BMC Primary Care

RESEARCH

Open Access

Development and implementation of a digital clinical decision support system to increase the quality of primary healthcare delivery in a refugee setting in Chad

B. Matthys[1,5*], N. Monnier[1,5], M. Ngaradoumadji[2], Y. Toubangue[2], P. Delcroix[1,5], M. Pereira[1,5], T. Schmitz[1,5], J. Armour-Marshall[3], M. Zahorka[1,5], K. Sugimoto[4], M. Léchenne[1,5], D. Revault[1,5], K. Wyss[1,5] and A. Montolnan[1,5]

Abstract

Background Digital clinical decision support systems (CDSS) enhance the quality of primary healthcare service delivery for vulnerable populations in resource-limited settings. This improvement occurs by strengthening healthcare providers' clinical skills and enabling them to operate more independently while adhering to standard treatment guidelines. From January 2019 to June 2023, we developed and implemented a digital, tablet-based CDSS for children aged 2–59 months. The phases of development, validation, and implementation, as well as lessons learnt and bottlenecks requiring attention, are analysed.

Methods The project was carried out in three primary healthcare facilities within a health district in southern Chad, covering a population of 48,000, which includes a significant number of refugees from the Central African Republic. The intended end users were nurses, nurse assistants, and midwives, with supervision provided by health district teams.

Results The CDSS, based on the WHO's Integrated Management of Childhood Illness (IMCI) and national guidelines, was tailored to the context of available resources and epidemiological patterns. From the outset, the active involvement of a diverse group of local, national, and international technical stakeholders (clinicians, information and communication technology (ICT) specialists, health workers, and district health authorities) facilitated mutual knowledge sharing and product co-creation processes. The CDSS was adapted to the local context, which enhanced local ownership. However, its complexity requires significant effort from clinicians and ICT specialists for development and validation. Additionally, health centres must rely on a technical infrastructure (electricity, internet connection, and server solutions).

Conclusions From the outset, a participatory approach involving key stakeholders from the local to the national level of the health system significantly contributed to the successful development and implementation of the CDSS. The sustainability of such an intervention necessitates ongoing long-term commitment. This includes establishing and maintaining the infrastructure, ensuring continuous human resources and technical expertise for implementation and quality assurance, and updating content to reflect advancements in clinical medicine.

*Correspondence:
B. Matthys
barbara.matthys@swisstph.ch
Full list of author information is available at the end of the article

Keywords Clinical decision support system (CDSS), Integrated management of childhood illnesses (IMCI), Resource-constrained settings, Refugees, Primary healthcare, Chad

Background

Healthcare in resource-constrained settings with a humanitarian context

The quality of healthcare and service delivery in resource-constrained settings is challenging due to a paucity of skilled health workers coupled with poor medical infrastructure and limited essential equipment, diagnostic capacity, and supply issues [1]. Conflicts marked by an influx of refugees and insufficient functionality of primary healthcare (PHC) services pose additional constraints requiring innovative and agile solutions to support healthcare delivery and ensure equity between the refugee and host area populations [2]. Despite a common vision of providing access to quality healthcare services to all populations in need, intervention principles differ between national health systems and humanitarian care providers in terms of policies, implementation modalities, and duration [2, 3]. Standard healthcare services and programs for the control and elimination of diseases (e.g., vaccination and deworming) in areas of conflict may be disrupted or inaccessible for refugee populations, which negatively affects access and ultimately health outcomes. The provision of quality healthcare delivery to large numbers of people in need calls for integrated approaches and strategies supporting and strengthening healthcare workers' capacity to detect, manage, and prevent health issues in primary healthcare [4].

Clinical decision-making

A series of WHO guidelines on the integrated management of childhood illness (IMCI) [5], maternal and newborn care [6, 7], and children and adolescents in health facilities [8] were produced to improve the quality of care at the PHC level. However, adherence to IMCI guidelines by health workers may be rather poor in practice [9–12].

Clinical decision support systems (CDSS) are "digitised job aids that combine an individual's health information with the health worker's knowledge and clinical protocols to assist health workers in making diagnosis and treatment decisions" [13]. CDSS offer promising agile solutions that play an increasingly significant role in improving the quality and comprehensiveness of primary healthcare service delivery and health outcomes for underserved populations [14]. The "Practical Approach to Care Kit (PACK)" is an example of a simplified and streamlined paper-based clinical decision support tool to support PHC providers. The tool was developed, implemented, and evaluated in South Africa and scaled up to various other countries. It is tailored to end users with different levels of training (clinicians, nurses, and nurse assistants) and is updated annually [15]. When provided on a hand-held mobile device, the CDSS can increase health workers' adherence to clinical guidelines [16]. Moreover, they hold potential for healthcare providers' capacity strengthening by building upon clinical skills, increasing knowledge, and raising awareness of lesser-known conditions. This empowers them to work more independently, which is key for maintaining basic quality services in resource-limited settings [17–19]. Studies from Tanzania using electronic IMCI algorithms demonstrated improved clinical assessment and management, resulting in improved health outcomes and quality of care [20] and reduced antibiotic treatment [21–24]. The processes of translating clinical guidelines into a digital decision support system follow a standardised nomenclature that builds on a five-level conversion system for the digitisation of SMART guidelines developed by the WHO [25]. Level 1 refers to available clinical guidelines in a narrative format (disease-specific or other written guidelines). Level 2 includes the semi-structured stage, which refers to the transformation of Level 1 guidelines to a decision tree format that is still human-readable. Level 3 presents the machine readability stage (with code, terminology and interoperability standards, and software-neutral specifications). Level 4 concerns the reference software used to execute the algorithms and interoperable digital components in a local execution environment. Level 5 encompasses trained and optimised dynamic executable clinical algorithms for prioritised outcomes.

The Chadian context

The Chadian health system is notoriously underfunded. The coverage and quality of healthcare services are poor because of a lack of qualified health staff and equipment, poor infrastructure (absence of electricity and clean water), and an unreliable supply of medicines and consumables [26–29]. Domestic governmental health expenditures as a percentage of government expenditures were 5.2% in Chad in 2019 [30], whereas the Abuja declaration of the African Head of State recommended a benchmark of 15% [31]. The density of medical doctors per 10,000 people was 0.6, and that of nursing and midwives was 2.0. Chad had one of the highest infant and maternal

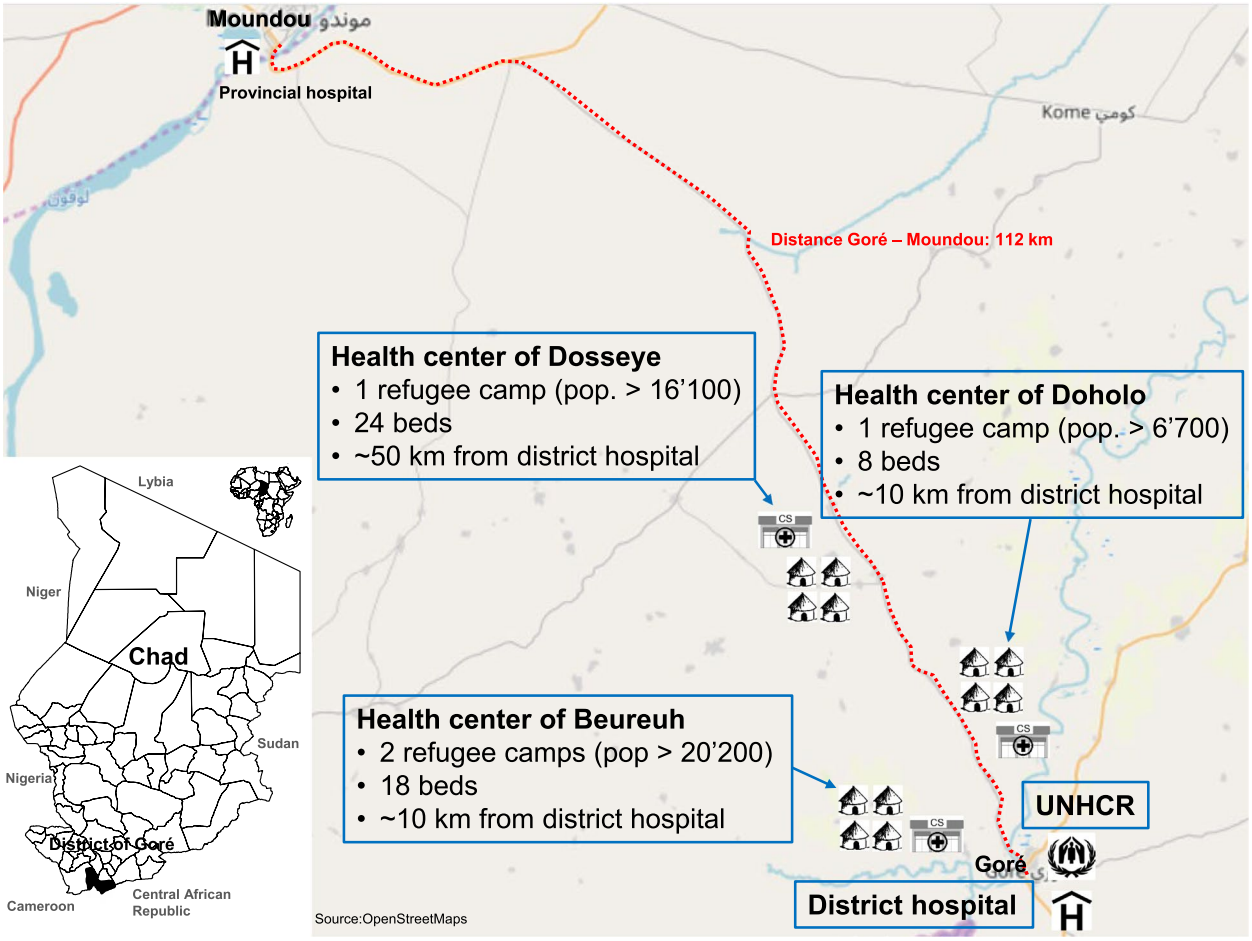

Fig. 1 Project zone including the health centres and refugee population in the district of Goré, Chad

mortality rates worldwide, with a value of 1,140 per 100,000 live births in 2017 [32]. Access to PHC services is low, the 'continuum of care' is dysfunctional (poor connection from the PHC level to a higher level of care for severe cases), and health management information systems in place are insufficient to produce quality data [33]. The humanitarian crises leading to the influx of refugees from neighbouring countries are overburdening the under-resourced national healthcare system, even if basic health services are partially covered by the humanitarian community [34]. Domestic insecurity results in more than 1 million internally displaced persons and returnees [35]. Refugees from the neighbouring countries of Sudan, the Central African Republic, Nigeria, and Cameroon numbered over 1.15 million in early 2024 [36]. More than 1.8 million children under 5 years of age are estimated to be acutely malnourished [37] as a result of food insecurity, childhood illnesses, displacement, limited access to healthcare, and poor sanitary conditions [35].

In acknowledging the challenges described above, we developed and implemented a digital CDSS in collaboration with the National Ministry of Health (MoH) and the UNHCR to improve the quality of PHC services for refugees in Southern Chad. The CDSS was based on IMCI guidelines and targeted children aged 2–59 months, and [38] end users at the PHC level included nurses, nurse assistants, and midwives. We first describe the phases and processes of developing, validating, and implementing the tablet-based CDSS tool, as well as the lessons learnt from development and testing. Second, we discuss encountered issues and bottlenecks within the project warranting attention by future similar initiatives.

Methods

Project zone

The health district of Goré in the Logone Oriental province in southern Chad was chosen based on a highly dynamic influx of refugees from the Central African Republic since 2003 and a high population density compared with other regions (Fig. 1). The project was conducted from January 2019 until June 2023 and covered 3

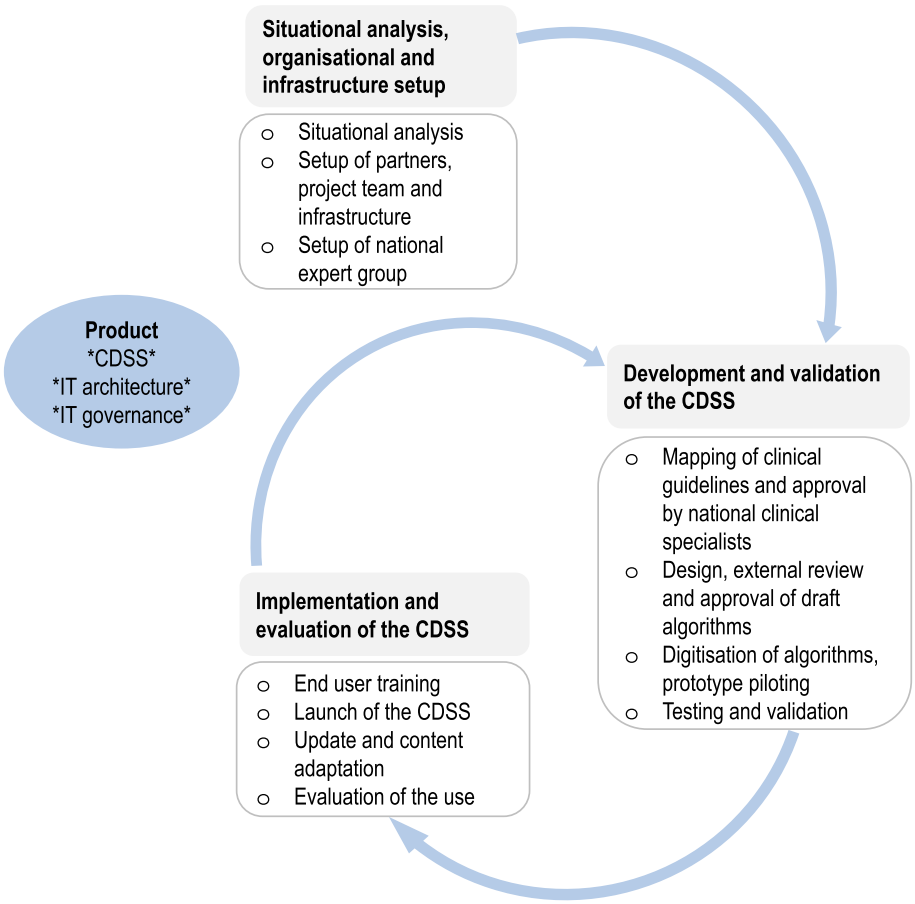

Fig. 2 Approach of CDSS development and implementation processes and product

PHC facilities serving a host population of approximately 48,000 in 2019 [39]. The villages of the host area and the refugee camps were physically separated. PHC services were accessible to all in the catchment area but were free of charge only for the refugees. The health facilities and services were supported by the UNHCR in terms of the health workforce, drug supply, and consumables. The facilities have no internet connection, but antennas were installed by the UNHCR in the refugee camps in 2019.

Framework for the CDSS development and implementation processes

The project encompassed the three phases of "situational analysis, organisation and infrastructure set up" from January-June 2019, "CDSS development and validation" from July 2019 to June 2021, and "CDSS implementation and evaluation" from July 2021 to June 2023. The phases and the CDSS product are illustrated in Fig. 2 and summarised below.

Situational analysis

The idea of a CDSS for better quality healthcare provision to refugees was introduced by the project team to national and local health authorities and other relevant stakeholders (the UNHCR and nongovernmental organisations) in Chad. The project team then conducted a situational analysis of the local context by assessing the infrastructure, workforce, capacity and skills, and local population health needs inspired by the WHO Service Availability and Readiness (SARA) tool [40, 41]. Within the health system, clinical priorities and resource gaps that affect the project's design, scale, and content of the CDSS were identified. These findings guided the selection of health centres, the identification of end users, and priority medical conditions along with requirements for technical and medical equipment.

Set up of partners, project team, and infrastructure

Cooperation agreements were signed with the key partners, i.e., the MoH, the UNHCR, and the national nongovernmental organisation "Centre de Support en Santé

Internationale" (CSSI). With support from the CSSI, we recruited a local project team, the local office infrastructure was set up, and solar panels and indoor lighting were installed in the selected health centres.

Setup of the national expert group

An initial workshop served to identify and endorse a national expert panel consisting of clinical specialists from the primary to the tertiary and central level of the MoH, national vertical programmes (IMCI, vaccination, nutrition, and malaria), international humanitarian organisations (UNHCR), NGOs and public health institutions (WHO), and the future end users of the CDSS. We also engaged with national specialists in paediatrics, internal medicine, tropical medicine, infectious diseases, and obstetrics and gynaecology to review and validate the content of the clinical algorithms for a PHC setting.

Mapping, selection, and approval of clinical guidelines by national experts

We collected and reviewed available clinical guidelines and protocols used at the local, national, and regional levels. These included, for example, recommendations and treatment guidelines from national programmes for malaria, immunisation, and neglected tropical diseases.

The algorithm design was based on the main source documents of the IMCI guidelines and the national standard guideline "ordinogram", which uses a symptom-based approach. The intended end users were expected to use the "ordinogram" and, thus be familiar with the design. Adaptations were made to reflect the local epidemiology and account for identified priority conditions. If relevant guidelines were absent or outdated, we sourced complementary topic-specific publications and recommendations from international public health and humanitarian organisations. For example, the WHO guidelines for skin-related diseases, as well as neglected tropical diseases and Médecins sans Frontiers (MSF) guidelines, were included, because they address a variety of options for clinical management under limited resources and logistical challenges [42, 43]. The national expert panel reviewed and formally approved the scope of medical conditions, including their diagnosis and management.

Design, external review, and approval of draft algorithms

The clinical algorithms were designed with open-source diagram software [44]. In the frame of an external review process of the draft algorithms, the national expert panel members were expected to provide feedback on language, local terms and content, and discrepancies and gaps in the L2 flow diagrams. This included critically reviewing diagnoses, management, treatment, and language before consensus and formal approval.

Digitisation of algorithms and prototype piloting

The designed clinical algorithms [44] were mapped on an open-source format (XLSForm/xlm) by the ICT specialists. Early versions of the approved clinical algorithms were manually digitised. The mapping process was later accelerated by introducing a "tool for rapid implementation of clinical content" (TRICC) that automatically converts the drawings into the XLSForm/xlm. TRICC was developed in-house and facilitates automatic updates of the digitised clinical algorithms. The XLSForm is then uploaded to an application of choice and presented on the electronic device as a questionnaire. To evaluate the CDSS's functionality, the project team, together with the health workers, tested an early prototype in the project health centres.

Testing and validation

The approval of the digitised clinical algorithms was preceded by an extensive iterative process, including repeated testing, reviewing, and refining by clinicians and ICT specialists. IT testing consisted of defining and executing an IT-related system and integration tests to validate the IT logic (order, structure, content, and form of questions and instructions, such as "observe", "determine", and "ask"). The consistency between each decision tree and the questions in the app was verified.

Owing to the complexity of the algorithms, it was not possible to manually verify each pathway. Hence, for the clinical content testing and validation, we used a priority matrix for key health conditions based on defined criteria concerning occurrence, severity, and needs for knowledge and management. Diagnoses with an overall score above a threshold were systematically tested. National clinicians with experience in primary healthcare developed clinical vignettes and tested the CDSS with these for a hypothetical consultation. We defined a clinical vignette as a test case to simulate a real-life scenario, which consisted of a variety of clinical symptoms and signs, followed by steps in clinical assessment leading to a specific diagnosis based on medical standards. The clinicians and ICT specialists discussed and resolved all apparent clinical and technical issues. A report was created for each test executed and later used for the validation of the clinical algorithm.

End-user training

We employed a 3-day training of trainers approach involving national clinicians at the central and district levels. The training material was prepared mainly by local project clinicians and ICT specialists. The content was tailored to clinical skills for diagnoses covered by the CDSS and included additional topics, such as patient management, pre-referral, referral, medical triage,

principles of consultation and communication, antibiotic stewardship, and technical skills to manipulate the electronic device. The participants' skills were assessed during each training session through pre- and post-tests via a questionnaire containing multiple-choice questions.

Quality assurance

Quality assurance measures were employed throughout all project phases. The national expert panel reviewed and approved the source documents and clinical algorithm design. The content and terminology were adapted to the local setting to minimise misunderstanding and misinterpretation. Testing and validation of the CDSS involved external national clinicians. The project team, together with central, provincial, and district health authorities and other partners, provided formative supervision and repeated refresher training to end users, including topics suggested by them, to strengthen their clinical and patient management skills.

Results

CDSS

The CDSS was developed as an offline-compatible tablet application for primary healthcare providers. It included a structured decision-support system to improve the diagnosis and management of common paediatric conditions. The CDSS was tailored to local priority health conditions, disease patterns, locally available resources, and sociocultural factors about the resident and refugee populations. The design integrated local terms, language, and images for appropriate clinical assessment. It was built on IMCI guidelines, which were adapted from the national standard guideline "ordinogram" [45], applying a symptom- and syndromic-based approach to facilitate the detection and management of lesser-known conditions. Where available, we integrated low-cost point-of-care diagnostics to support and/or confirm clinical diagnosis. We also included clinical algorithms to support the healthcare provider in the evaluation, case detection, and management of febrile conditions about emerging or re-emerging infectious diseases causing recent regional outbreaks, such as dengue and chikungunya [46, 47]. The project team developed 33 paediatric clinical algorithms and tested 40 priority diagnoses via self-developed clinical vignettes. Six workshops with the clinical expert panel were organised to review and validate the clinical guidelines and algorithms. Advantages of the CDSS with expected impact in terms of design and clinical and therapeutic management and advice, as well as issues encountered, are summarised in Table 1.

IT architecture

Figure 3 outlines the CDSS' architecture. The CDSS ran on the initially chosen application CommCare [48] and was later migrated to the Community Health Toolkit [49]. The health facilities had no internet; therefore, the application stored the case recorded by the health worker offline on the electronic tablet. The data were regularly synchronised by the health centre manager with an online data server via a mobile router.

IT governance (data management, protection, and security)

The patient data were de-identified, and the information was encrypted and password-protected [50]. A unique code was assigned to each patient. The code was drawn from a list of automatically created codes continuously distributed to the health facilities. It was recorded in the health booklet at the patient registration service and then entered into the electronic tablet by the consulting health worker for the first visit of a case and used for follow-up visits. To secure electronic devices, a liability contract was signed by the involved parties (the project coordinator, the district medical officer, and the health centre manager). The devices, accessories, and their conditions were recorded in a handover book at every shift change to produce traceability. The devices were tracked by geolocation and locked in cupboards when not in use. User access and rights were restricted by creating individual user accounts according to the type of utilisation. New account and access requests were analysed and approved by the project coordinator. A guideline on the project's data governance was developed.

Implementation of the CDSS

The implementation phase included end-user training, a CDSS launch, a user satisfaction study, and content update and adaptation. The CDSS was launched in June 2021. The end users were trained before and received repeated refresher training in October 2021, April 2022, and January 2023. They were also closely accompanied and supervised jointly by the project and health district teams. A total of 77,214 consultations eligible for use of the CDSS were performed, and the CDSS was effectively used for 25,621 consultations (33.2%) between July 2021 and April 2023. To sustain the intervention, all the project equipment was retained by the implementers at the end of the project. The health district team and a focal point in each of the health centres were designated by the MoH to continue providing technical supervision to the CDSS end users in the health centres. Moreover, they were supported remotely by the project's former clinician

Table 1 Advantages of the CDSS with expected impact

Advantage	Description	Expected impact	Issues encountered
Integrated management of diseases	• Main complaint and reason for consultation as entry point (symptom-based approach) • Clinical topics were designed in a way to avoid repetitive questions in the event of an additional health problem	• Better management of a broad range of health conditions of refugees within in routine health-care settings	• Some of the local guidelines were partially outdated and showed gaps that had to be complemented with international standard guidelines
Evidence-based decision support	• CDSS was built on national and international standard guidelines • Integrated prompts with culturally adapted visuals, e.g. for skin diseases • Possible diagnoses for comorbidities	• Improved diagnosis, management, awareness and knowledge of less well known conditions • Enhanced usability of the CDSS	• Some point-of-care tests (POCTs) included in the clinical algorithms and supporting decision-making were frequently out of stock. The lack of confirmation of clinical diagnosis may have increased the referrals and generally reduced the CDSS' added value of evidence-based support
Harmonised treatment recommendations	• Treatment advices were aligned for multiple diagnoses and adapted to local medications available (alternative treatments proposed if the first line treatment was out of stock) • Drug recommendations were provided with automated weight-based calculation of dosages	• Reduced over prescription and over- or under dosage of medications • Patient received treatment at health centre pharmacy • Consideration of stock outs	• The recommended treatment was based on the restricted availability of diagnostic tests, which limited a targeted treatment. Therefore, a syndromic management was adopted to this specific setting
Pre-referral management and patient advice	• Advices for pre-referral management and treatment, and for patient management at home	• Available pre-referral management and treatment advices, which are possibly life-saving for critical conditions	• Referral was not effective due to a dysfunctional continuum of care (health centres were better equipped in terms of infrastructure und skilled health professionals than the district hospital)
Patient follow-up	• Integrated function of call up of previous visits for follow-up visits	• The patient consultation can be interrupted, e.g. for ordering a rapid test	• This function requires a functioning archiving system of patient files
Reminders and prompts	• The clinical algorithm contained reminders (patient history, examinations, investigations, diagnostic tools) • Integrated prompts to respond to each question and to confirm key questions (e.g. weight) • Filters to reduce typing errors	• Predefined processes prevented skipping • Improved data quality by reducing missing and erroneous data	

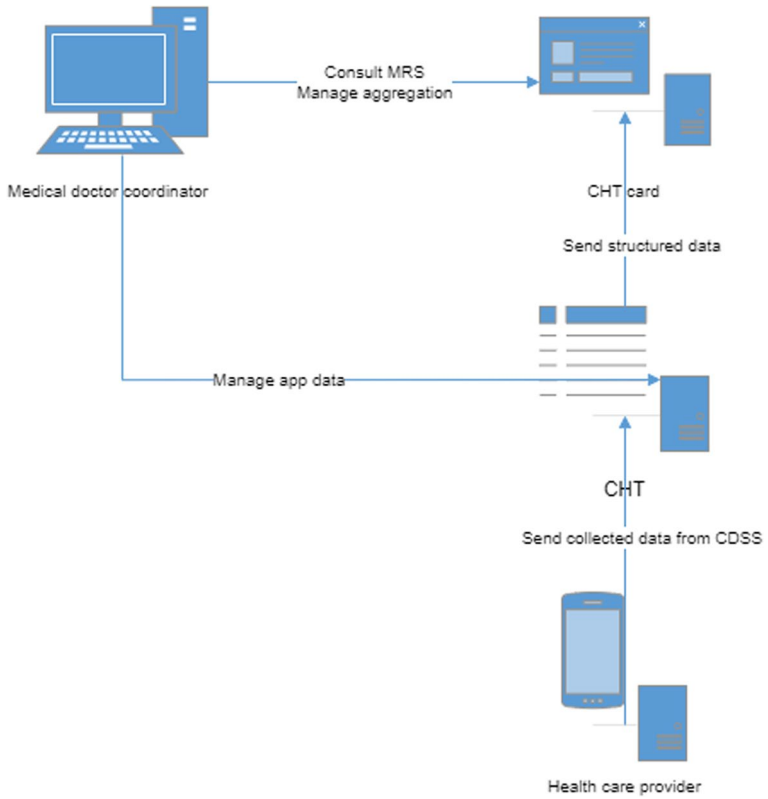

Fig. 3 Architecture of the CDSS

Fig. 4 Medical consultation of a child in the health district of Goré, Chad, January 2023. Picture credit: Salomon Djekorgee Dainyoo/ Swiss Tropical and Public Health Institute/Stanley Thomas Johnson Foundation/Fairpicture

and ICT specialist [51]. Figure 4 shows a medical consultation of a child in the health district of Goré, Chad.

Update and content adaptation

The end users were encouraged to provide feedback on the CDSS during piloting, validation, and implementation, and their inputs were collected mainly through supervision visits, analysed, and addressed as appropriate.

Evaluation of use

Five evaluations were carried out by the national MoH and the "Ministry of Economic Forecasting and International Partners". In addition, the Foundation commissioned an evaluation given its funding programme's future. We conducted a user satisfaction study with end users of the CDSS and auxiliary personnel who did not directly use the CDSS but were impacted by changes in the CDSS implementation in their daily work. The study is detailed elsewhere [52]. The study design and questionnaire were adapted from a previous study that assessed key elements of successful CDSS implementation, including adaptation, adoption, feasibility, acceptability, and sustainability [53]. Two-point data collection 6 and 16 months after implementation allowed the assessment of satisfaction over time. Using a mixed methods approach combining semi-quantitative and qualitative data allowed the authors to quantify and compare satisfaction between the two study time points and find explanations for the observed changes in satisfaction.

Table 2 Phases and activities, approaches and outcomes of the CDSS development and implementation

Phase, activity	Methodological approach	Outcome
Situational analysis, organisational and infrastructure setup		
Situational analysis	• Appraisal of health management and services, infrastructure, technology, workforces and skills, and guidelines	• Better understanding of the local context
Setup of partners, project team and infrastructure	• Setup of local office infrastructure, rehabilitation of health centres • Recruitment of project team • Collaboration agreements with key project partners	• Operational framework conditions created • IT architecture tailored to a local low-resource setting
Setup of national expert group	• Setup and endorsement by the MoH of a national expert panel • Creation of a national technical working group (national expert panel members, national medical specialists)	• Compliance with quality assurance measures throughout project duration • Ensure adaptations to local context and setting
Development and validation of the CDSS, content update		
Mapping of clinical guides and approval by national clinical specialists	• Selection and approval clinical guidelines and local priority medical conditions	• Medical conditions and reference documents for clinical algorithm development build on local needs and take into account low-resource setting
Design, external review and approval of draft algorithms	• Clinical algorithms build on national and on standard international guides and on a symptom- and syndrome-based approach • Revision and refinement of clinical algorithms based on repeated reviews by end users and national clinical specialists	• Consideration of the local setting (epidemiological and sociocultural factors, available resources and skills, national policy) • Adaptation and formal approval of clinical algorithms
Digitisation of algorithms, prototype piloting	• Digitisation of clinical algorithms via an automatic transcription programme • Pilot test of a CDSS prototype	• Digitised algorithms (interrogatory) are ready for testing • Functionality of CDSS tested, major issues identified
Testing and validation	• Definition and execution of IT-related system and integration tests on interrogatory • Priorisation and scoring of clinical algorithms to be tested based on clinical diagnoses and selected key criteria (likelihood, clinical severity, epidemiological risk, knowledge) • Systematic testing of diagnoses with defined high scores • Development, review, and approval of clinical vignettes • Testing of clinical vignettes with CDSS interrogatory by clinicians • Adaptation of drawn and digitised algorithms based on feedback, repeated testing until no single issue is detected • Final review and approval of tested clinical algorithms by national clinicians	• Validation of IT logic • Priorisation of health issues for clinical testing • Clinical validation of digitised algorithms • Issues on clinical approach, diagnosis and validation of clinical vignettes identified and addressed
Implementation and evaluation of the CDSS		
End user training and CDSS launch	• Preparation of training course and material • Training of national trainers and of end users • Assessment of participant's skills via pre- and post-test • Participants feedback on training (evaluation form) • Launch of the CDSS	• National clinical, analytical and teaching skills strengthened • Participant's evaluation to improve following trainings
Update and content adaptation	• Regular feedback on the CDSS by end users • Technical working group of national clinical and IT specialists created to regularly update the tool	• Ensuring crucial adaptations
Evaluation of the use	• End user satisfaction study conducted	• Evaluation of five satisfaction indicators (adaptation, adoption, acceptability, feasibility and sustainability) of the CDSS 6 and 16 months after implementation

The phases and related activities, methodological approaches, and outcomes of the CDSS development and implementation are summarised in Table 2.

Discussion

We developed and implemented a digital CDSS targeting children aged 2–59 months. The design and clinical content were tailored to the end users' competencies and resources available to them, thereby taking into account the context. Key achievements and issues encountered and limitations identified in the different phases of the project, are discussed here and structured along 'impact', 'potential', 'adoption', and 'challenges and weaknesses'.

Impact

Even though the project's approach to outcome and impact monitoring did not allow to establish evidence in respect to quality of care changes or other clinical outcomes, the CDSS contributed to strengthening the end user's clinical knowledge and skills, and their awareness of less well-known diseases. The provision of repeated refresher training and formative supervision to end users to build and maintain their knowledge and skills in clinical and patient management and to use the CDSS was crucial to sustaining such an intervention, as also mentioned in other sub-Saharan settings [10, 11, 54]. The CDSS is currently replicated in an additional selected health district within the national health system. The involved stakeholders and end users expressed their strong interest in the continuation and expansion of CDSS use, which would require the involvement of key stakeholders at all levels of the MoH.

Potential

An integrated disease management approach beyond IMCI, including priority and less well-known conditions, may consider integrating adapted algorithms for syndromic disease management, such as sexually transmitted infections. This approach would allow accounting for endemic parasitic diseases with confounding clinical symptoms (e.g. female genital schistosomiasis), to guide assessment and management in girls as a vulnerable group. Coupled with a reliable electronic recording and reporting system, the CDSS has the potential for health facility-based disease surveillance. CDSS-based real-time data generated can be fed into dashboards for case detection, support basic mapping and monitoring of potential outbreaks, and identify trends of notifiable, epidemic-prone, and emerging infectious diseases. Health facility-based electronic integrated disease surveillance and response (eIDSR) systems are increasingly implemented, e.g., in Nigeria [55], Sierra Leone [56–58], and Tanzania [59]. Refugee settlements are particularly at risk of endemic disease outbreaks because of poor sanitary infrastructure and high population density. Population and cross-border movements and alterations in local vector abundance can facilitate the emergence or re-emergence of communicable and vector-borne diseases, such as dengue, chikungunya, and zika, which can then spread among formerly disease-naïve populations [60, 61].

Adoption

Partner commitment benefitted from an established long-term network in Chad through previous projects and programmes. The MoH's interest and commitment throughout all project phases were crucial. The national expert panel established by the MoH's Department of Health Services Organisation and Quality of Care brought different stakeholders from the ministry, national vertical programmes, NGOs, and academia together and substantially contributed to strengthening the technical capacity of digital health. The organisation of national workshops on the capitalisation of the project and digital health contributed to advocating the CDSS at the national and regional levels. The active involvement of the national expert panel that also included end users in the development and validation processes and provision of feedback on the design of the clinical algorithms helped to refine and adapt the CDSS and enhanced co-creation and local ownership of the CDSS. Being aware of the need to keep exchanges for regular content updates to sustain the intervention, the national clinicians from the expert panel formed a technical working group on their initiative. The content update consists of reviewing and updating the clinical content of the CDSS based on novel drugs, diagnostics, clinical guidelines, and changing patterns of disease epidemiology. Access by health professionals from resource-constrained settings to communities of practice is crucial to strengthen the collaboration and regional and international networks [62] and can be a well-accepted resource for clinical decision-making by peers [63].

The findings from the user satisfaction study indicated high acceptance of the CDSS by the end users. Adapting the CDSS to the local context, building a co-creation and constant feedback process, and providing continuous technical support to the end users was key to a successful implementation of the CDSS [52].

From a gender perspective, female health professionals at the local and national levels were represented in the expert panel. The national clinical consultants to develop locally adapted clinical vignettes were men, as no female clinical consultants could be engaged in this task.

The situational analysis allowed the identification of significant pre-existing resource limitations, namely, poor medico-technical equipment and stock shortages of medications and rapid diagnostic tests. The project thus provided health centres with medico technical equipment, and the CDSS was adapted to suggest second and third-line medications as well as offer decision points with and without test availability.

The project team and national clinical specialists involved underwent a mutual learning process during the development and validation phases, from reaching a common understanding of the concept and scope of the CDSS to thorough testing, reconsidering, and adapting different approaches, which required agile management. The complexity of the CDSS is an approximate reflection of clinical decision-making. It is thus essential to what, how, and in which order information is presented. The information chosen out of a diagnostic process can be as important as the information chosen to be included. The clinical content must be up-to-date and evidence-based, incorporate and balance national and international standards and guidelines, and be appropriate and useful to end users. Therefore, the development of clinical content for a decision tool is completely different from translating a pre-existing guideline into a digital format and requires a high investment of reflection, focus, and attention at various levels. The CDSS provides clinical decision support and is not intended to provide the user with a diagnosis. The user has the freedom to rely on her or his judgment and retains ultimate responsibility for the decision that has been made or the medication that has been prescribed. The end users come with varying levels of training, experience, and baseline knowledge, and the tool might replace individual judgments or assert a cognitive bias. For accuracy and clinical safety, therefore, the tool should, as far as possible, reflect the decision logic that a majority of clinicians would most likely make if presented with the same set of parameters and background information. A comparative analysis of four IMCI-related CDSS showed that conversion of narrative guidelines in a decision logic requires interpretation, which calls for CDSS development standards to ensure health and quality of care outcomes [64].

The testing and validation of digitised clinical algorithms are crucial for providing end users with a safe digital tool and ensuring sufficient adaptation by minimising the risk of providing erroneous advice, which is more harmful than beneficial. Every conceivable scenario should be considered; therefore, various clinical tests (clinical vignettes) were developed and carried out. The approval of the digitised clinical algorithms is thus preceded by an extensive iterative process of testing, reviewing, and refining each of the prioritised clinical diagnoses, involving close interactions between clinicians and ICT specialists. End users should be actively involved in this process from the beginning to foster their understanding. Early testing focused more on the IT logic and clinical vignettes covering diagnoses of common childhood illnesses, whereas later testing was built on lessons learnt and included a broad range of additional clinical vignettes developed by national clinicians. To respond to new evidence and updated guidelines, a process of regularly refreshing the clinical content (by periodical revisits of the clinical algorithms and adaptation if required), is needed to ensure that it remains relevant. To sustain certain agility of the CDSS over time, processes should be established to clinically and technically reassess and test it after each adjustment. This should be addressed at both the planning stage and during the initial development.

The national expert panel reviewed and approved the source documents and algorithm design during repeated validation workshops. However, a critical review of inputs questioning the content and quality of the algorithm and feedback on discrepancies and gaps was rather poor for the paediatric algorithms. This lesson was taken into account during the development of adult clinical algorithms (which are not further discussed here). We adapted the review approach by building small working groups of national clinicians and assigned them several clinical algorithms for a thorough review and a later discussion in the plenum. This approach provoked lively debate among the panel members and encouraged critical input. Moreover, the repeated workshops likely allowed gradual familiarity with the project team, encouraging the expert panel members to question the clinical algorithms.

Challenges and weaknesses

The major challenge of the development, validation, and deployment of a CDSS to a refugee context in southern Chad was its complexity. It required a strong commitment and a substantial effort, particularly from the clinicians and ICT specialists, during the development and validation phases, which resulted in an unexpectedly high workload. At the beginning, the project team had to reach a common understanding and consensus of the concept and procedures. The decision on the algorithm's design had to be weighted between its complexity and the usability of the end product (CDSS) in a resource-constrained local context. Some of the algorithms were thus decided to be slightly reduced to keep the number of items to answer per consultation as short as possible. We believe that work overload may affect health professionals' ability to perform their duties at a high quality, including consistently using the tools and tests provided, which may result in inaccurate diagnoses

and inappropriate treatment. These compromises have also been reported in other settings of low- and middle-income countries [65]. Importantly, the development process is not complete with the launch of a CDSS; its use needs to be solidly embedded into working routines and local training curricula.

The local setup and sustainment of a CDSS involves the continuous maintenance of infrastructure resources, including technology and equipment, by local clinical and ICT expertise, which requires solid long-term commitment, including funding, as it has also been pointed out in comparable settings, such as in Burkina Faso [66], Cameroon [67], and in Tanzania [68]. The setup of the current project's IT infrastructure faced several bottlenecks. For example, health centres had to be equipped with solar panels for electricity provision for room lighting and charging electronic tablets. Mobile routers had to be installed for data synchronisation between the online server and the electronic devices. Regarding data hosting, storage, and transfer, the project team made extensive inquiries about a host server solution in Chad. The governmental infrastructure and technology were insufficient at that time to host a local server, so the team had to opt for a cloud server subscription.

A limitation of the project design was the evaluation framework, which lacked a robust research design to evaluate the clinical outcome, efficacy, safety, and quality of care of the intervention. This would however require substantial financial resources for the conduct of a clinical trial or a pre-post study which was unfortunately not available. The assessment and analysis of the target population's health priorities should have been based on different sources instead of mainly routine health data. This would have allowed the project team to gain a deeper understanding of key issues and gaps and to set a reliable baseline benchmark of the target population's health situation to design project indicators adapted to this specific local context.

An important health workforce-related barrier to embedding the CDSS into routine healthcare delivery was the mobility of health workers. Their observed monthly patterns influenced the use of the CDSS, explaining the comparatively low use of the CDSS. Towards the end of the project, the health staff in the facilities was drastically reduced due to funding issues. The user satisfaction survey indicated that nurses organised themselves into a team of two, whereby one performed the patient consultation, and the other applied the CDSS and recorded the information in the patient registry. When the patient consultation was performed by one nurse, the motivation to use the CDSS decreased because of the additional workload and increased consultation time [52]. A scoping review investigating the use of the CDSS by health workers and the associated effects on workload and workflow indicated that using the CDSS did not necessarily lead to increased or decreased consultation duration. However, perceived additional time taken for consultation, increased administrative workload, and disrupted workflow patterns were identified as barriers to the use of the CDSS and point-of-care diagnostic testing in daily practice [69–72]. Besides that, incoming health workers were entitled to use the CDSS only after successfully completing a CDSS user training, which may have influenced the share of consultations using the CDSS as a support tool. The project team could mitigate the consequences of this dynamic only to a limited extent, for example, through regular supervision and the design of the CDSS. Various clinical topics were linked so that the questionnaire did not need to be restarted in the event of another health problem.

Conclusions

We described here the development and implementation of a CDSS in Southern Chad, taking into account the context, such as high constraints regarding resources addressing priority needs of vulnerable and mobile refugee population groups. A participatory approach engaging key stakeholders from the local to the national level of the health system in the process from the beginning considerably contributed to successful development and implementation. The sustainment of such an intervention requires a solid commitment to establish and maintain the technical and infrastructural setting (electricity, internet connection, and server solutions), continuous human resources, and technical support (medical professionals and ICT specialists). The CDSS reflects realities on the ground and thus requires continuous content updates to integrate the evolving clinical medicine (refreshed standard guidelines and new medicines and diagnostics) and refine for sustainability. A clinical trial or pre-post study allowing measuring clinical outcome, efficiency, and safety of the CDSS and quality of care aspects would contribute to generating evidence of its benefit and the value of the approach applied for its development and implementation.

Abbreviations

CDSS	Clinical decision support system
CSSI	Centre de Support en Santé Internationale
ICT	Information, communication and technology
IMCI	Integrated management of childhood illnesses
MoH	Ministry of Health
MSF	Médecins sans Frontières
PHC	Primary healthcare

Acknowledgements

We are grateful to the children and caregivers for their participation in the project and to healthcare providers from the selected health centres for their commitment in all project phases, allowing us to improve the CDSS. The local

authorities of the Goré health district and the UNHCR ensured a welcoming and safe working environment. The MoH, through the MoH's Department of Health Services Organisation and Quality of Care (DOSSQS), was actively involved in all project phases and strongly supported the project. The CSSI provided administrative and logistical support to the project and staff. We thank Peter Steinmann, and Talia Salzmann, and the external reviewers for reviewing the manuscript. We are grateful to the Stanley Thomas Johnson Foundation for their strong support of the project.

Authors' contributions
BM drafted the manuscript and led its development process. AM, NM, DN, YT, PD, MP, TS, JA, MZ, and KS contributed to the content development of the CDSS. AM, DN, and YT were in charge of the implementation of the tool, and ML and BM were in charge of its monitoring and evaluation. DR and KW led the project. All co-authors contributed intellectual content, and reviewed and approved the final manuscript. The manuscript underwent a language check and edit suggestions by the AI-supported software "Curie" from AJE (https://beta.springernature.com/pre-submission/writing-quality?utm_source=Website_BMC&utm_medium=Digital_Edit&utm_campaign=Free+Digital+Edit+Referral+2023&utm_id=Curie2023).

Funding
Open access funding provided by University of Basel The project was funded by the Stanley Thomas Johnson Foundation based in Switzerland.

Data availability
Aggregated data and materials are available on request.

Declarations

Ethics approval and consent to participate
The project was approved by the Government of the Republic of Chad (letter of approval no. 0230/MEPD/SE/DG/0004/DONGAH/2019, project agreement no. 0668/DSAONGOC/2019). The study protocol for the situational analysis was approved by the Chadian National Bioethics Committee (authorisation no. 155/PR/MESRI/SG/CNBT/2019). The research protocol for the user satisfaction study was approved by the Chad National Bioethics Committee (CNBT) (authorisation no. 11/PR/MESRSI/SE/DG/CNBT/SG/2021). The North-Western and Central Switzerland Ethics Commission (Ethikkommission Nordwest- und Zentralschweiz; EKNZ) confirmed that the study met all the requirements of a Swiss research project (AO_2021 - 00068), implying accordance with the protocol, the Declaration of Helsinki, the principles of Good Clinical Practice, the Human Research Act and the Human Research Ordinance. Written informed consent was obtained from all interviewees who agreed to participate in the studies.

Consent for publication
Consent for publication for Figure 4 from the health care provider and caregiver of the child is available.

Competing interests
The authors are members of the project team, contributing to the design and implementation of the CDSS examined in this study. They hold a financial and employment relationship with the project under review.

Author details
[1]Swiss Tropical and Public Health Institute, Allschwil, Switzerland. [2]Centre de Support en Santé Internationale, N'Djamena, Chad. [3]Lewisham and Greenwich NHS Trust, London, UK. [4]Cantonal Hospital Winterthur, Winterthur, Switzerland. [5]University of Basel, Canton of Basel Stadt, Basel, Switzerland.

Received: 31 October 2024 Accepted: 2 April 2025
Published online: 16 April 2025

References

1. Jordan K, Lewis TP, Roberts B. Quality in crisis: a systematic review of the quality of health systems in humanitarian settings. Confl Health. 2021;15(1):7.
2. Singh NS, Ataullahjan A, Ndiaye K, Das JK, Wise PH, Altare C, et al. Delivering health interventions to women, children, and adolescents in conflict settings: what have we learned from ten country case studies? Lancet. 2021;397(10273):533–42.
3. Iqbal PM, Walpola R, Harris-Roxas B, Li J, Mears S, Hall J, et. al. Improving primary health care quality for refugees and asylum seekers: A systematic review of interventional approaches. Health Expect. 2022;25(5):2065–94.
4. Ekezie W, Adaji EE, Murray RL. Essential healthcare services provided to conflict-affected internally displaced populations in low and middle-income countries: A systematic review. Health Promot Perspect. 2020;10(1):24–37.
5. WHO. Integrated management of childhood illness: distance learning course. Geneva: World Health Organization; 2014.
6. WHO. Standards for improving quality of maternal and newborn care in health facilities. Geneva: World Health Organization; 2016.
7. WHO. Standards for improving quality of care for small and sick newborns in health facilities. Geneva: World Health Organization; 2020.
8. WHO. Standards for improving the quality of care for children and young adolescents in health facilities. Geneva: World Health Organization; 2018.
9. Walter ND, Lyimo T, Skarbinski J, Metta E, Kahigwa E, Flannery B, et al. Why first-level health workers fail to follow guidelines for managing severe disease in children in the Coast Region, the United Republic of Tanzania. Bull World Health Organ. 2009;87(2):99–107.
10. Kruger C, Heinzel-Gutenbrunner M, Ali M. Adherence to the integrated management of childhood illness guidelines in Namibia, Kenya, Tanzania and Uganda: evidence from the national service provision assessment surveys. BMC Health Serv Res. 2017;17(1):822.
11. Horwood C, Vermaak K, Rollins N, Haskins L, Nkosi P, Qazi S. An evaluation of the quality of IMCI assessments among IMCI trained health workers in South Africa. PLoS ONE. 2009;4(6):e5937.
12. Bjornstad E, Preidis GA, Lufesi N, Olson D, Kamthunzi P, Hosseinipour MC, et al. Determining the quality of IMCI pneumonia care in Malawian children. Paediatr Int Child Health. 2014;34(1):29–36.
13. WHO. WHO guideline: recommendations on digital interventions for health system strengthening. Geneva: World Health Organization; 2019.
14. Sutton RT, Pincock D, Baumgart DC, Sadowski DC, Fedorak RN, Kroeker KI. An overview of clinical decision support systems: benefits, risks, and strategies for success. NPJ Digital Medicine. 2020;3:17.
15. Cornick R, Picken S, Wattrus C, Awotiwon A, Carkeek E, Hannington J, et al. The Practical Approach to Care Kit (PACK) guide: developing a clinical decision support tool to simplify, standardise and strengthen primary healthcare delivery. BMJ Glob Health. 2018;3(Suppl 5):e000962.
16. Mitchell M, Hedt-Gauthier BL, Msellemu D, Nkaka M, Lesh N. Using electronic technology to improve clinical care - results from a before-after cluster trial to evaluate assessment and classification of sick children according to Integrated Management of Childhood Illness (IMCI) protocol in Tanzania. BMC Med Inform Decis Mak. 2013;13:95.
17. Orton M, Agarwal S, Muhoza P, Vasudevan L, Vu A. Strengthening Delivery of Health Services Using Digital Devices. Glob health sci pract. 2018;6(Suppl 1):S61–71.
18. Asi YM, Williams C. The role of digital health in making progress toward Sustainable Development Goal (SDG) 3 in conflict-affected populations. Int J Med Inform. 2018;114:114–20.
19. Bessat C, Zonon NA, D'Acremont V. Large-scale implementation of electronic Integrated Management of Childhood Illness (eIMCI) at the primary care level in Burkina Faso: a qualitative study on health worker perception of its medical content, usability and impact on antibiotic prescription and resistance. BMC Public Health. 2019;19(1):449.
20. Schmitz T, Beynon F, Musard C, Kwiatkowski M, Landi M, Ishaya D, Zira J, et al. Effectiveness of an electronic clinical decision support system in improving the management of childhood illness in primary care in rural Nigeria: an observational study. BMJ Open. 2022;12(7):e055315.
21. Keitel K, Kagoro F, Samaka J, Masimba J, Said Z, Temba H, et al. A novel electronic algorithm using host biomarker point-of-care tests for the management of febrile illnesses in Tanzanian children (e-POCT): A randomized, controlled non-inferiority trial. PLoS Med. 2017;14(10):e1002411.
22. Tan R, Kavishe G, Luwanda LB, Kulinkina AV, Renggli S, Mangu C, et al. A digital health algorithm to guide antibiotic prescription in pediatric outpatient care: a cluster randomized controlled trial. Nat Med. 2024;30(1):76–84.

23. Shao AF, Rambaud-Althaus C, Samaka J, Faustine AF, Perri-Moore S, Swai N, et al. New algorithm for managing childhood illness using mobile technology (ALMANACH): A controlled non-Inferiority study on clinical outcome and antibiotic use in Tanzania. PLoS ONE. 2015;10(7):e0132316.
24. Bernasconi A, Crabbe F, Adedeji AM, Bello A, Schmitz T, Landi M, et al. Results from one-year use of an electronic clinical secision aupport aystem in a post-conflict context: An implementation research. PLoS ONE. 2019;14(12):e0225634.
25. WHO. SMART guidelines: World Health Organization; 2023. Available from: https://www.who.int/teams/digital-health-and-innovation/smart-guidelines.
26. Erismann S, Gami JP, Ouedraogo B, Revault D, Prytherch H, Lechthaler F. Effects of a four-year health systems intervention on the use of maternal and infant health services: results from a programme evaluation in two districts of rural Chad. BMC Public Health. 2021;21(1):2304.
27. Lechthaler F, Abakar MF, Schelling E, Hattendorf J, Ouedraogo B, Moto DD, et al. Bottlenecks in the provision of antenatal care: rural settled and mobile pastoralist communities in Chad. Trop Med Int Health. 2018;23(9):1033–44.
28. Dansereau E, Miangotar Y, Squires E, Mimche H, group UND, group I, et al. Challenges to implementing Gavi's health system strengthening support in Chad and Cameroon: results from a mixed-methods evaluation. Global Health. 2017;13(1):83.
29. Azétsop J, Ochieng M. The right to health, health systems development and public health policy challenges in Chad. Philos Ethics Humanit Med. 2015;10:1.
30. WHO. Global Health Observatory data repository. Domestic general government health expenditure (GGHE-D) as percentage of general government expenditure (GGE) (%). Data by country.: World Health Organization; 2022.
31. Organisation of African Unity. Abuja declaration on HIV7AIDS, Tuberculosis and other related infectious diseases. In: African summit on HIV/Aids Taoridf-A, editor. Abuja, Nigeria: Federal Republic of Nigeria; 2001.
32. WHO. World health statistics 2022: monitoring health for the SDGs, sustainable development goals. Geneva; 2022. Report No.: CC BY-NC-SA 3.0 IGO.
33. Moukénet A, de Cola MA, Ward C, Beakgoube H, Baker K, Donovan L, et al. Health management information system (HMIS) data quality and associated factors in Massaguet district, Chad. BMC Med Inform Decis Mak. 2021;21(1):326.
34. Samarasekera U. Huge health needs for refugees in Chad. Lancet. 2024;403(10427):603.
35. OCHA. Global humanitarian overview 2022: OCHA; 2022 [Available from: https://gho.unocha.org/chad. Accessed Sept 2022.
36. UNHCR. Rapport opérationnel Chad du 29 mars 2024. N'Djamena, Chad: UNHCR; 2024.
37. IPC. Chad: acute malnutrition snapshot October 2022 - September 2023. N'Djamena, Chad: Integrated Food Security Phase Classification; 2023.
38. Gove S. Integrated management of childhood illness by outpatient health workers: technical basis and overview. The WHO working group on guidelines for integrated management of the sick child. Bull World Health Organ. 1997;75 Suppl 1(Suppl 1):7–24.
39. UNHCR. Population réfugiée dans le district sanitaire de Goré, Tchad en 2019. In: UNHCR, editor. Goré, Chad: UNHCR; 2023.
40. WHO. Service availability and readiness assessment (SARA). Annual monitoring system for service delivery. Implementation guide. Geneva, Switzerland: World Health Organization; 2015.
41. WHO. Service availability and readiness assessment (SARA). Annual monitoring system for service delivery. Reference manual. Geneva, Switzerland: World Health Organization; 2015.
42. MSF. Guide clinique et thérapeutique. Pour les programmes curatifs des hôpitaux et des dispensaires. A l'usage des prescripteurs.: Médecin sans frontière; 2019.
43. OMS. Comment reconnaître les maladies tropicales négligées selon les altérations de la peau : guide de formation à l'usage du personnel sanitaire de première lignes. Genève: Organisation mondiale de la Santé; 2018.
44. draw.io. The easiest way for confluence teams to collaborate using diagrams. Available from: https://drawio-app.com/.
45. Ministère de la Santé Publique. Manuel d'ordinogrammes à l'usage des agents de santé de base. N'Djamena, Tchad: Ministère de la Santé Publique, Délégation sanitaire du Logone occidental, CIDR/CPG; 2006.
46. WHO. Disease outbreak news. Dengue - Chad: World Health Organization; 2023 [16 October 2023]. Available from: https://www.who.int/emergencies/disease-outbreak-news/item/2023-DON491.
47. WHO. Disease outbreak news. Chikungunya - Chad.: World Health Organization; 2020 [24 September 2020]. Available from: https://www.who.int/emergencies/disease-outbreak-news/item/chikungunya-chad.
48. Dimagi. CommCare 2024. Available from: https://dimagi.com/commcare/.
49. Community Health Toolkit. The Community Health Toolkit 2024 [cited 2024 July]. Available from: https://communityhealthtoolkit.org/.
50. WCG. WCG whitepapers [Internet]. Princeton, USA: WCG. 2021. [cited 2021 28 October 2024]. Available from: https://www.wcgclinical.com/insights/do-you-know-me-the-subtle-distinction-between-anonymous-and-de-identified-data-in-clinical-research/.
51. SPONGAH. Rapport d'évaluation finale. Projet : Système Numérique pour une meilleure gestion de la santé des réfugies » (SysRef) dans le District Sanitaire de Goré, Délégation Provinciale de la Santé et de la Prévention du Logone Oriental. N'Djamena, Chad: Secretariat permanent des organisations non gouvernementales et des affaires humanitaires au Ministère de la prospective economique et des partenariats internationaux du Tchad (SPONGAH); 2023 August 2023.
52. Léchenne M, Montolnan A, Revault D. Digital system for better management of refugee health care (SysRef). Summary of the results of the user satisfaction study. N'Djamena, Chad: Swiss Tropical and Public Health Institute; 2023.
53. Muhindo M, Bress J, Kalanda R, Armas J, Danziger E, Kamya MR, et al. Implementation of a Newborn Clinical Decision Support Software (NoviGuide) in a Rural District Hospital in Eastern Uganda: Feasibility and Acceptability Study. JMIR Mhealth Uhealth. 2021;9(2):e23737.
54. Bucher SL, Cardellichio P, Muinga N, Patterson JK, Thukral A, Deorari AK, et al. Digital Health Innovations, Tools, and Resources to Support Helping Babies Survive Programs. Pediatrics. 2020;146(Suppl 2):S165–82.
55. Ibrahim LM, Okudo I, Stephen M, Ogundiran O, Pantuvo JS, Oyaole DR, et al. Electronic reporting of integrated disease surveillance and response: lessons learned from northeast, Nigeria, 2019. BMC Public Health. 2021;21(1):916.
56. Martin DW, Sloan ML, Gleason BL, de Wit L, Vandi MA, Kargbo DK, et al. Implementing nationwide facility-based electronic disease surveillance in Sierra Leone: lessons learned. Health Secur. 2020;18(S1):S72–80.
57. Njuguna C, Jambai A, Chimbaru A, Nordstrom A, Conteh R, Latt A, et al. Revitalization of integrated disease surveillance and response in Sierra Leone post Ebola virus disease outbreak. BMC Public Health. 2019;19(1):364.
58. Njuguna C, Vandi M, Squire JS, Kanu JS, Gachari W, Liyosi E, et al. Innovative approach to monitor performance of integrated disease surveillance and response after the Ebola outbreak in Sierra Leone: lessons from the field. BMC Health Serv Res. 2022;22(1):1270.
59. Joseph JJ, Mkali HR, Reaves EJ, Mwaipape OS, Mohamed A, Lazaro SN, et al. Improvements in malaria surveillance through the electronic Integrated Disease Surveillance and Response (eIDSR) system in mainland Tanzania, 2013–2021. Malar J. 2022;21(1):321.
60. Mordecai EA, Ryan SJ, Caldwell JM, Shah MM, LaBeaud AD. Climate change could shift disease burden from malaria to arboviruses in Africa. Lancet Planet Health. 2020;4(9):e416–23.
61. Ahmed A, Ali Y, Mohamed NS. Arboviral diseases: the emergence of a major yet ignored public health threat in Africa. Lancet Planet Health. 2020;4(12):e555.
62. Beynon F, Salzmann T, Faye PM, Thiongane A, Ndiaye O, Luwanda LB, et al. Systèmes d'aide à la décision clinique pour la pédiatrie en santé globale. Rev Med Suisse. 2023;19(836):1398–403.
63. Rodríguez-Ortega M, Ortega-Latorre Y, Montano-Navarro E, Casado-Collado AJ, Nguepy FR, Damou F. Telemedicine as a counselling tool for nurses in Central Africa. J Adv Nurs. 2025;81(5):2477–86.
64. Beynon F, Guérin F, Lampariello R, Schmitz T, Tan R, Ratanaprayul N, et. al. Digitalizing clinical guidelines: experiences in the development of clinical decision support algorithms for management of childhood illness in resource-constrained settings. Glob Health Sci Pract. 2023;28;11(4):e2200439.
65. Tan R, Cobuccio L, Beynon F, Levine GA, Vaezipour N, Luwanda LB, et al. ePOCT+ and the medAL-suite: Development of an electronic clinical decision support algorithm and digital platform for pediatric outpatients in low- and middle-income countries. PLOS digit health. 2023;2(1):e0000170.

66. Blanchet K, Sanon VP, Sarrassat S, Some AS. Realistic evaluation of the integrated electronic diagnosis approach (IeDA) for the management of childhood illnesses at primary health facilities in Burkina Faso. Int J Health Policy Manag. 2023;12:6073.
67. Jonnalagedda-Cattin M, Moukam Datchoua AM, Yakam VF, Kenfack B, Petignat P, Thiran JP, et al. Barriers and facilitators to the preadoption of a computer-aided diagnosis tool for cervical cancer: qualitative study on health care providers' perspectives in western Cameroon. JMIR Cancer. 2025;11:e50124.
68. Mwogosi A, Kibusi S. Effectiveness of EHR systems on decision support in primary healthcare: a technology acceptance model 3 perspective. J Health Organ Manag. 2024. Ahead-of-print.
69. Fletcher E, Burns A, Wiering B, Lavu D, Shephard E, Hamilton W, et al. Workload and workflow implications associated with the use of electronic clinical decision support tools used by health professionals in general practice: a scoping review. BMC Prim Care. 2023;24(1):23.
70. Rosenberg J, Miller K, Pickard O, Henrich N, Karlage A, Weintraub R. Barriers and facilitators to use of a digital clinical decision support tool: a cohort study combining clickstream and survey data. BMJ Open. 2022;12(11):e064952.
71. Ansu-Mensah M, Bawontuo V, Kuupiel D, Ginindza TG. Sustainable solutions to barriers of point-of-care diagnostic testing services in health facilities without laboratories in the bono region, Ghana: a qualitative study. BMC Prim Care. 2024;25(1):179.
72. Horwood C, Luthuli S, Mapumulo S, Haskins L, Jensen C, Pansegrouw D, et al. Challenges of using e-health technologies to support clinical care in rural Africa: a longitudinal mixed methods study exploring primary health care nurses' experiences of using an electronic clinical decision support system (CDSS) in South Africa. BMC Health Serv Res. 2023;23(1):30.

Publisher's Note