



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

Mapping national information and communication technology (ICT) infrastructure to the requirements of potential digital health interventions in low- and middle-income countries

Citation for published version:

Hui, I, Abdullah, A, Ahmed, Z, Goel, H, Habib, M, Hock, TT, Khandakr, P, Mahmood, H, Nautiyal, A, Nurmansyah, M, Panwar, S, Patil, R, Rinawan, FR, Salim, H, Satav, A, Shah, JN, Shukla, A, Tanim, CZH, Balharry, D & Pinnock, H 2022, 'Mapping national information and communication technology (ICT) infrastructure to the requirements of potential digital health interventions in low- and middle-income countries', *Journal of Global Health*, vol. 12, no. 04094. <https://doi.org/10.7189/jogh.12.04094>

Digital Object Identifier (DOI):

[10.7189/jogh.12.04094](https://doi.org/10.7189/jogh.12.04094)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Publisher's PDF, also known as Version of record

Published In:

Journal of Global Health

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



Mapping national information and communication technology (ICT) infrastructure to the requirements of potential digital health interventions in low- and middle-income countries

Chi Yan Hui¹, Adina Abdulla², Zakiuddin Ahmed³, Himanshi Goel⁴, G M Monsur Habib⁵, Toh Teck Hock⁶, Parisa Khandakr⁷, Hana Mahmood⁸, Animesh Nautiyal⁹, Mulya Nurmansyah¹⁰, Shweta Panwar⁴, Rutuja Patil^{1,11}, Fedri Ruluwedrata Rinawan¹⁰, Hani Salim¹², Ashish Satav¹³, Jitendra Nandkumar Shah^{13,14}, Akshita Shukla⁴, Chowdhury Zabir Hossain Tanim¹⁵, Dominique Balharry¹, Hilary Pinnock¹; the RESPIRE Group

¹NIHR Global Health Research Unit on Respiratory Health (RESPIRE), Usher Institute, University of Edinburgh, UK

²Department of Primary Care Medicine, Faculty of Medicine, University Malaya, Kuala Lumpur, Malaysia

³Riphah Institute of Healthcare Improvement & Safety and Secretary, Islamabad, Pakistan

⁴Centre for Technology Alternatives for Rural Areas (CTARA), Indian Institute of Technology Bombay, Mumbai, India

⁵Bangladesh Primary Care Respiratory Society (BPCRS), Khulna, Bangladesh

⁶Clinical Research Centre, Sibuhospital, Ministry of Health Malaysia, Kuala Lumpur, Malaysia

⁷Medinova Medical Services Ltd, Dhaka, Bangladesh

⁸Neoventive Solutions, Islamabad, Pakistan

⁹Indian Institute of Technology Bombay, Mumbai, India

¹⁰Department of Public Health, Faculty of Medicine, Universitas Padjadjaran, Bandung, West Java, Indonesia

¹¹Vadu Rural Health Program, King Edward Memorial Hospital Research Centre, Pune, India

¹²Department of Family Medicine, Faculty of Medicine and Health Sciences, University Putra Malaysia, Kuala Lumpur, Malaysia

¹³MAHAN Trust, Mahatma Gandhi Tribal Hospital, Maharashtra, India

¹⁴Indian Institute of Technology Bombay, Mumbai, India

¹⁵Department of Physical Medicine and Rehabilitation, Sylhet MAG Osmani Medical College Hospital, Sylhet, Bangladesh

Background: Digital health can support health care in low- and middle-income countries (LMICs) by overcoming problems of distance, poor infrastructure and the need to provide community practitioners with specialist support. We used five RESPIRE countries as exemplars (Bangladesh, India, Indonesia, Malaysia, Pakistan) to identify the digital health solutions that are valuable in their local setting, worked together with local clinicians and researchers to explore digital health policy, electricity/ICT infrastructure, and socio-cultural factors influencing users' ability to access, adopt and utilise digital health.

Methods: We adopted the Joanna Briggs Institute's scoping review protocol and followed the Cochrane Rapid Review method to accelerate the review process, using the Implementation and Operation of Mobile Health projects framework and The Extended Technology Acceptance Model of Mobile Telephony to categorise the results. We conducted the review in four stages: (1) establishing value, (2) identifying digital health policy, (3) searching for evidence of infrastructure, design, and end-user adoption, (4) local input to interpret relevance and adoption factors. We used open-source national/international statistics such as the World Health Organization, International Telecommunication Union, Groupe Speciale Mobile, and local news/articles/government statistics to scope the current status, and systematically searched five databases for locally relevant exemplars.

Correspondence to:

Hilary Pinnock
Asthma UK Centre for Applied Research, Usher Institute, University of Edinburgh
Doorway 3, Medical School, Teviot Place
Edinburgh
United Kingdom
Tel: 0131 650 8102
Fax: 0131 650 9119
hilary.pinnock@ed.ac.uk

Results: We found 118 studies (2015-2021) and 114 supplementary online news articles and national statistics. Digital health policy was available in all countries, but scarce skilled labour, lack of legislation/ interoperability support, and interrupted electricity and internet services were limitations. Older patients, women and those living in rural areas were least likely to have access to ICT infrastructure. Renewable energy has potential in enabling digital health care. Low usage mobile data and voice service packages are relatively affordable options for mHealth in the five countries.

Conclusions: Effective implementation of digital health technologies requires a supportive policy, stable electricity infrastructures, affordable mobile internet service, and good understanding of the socio-economic context in order to tailor the intervention such that it functional, accessible, feasible, user-friendly and trusted by the target users. We suggest a checklist of contextual factors that developers of digital health initiatives in LMICs should consider at an early stage in the development process.

Low- and middle-income countries (LMICs) face many challenges providing health care for their populations. Digital health solutions can overcome the problems of distance, poor transport infrastructure, limited medical provision in rural areas and the need to provide rural practitioners with specialist support [1]. Recent telehealth examples from the National Institute for Health and Care Research (NIHR) Global Health Research Unit on Respiratory Health (RESPIRE) include digital auscultation to improve diagnosis of paediatric pneumonia [2], computational frameworks to interpret chest x-rays [3], home-based pulmonary rehabilitation [4], mHealth support for Community Health Workers [5,6], remote teleconsultation facilities (Micro-Health Centres) [7] mobile-based interventions for adults with asthma with limited health literacy [8] and blended learning for professional [9,10]. However, poor mobile signal coverage [11] and limited availability of mobile/smart devices [12] hinder the application of digital health in rural and/or deprived communities.

There is a need when planning digital health projects to understand the local information and communications technology (ICT) infrastructure to ensure interventions are developed and delivered in such a way that they are accessible to the majority of the population. This review, commissioned by RESPIRE, aimed to scope the current ICT context in member countries and to develop a practical approach that could be applied to future projects proposed by partners in South/Southeast Asia.

We aimed to identify and describe the evidence available in open-source data and existing literature regarding implementation of digital health applications in five exemplar RESPIRE LMICs (Bangladesh, India, Indonesia, Malaysia, Pakistan). Our questions were:

1. What digital health policy, electricity and ICT infrastructures are available to support digital health?
2. What socio-cultural factors influence access to the infrastructures, and users' ability to adopt and utilise digital health?

METHODS

The review was conducted from May to December 2021, by colleagues from the RESPIRE partner countries in an iterative process to ensure that findings would address local needs.

We adopted the Joanna Briggs Institute's scoping review protocol [13], and followed Cochrane Rapid Review methodology to accelerate the review process [14]. Clinicians and researchers from the RESPIRE countries formed the review team enabling us to frame the questions to ensure the knowledge generated would address the practical factors relevant to the digital health projects they are planning, as well as the general issues that need to be considered in a successful technology initiative in an LMIC. We use PRISMA (scoping reviews extension) to report the data. PROSPERO does not accept scoping review registrations, but the search strategy, inclusion criteria, exclusion criteria, and analysis plan were specified a priori in a protocol that was reviewed by the RESPIRE group.

Over-arching framework

The Implementation and Operation of Mobile Health projects roadmap (IOMH-roadmap) [15] summarises the policy, infrastructure and end-user factors to be considered for a successful digital health implementation (Question 1). The seven factors that contribute to the current status and enabling environment, are value, public policy, infrastructure, design, end-user adoption, personnel and finances. We investigated five fac-

tors in this review, excluding personnel and finance as these are the requirements of people, costs and project management related to specific digital health projects and hence should be considered on a case-by-case basis with guidance such as the World Health Organization (WHO) Digital implementation investment guide 2020 (DIIG) [16]. **Figure 1** illustrates how we shaped our review around this framework. We followed a four-stage process to collect data on the five factors from the IOMH-roadmap.

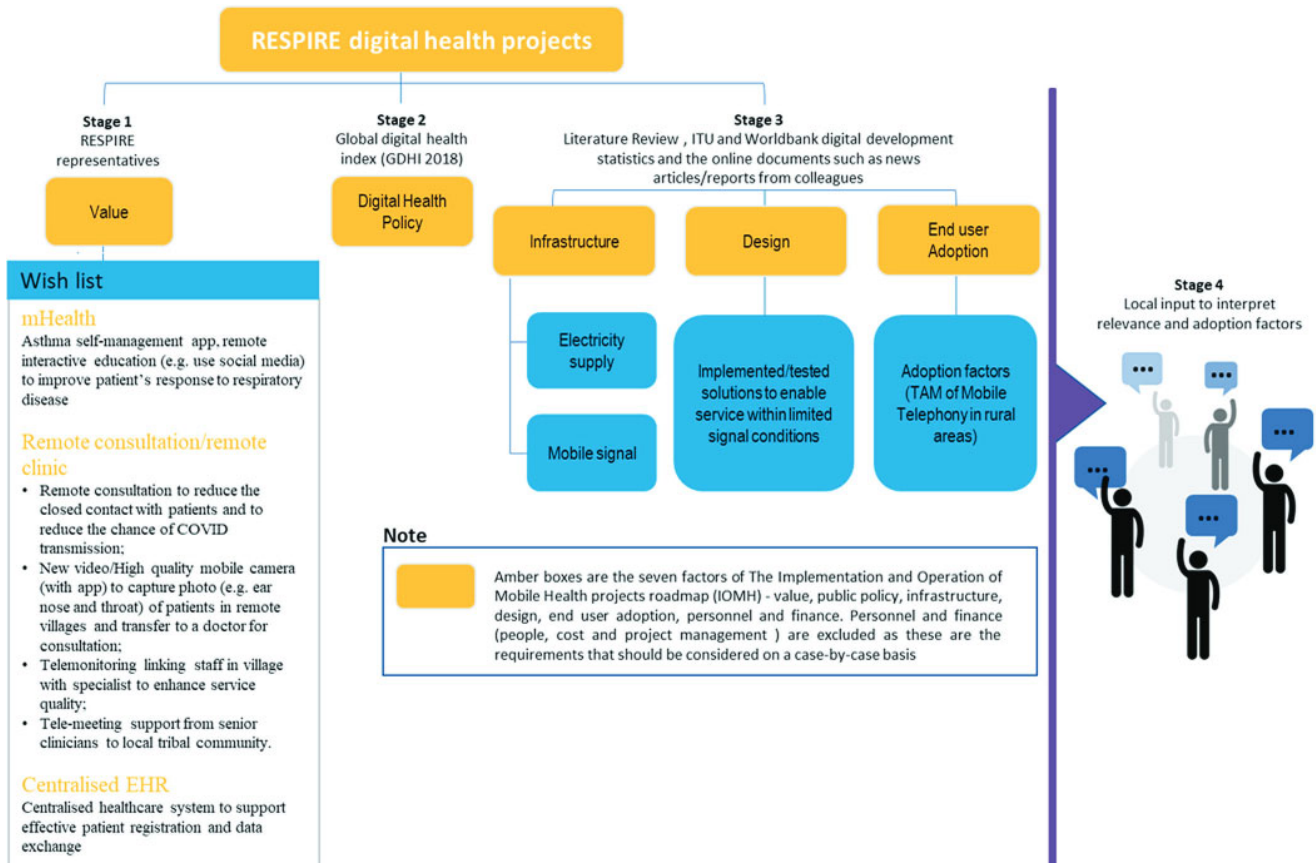


Figure 1. Review flowchart using the Implementation and Operation of Mobile Health projects roadmap.

Stage 1. Establishing value

The local RESPIRE clinicians and researchers defined the digital health applications they thought would be valuable in their countries (we called this the “wish list”). We used the technologies in the “wish list” to inform the search terms and eligibility criteria in Stage 3.

Stage 2. Identifying digital health public policy

Digital policy provides insight into government support and potential available funding to implement digital health applications in the countries. We searched the countries in the Global Digital Health Index (GDHI) which “scores” the local leadership and governance, strategy and investment, legislation, policy and compliance, workforce, standards and interoperability, infrastructure and the digital health services and applications to provide an understanding of local policy[17].

Stage 3. Searching for evidence of infrastructure, design, and end-user adoption

Infrastructure refers to electricity and mobile signal coverage required to implement digital health. Adoption is influenced by the user-friendliness of the design, the end user's attitude towards the technology and the socio-cultural context (eg, barriers related to gender, age, and affordability of technology). We sought evidence of research at local community level and the latest statistics of technology ownership and signal penetration at country level. The procedure is described below with additional details in **Table 1**.

Table 1. Scoping review search strategy

INCLUSION AND EXCLUSION CRITERIA, DATA RANGE AND SOURCES OF SEARCHES	
Definitions used in this scoping review	IT infrastructure is the hardware and software to support data or electricity transmission Examples in this review of – Hardware are personal digital assistant (PDA), call machine, 2G-5G mobile phones, sensors, computer, electrical socket point and signal tower. Software can refer to a computer or mobile application and its architectures such as applications on its interoperability layer (use of API/SKD) and presentation layer (app interface design).
Initial questions	(Primary) What IT infrastructure is available to support digital health in different countries/regions?(Secondary) What socio-cultural factors influence the access to IT infrastructure, and ability to adopt and utilise digital health?
Population	Stakeholders of digital health such as users (patients and clinicians), technology developers, health /technology service providers and researchers.
Intervention	Any IT infrastructure that could support a digital health intervention.
Settings	Any health care setting in the five exemplar countries.
Study focus	All studies, clinical and technology systematic/scoping reviews, best practice framework, and grey literature (eg, WHO and GSMA reports), open-source IT infrastructure statistics with themes that relate to digital health for respiratory health in India, Indonesia, Malaysia, Pakistan or Bangladesh.
Languages	All
Date range	January 1, 2015 to June 18, 2021. The date limit of 2015 ensured we only included recently completed infrastructures. The typical implementation lifecycle of ICT infrastructure is three to five years.
Databases	Open-source telecommunication databases and mobile signal/electricity grid map (ITU, WHO, International energy agency (https://www.iea.org/data-and-statistics), World bank and include any open sources suggested by colleagues/ found to be useful / in literature or the statistics. Web of Science Core Collection and ISI Proceedings (SCI-EXPANDE; SSC; A&HCI; CPCI-S; CPCI-SSH; BKCI-S; BKCI-SSH), IEEE Xplore Digital Library, Compendex, Inspec & Knovel, Scopus (5 databases in total).
Search terms	mhealth OR Remote consultation telemonitoring/remote clinic OR centralised electronic health record OR the specific technologies that could be used to implement the projects in the “wish list”.
Exclusion criteria	Exclude in the first phase: data out of range, proposing new technology/ tool only (geographic information system (GIS)/ Zigbee flooding system). Exclusion criteria: 1. Study that was not in Bangladesh, India, Indonesia, Malaysia and Pakistan. 2. Study did not use on-site data to evaluate the local public infrastructure services (eg, author's opinions on existing infrastructure without analysis). 3. Study on new digital health or ICT infrastructures without implementation and on-site evaluation. (eg, author's opinions on new technology). 4. Study on electricity demand, internet service and mobile consumption modelling without providing the reasons for services disturbance (eg, demand prediction model). 5. Study on digital adoption assessment methodologies or reporting on co-design workshops without providing technical/legislation/socio-cultural factors that influence the access to existing IT infrastructure, and the users' ability to adopt and utilise existing ICT infrastructure. We used specific criteria to exclude renewable energy simulation studies. 6. Renewable energy review before Jan 2021 Author opinion to provide suggestions to renewable energy policy. 7. Study not reporting potential energy generation or cost for the system such as Cost per energy (COE). 8. Study for specific commercial building or robot or smart city planning. 9. Study without site evaluation or justifications on the choices of the simulation parameters.

We searched five databases and the International Telecommunication Union (ITU) digital development statistics, to identify the existing infrastructures, their design and end-user adoption factors relevant to the valued technology that we identified in stage 1 [18]. Search terms were formed from the RESPIRE partners' “wish-list” (see **Table 1** for the search terms and searched databases). We included studies (implementation projects, case studies, technical reports and systematic/scoping reviews) that assessed performance and user experience of locally implemented infrastructures including renewable technology that could generate electricity to support digital health applications with a date range of January 1, 2015 to June 18, 2021.

Screening and study selection

Title and abstracts were screened by one reviewer (CyH). The full text of all potentially eligible studies were retrieved and assessed against the inclusion criteria (**Table 1**) by CyH and checked by second reviewers from the RESPIRE countries (TZ, RP, SP, AS, AH, HG, HS, HM and HP). Initial agreement was 88%, but after discussion we achieved 100% agreement.

Data extraction

Due to the resources and time limitations, one reviewer (CyH) extracted data using a piloted extraction sheet under heading characteristics of the included studies (publication year, study methods and conclusion). Study design, intervention, and outcomes were extracted where appropriate (some papers were reviews or performance evaluations). We extracted all the data from the study as reported, and did not contact study authors for additional information. CyH presented the data extraction results in the group meetings inviting feedback on the coherence of the findings with the real-life scenario in the local areas.

Stage 4. Local input to find supplementary data, and interpret relevance

RESPIRE colleagues suggested additional publications and strategies to identify local information not addressed in the (English) published literature and the GDHI [17]. We used the IOMS-roadmap to categorise the studies according to the factors addressed: infrastructure (electricity, mobile signal, renewable energy), end user adoption and design.

Custom searches were performed using a Google search engine to find supplementary data (for example: local news web links) about the issue of electricity that was lacking of addressing in the literatures but were found important from the RESPIRE colleagues in the real life implementation. Local search terms such as the “power outage”, “[electricity issue](#)”, “100% electrification”, “un-electrified villages” were used. Thruuu data scraper was used to extract data from the Google search [19].

As a scoping review, we did not assess the quality of the included studies. Our aim was to identify the breadth and sources of data available, and we therefore provide a descriptive synthesis of the authors’ conclusions in terms of the intervention and population characteristics, technologies and study outcomes.

The roles of the reviewers

The first reviewer (CyH) has experience in working with multi-cultural teams in the UK and Asia, with background in engineering and public health studies. Second reviewers (TZ from Bangladesh; HG, RP, SP and AS from India; HS from Malaysia; MN from Indonesia, HM from Pakistan), and other RESPIRE colleagues are local researchers or clinicians, who are fluent in English and their local languages. They duplicated the selection at full text stage. HP is a senior clinical academic from the UK who oversaw the process and acted as an advisor and, as necessary, an arbiter.

Narrative data synthesis

Question 1: We synthesised the conclusions of the heterogeneous studies, categorised by the IOMH-roadmap infrastructure (electricity, mobile signal, renewable energy), end user adoption and design.

Question 2: We plotted effective end-users’ adoption factors (eg, perceived usefulness and ease of use [20,21]), infrastructure and study characteristics on a harvest plot. Over and above individual preferences, various socio-cultural factors (eg, availability of technology gender inequalities) influence what is available and possible in the context of LMICs. The adoption factors were categorised by the “micro-factors” (personal image, mobility, cost of service and handset, social influence, perceived health hazard, service quality, transparency of service offerings, mass media, ease of service availability) of the Extended Technology Acceptance Model (TAM) of Mobile Telephony [22].

Mapping the review data with the real-life scenario

We used the International Telecommunication Union (ITU) and the World Bank open sources statistics to triangulate the data extracted from the studies [18,23]. The RESPIRE teams in the five countries commented on the review data, and identified any gaps or discrepancies between those data and the real-life scenario that they observed in everyday practice. We developed a descriptive summary of the ITU and World Bank data with all the review findings.

RESULTS

Characteristics of the included studies and online open sources (all stages)

The identified papers and open-source online records, the screening process, and the final number of studies and records are detailed in the PRISMA flowchart ([Figure 2](#)).

Table 2 shows the data we included in the review in the various stages. 10 colleagues (clinicians and clinical/technology researchers) from Bangladesh, India, Indonesia, Malaysia and Pakistan completed a survey on the valued digital health applications in their countries and the potential day-to-day challenges to form a “wish list”. Open source data such as the Global Digital Health Index, the World Bank data and the International Telecommunication Union (ITU) statistics provided national data (excluding India) [17,18,23]. The database search retrieved 118 studies, and local colleagues advised customised google searches that identified 82 local news articles about the quality of electricity and internet services that they had observed was an important is-

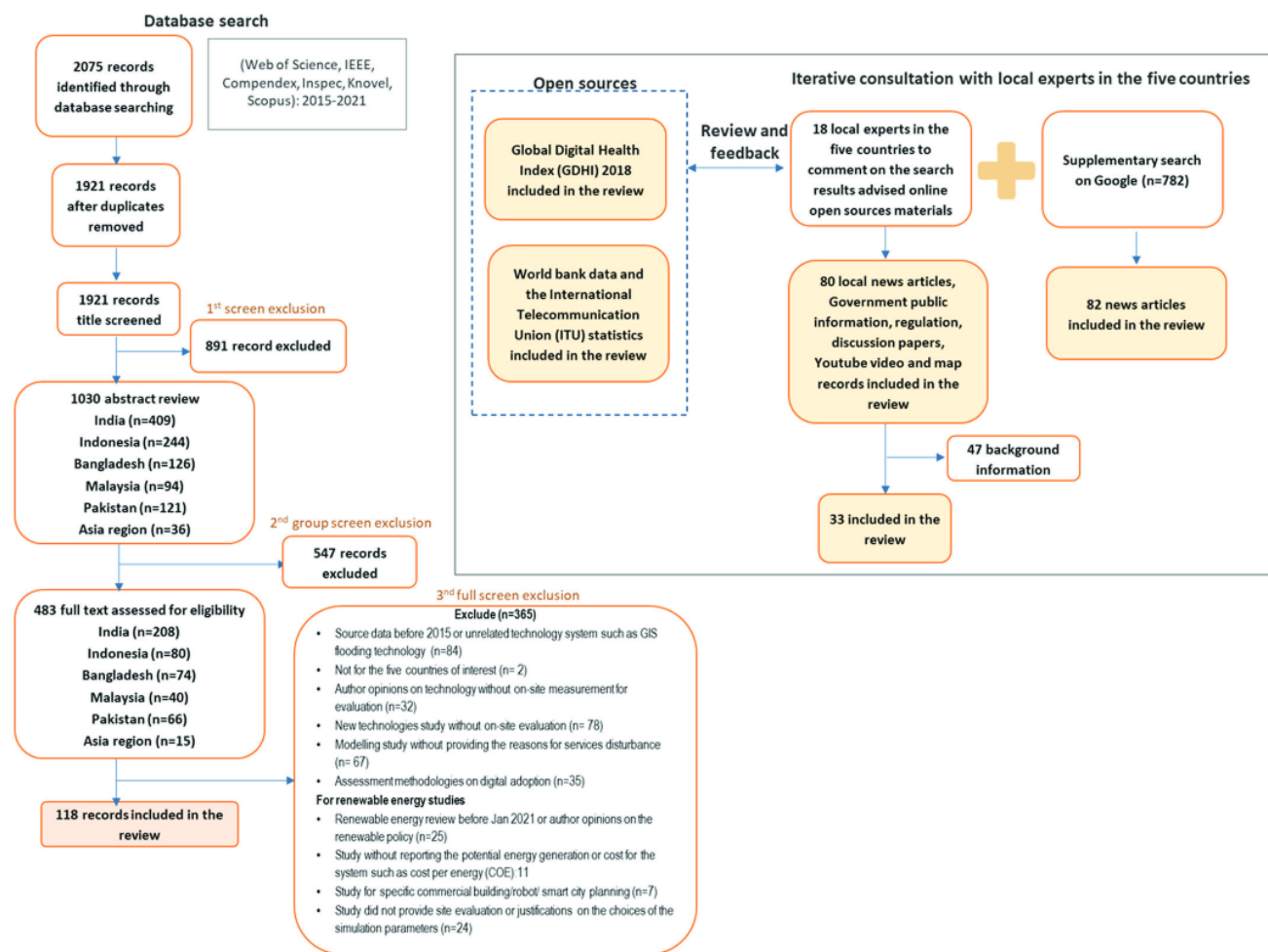


Figure 2. PRISMA flowchart.

Table 2. Process, timeline and data included in the review stages

STAGES IN THE SEARCH PLAN	SOURCES	MAY 2021	JUNE 2021	JULY 2021	AUG 2021	SEPT 2021	OCT 2021	NOV 2021	DEC 2021	RECORDS INCLUDED
1. Value	Survey to local RESPIRE teams (Bangladesh, India, Indonesia, Malaysia and Pakistan)	Stage 1								10 local experts and their teams in the five countries replied to the survey
2. Digital health public policy	Global Digital Health Index (GDHI) 2018		Stage 2							GDHI of 4 countries Bangladesh, Indonesia, Malaysia, Pakistan
3. Infrastructure, end user, design	Database search (Web of Science, IEEE, Compendex, Inspec, Knovel, Scopus): 2015-2021					Stage 3				118 studies from 5 databases (2015-2021)
	World bank data and the International Telecommunication Union (ITU) statistics									Access to electricity and internet ICT, price and affordable cost
4. Feedback from local RESPIRE colleagues	Google search to explore further issues after feedback from the group							Stage 4		82 online records (Appendix 1)
On-going iterative discussions	Feedback collected from group meetings			On-going iterative discussions						33 online records (Appendix 2)

sue but was not addressed in the statistics and studies. An additional 33 online records such as local news articles, Government public information, regulation, discussion papers, YouTube videos and map records, supplemented missing data.

The included studies

We included 118 studies in the review (Appendix 3 in the **Online Supplementary Document**) and, following the IOMH-roadmap (**Figure 1**), grouped them into six categories (electricity (n=15), renewable energy (n=47), mobile signal coverage (n=20), design (n=17) and end-user adoption (n=19)). Appendix 3 in the **Online Supplementary Document** provides details of the included studies. Of the 118 studies, most were from India (39%, 46/118), others were from Indonesia (21%, 25/118), Pakistan (17%, 20/118), Malaysia (12%, 14/118) and Bangladesh (11%, 13/118). India also contributed most of the papers in the renewable energy category (45%, 21/47).

1: Value

The “wish-list” of digital health care from the five RESPIRE countries was broad and encompassed features of m-Health, telehealth and centralised electronic health records (EHRs) (**Table 3**). m-Health includes digital health applications that use (web/standalone) mobile apps as a medium to support patients’ health care [24]. Telehealth is the use of telecommunications and virtual technology to deliver health care outside traditional health care facilities [25]. The most valued digital health applications were information provision (for patients and professional development), mapping service availability, remote consulting, remote monitoring of patients’ condition, remote tracking of field staff (eg, when conducting home visit to patients), open centralised health care system and air pollution monitoring.

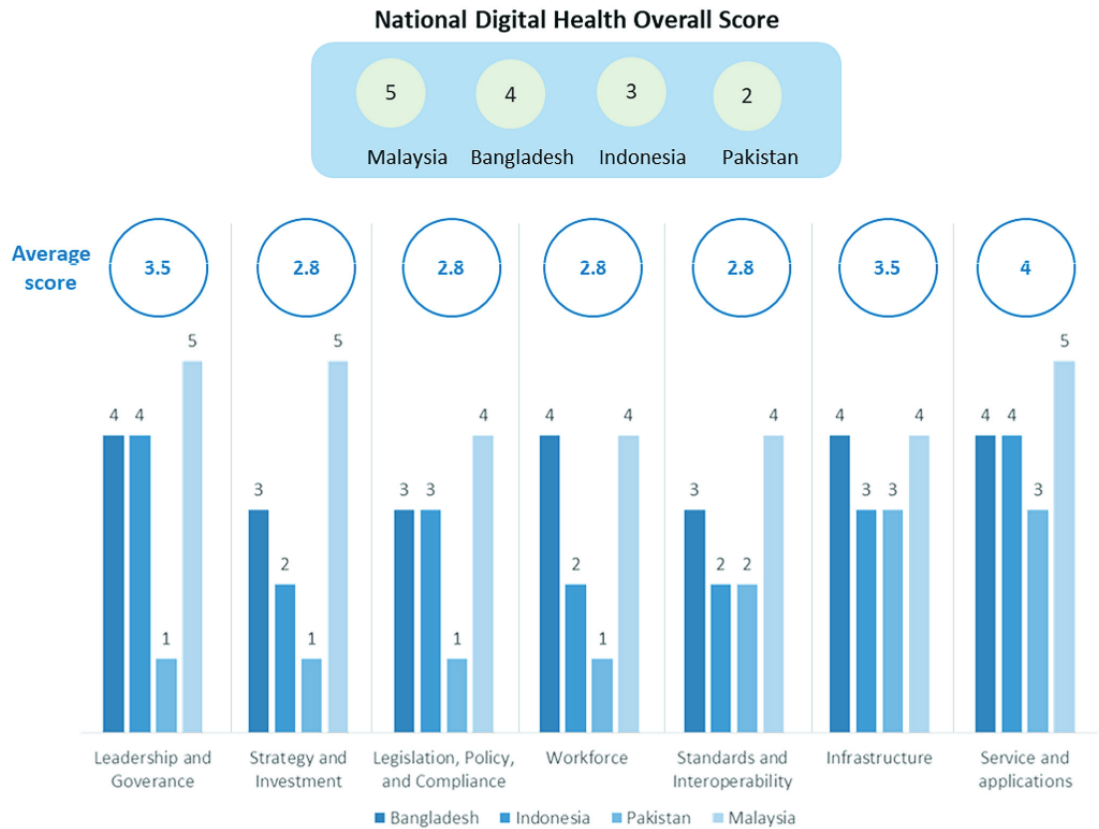
Table 3. Wish list: Valued digital health applications and observed challenging in the five countries (India, Indonesia, Malaysia, Bangladesh and Pakistan)

Wish list in the five countries (India, Indonesia, Malaysia, Bangladesh and Pakistan)	
Pakistan	<ul style="list-style-type: none"> A service availability mapping system; diagnosis and referral app for under five pneumonia; a SMS chatbot in Roman Urdu about respiratory information; interactive mobile game to spread correct health care information and encourage self-reporting of data; remote health information for patients.
Malaysia	<ul style="list-style-type: none"> Asthma self-management app for clinical guideline information and updates.
Indonesia	<ul style="list-style-type: none"> An open (FHIR) centralised health care system.
India	<ul style="list-style-type: none"> Telehealth platforms with implementation research to encourage the adoption and use; air pollution mapping; remote consultations between village communities and hospitals; digital examinations: high quality mobile camera to capture specialist images (eg, of ear nose, and throat, video laryngoscopy, and transfer to doctor/technicians for consultation; telemonitoring to support field staff – enabling joint consultant consultation; remote interactive education (eg, use social media) to improve patient’s response to respiratory disease; tele-meeting support with senior clinicians for the local tribal community members.
Bangladesh	<ul style="list-style-type: none"> Exploratory study (with online questionnaire) on physical activities or pulmonary rehabilitation.
Observed challenges in the five countries (India, Indonesia, Malaysia, Bangladesh and Pakistan)	
Policy	<ul style="list-style-type: none"> Interoperability: different providers and systems in primary/sary practices, lack of standardised protocol makes it difficult to share medical information and make joint decisions on patient management; regulation: lack of government regulations to use/store health data to drive a seamless centralised health care; no clear legal framework on how to use technology for health care delivery (liability issues); government: no clear development roadmap on digital health, diverse local policies (Pakistan); human resources: lack of skilled manpower in community health projects, and limited technology support.
Infrastructure	<ul style="list-style-type: none"> Poor mobile coverage in urban and remote area; limited/unstable internet coverage especially in remote areas; unstable electricity supply (seasonal peaks (Pakistan), rainy season (India)), lack of electrical charging points; lack of equipment (eg, digital stethoscope) and computer hardware (dependents on importing (Pakistan)); no real time dashboard for hospital colleagues to monitor telemedicine devices; lack of software resources and poor maintenance to update the software; multiple mobile suppliers in one area, need two sim cards to access mobile signal (India); multiple mobile OS/device resolution makes user interface design difficult; telecommunication infrastructure is monopolised by government-link company, challenging to improve service (eg, too focused on fibre deployment as opposed to affordable and faster internet wiring to wider community); technology companies want profitable technology (Pakistan).
Social cultural adoption and utilisation	<ul style="list-style-type: none"> Low mobile phone ownership. Households may have one smart phone shared between family; affordability of internet plan/access to internet; low technology literacy in both clinicians and patients; low health literacy in patients; lack of confidence in data protection and effectiveness of technology; language: multilingual community want technology in their own language (Malaysia); lack of awareness of available digital health services, and unsure about the health benefits, digital divide.

Table 3 also lists the potential challenges to implementing digital health applications identified by the colleagues in their local settings. Challenges such as poor/unstable electricity supply and mobile signal coverage, unaffordability of mobile phone ownership/access to internet, were applicable in all the countries, especially in rural areas. No clear legal framework on use of technology for health care access and delivery was a concern because of lack of clarity who (the clinician, the health care organisation, patient, technology manufacturer) were liable if the application went wrong. Lack of skilled manpower and hardware/software equipment challenged deployment of their wish-list of digital health solutions.

2: Digital health policy

The GDHI, which benchmarked self-reported scores across seven domains for Bangladesh, Indonesia, Malaysia, and Pakistan in 2018 (Figure 3), described 50%-75% of the population in Malaysia, Bangladesh and Indonesia, and 25%-50% of the population in Pakistan as “supported by digital health systems”. In Bangladesh and Malaysia, the public health care facilities were tagged to allow Geographic Information Systems to map their location. Secured patient registries were available for more than 75% of population in Indonesia and Malaysia; in Bangladesh and Pakistan, registries were available for less than a quarter of the population and irregular maintenance limited usage.



Source: Global Digital Health Index

Notes: The GDHI provides a score to assess the enablers of digital health in the countries that have responded to their assessment questions on the governance, interoperability, privacy and security policies, workforce, and infrastructure[17].

Higher the score represents the country has a more mature environment to enable a digital health to be implemented.

Figure 3. Global Digital Health Index (GDHI) 2018 for Bangladesh, Indonesia, Malaysia, and Pakistan (no scores available for India). The GDHI provides a score to assess the enablers of digital health in the countries that have responded to their assessment questions on the governance, interoperability, privacy and security policies, workforce, and infrastructure [17]. Higher the score represents the country has a more mature environment to enable a digital health to be implemented.

Although the governments of Bangladesh, Indonesia and Malaysia had prioritised digital health in relevant national plans and had strategies for upgrading hardware and software for health care purposes, legislation and standards for interoperability were less well addressed. Lack of professionals with expertise in health informatics and minimal training for clinicians and community health workers were identified as limitations in Indonesia and Pakistan. Pakistan did not have a coordinating body for digital health, and scored relatively poorly in categories related to leadership, governance, investment strategy, legislation, and policy.

The GDHI does not include scores for India [17], however, the Indian government's Ayushman Bharat Digital Mission, describes a "citizen-centric" National Digital Health Blueprint and the key building blocks for India's Digital Health Ecosystem. The Blueprint defines data standards/regulations, describes plans for unique patient digital IDs, registries of private and public health facilities and health care professionals, and increased digital access for the population [26-28]. There is less clarity within the implementation plan on developing expertise in health informatics and on provision of training for clinicians and community health workers [25].

3: Infrastructure, design, and end user adoption

Infrastructure: Electricity

Electricity is essential for deployment and operation of a digital health service. Mobile phones need to be charged to deliver a mhealth service, remote clinics need lighting and computers to support video-consultations and diagnostic testing, electricity is needed to transmit mobile signals.

In 2019, the percentage of the population with access to electricity was 100% (or nearly) in urban areas of all RESPIRE countries. However (apart from Malaysia) rural areas were less well served, especially in Bangladesh and Pakistan where the proportion of the rural population with access to electricity was 89% and 59% respectively (Appendix 4 in the [Online Supplementary Document](#)) [21]. In reality, however, the affordability, reliability, and duration of access to electricity remains an issue [29] (also see Appendix 1 and Appendix 2 in the [Online Supplementary Document](#)). For example, in the rural areas of India, 50% of households experienced power cuts for 8 hours/d [30]. In Pakistan, electricity shortage results in power outages for 8-10 hours in urban areas while rural areas face load-shedding up to 18 hours/d [31]. Flooding in the rainy season in Malaysia caused electricity outages [32].

Renewable energy could potentially provide 24-hour/d electricity in rural areas, either on-grid (as an alternative electricity supply when the grid is lost) or off-grid (as an electricity source for areas without grid coverage). ZigBee PRO protocol (with together with sensors and embedded system) could be a cost-effective option to support full integration of intelligent Distributed Renewable Generation (DRG) and small scale Building-Integrated Photovoltaic (BIPV) [33]. In the techno-economic studies of hybrid renewable energy that we identified across the five countries (Appendix 3 in the [Online Supplementary Document](#)), 47 studies reported the potential to generate 6.55-30 kWh/d off-grid electricity in rural areas, that could support digital health applications such as mHealth and a remote clinic as well as enable basic mobile signal transmission (see Appendix 3 in the [Online Supplementary Document](#), 72-118 renewable energy category). By reducing energy insecurity, such schemes have multiple other socio-economic benefits for local households [34], mitigating electricity costs, greenhouse gas emissions, and (in Bangladesh) improving political trust [35].

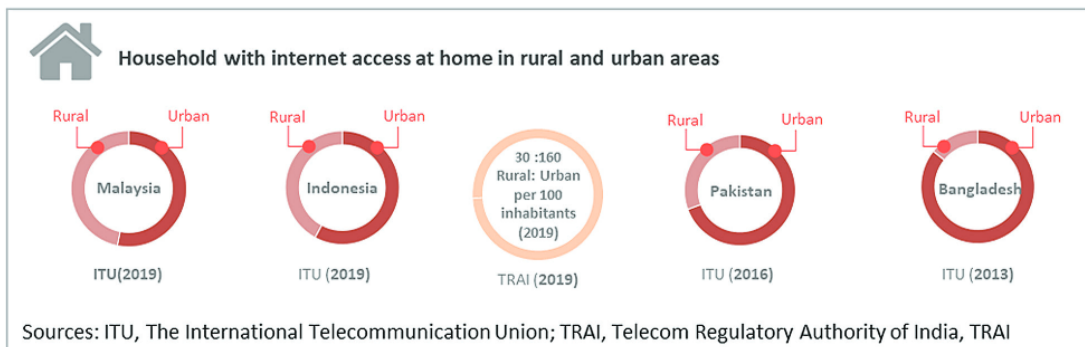
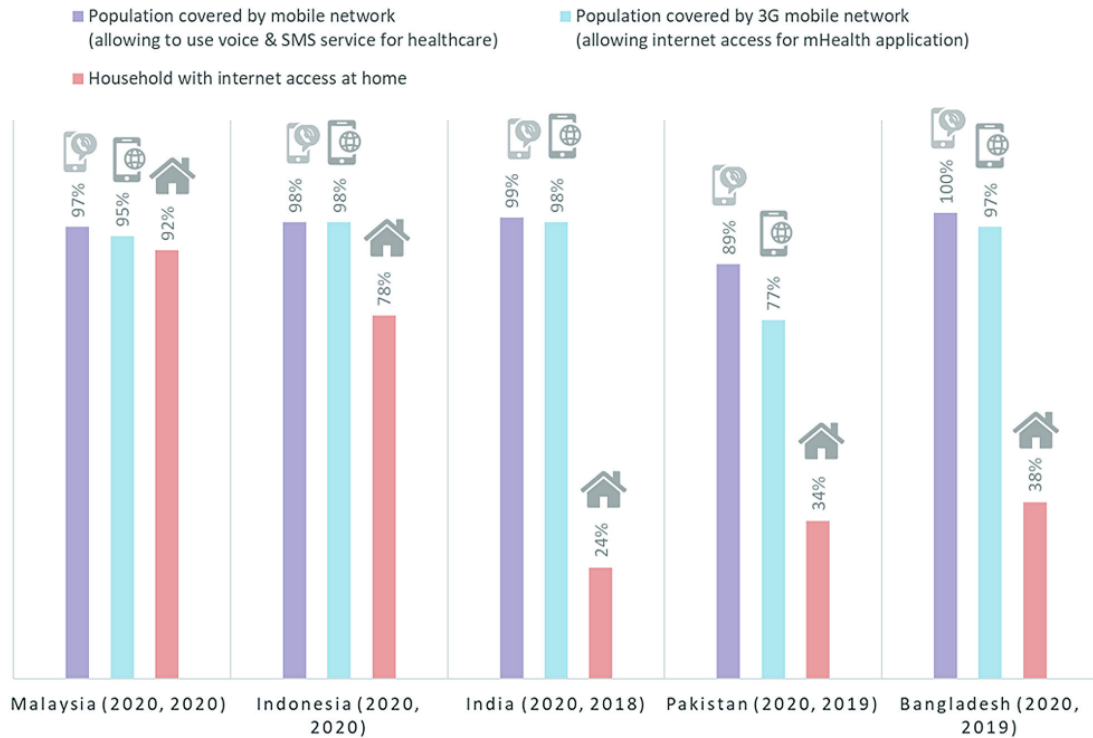
Renewable energy policies exist in all five countries, reflecting their governments' intention to develop sustainable energy in rural areas and in response to climate change. However, critics predict delays as plans are complex or vague (eg, in Pakistan [36]) or financial and governance procedures are unclear (eg, in Bangladesh [37]). There are significant logistical challenges deploying these alternative power supplies in rural or remote tribal areas, such as lack of local skilled labour for installing equipment and problem solving, procedural delays in approving deployment, lack of incentives, market and business environments to sustain off-grid electricity [32].

Infrastructure: Mobile signal coverage and adoption cost

Figure 4 and Appendix 4 in the [Online Supplementary Document](#) provide details of the mobile signal data. By 2020, mobile and data networks covered at least 77% of the population in the five countries with greater coverage in urban than in rural areas [38-40]. In contrast, the proportion of households with home broadband access to the internet is low in India (24% in 2019), Pakistan (34% in 2019) and Bangladesh (38% in 2019). This low uptake is correlated with the cost of fixed broadband packages which in all the countries is above the "2% of monthly Gross National Income per capita" (GNIpc) affordability threshold. This is particularly true in Indonesia and Pakistan in which fixed broadband costs an estimated 11% of GNIpc (compared to 3.2% in India; 2.6% in Bangladesh; 2.2% in Malaysia). In contrast, mobile data and voice services are a relatively affordable option for mHealth in all the countries.

Poor/unstable signal quality was a concern [41-46] despite innovative strategies to support mobile signal in rural areas. Published studies, observation of local colleagues and the local news articles identify factors such as obstruction from buildings/trees, distance to transmitter, high use and limited capacity that lead to signal disturbance (**Table 4**). Practical considerations which act as barriers include unprofitable business models (eg, in Pakistan [87]), and multiple service providers.

Population covered by voice and data network



Note:

- By 2020, patients can access internet via smart mobile phone (at least 77% of the population) or fixed broadband at home (at least 24%) to access the mobile health care services. Mobile internet is more affordable than fixed broadband at home.
- At least 89% of population can use basic voice and SMS service for healthcare services (e.g. make a call to the healthcare facilities/ receiving a notification text message on phone about the appointment).
- Less rural household can afford to install/subscript the fixed broadband at home than the urban household.

Figure 4. Network coverage 2020. By 2020, patients can access internet via smart mobile phone (at least 77% of the population) or fixed broadband at home (at least 24%) to access the mobile health care services. Mobile internet is more affordable than fixed broadband at home. At least 89% of population can use basic voice and SMS service for health care services (eg. make a call to the health care facilities/ receiving a notification text message on phone about the appointment). Less rural household can afford to install/subscript the fixed broadband at home than the urban household.

Design and tested solutions

We identified 17 studies reporting digital health solutions that provided exemplar designs of the initiatives that RESPIRE colleagues had included on their “wish list” (Table 4). Examples included remote clinics for consultation and diagnosis, pregnancy monitoring system, centralised EHR, ICT in community pharmacies, though there were challenges such as lack of interoperable systems; unstable internet connections; and lack of security and legislative frameworks [82-86].

Table 4. Mobile signal: signal disturbance factors, proposed technologies and exemplar digital health intervention summary

Signal disturbance factors	The building, trees, network density and heavy rains can cause reflection, diffraction and scattering of the mobile signal [47-50]; long distances between transmitter to receiver in the rural villages decreases the signal received by the users [51]; multiple service providers, (for example in India) such that users need to subscribe to two sim cards in a mobile phone to maintain a seamless signal coverage [52]; poor indoor coverage where signals cannot penetrate (for example inside shopping malls) [53]; network characteristics. 4G networks perform much better than 3G networks (for example in regions of Malaysia) [54]; unexpected high use of internet can exceed the capacity of the infrastructure (for example during the COVID pandemic) [55]; loss of internet for political (for example in Indonesia) [56], internet service providers (for example in Pakistan) [57] or other organisational reasons.
Range of proposed technologies to provide mobile signal in rural areas	Implementing 5G [58-62], utilising multi-operator core network to enable spectrum sharing [63], WebRTC API for real-time streaming [64]; High Throughput Satellite (HTS) to co-channel [65]; spectrum of DVB and GSM band [66]; utilising the existing TV bands to build a frugal 5G architecture [67-69].
Exemplar digital health interventions	Remote clinic for consultation and diagnosis: Despite limited internet access, in rural villages a remote digital clinic can enable specialist consultations and transfer diagnostic images to professionals in the hospitals for real-time advice. In India, teleconsultations used a specially designed ambulance, equipped to transmit 2G(voice) mobile data signals with a camera, VSAT broadband network, SMS/MMS, and 3G/4G internet antennae [70-73]. Of the four solutions, the VSAT broadband network and SMS/MMS were successfully implemented in 108 villages throughout India [74]. Raspberry Pi have been used in Telecytology, Tele-pathology system, Tele-EyeCare Service System to transfer images from areas with limited mobile network coverage to distant specialist centres for example in Indonesia and Bangladesh [74-76]. Pregnancy monitoring system: Three studies reported the mobile app monitoring tools deployed in India and Pakistan to monitor pregnancy [77-79]. The Daksh system monitored intra partum care [79]; the Continuum of Care mhealth platform was used for pregnancy registration and monitoring care [80], and a mhealth app in Pakistan managed the clinical workforce and provision of health care equipment [81]. Healthcare facilities app: A mobile app in Malaysia provided information about local facilities with maps, health care information, cost estimation, and online survey feedback [81]. ICT in community pharmacies: ICT features such as electronic health records, electronic payment systems, accounting and logistics software, barcode reading system for medicines, online stores, as well as systems for communication with patients (Whatsapp, SMS) were implemented in pharmacies in Malaysia. The accounting and logistics software was the most used feature [80]. Centralised electronic health record (EHR): Five studies in India and Pakistan implemented proof-of-concept EHR systems in hospital and primary health centre with limited resources [82-86]. Major challenges were the lack of interoperable systems; logistical issues (unstable internet connections, lack of eHealth skills); staff perceptions that the system was time-consuming, differences in the native languages, gender imbalances and lack of national standardisation, security and legislative framework.

End users' adoption

We included 19 studies that reported users' adoption of digital health care (Appendix 3 in the **Online Supplementary Document**), reporting multiple factors that affected usage. Trust was emphasised as influencing adoption: both trust in the intervention (the degree to which the participant believed the digital intervention was accurate or reliable), and trust in the caller (degree to which people believed the call or message was genuine (as opposed to marketing) [45,46,87-92]. Other factors included relevance of the information, gender, age, literacy, occupation, ICT skills/experience, and belief in ability to use the technology (the Har-vest plot, **Figure 5**).

4. Local input to interpret relevance and adoption factors

We identified a significant gender gap in mobile ownership and use of internet in the five countries which is illustrated in Appendix 4 in the **Online Supplementary Document** [18,93,94]. Fewer women owned a mobile phone and used the internet in all the countries, though the gender gap was only 3% in Malaysia in 2020. Pakistan had the widest gap in mobile ownership (33% in 2020); India, Bangladesh and Pakistan had a wide gender gap in internet use (India:42% in 2020; Bangladesh: 38% in 2019; and Pakistan: 38% in 2017).

DISCUSSION

Summary of findings

RESPIRE colleagues from Bangladesh, India, Indonesia, Malaysia and Pakistan wished to implement a wide range of mhealth, telehealth and centralised EHR applications, but several practical barriers exist, challenging the deployment in their local areas. We investigated the national policy, infrastructure, design, and end user adoption to understand the challenges. Digital health policies were available in all the countries, but often lacked the backing of legislation and regulations governing standardisation and interoperability, and with limited strategies for ensuring a skilled workforce and training for clinicians in using digital technolo-

Note:

- Each plot represents an adoption factor
- The bar illustrates individual studies that emphasize the factor that has been reported. The plot uses several bars to imply a factor that was considered by multiple studies. Features of the different interventions are illustrated according to the legend below.

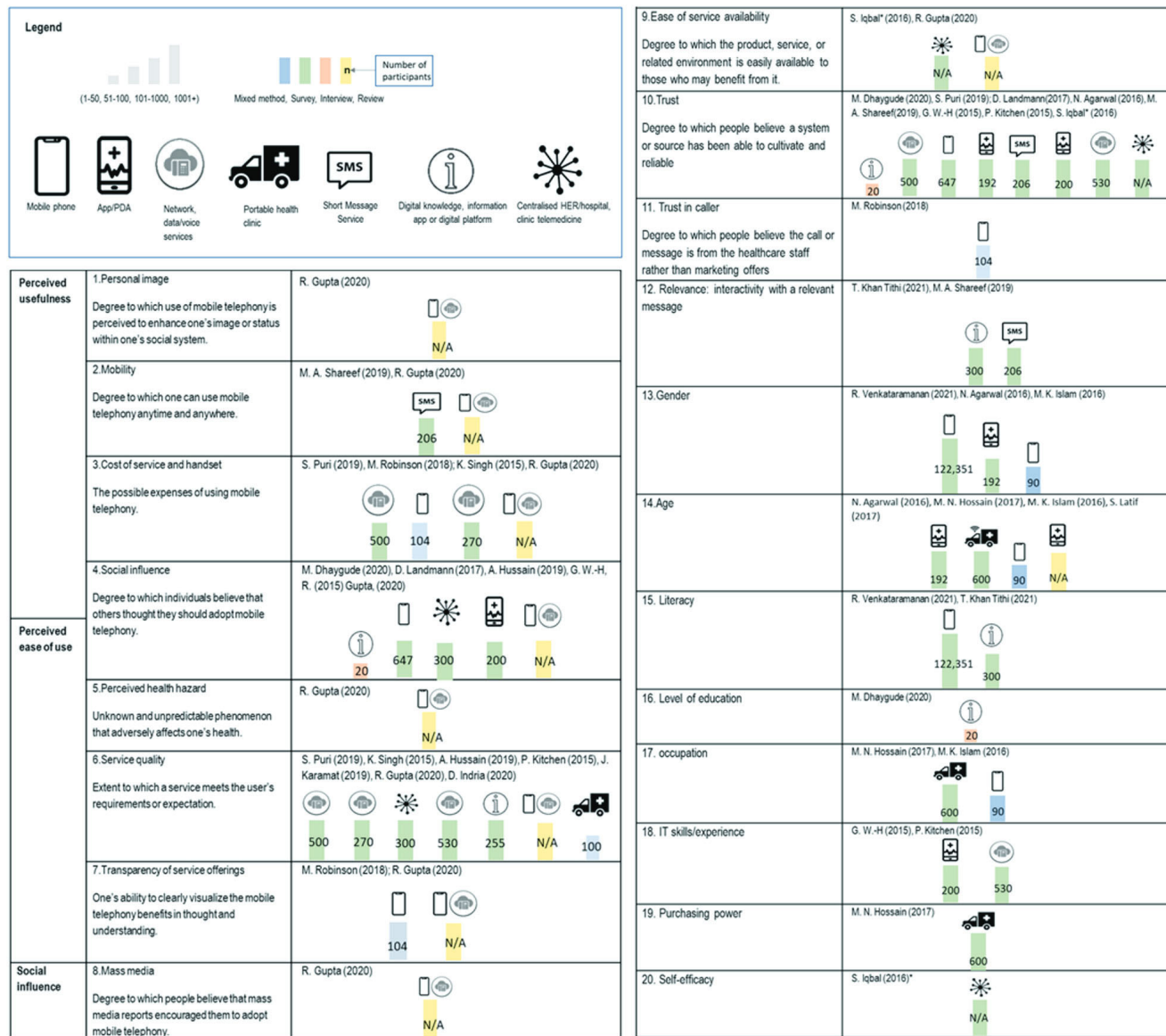


Figure 5. Harvest plots illustrating use of digital interventions related to adoption factors. Each plot represents an adoption factor. The bar illustrates individual studies that emphasize the factor that has been reported. The plot uses several bars to imply a factor that was considered by multiple studies. Features of the different interventions are illustrated according to the legend below.

gies in routine practice. While almost all the population could access electricity, this was often unstable especially in rural areas making it difficult to achieve a reliable remote clinical service. Renewable energy may offer solutions for the future. Mobile internet coverage has increased over recent years and in urban (but not rural) areas is almost universal, but the cost of fixed broadband makes this unaffordable in the low-income countries. Substantial gender disparities in internet access challenge deployment of equitable digital health solutions. There are innovative studies from the five countries using technology that could be deployed to deliver the projects on the "wish-lists" of the partners. Apart from ease of use and the perceived usefulness of the technology, users' trust in the accuracy and reliability of the service was crucial to engaging users in the digital services.

Strength and limitations

Our review scoped the current policy, infrastructure and enabling environment that form the context for the digital health solutions valued by RESPIRE colleagues. Our findings are specific to their South/South East Asian countries, though the approach and the open access sources used are likely to be applicable to other LMIC countries (and potentially remote/low-resource settings in high income countries) as considerations of policy, infrastructure, design and user-adoption are universally relevant. Our focus was on the context, so we did not consider the characteristics of the individual digital health project (thus we identified national workforce/costs data from the global digital health index but not the specific requirements for people, costs and project management) which are inherent to planning a novel intervention and can be informed by WHO toolkits [16].

We searched for the most recent data available, but in some cases, these were a few years out of date. Accelerated by the COVID-19 pandemic, patients are increasingly motivated to adopt digital options for their health care and technology adoption status such as the mobile phone ownership and internet access gap could change rapidly [18,95-100]. Planning a new digital health intervention involves checking the open access sources that we have identified to gather the most up-to-date information.

There are some methodological limitations. Due to resources and time constraints, we were unable to duplicate the full selection and data extraction processes, though the single researcher (CyH) erred on the side of caution to reduce the risk of rejecting a useful publication. RESPIRE colleagues reviewed the full text screening for publications from their countries and contributed to operationalising the inclusion and exclusion criteria. Whilst this is a limitation for a systematic scoping review, it most likely represents the real-world scenario in a team developing a novel digital health intervention. Different colleagues (researchers/academics with different backgrounds) were involved in the five countries which might have led to different approaches, though the main researcher was common to all sites and we had a number of video-conference meetings at which views were exchanged to facilitate standardisation. Although we acknowledge this diversity between countries is a limitation, we believe this collaboration was also a strength that enabled this complex multinational project to be conducted. The multi-disciplinary background of the reviewer team provided a broad spectrum of opinions to be included in the scoping process and to facilitate a balanced interpretation.

In line with scoping review methodology, we did not assess quality and were reliant on the accuracy and completeness of the original authors' descriptions of their results and conclusions. There were missing data in the open source statistics, though we used studies and the local news articles to supplement the missing information. Finally we will have missed emerging technologies that were not indexed in the databases.

Interpretation in relation to the published digital health guidelines and literature

Assessing the 'enabling environment', including the current status of ICT infrastructure (power supply and internet network), the readiness of the national/local digital health policy (leadership & governance, strategy

Table 5. Checklist of contextual factors

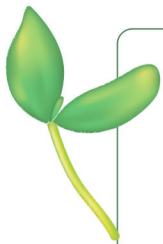
CHECKLIST OF CONTEXTUAL FACTORS THAT DEVELOPERS OF DIGITAL HEALTH INITIATIVES IN LMICs SHOULD CONSIDER AT AN EARLY STAGE IN THE DEVELOPMENT PROCESS	
Policy, legislation and standards	Be aware of the legislative context (and also the lack of regulation and standardisation) for digital health and ensure the solution complies with requirements – and also how lack of regulation will be managed.
Infrastructure	Identify national statistics on access to electricity and the internet, but also explore the reality which, especially in rural areas maybe unstable supply or “patchy” coverage. Consider implementing a strategy that enables the digital health solution to work “offline” and/or on battery mode. Consider renewable energy as an alternative source of electricity and using technologies such as Raspberry Pi, SMS, VSAT broadband network in areas with limited access to the internet.
Interoperability	Explore policies for interoperability, and ensure the digital health intervention is open and able to connect with the centralised health care system (if/when available).
Workforce	Consider the skilled workforce situation and allow adequate resources to address any shortfall. On-going technological support will be necessary to support the deployment and training for existing clinicians to operate the technologies.
Adoption costs	Understand the local costing structure for landline internet compared to low usage mobile data and voice service packages as the latter may be the only affordable option in LMICs and the technology needs to be designed accordingly.
Digital inequalities	Social norms and gender disparities in accessing mobile and internet, digital literacy and online safety are barriers for woman to access technologies. Understand the local context and adapt technology requirements to avoid increasing inequalities for women (and other disadvantaged groups: elderly, deprived communities, minority groups, poorly literate).
Encouraging adoption features	In addition to the typical factors of age, gender, and literacy, consider the key factors of perceived usefulness; perceived ease of use, service quality and the perceived trust in the technology when designing the features of the intervention. End users co-design will help ensure the intervention responds to the user's needs.

and investment, legislation, human resources, standards and interoperability, services and applications) and the factors that determine uptake (including the risk of increasing inequities) form the crucial context when designing a novel digital health solution. In this review, we provide a high-level review of these contextual issues for five South/Southeast Asian countries as a practical exemplar of applying the WHO DIIG advice [16] and the framework to improve the health service delivery [101]. We conclude that an assessment of these contextual issues should proceed in parallel (or even precede) developing specific plans. These are summarised in a checklist (Table 5).

We highlight a number of gaps in the policy context, infrastructure and workforce which echoes the findings of Leonard et al.'s systematic review on barriers and facilitators to implementing evidence-based interventions in LMICs [102]. In discussion with RESPIRE colleagues we extended our investigation to include gender imbalance, and the news items that exposed the variable reality behind headline statistics, especially in rural areas. United States Agency for International Development (USAID) further highlights the on-going financial investment needed to cover the cost of the technology replacement because of the theft, loss or damage and expected device life-span [103].

CONCLUSION

Effective implementation of digital health technologies requires a supportive policy, stable electricity infrastructures, affordable mobile internet service, and good understanding of the socio-economic context in order to tailor the intervention such that it functional, accessible, feasible, user-friendly and trusted by the target users. Using digital health initiatives planned in five South/Southeast Asian countries as exemplars, we have searched open access sources and published literature to explore the context in discussion with local colleagues. Learning from our experience and findings we suggest a checklist of contextual factors that developers of digital health initiatives in LMICs should consider at an early stage in the development process.



Data availability: HealthEnabled. Global Health Index: <http://index.digitalhealthindex.org/map>; World Bank Statistics: <https://data.worldbank.org/>; International Telecommunication Union (ITU) Statistics: <https://www.itu.int/itu-d/sites/statistics/>; International Telecommunication Union (ITU), Policy Brief - The Affordability Of ICT Services 2021: <https://www.itu.int/en/ITU-D/Statistics/Pages/ICTprices/default.aspx>; Telecom Regulatory Authority of India. The Indian Telecom Services Performance Indicators. April-June 2020: https://traf.gov.in/sites/default/files/Report_09112020_0.pdf; Ministry of Health and Family Welfare. Government of India. National Family Health Survey. 2019-2021: http://rchiips.org/nfhs/NFHS-5_FCTS/India.pdf; Groupe Speciale Mobile Association. GSMA mobile gender gap report. 2021: <https://www.gsma.com/t/wp-content/uploads/2021/06/The-Mobile-Gender-Gap-Report-2021.pdf>; URLs of the news and articles are reported in the Appendix 1 and Appendix 2.

Funding: This research was funded by the UK National Institute for Health Research (NIHR) (Global Health Research Unit on Respiratory Health (RESPIRE); 16/136/109) using UK aid from the UK Government to support global health research; and part funded by an internal partnership award, part of the Scottish Funding Council Global Challenges Research Fund institutional grant to the University of Edinburgh. The RESPIRE collaboration comprises the UK Grant holders, Partners and research teams as listed on the RESPIRE website (www.ed.ac.uk/usher/respire), including Satumino Luz.

Authorship contributors: CyH, HP and DB designed the study. CyH reviewed, co-authors conducted second review on the data. CyH undertook the data extraction and synthesised the data with HP and co-authors. HP is the study guarantor. CyH with HP wrote the initial draft and final version of the manuscript. Co-authors reviewed the draft and the final manuscript. All authors approved the final version.

Disclosure of interest: The authors completed the ICMJE Disclosure of Interest Form (available upon request from the corresponding author) and declare that the views expressed in this publication are those of the author(s) and not necessarily those of the NIHR or the UK Government.

Additional material

Online Supplementary Document

- 1 Beratarrechea A, Lee AG, Willner JM, Jahangir E, Ciapponi A, Rubinstein A, et al. The impact of mobile health interventions on chronic disease outcomes in developing countries: a systematic review. *Telemed J E Health*. 2014;20:75-82. Medline:24205809 doi:10.1089/tmj.2012.0328
- 2 Ahmed S, Mitra DK, Nair H, Cunningham S, Khan AM, Islam MS, et al. Digital auscultation as a novel childhood pneumonia diagnostic tool for community clinics in Sylhet, Bangladesh: protocol for a cross-sectional study. *BMJ Open*. 2022;12:e059630. Medline:35140164 doi:10.1136/bmjopen-2021-059630
- 3 Sun MG, Saha S, Shah SA, Luz S, Nair H, Saha S, et al. Study protocol and design for the assessment of paediatric pneumonia from X-ray images using deep learning. *BMJ Open*. 2021;11:e044461. doi:10.1136/bmjopen-2020-044461
- 4 Uzzaman MN, Chan SC, Shunmugam RH, Engkasan JP, Agarwal D, Liew SM, et al. Clinical effectiveness and components of Home-pulmonary rehabilitation for people with chronic respiratory diseases: a systematic review protocol. *BMJ Open*. 2021;11:e050362. Medline:34642195 doi:10.1136/bmjopen-2021-050362
- 5 Mahmood H, Mckinstry B, Luz S, Fairhurst K, Nasim S, Hazir T, et al; RESPIRE Collaboration. Community health worker-based mobile health (mHealth) approaches for improving management and caregiver knowledge of common childhood infections: A systematic review. *J Glob Health*. 2020;10:020438. Medline:33437462 doi:10.7189/jogh.10.020438
- 6 Mahmood H, Sheraz SY, Kiani H, Mckinstry B, Fairhurst K, Hameed R, et al. 2020. mHealth for Pneumonia Prevention. *Eur J Pub Health*. 2020;30(Supplement_5):pp.ckaa165-1033.
- 7 Patil R, Mckinstry B, Juvekar S, McKinstry B, Fairhurst K, et al. Specialist to non-specialist teleconsultations in chronic respiratory disease management: A systematic review. *J Glob Health*. 2021;11:04019. Medline:34326988 doi:10.7189/jogh.11.04019
- 8 Salim H, Lee PY, Sharif-Ghazali S, Cheong AT, Wong J, Pinnock H, et al. Developing an Asthma Self-management Intervention Through a Web-based Design Workshop For People With Limited Health Literacy: User-Centered Design Approach. *J Med Internet Res*. 2021;23:e26434. Medline:34499039 doi:10.2196/26434
- 9 Uzzaman MN, Jackson T, Uddin A, Rowa-Dewar N, Chisti MJ, Pinnock H, et al. Blended learning on chronic obstructive pulmonary disease for general practitioners (GPs): a feasibility study in Bangladesh. *BMC Fam Pract*. 2020;21:203. Medline:32988371 doi:10.1186/s12875-020-01270-2
- 10 RESPIRE. Available: <https://www.ed.ac.uk/usher/respire>. Accessed: 23 June 2022.
- 11 Groupe Spécial Mobile Association (Global System for Mobile Communications). The State of Mobile Internet Connectivity, 2020. Available: <https://www.gsma.com/tr/wp-content/uploads/2020/09/GSMA-State-of-Mobile-Internet-Connectivity-Report-2020.pdf>. Accessed: 23 June 2022.
- 12 Wallis L, Blessing P, Dalwai M, Shin SD. Integrating mHealth at point of care in low-and middle-income settings: the system perspective. *Global health action*. 2017;10(sup3):1327686. Medline:28838302 doi:10.1080/16549716.2017.1327686
- 13 Peters MDJ, Godfrey C, McInerney P, Munn Z, Tricco AC, Khalil H. Chapter 11: Scoping Reviews (2020 version). In: Aromataris E, Munn Z (Editors). *JBIManual for Evidence Synthesis*, JBI, 2020. Available: <https://synthesismanual.jbi.global>. Accessed: 23 June 2022.
- 14 Garrity C, Gartlehner G, Nussbaumer-Streit B, King VJ, Hamel C, Kamel C, et al. Cochrane Rapid Reviews Methods Group offers evidence-informed guidance to conduct rapid reviews. *J Clin Epidemiol*. 2021;130:13-22. Medline:33068715 doi:10.1016/j.jclinepi.2020.10.007
- 15 Zalzal AM, Roy A. Management of mobile health projects in developing countries: An empirical study. In: 2017 IEEE 3rd International Forum on Research and Technologies for Society and Industry (RTSI) 2017 Sep 11 (pp. 1-6). IEEE.
- 16 World Health Organization. Digital Implementation Investment Guide (DIIG): integrating digital interventions into health programmes. 15 September 2020. Available: <https://www.who.int/publications-detail-redirect/9789240010567>. Accessed: 23 June 2022.
- 17 HealthEnabled. Global Health Index. Various years. Available: <http://index.digitalhealthindex.org/map> Accessed: 23 June 2022
- 18 International Telecommunication Union (ITU). ICT Statistics. 2022. Available: <https://www.itu.int/itu-d/sites/statistics/> Accessed: 23 June 2022
- 19 Thruuu. Data scraper. Available: <https://app.samuelschmitt.com/scrapper> Accessed: 23 June 2022
- 20 Davis FD. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *Manage Inf Syst Q*. 1989;13:319-40. doi:10.2307/249008
- 21 Venkatesh V, Morris MG, Davis GB, Davis FD. User acceptance of information technology: Toward a unified view. *Manage Inf Syst Q*. 2003;27:425-78. doi:10.2307/30036540
- 22 Gupta R, Jain K. Adoption behavior of rural India for mobile telephony: A multigroup study. *Telecomm Policy*. 2015;39:691-704. doi:10.1016/j.telpol.2015.01.001
- 23 The World Bank. World Bank Open Data. Various years. Available: <https://data.worldbank.org/>. Accessed: 23 June 2022.
- 24 HIMSS. Definitions of mHealth. 5 January 2012. Available: <http://www.himss.org/definitions-mhealth>. Accessed: 23 June 2022.
- 25 IEEE. Networking architectures for healthcare wireless sensor networks comparison of architectures used for remote patient monitoring. 2013. Available: <https://ieeexplore.ieee.org/document/6511728/>. Accessed: 23 June 2022.
- 26 PM Modi launches Ayushman Bharat Digital Mission. *The Indian Express*. Updated 28 September 2021. Available: <https://indianexpress.com/article/india/narendra-modi-pradhan-mantri-ayushman-bharat-digital-health-mission-7536669/>. Accessed: 23 June 2022.
- 27 National Health Authority. Ayushman Bharat Digital Mission. 2022. Available: <https://abdm.gov.in/>. Accessed: 23 June 2022.
- 28 The Indian Express. Explained: Unique Digital Health ID and you. 7 April 2022. Available: <https://indianexpress.com/article/explained/ayushman-bharat-digitalF-mission-national-health-id-narendra-modi-7540456/>. Accessed: 23 June 2022.

- 29 Aklin M, Cheng CY, Urpelainen J, Ganesan K, Jain A. Factors affecting household satisfaction with electricity supply in rural India. *Nat Energy*. 2016;1:16170. doi:10.1038/nenergy.2016.170
- 30 The time of India. Beyond access: The future of electricity in India. 19 October 2021. Available: <https://timesofindia.indiatimes.com/blogs/voices/beyond-access-the-future-of-electricity-in-india/>. Accessed: 23 June 2022.
- 31 Shah SA, Valasai GD, Memon AA, Laghari AN, Jalbani NB, Strait JL. Techno-economic analysis of solar pv electricity supply to rural areas of Balochistan, Pakistan. *Energies*. 2018;11:1777. doi:10.3390/en11071777
- 32 Rostam NE, Mohd Sidek L, Marufuzzaman M, Fai CM, Basri H, Hayder G, et al. Urban Flood Impact Assessment for the Electricity Supply Industry in Malaysia. In: *International Conference on Dam Safety Management and Engineering 2019* Nov 19 (pp. 237-244). Springer, Singapore.
- 33 Zahurul S, Mariun N, Grozescu IV, Othman ML, Hizam H, Abidin IZ, et al. Future strategic plan analysis for integrating distributed renewable generation to smart grid through wireless sensor network: Malaysia prospect. *Renewable and Sustainable Energy Reviews*. 2016;53:978-92. doi:10.1016/j.rser.2015.09.020
- 34 Nair R, Ravishankar AN, Ilango K, Shibu NS, Deepthi B, Mohan R, et al. Community development and energy equality: Experiences from micro hydro implementation in a tribal settlement in India. In *2016 IEEE Region 10 Humanitarian Technology Conference (R10-HTC)* 21 December 2016 (pp. 1-7). IEEE.
- 35 Gulagi A, Ram M, Solomon AA, Khan M, Breyer C. Current energy policies and possible transition scenarios adopting renewable energy: A case study for Bangladesh. *Renew Energy*. 2020;155:899-920. doi:10.1016/j.renene.2020.03.119
- 36 Yousaf A, Khan BA, Bashir U, Ahmad F. Overview of implementing microgrid, its policies, incentives and challenges in Pakistan. In *2019 6th International Conference on Electrical and Electronics Engineering (ICEEE) 2019* Apr 16 (pp. 6-11). IEEE.
- 37 Zaman R, Bruderermann T. Energy governance in the context of energy service security: A qualitative assessment of the electricity system in Bangladesh. *Appl Energy*. 2018;223:443-56. doi:10.1016/j.apenergy.2018.04.081
- 38 The International Telecommunication Union. Nearly half of people with 4G network coverage remain offline, mainly due to high cost of Internet access. Available: <https://www.itu.int/en/mediacentre/Pages/pr02-2021-The-affordability-of-ICT-services-2020.aspx>. Accessed: 23 June 2022.
- 39 Telecom Regulatory Authority of India. The Indian Telecom Services Performance Indicators. April-June 2020. Available: https://traai.gov.in/sites/default/files/Report_09112020_0.pdf. Accessed: 23 June 2022.
- 40 The New Leam. Rural Internet Connectivity in India: Gaps and Challenges. 31 May 2021. Available: <https://www.thenewleam.com/2021/05/rural-internet-connectivity-in-india-gaps-and-challenges/>. Accessed: 23 June 2022.
- 41 Metro My. Camping on the hill looking for a 'line' to answer the check. 10 April 2022. Available: <https://www.hmetro.com.my/mutakhir/2020/11/647378/berkhemah-di-atas-bukit-cari-line-nak-jawab-periksa-metrotv>. Accessed: 23 June 2022.
- 42 Metro My. Resist the smell of cow dung for Internet coverage. 10 April 2022. Available: <https://www.hmetro.com.my/mutakhir/2020/12/651272/tahan-bau-najis-lembu-demi-liputan-internet-metrotv>. Accessed: 23 June 2022.
- 43 Malaysian Communications And Multimedia Commission. SKMM proactively tackles internet access problems throughout the country. 18 February 2021. Available: https://www-mcmc-gov-my.translate.goog/ms/media/press-clippings/skmm-proaktif-tangani-masalah-capaian-internet-sel?_x_tr_sl=ms&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=nui,sc. Accessed: 23 June 2022.
- 44 Khan MA Yasir S, KHAN SA, Shakir M. Deployment Of 3g/4g Technologies In Pakistan. *Journal of the Institute of Telecommunications Professionals*. 2017;11:28-32.
- 45 Dhaygude M, Chakraborty D. Rethinking design of digital platforms for emergent users: Findings from a study with rural Indian farmers. In *IndiaHCI'20: Proceedings of the 11th Indian Conference on Human-Computer Interaction 2020* Nov 5 (pp. 62-69).
- 46 Puri S, Rai RS, Saxena K. A Model of Factors Affecting Adoptions of Mobile Services in India. *Pacific Business Review International*. 2019;11:15-26.
- 47 Soliman MM, Sabbir MM, Alkaeed M, Ahmed MR, Rafi IA, Mahfuz MH. Investigation of Signal Penetration Loss Variation on Different Building Components and Disparity of Receiver Location on 3G/4G Network in the Context of Bangladesh. In *2020 11th IEEE Control and System Graduate Research Colloquium (ICSGRC) 2020* Aug 8 (pp. 53-58). IEEE.
- 48 Ulaganathen K, Tharek AR, Islam RM, Abdullah K. Rain attenuation for 5g network in tropical region (malaysia) for terrestrial link. In *2017 IEEE 13th Malaysia International Conference on Communications (MICC) 2017* Nov 28 (pp. 35-38). IEEE.
- 49 Al-Samman AM, Hindia MN, Rahman TA. Path loss model in outdoor environment at 32 GHz for 5G system. In *2016 IEEE 3rd International Symposium on Telecommunication Technologies (ISTT) 2016* Nov 28 (pp. 9-13). IEEE.
- 50 Internet content download speed in Malaysia is less than 100 Mbps – Study. *Astroawani*. 15 February 2021. Available: https://www-astroawani-com.translate.goog/berita-malaysia/kelajuan-muat-turun-kandungan-internet-di-malaysia-tidak-sampai-100-mbps-kajian-283039?_x_tr_sl=ms&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=nui,sc. Accessed: 23 June 2022.
- 51 Putra GM, Budiman E, Malewa Y, Cahyadi D, Taruk M, Hairah U. 4G LTE Experience: Reference Signal Received Power, Noise Ratio and Quality. In *2021 3rd East Indonesia Conference on Computer and Information Technology (EIConCIT) 2021* Apr 9 (pp. 139-144). IEEE.
- 52 Robinson M, Imran A, Barlow M. Impact of Macro-level Regulations on Micro-level (Individual) Use of ICT: A case of mobile services in India. In *Proceedings of the 11th International Conference on Theory and Practice of Electronic Governance 2018* Apr 4 (pp. 175-182).
- 53 Shayea I, Rahman TA, Azmi MH, Han CT, Arsad A. Indoor network signal coverage of mobile telecommunication networks in West Malaysia: Selangor and Johor Bahru. In *2017 IEEE 13th Malaysia International Conference on Communications (MICC) 2017* Nov 28 (pp. 288-293). IEEE.
- 54 Shayea I, Azmi MH, Ergen M, El-Saleh AA, Han CT, Nandi D, et al. Performance analysis of mobile broadband networks with 5g trends and beyond: Urban areas scope in malaysia. *IEEE Access*. 2021;9:90767-94. doi:10.1109/ACCESS.2021.3085782

- 55 Datahaus KASPR. Slow Internet? How Covid-19 is Stressing Internet Infrastructure in Your Country. 15 March 2020. Available: <https://medium.com/@kasprdata/slow-internet-how-covid-19-is-stressing-internet-infrastructure-in-your-country-f94ee6e3b156>. Accessed: 23 June 2022.
- 56 Rest of World. Indonesia said a broken cable caused an internet blackout in Papua. Locals aren't buying it. 20 May 2021. Available: <https://restofworld.org/2021/west-papua-deliberate-internet-blackout/>. Accessed: 23 June 2022.
- 57 Awan MF, Ahmad T, Qaisar S, Feamster N, Sundaresan S. Measuring broadband access network performance in Pakistan: A comparative study. In 2015 IEEE 40th Local Computer Networks Conference Workshops (LCN Workshops) 2015 Oct 26 (pp. 595-602). IEEE.
- 58 Aprilianto Y, Asrol M, Gunawan FE. Economic Feasibility Analysis in Developing 5G Infrastructure and Locations in Indonesia. *TEM Journal*. 2021;10:121-32. doi:10.18421/TEM101-15
- 59 Yogapratama AS, Suryanegara M. Dealing with the Latency Problem to Support 5G-UURLLC: A Strategic View in the Case of an Indonesian Operator. In 2020 2nd International Conference on Broadband Communications, Wireless Sensors and Powering (BCWSP) 2020 Sep 28 (pp. 96-100). IEEE.
- 60 Riyadi R, Gaol DC, Shalannanda W, Hakimi R. Analyzing the Initial Deployment of 5G Service in Indonesia: A Literature Survey. In 2020 6th International Conference on Wireless and Telematics (ICWT) 2020 Sep 3 (pp. 1-8). IEEE.
- 61 Raharjo AM, Maryam Z, Hakimi R. Spectrum Analysis of 5G Initial Deployment for Indonesia. In 2020 14th International Conference on Telecommunication Systems, Services, and Applications (TSSA 2020 Nov 4 (pp. 1-4). IEEE.
- 62 Sastrawidjaja LS, Suryanegara M. Social and economic aspects when allocating a 3.5 GHz frequency band for 5G Mobile in Indonesia. In 2019 Asia Pacific Conference on Research in Industrial and Systems Engineering (APCoRISE) 2019 Apr 18 (pp. 1-5). IEEE.
- 63 Hafiza L, Reza M, Adriansyah NM, Setiawan ID. Techno-Economics Study of Spectrum Sharing for Mobile Network Operator in Rural Area: Study Case: Multi-Operator Core Network (MOCN) Band 1800 MHz. In 2019 Asia Pacific Conference on Research in Industrial and Systems Engineering (APCoRISE) 2019 Apr 18 (pp. 1-6). IEEE.
- 64 Bandung Y, Tanuwidjaja HC, Subekti LB. Development of multimedia streaming technology over bandwidth-limited network and its implementation in rural area. In 2016 International Conference On Advanced Informatics: Concepts, Theory And Application (ICAICTA) 2016 Aug 16 (pp. 1-6). IEEE.
- 65 Situmorang AC, Yoshua NF, Gunawan D. Analysis of Interference Mitigation between Earth Station-High Throughput Satellite towards 5G Terrestrial Network in 28 GHz Co-channel Frequency. In 2020 International Symposium on Networks, Computers and Communications (ISNCC) 2020 Oct 20 (pp. 1-5). IEEE.
- 66 Chandhar P, Pai VU. On collaborative radio frequency observatory in india. In 2020 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS) 2020 Dec 14 (pp. 1-6). IEEE.
- 67 Khaturia M, Singh J, Patil A, Belur SB, Karandikar A, Ghadge T, et al. Towards frugal 5G: A case study of palghar test-bed in india. In 2019 IEEE Wireless Communications and Networking Conference Workshop (WCNCW) 15 Apr 2019 (pp. 1-6). IEEE.
- 68 Laksana GU, Wiharta D. Radio Frequency Band 700 MHz Utilization Plan for 5G Technology Implementation in Bali Province. In 2021 IEEE Asia Pacific Conference on Wireless and Mobile (APWiMob) 2021 Apr 8 (pp. 167-172). IEEE.
- 69 Abd Rahman NH, Yamada Y, Husni MH, Aziz NA. Analysis of propagation link for remote weather monitoring system through LoRa gateway. In 2018 2nd International Conference on Telematics and Future Generation Networks (TAFGEN) 2018 Jul 24 (pp. 55-60). IEEE.
- 70 Bhattacharyya A, Agrawal S, Rath HK, Pal A. Towards Democratizing E-health Under Constrained ICT Infrastructure Through 'A-REaLiST'Solution. In 2019 European Conference on Networks and Communications (EuCNC) 18 Jun 2019 (pp. 533-538). IEEE.
- 71 Kapoor R, Sidhu JS, Chander S. IoT based National Healthcare Framework for Vector-Borne diseases in India perspective: A Feasibility Study. In 2018 International Conference on Advances in Computing, Communication Control and Networking (ICACCCN) 2018 Oct 12 (pp. 228-235). IEEE.
- 72 Pathinarupothi RK, Rangan E. Large scale remote health monitoring in sparsely connected rural regions. In 2016 IEEE Global Humanitarian Technology Conference (GHTC) 2016 Oct 13 (pp. 694-700). IEEE.
- 73 Saravanan S, Harikrishna P, Vaideeswaran J. Big data exchange between Ambulance bus to hospital network through internet in Telemedicine using computer communication network and 3G Mobile antenna. In 2015 International Conference on Computer Communication and Informatics (ICCCI) 2015 Jan 8 (pp. 1-7). IEEE.
- 74 Bahaweres RB, Santoso NB. A preliminary study: Implementation and QoS analysis of dynamic telecytology system on broadband and 3G/4G network in Indonesia. In 2016 4th International Conference on Cyber and IT Service Management 2016 Apr 26 (pp. 1-6). IEEE.
- 75 Kurniawati N, Affandi A, Pratomo I, Gyoda K. Raspberry Pi-Based VoIP System for Rural Area. In 2018 International Seminar on Intelligent Technology and Its Applications (ISITIA) 2018 Aug 30 (pp. 33-38). IEEE.
- 76 Islam R, Nohara Y, Rahman MJ, Sultana N, Ahmed A, Nakashima N. Portable health clinic: An advanced tele-healthcare system for unreached communities. In MEDINFO 2019: Health and Wellbeing e-Networks for All 2019 (pp. 616-619). IOS Press.
- 77 Tandon A, Hari K. Case study: paperless labour monitoring system in low resource healthcare settings. In Proceedings of the 10th Indian Conference on Human-Computer Interaction 2019 Nov 1 (pp. 1-5).
- 78 Bhatti UA, Huang M, Zhang Y, Feng W. Research on the Smartphone Based eHealth Systems for Strengthening Healthcare Organization. In: International Conference on Smart Health 2016 Dec 24 (pp. 91-101). Springer, Cham.
- 79 Balakrishnan R, Gopichandran V, Chaturvedi S, Chatterjee R, Mahapatra T, Chaudhuri I, et al. Continuum of Care Services for Maternal and Child Health using mobile technology—a health system strengthening strategy in low and middle income countries. *BMC Med Inform Decis Mak*. 2016;16:84. Medline:27387548 doi:10.1186/s12911-016-0326-z

- 80 Kc B, Lim D, Low CC, Chew C, Blebil AQ, Alrasheedy AA, et al. Positioning and utilization of information and communication technology in community pharmacies of Selangor, Malaysia: cross-sectional study. *JMIR Med Inform.* 2020;8:e17982. Medline:32463787 doi:10.2196/17982
- 81 Rashid AZ, Rasam AA, Idris AN, Adnan NA, Othman F. Online mapping and GIS mobile healthcare systems for intensifying low-and-middle-income community accessibility. *InIOP Conference Series: Earth and Environmental Science* 2019 Nov 1 (Vol. 385, No. 1, p. 012038). IOP Publishing.
- 82 Pai MM, Ganiga R, Pai RM, Sinha RK. Standard electronic health record (EHR) framework for Indian healthcare system. *Health Serv Outcomes Res Methodol.* 2021;21:339-62. doi:10.1007/s10742-020-00238-0
- 83 Barigela R, Kodali PB, Hense S. What is stopping primary health centers to go digital? Findings of a mixed-method study at a district level health system in Southern India. *Indian J Community Med.* 2021;46:97-101. Medline:34035586 doi:10.4103/ijcm.IJCM_304_20
- 84 Patel SA, Sharma H, Mohan S, Weber MB, Jindal D, Narayan KM, et al. The Integrated Tracking, Referral, and Electronic Decision Support, and Care Coordination (I-TREC) program: scalable strategies for the management of hypertension and diabetes within the government healthcare system of India. *BMC Health Serv Res.* 2020;20:1022. Medline:33168004 doi:10.1186/s12913-020-05851-w
- 85 Yaqoob T, Mir F, Shahid WB, Shafqat N, Amjad MF. Feasibility analysis for deploying national healthcare information system (NHIS) for Pakistan. In 2017 IEEE 19th International Conference on e-Health Networking, Applications and Services (Healthcom) 2017 Oct 12 (pp. 1-6). IEEE.
- 86 Sajwani A, Qureshi K, Shaikh T, Sayani S. eHealth for remote regions: findings from Central Asia health systems strengthening project. *Stud Health Technol Inform.* 2015;209:128-34. Medline:25980715
- 87 Landmann D, Lagerkvist CJ, Otter V. Determinants of Small-Scale Farmers' Intention to Use Smartphones for Generating Agricultural Knowledge in Developing Countries: Evidence from Rural India. *Eur J Dev Res.* 2021;33:1435-54. doi:10.1057/s41287-020-00284-x
- 88 Agarwal N, Sebastian MP, Agarwal S. Assessing the adoption of a home health provisioning system in India: An analysis of patients. *Health Policy Technol.* 2016;5:74-83. doi:10.1016/j.hlpt.2015.10.009
- 89 Shareef MA, Raman R, Baabdullah AM, Mahmud R, Ahmed JU, Mukerji B, et al. Public service reformation: Relationship building by mobile technology. *Int J Inf Manage.* 2019;49:217-27. doi:10.1016/j.ijinfomgt.2019.03.007
- 90 Tan GW, Siah MW, Ooi KB, Hew TS, Chong AY. The adoption of PDA for future healthcare system: an emerging market perspective. *IJMC.* 2015;13:65887. doi:10.1504/IJMC.2015.065887
- 91 Kitchen PJ, Martin R, Che-Ha N. Long term evolution mobile services and intention to adopt: a Malaysian perspective. *J Strateg Mark.* 2015;23:643-54. doi:10.1080/0965254X.2014.1001869
- 92 Iqbal S, Khan N. Assessment of Telemedicine Health System's Practices in Public & Private Hospitals of Pakistan: A EM Based Approach. *International Journal of Computer Science and Network Security.* 2016;16:34.
- 93 Groupe Speciale Mobile Association. GSMA mobile gender gap report. 2021. Available: <https://www.gsma.com/r/wp-content/uploads/2021/06/The-Mobile-Gender-Gap-Report-2021.pdf>. Accessed: 23 June 2022.
- 94 Ministry of Health and Family Welfare. Government of India. National Family Health Survey. 2019-2021. Available: http://rchiips.org/nfhs/NFHS-5_FCTS/India.pdf. Accessed: 23 June 2022.
- 95 India Business standard. India plugged: Work from home drives laptop sales amid Covid-19 lockdown. 12 August 2020. Available: https://www.business-standard.com/article/companies/india-plugged-work-from-home-drives-laptop-sales-amid-covid-19-lockdown-120081101812_1.html. Accessed: 23 June 2022.
- 96 De R, Pandey N, Pal A. Impact of digital surge during Covid-19 pandemic: A viewpoint on research and practice. *Int J Inf Manage.* 2020;55:102171. Medline:32836633 doi:10.1016/j.ijinfomgt.2020.102171
- 97 Indian Television.com. MUMBAI: As India went into a lockdown mode due to COVID-19. 2 April 2020. Available: <https://indiantelevision.com/television/tv-channels/viewership/tv-consumption-up-by-37-in-week-12-due-to-covid-19-lockdown-barc-india-nielsen-200402>. Accessed: 23 June 2022.
- 98 Standard B. Covid-19 lockdown effect: Every second Indian now on internet in cities. 9 May 2020. Available: https://www.business-standard.com/article/economy-policy/covid-19-lockdown-effect-every-second-indian-now-on-internet-in-cities-120050801805_1.html. Accessed: 23 June 2022.
- 99 Khazanah Research Institute. Broadband Quality in the Face of Covid-19 Shocks. 27 March 2020. Available: http://www.krinstitute.org/assets/contentMS/img/template/editor/Views_Mutu%20Jalur%20Lebar%20Dalam%20Menghadapi%20Kejutan%20Covid-19_01.pdf. Accessed: 23 June 2022.
- 100 Internet M. Ganggu Produktiviti, Susah Bekerja. 14 November 2020. Available: <https://www.youtube.com/watch?v=FXU3M-J2rwYk>. Accessed: 23 June 2022.
- 101 World Health Organization. Regional action agenda on harnessing e-health for improved health service delivery in the Western Pacific. 2019. Available: <https://apps.who.int/iris/handle/10665/330700>. Accessed: 23 June 2022
- 102 Leonard E, de Kock I, Bam W. Barriers and facilitators to implementing evidence-based health innovations in low-and middle-income countries: a systematic literature review. *Evaluation and Program Planning.* 2020;82:101832. Medline:32585317 doi:10.1016/j.evalprogplan.2020.101832
- 103 MCSP and Partners. Digital Health Investment Review Tool. December 2018. Available: <https://www.mcsprogram.org/resource/digital-health-investment-review-tool/>. Accessed: 23 June 2022.