 4 (very important). Indicators where at least 75% of all authors voted for 3-4 were included, while the other indicators were excluded. The selected indicators were then categorized by two authors independently, depending on whether they measured digital maturity, digital readiness, or both (based on the definition given above). We chose “both” as the final conclusion, where the authors decided differently. We summarized the identified indicators using a narrative synthesis and descriptive statistics as appropriate.

Results

Descriptive results of the screening clustering procedure for all indicators

The overall screening and indicator selection process is displayed in Figure 2. Of 13430 screened references from the country search, 1462 explicitly named terminology related to indicators (such as index, indices, indicator, or indicators). An additional 14 references were identified through the search on organization websites, and we identified eight more references through reference list searches among the other publications (red boxes in Figure 2). References stating at least one indicator were screened for eligibility, which resulted in 133 references naming 15806 indicators (orange boxes in Figure 2).

After assessing the suitability of the indicators and analyzing for duplications, the remaining 2129 indicators were clustered across the four overarching domains, with the majority of indicators being distributed to the Legal or Social domain. Kohen's Cappa for the overarching domains ranged between 85% and 95%, displaying almost perfect strength of agreement [56]. For the sub-domains, Kappa values ranged from 46% for Application to 96% for Legal, with an overall average Kappa of 77%, displaying substantial strength of agreement (yellow boxes in Figure 2). However, the clustering process was complicated due to missing indicator descriptions or data sources. In fact, only 40% of all initial indicators (6308/15806) provided a description, and even fewer listed their data sources (27%; 4292/15806).

Eventually, we considered 286 indicators (blue box in Figure 2) as essential to measure national DiPH system maturity and readiness.

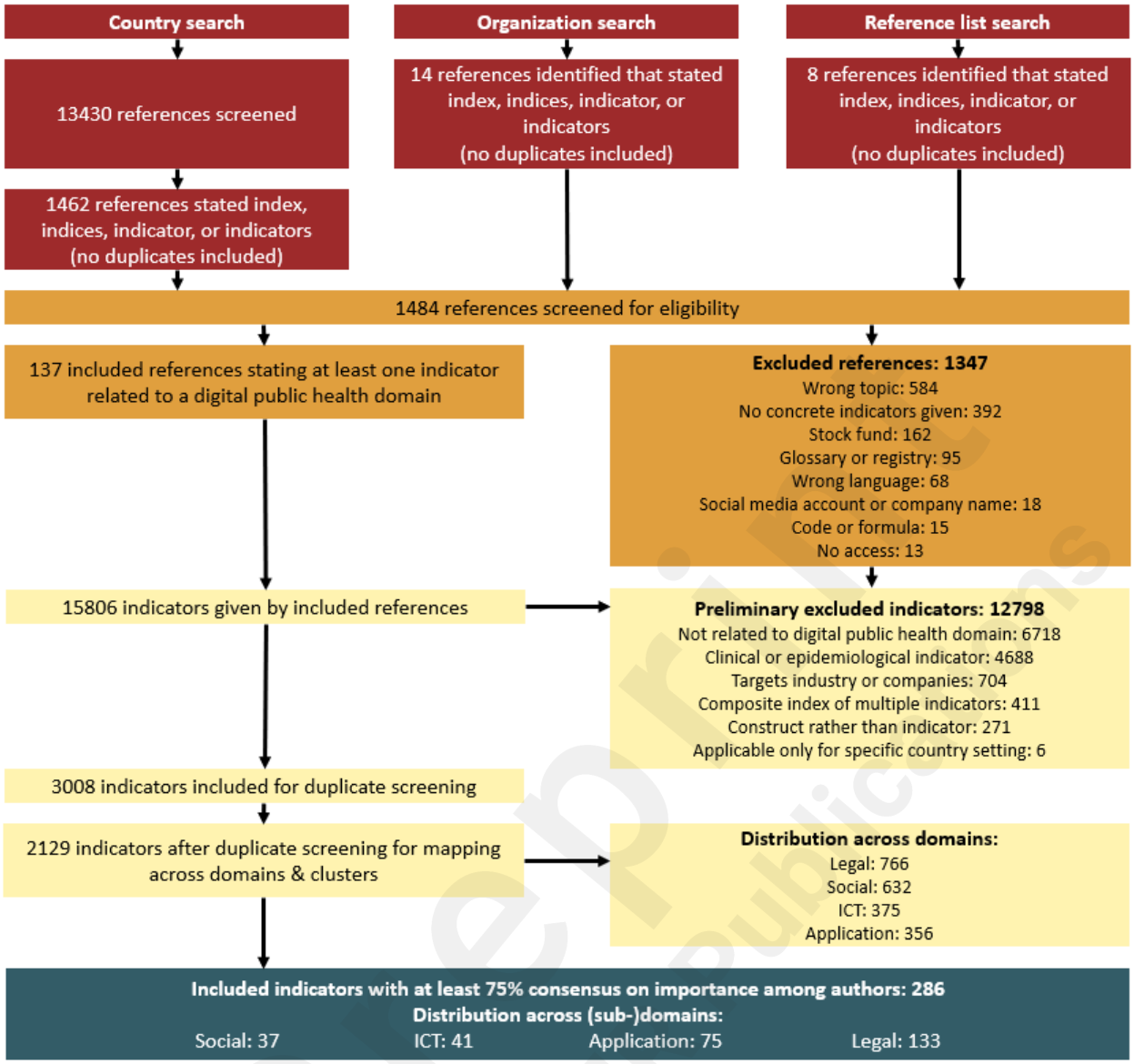

Figure 2. Screening and indicator selection procedure.

Distribution of indicators across domains

The selected indicators stem from 90 sources [26, 27, 34, 57-143]. Six references included at least one indicator per pre-defined domain [26, 27, 65, 69, 78, 79]. Most of the overall indicators came from a legal perspective (133/286), coming from only 27 different references [26, 27, 34, 57-80]. The second biggest indicator group were those targeting the application of DiPH interventions and services in healthcare and health promotion settings for which we identified 75 indicators from 29 sources [26, 27, 34, 57, 60, 62, 65, 67-69, 71, 72, 74-79, 81-91]. We also found 41 ICT indicators from 53 references [26, 27, 34, 58, 63-65, 67, 69-71, 76-79, 82, 84, 91-126], making the social dimension the smallest with 37 indicators provided by 49 sources [26, 27, 57, 58, 62-65, 69, 74, 75, 78, 79, 83, 84, 86-89, 94, 95, 98, 101, 104-106, 113, 114, 117, 118, 123, 124, 127-143].

Regarding maturity or readiness, we categorized 14 indicators as solely describing readiness towards emerging technologies. These included trust in emerging technologies such as AI from a Social perspective [27, 74, 83], but also having budget plans for new technologies with a population health impact [70] and national policies to promote the implementation of information exchange networks for the later uptake of DiPH interventions [78] with institutions or public bodies being responsible for the execution of such plans [26, 78]. By far the bigger group of indicators was categorized as measuring the system's current status, and thereby, its digital maturity (8/37 indicators of the Social

dimension, 11/41 for ICT, 42/75 for Application, and 49 or 133 Legal indicators). The remaining 162 indicators are applicable for both, maturity and readiness assessment as they define constructs that are important for the development phase as well as for paving the way for emerging technologies.
All indicators that we deemed essential for an assessment are displayed in Multimedia Appendix 2 (pages 1-4).

The Social dimension of digital public health maturity

We found the fewest unique indicators tracking DiPHSMR related to social willingness and capability to use DiPH tools, especially in healthcare (37/286). Most indicators were related to people's ability and capacity to use digital tools like electronic medical records, ePrescriptions, telemedicine, health apps, and health portals (Figure 3). We found indicators tracking *Trust, awareness, and motivation* to use DiPH tools among various populations. Indicators tracking trust explored trust concerning DiPH systems and the trust of governments and public entities supporting the development and deployment of these systems [27, 69, 83]. We also found indicators tracking peoples' use of devices, digital and internet services beyond healthcare [57, 58, 62, 69, 131, 140], as well as digital literacy [127, 131, 134, 136, 141, 143], identifying these as social issues with public health implications.

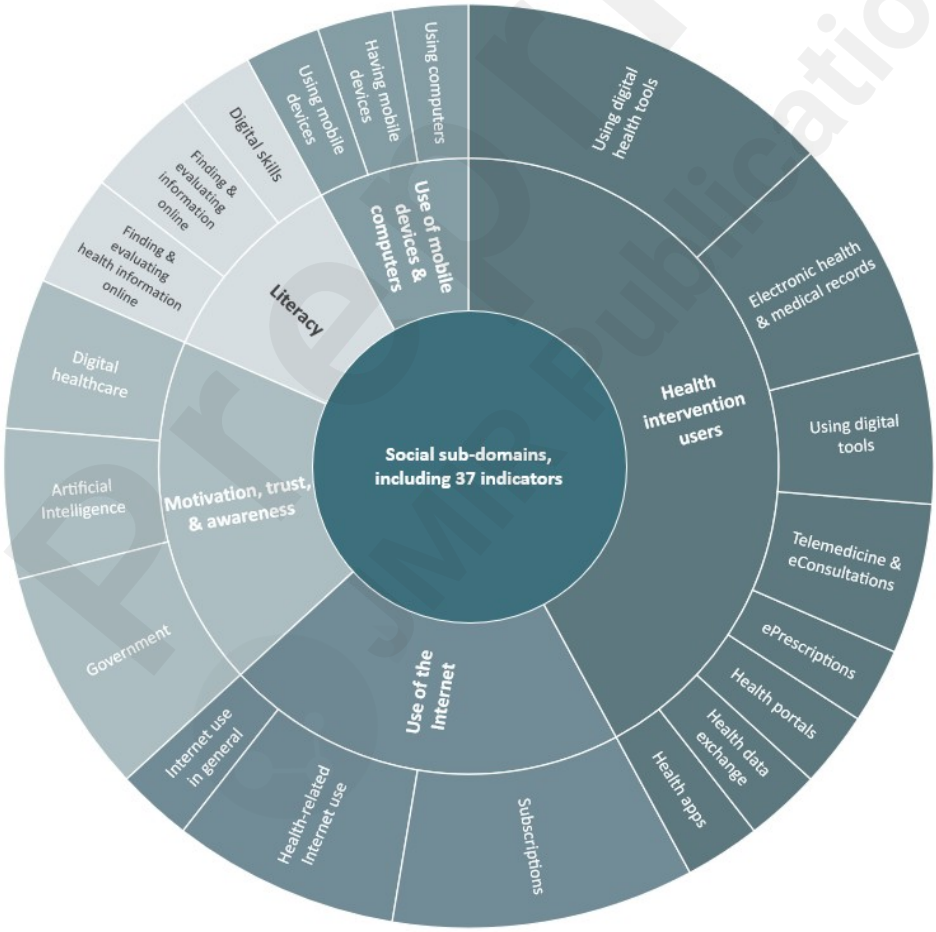

Figure 3. Social sub-domains, including indicators per indicator clusters.

The ICT dimension of digital public health maturity

Overall, 41 indicators tracked ICT systems' maturity and capacity as crucial enablers for DiPH implementation in health systems (Figure 4). Key indicators emphasized the need for the availability and accessibility of high-quality internet services [58, 78, 84]. They tracked the availability of mobile and fixed broad broadband services, the type of coverage across urban-rural divides [27, 58, 65, 84,

94, 96, 99, 104, 105, 114], and the availability of public Wi-Fi infrastructure [99, 103]. Similarly, indicators tracked the availability of digital infrastructure, including computers, at a population level and across different population groups [64, 92, 94, 95, 114, 123]. We also found indicators assessing the existence and level of implementation of infrastructure and interoperability standards, including standards for internet services [27, 71, 76, 109], electricity [79, 98], data governance and exchange (e.g., ISO standards) [27, 76, 109], and a general Artificial Intelligence (AI) infrastructure (e.g., computing and network capacity) [78, 104]. Further, we found indicators tracking investment in ICT infrastructure on a systems and population level. These include average individual or household costs of accessing internet services and acquiring digital devices alongside public or private investments in ICT infrastructure [63, 108, 113, 117]. We also found indicators assessing the workforce's capacity to deploy and leverage ICT infrastructure to advance public health outcomes as part of DiPHSMR [26, 34, 65, 76, 77, 91, 93].

Figure 4. ICT sub-domains, including indicators per indicator clusters.

The intervention Application dimension of digital public health maturity

Regarding indicators tracking the development and implementation of DiPH tools, we found 75 unique indicators (Figure 5). Indicator clusters included *Access to DiPH services* through digital tools like health portals, online booking systems and electronic health records [26, 34, 85]. We also found indicators tracking interventions to promote digital inclusion among historically marginalized groups [68, 69]. Similar indicators assess DiPH services' *Implementation* of health apps, social media, AI, and other data analytic tools [26, 27, 57, 65]. Additionally, we identified indicators tracking the *Secondary use of health data* from digitalized patient-facing systems for public health functions like disease surveillance and monitoring [26, 27, 57, 76, 79]. This subdomain also tracked the implementation of interoperable health information systems and unique identifiers to allow data

linkage across various public health systems to inform analyses and actions [65, 69, 77, 79].

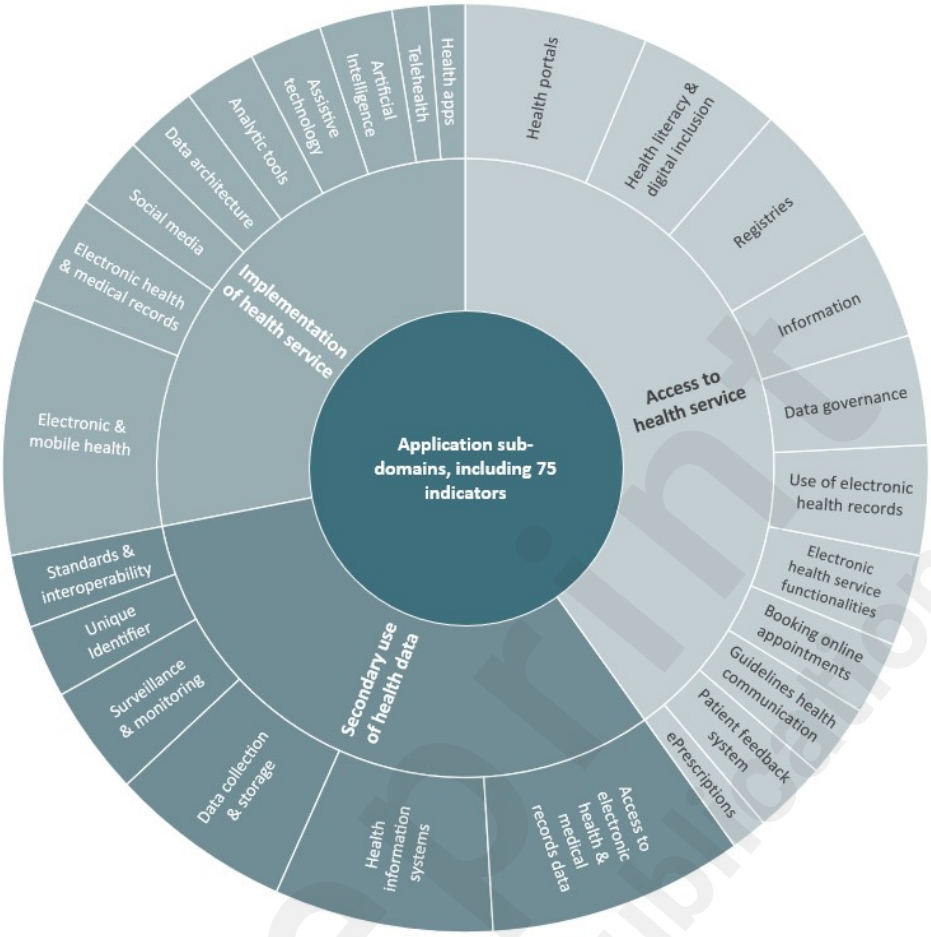

Figure 5. Application sub-domains, including indicators per indicator clusters.

The Legal dimension of digital public health maturity

Indicators tracking the legal and data protection regulations supporting the delivery of digital interventions dominate the literature (Figure 6). As only four indicators from 2 references explicitly mentioned public health [27, 79], it becomes evident that most of the identified 133 Legal indicators apply to digital health as the clinical sub-dimension of DiPH. Sub-domains tracked *Health data regulation*, including health data frameworks and strategies [26, 60, 65, 71, 76-79], ICT and data standards and interoperability regulations [65, 76, 79], data protection, governance, and cybersecurity [27, 78, 79]. Indicators in this domain also relate to regulating *Digital assets* for public health, such as medical devices [76, 79], health information exchange [26, 76, 79], health apps and portals [26, 64, 75-77], and cybersecurity [58]. Additionally, we found indicators tracking the existence of robust digital health and DiPH strategies [59, 67, 69], digital governance [34, 65], big data and AI [76, 79], and public health workforce capacity to leverage these DiPH tools effectively [67, 79].

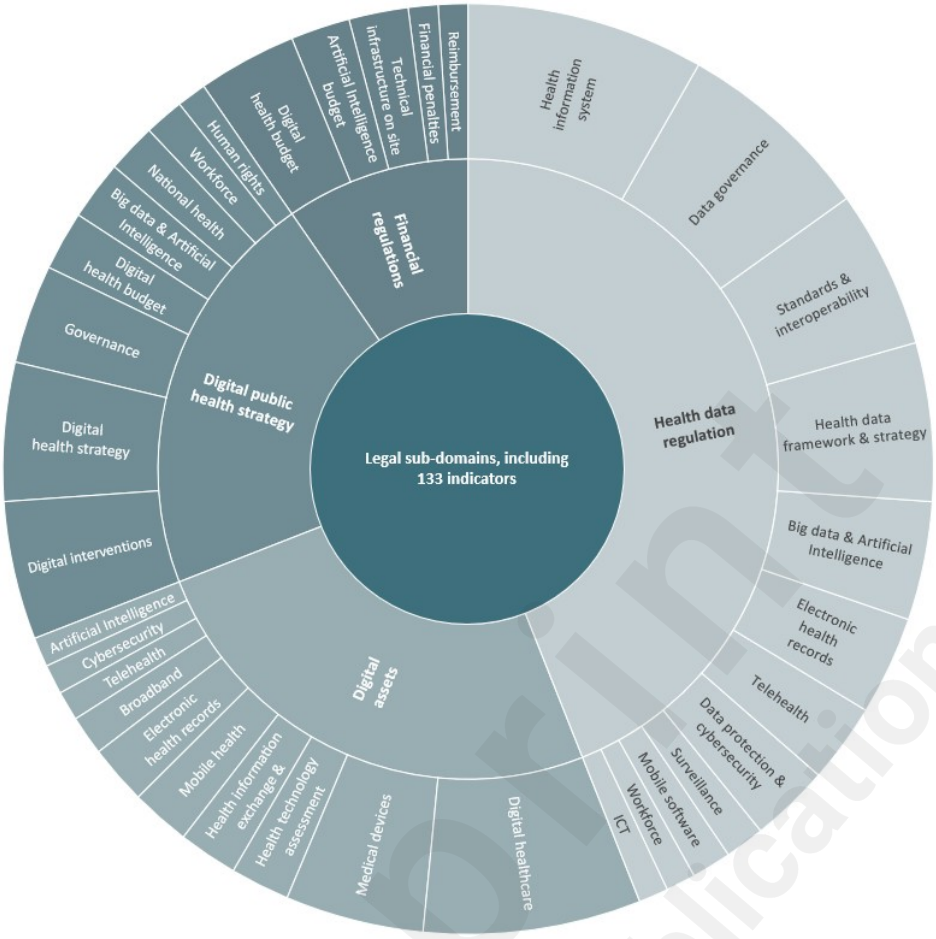

Figure 6. Legal sub-domains, including indicators per indicator clusters.

Discussion

Discussion of results

In this comprehensive review of existing indicators assessing the maturity and readiness of DiPH systems, we identified and described 286 unique indicators across four main domains. Among these were 37 Social, 41 ICT, 75 Application, and 133 Legal indicators describing potential DiPHSMR to leverage digital systems to advance public health goals. Unsurprisingly, the largest group of indicators (47%) was related to legal and data protection regulations, highlighting long-standing and potentially escalating concerns about the need for legal and regulatory frameworks to support effective development and deployment of DiPH interventions that can potentially support health for all ethically and responsibly [144].

This review extends the literature by comprehensively exploring the gray literature to outline potential indicators across four domains that could contribute to a holistic understanding of DiPHSMR. Findings from this review specifically complement those from a recent multidisciplinary Delphi study conducted by our team, which identified 96 indicators necessary to measure DiPH systems maturity. In the Delphi study, the proposed indicators overlapped with 48% of the indicators found in the published literature [15]. While experts' suggestions for DiPH indicators during the Delphi study implied the need for new DiPH indicators, our narrative review identified a significant number of developed and validated indicators applicable across various digital health and DiPH contexts. Nevertheless, the question remains about how far the identified indicators and those proposed during the Delphi study will be applicable for holistically assessing DiPHSMR for various countries.

Currently, many jurisdictions have undertaken digital health strategies or are creating such strategies

to leverage DiPH's opportunities to optimize public health outcomes adequately [9, 145, 146]. However, most of these strategies have not sufficiently considered perspectives unique to DiPH; instead, they have taken a clinical and healthcare-focused digital health perspective [17]. Findings from our narrative review extend the literature by having more Application-oriented indicators tracking the implementation of potential DiPH interventions, including leveraging electronic medical records to inform digital disease surveillance [27, 57, 81], using modern analytic techniques like AI as a core of public health systems [70, 77, 78], and having the capacity to leverage these tools for analyses and modern communication [75, 91].

Should we measure the systems' maturity or readiness?

The differentiated maturity and readiness assessment perspective has several implications for the identified indicators. Nevertheless, both are crucial for successfully implementing and advancing DiPH initiatives. Some of the identified indicators are more applicable to measure DiPH maturity, focusing on the current state and sophistication of the existing system. However, others relate to DiPH readiness, which explores the system's potential and preparedness to adopt and utilize emerging systems. For instance, *The percentage of households with a computer* [113] is a classical indicator to measure the current degree of digitalization and, therefore, the system's maturity. However, indicators like *The* p*ercentage of patients and physicians who are comfortable with AI being used as a tool in healthcare* [74] assess perspectives needed for the continuous development of DiPH systems (readiness assessment) as AI will play a more central role in health promotion, treatment, and surveillance in the following decades [147, 148].

Additionally, some indicators might be applicable for both constructs. For instance, *The percentage of the population who have achieved at least a minimum level of proficiency in digital literacy skills* [141] can describe the maturity of a current system as digital skills are needed to operate digital tools. However, the higher this percentage is and the higher the digital skills are, the more prepared a population will be to use emerging DiPH technologies.

While both concepts are theoretically distinct from each other, separating them in practice for assessments becomes challenging due to the fast-moving pace of the evolution of digital technologies in all sectors [9]. System evaluations like this take their strength from the ability to benchmark not only between systems but also for the same system across multiple years. Continuously measuring the readiness of a system requires regular updates in the evaluation methodology, limiting the comparison of results over years [82].

Strengths and limitations

This review has multiple strengths, including its multidisciplinary focus, being implemented by researchers with expertise across various fields of public health, including clinical public health, health systems and services research, and health informatics. To further ensure the comprehensiveness of the review, our search was conducted across multiple languages (English, German, Portuguese, and Spanish) instead of being restricted to one or two languages, as is commonly done. Further, this review leveraged a comprehensive approach to searching the gray literature, given indicators are not well captured or published in peer-reviewed journals. Lastly, several indicators were applied to multiple assessment tools, which increased our confidence in their importance.

However, we acknowledge the limitations inherent in the review. For example, using search engines like Google or DuckDuckGo limited the adoption of a complex search string and a systematic search. Although DuckDuckGo claimed to display the same results to every individual due to them not collecting personal data (unlike Google), which was proven by our test for the same results as explained in the Methods, there is still no guarantee that every person would have seen the same results as we did (known as "filter bubble"). Additionally, based on the ever-changing nature of files

and documents available on the Internet, lacking archives, and the rapidly changing website domains and websites, there is a risk that documents that were available during our screening might have disappeared or will eventually disappear [33]. This limits the reproducibility of our search and limits a review update. We are publishing this narrative review with our initially identified search results in Multimedia Appendix 1 to increase transparency. Further, screening all results retrieved from Google or DuckDuckGo was impossible. Therefore, we followed the assessment by Godin et al. (2015) [33], encouraging researchers to rely on the relevancy ranking in search engines and trust that the most important results will be displayed on the first pages. Unfortunately, DuckDuckGo does not display the total number of results per search (contrary to Google).

The assessment also includes a variety of limitations. Due to the broad nature of DiPH and its assessment, we identified too many indicators for a feasible content analysis. Additionally, we did not statistically test for indicators measuring the same construct. Further, the list of agreed-upon indicators needs to be validated by other researchers through an international and multidisciplinary Delphi study, such as we have previously conducted for new DiPH indicators [15].

Further research

This narrative review can only serve as a first step to setting ground for this relevant topic. The list of agreed-upon indicators by the authors needs to be validated by other researchers in the form of an international and multidisciplinary Delphi study, such as we have previously conducted for new DiPH indicators [15]. Combining both studies will result in a list of essential indicators for mapping maturity and readiness across DiPH systems. Further, statistical assessments must be conducted in case studies to identify indicators measuring the same construct. They must also be tested on various DiPH systems to assess their applicability to different settings. This procedure will most likely decrease the number of indicators and make their application in evaluation procedures more feasible.

Acknowledging that academic disciplines are increasingly becoming connected leads to interdisciplinary research and essential publications outside the classic peer-reviewed articles published in scholarly journals. Instead, research is increasingly published in other formats and is not necessarily listed in major scientific databases. We encourage researchers to conduct methodological research on how to incorporate grey literature in research projects and how to systematically assess this kind of literature to increase the study results' validity of such exercises.

Additionally, future research and public health policy-making must strive to prioritize the development and dissemination of well-defined, transparent indicators. These should include detailed descriptions and data sources to enhance their utility and reliability. Our study identified that only a minority of all indicators gave a definition, and even fewer published their data sources (see Multimedia Appendix 1, page 7). Establishing standardized guidelines for creating and reporting these indicators will not only improve their applicability but also foster greater consistency and comparability across different regions and studies. Such development is urgently needed for an impact in the evaluation of maturity and readiness of DiPH systems.

Conclusion

This narrative review aimed to explore and consolidate the various indicators used to measure national DiPH maturity and readiness. Through our extensive analysis, we identified 286 individual indicators that assess system maturity and readiness from multidisciplinary perspectives on topics such as digital literacy, adoption of DiPH interventions, data protection, system interoperability, investment in and regulation of DiPH interventions, and the necessary hardware and software infrastructure needed to use such tools. Further, our findings reveal a critical interdependence between readiness and maturity assessments: readiness evaluations cannot be effectively conducted without first understanding the maturity of the system. Hereby, maturity assessments provide valuable insights into a system's current capabilities. A significant issue uncovered during our review

is the lack of comprehensive descriptions and data sources for the vast majority of indicators. This deficiency hampers the applicability and transparency of these indicators, ultimately limiting their usefulness for policy-makers and public health researchers who rely on clear, detailed metrics to guide their decisions and strategies. As digital technologies continue to evolve, it is imperative that our methods for assessing DiPH systems keep pace, ensuring that we can accurately measure and enhance our preparedness for future challenges. By addressing these gaps and improving the robustness of our assessment tools, we can better support the advancement of DiPH initiatives worldwide, ultimately leading to more resilient and effective health systems. Finally, integrating readiness assessments with maturity evaluations will provide a more holistic view of DiPH systems, enabling more effective planning and implementation of interventions.

Acknowledgments

Author contributions

LM initiated and designed the study, developed the search strategy, conducted the literature search and screening, led the data extraction and analysis, participated in the final indicator selection, wrote and edited the manuscript.
II supported in developing the search strategy, conducted the literature search and screening, participated in the analysis and the final indicator selection, wrote and edited the manuscript.
MB supported in developing the search strategy, conducted the literature search and screening, participated in the data extraction, analysis and the final indicator selection.
FH supported in clustering of the extracted indicators, participated in the analysis and the final indicator selection, and edited the manuscript.

Data availability

The data sets used and analyzed during this study are available from the corresponding author on reasonable request.

Use of generative artificial intelligence

This project did not make use of any generative artificial intelligence.

Conflict of interest

None declared.

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Multimedia appendix

Multimedia Appendix 1: Overview of included indicators for all four domains, the search strategy with results, included references, and the raw list of all extracted indicators.

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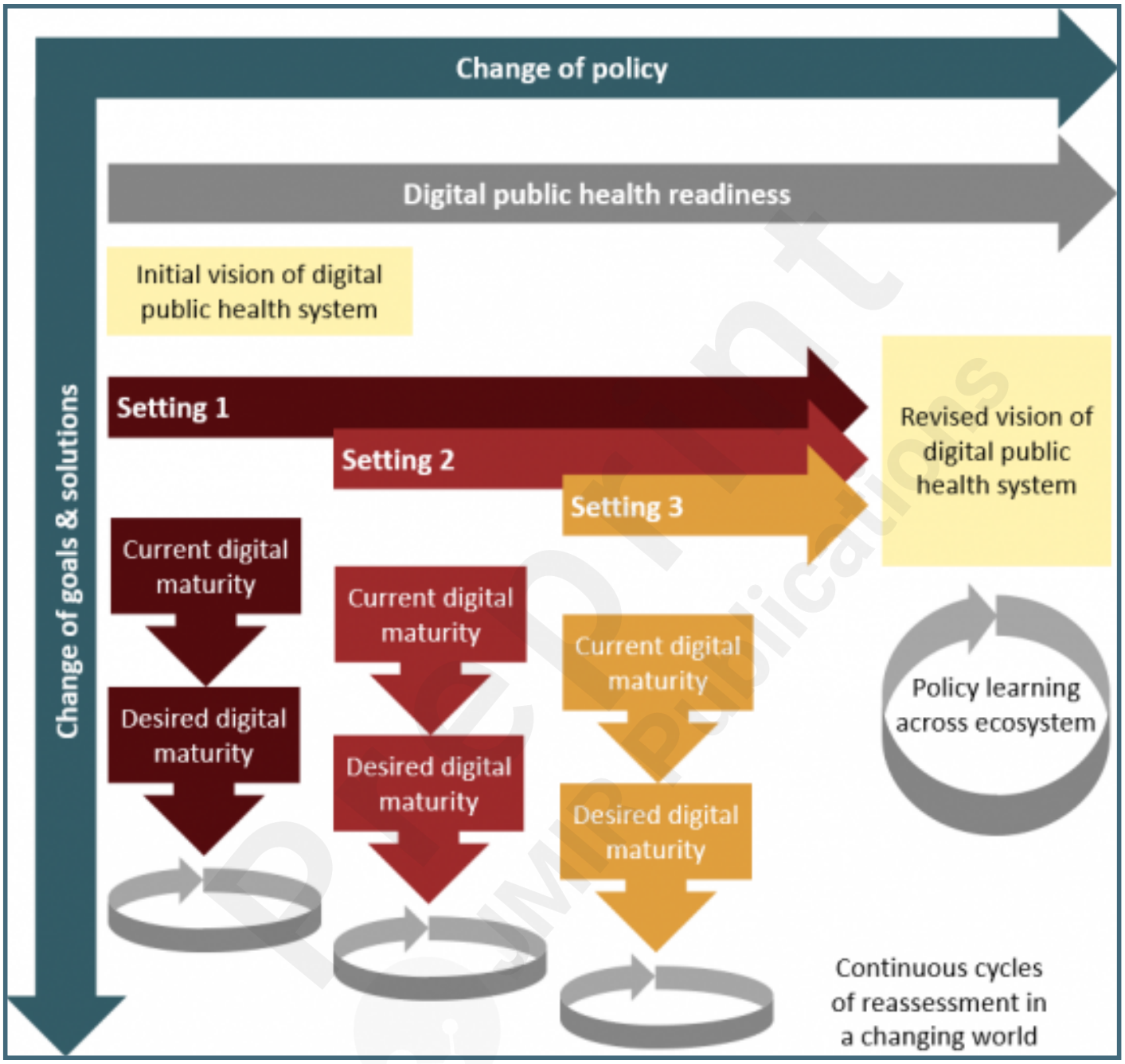
Abbreviations

AI	Artificial Intelligence
DiPH	Digital public health
DiPHSMR	Digital public health systems maturity and readiness
GDHM	Global Digital Health Monitor
ICT	Information-communication-technologies
IT	Information technology
WHO	World Health Organization

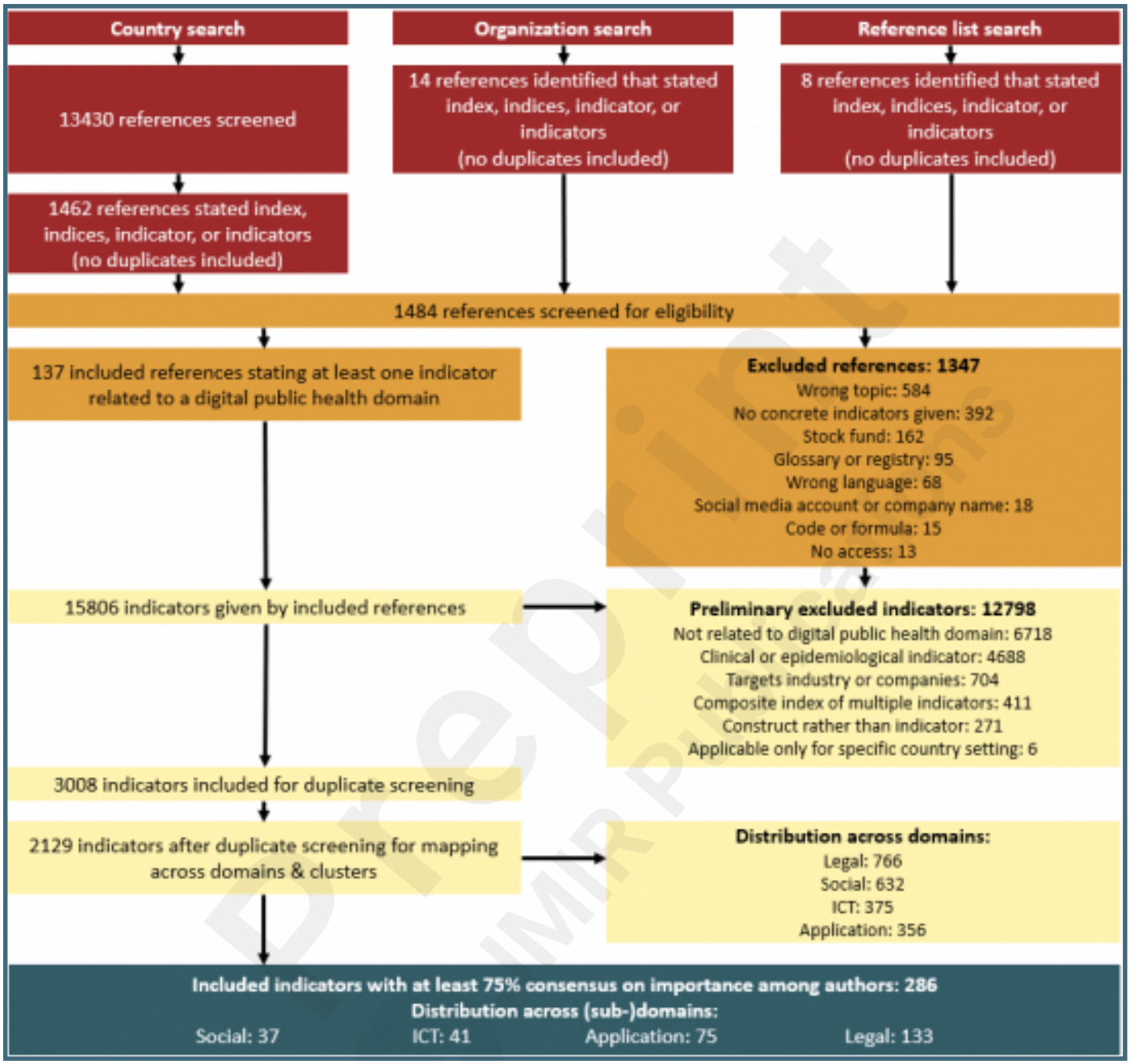
Supplementary Files

Figures

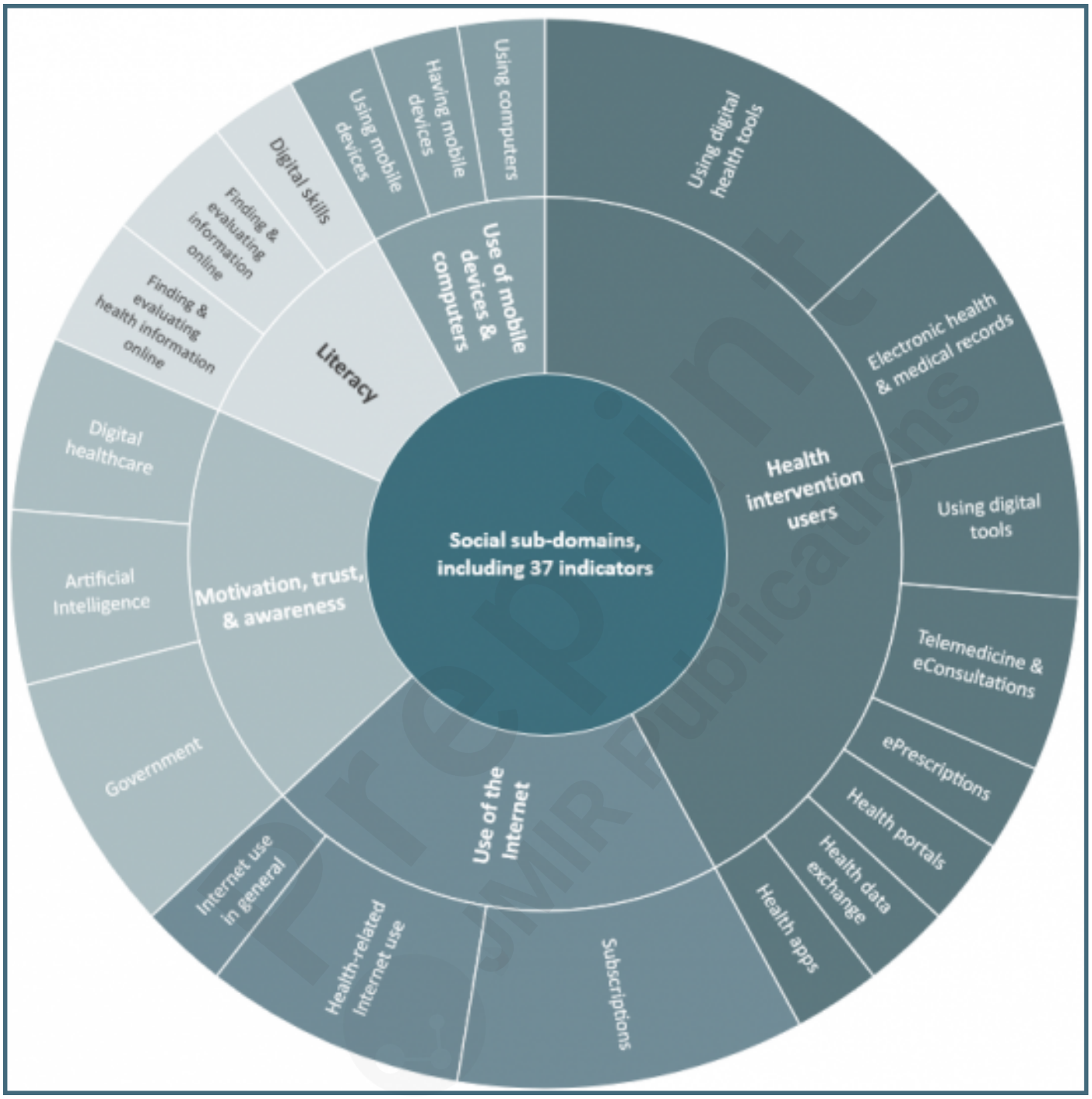
Reconceptualizing the digital maturity of public health systems. Adapted from Cresswell et al. (2019) and Yusif et al. (2017).



Screening and indicator selection procedure.

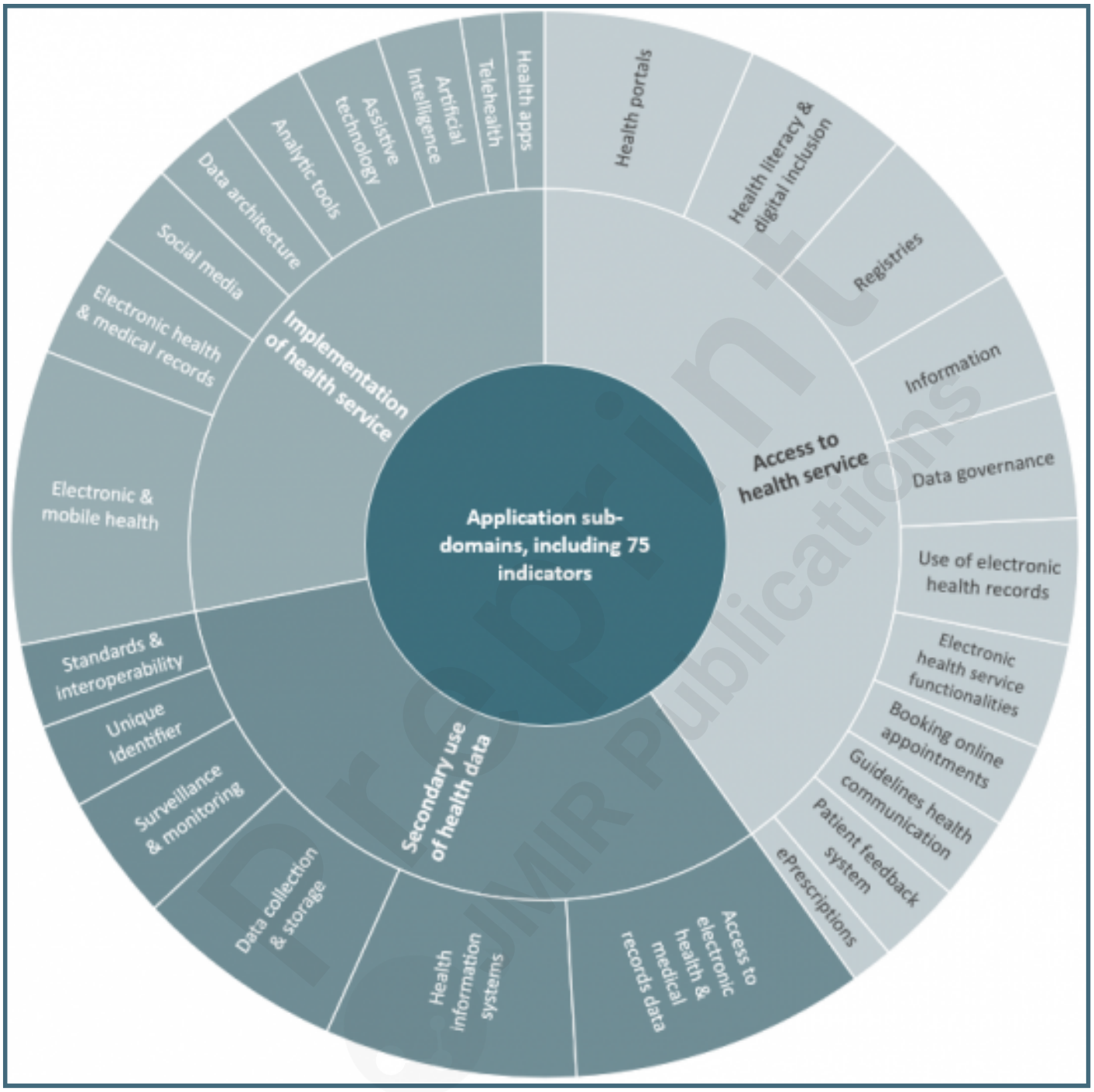


Social sub-domains, including indicators per indicator clusters.

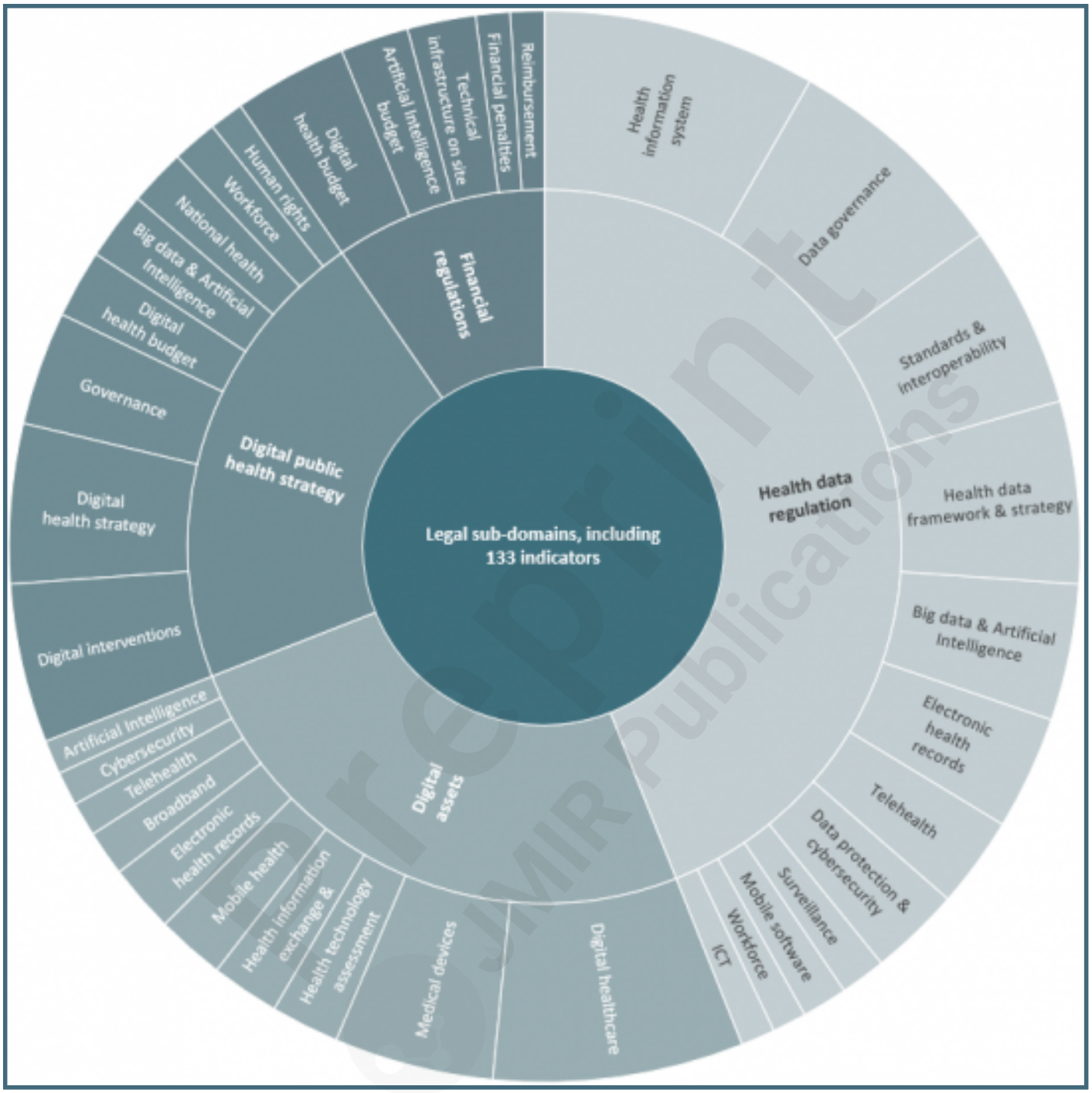


ICT sub-domains, including indicators per indicator clusters.

Application sub-domains, including indicators per indicator clusters.



Legal sub-domains, including indicators per indicator clusters.



Multimedia Appendixes

Overview of included indicators for all four domains, the search strategy with results, included references, and the raw list of all extracted indicators.
URL: http://asset.jmir.pub/assets/3ebe6824f4904632d2a8028857c153ca.xlsx

TOC/Feature image for homepages

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