PhD-Synopsis


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by

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LIST OF ABBREVIATIONS

CDC Centers for Disease Control and Prevention
CI Confidence Interval
CDC US Centers for Disease Control and Prevention
DZIF Deutsches Zentrum für Infektionsforschung
EVD Ebola Virus Disease
EU European Union
GGMM Global Goods Maturity Model
GIZ Deutsche Gesellschaft für Internationale Zusammenarbeit
HZI Helmholtz Centre for Infection Research
IDSR Integrated Disease Surveillance and Response
IHR International Health Regulations
BMZ Federal Ministry of Economic Cooperation and Development
LGA Local Government Area
NCDC Nigeria Center for Disease Control
GHS Ghana Health Services
GCNET Ghana Community Network
ODK Open Data Kit
SORMAS Surveillance Outbreak Response Management and Analysis System
VHF Viral hemorrhagic fevers
WHO-AFRO World Health Organization African Regional Office
WHO World Health Organization
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ABSTRACT

Introduction

Electronic and mobile digital health (eHealth, mHealth) are fast developing fields from which a large number of digital software tools are implemented. The 2014-15 Ebola Virus Disease (EVD) outbreak identified gaps that revealed a lack of a summary of tools that were available and used based on the functionalities they offered. It was essential to identify the most promising methodologies and tools guided for further development. Equipping health workers with the right user-centric software tools and efficiently following them up provides a framework that creates acceptance and intrinsically motivates them to use the tool for their daily work. For any tool to be classified a global goods, it must be globally useful, acceptable to the community. It must have the ability to dynamically mature with the users’ perception and increasing needs. Surveillance Outbreak Response Management and Analysis System (SORMAS) is an open-source mobile and web application software developed to enable health workers to notify about new cases of epidemic-prone diseases, detect outbreaks and manage the response at the same time. The primary aim of the thesis is to systematically assess SORMAS in comparison to other related tools in terms of functionality and technical characteristics, evaluate how end-user health workers in Nigeria perceive, accept, use it, and to assess to what extent the tool is mature in the context of global goods.

Methods

Following the PRISMA guidelines, we searched for all reports on mHealth tools developed in the context of the 2014-15 EVD outbreak. Using a four-eye approach, we selected relevant publications utilizing a search strategy from Google scholar and MEDLINE. We applied a standardized extraction form to identify tools that contained surveillance, case management, laboratory data management, and contact tracing functionalities. We conducted a 4-week pilot and eight week-implementation of SORMAS among hospital informants in Kano state, Nigeria, in 2015 and 2018, respectively. We carried out usefulness and acceptability surveys after the pilot and implementation. From November 2017 until October 2019, we applied the Global Goods Maturity Model (GGMM) on SORMAS to assess the maturity of SORMAS over time. The GGMM comprised of core indicators: (1) global utility, (2) community support, and (3) software maturity.

Results

From the systematic review of the selected 58 of specific mHealth tools out of 1200 publications, only three tools, namely Community Care, Sense Ebola Followup, and SORMAS, supported all four of these functionalities (surveillance, case management, laboratory data management, and contact tracing functionalities). A total of 31 and 74 health workers took part in the survey in 2015 and 2018, respectively. In 2018, 94% (CI: 89-100%) of users stated that the tool was useful, 92% (CI: 86-98%) would recommend SORMAS to colleagues. In 2015, the percentages were 74% (CI: 59-90%), 90% (CI: 80-100%), respectively. The assessment of SORMAS applying the GGMM showed that SORMAS had ten point-score each in global utility, community support, and software maturity. In 2019, SORMAS had reached a combined total score of 30/30 (100%) of the GGMM for digital health software tools.

Conclusion

Only three tools seemed to cover all four key functionalities relevant for the response to EVD outbreaks and possibly most promising for further development of which SORMAS is one of them. Health workers have recurrently rated SORMAS very high on usefulness, acceptability, and reported definite improvement over time from 2015 to 2018. SORMAS is the first eHealth tool for public health disease surveillance that has accomplished the full 100% score of the GGMM and the first outbreak
response tool to do so. SORMAS seems to be one of the most comprehensive and mature tools of its kind.

1 INTRODUCTION

Electronic and mobile digital health (eHealth and mHealth) are fast developing fields from which a large number of digital software tools are implemented. Many initiatives and programs integrate eHealth tools for secure, useful, and timely dissemination of data for action. Despite the expansion of these tools to several areas of need, many of them are developed and implemented in selected geographical regions as pilots and for a limited time (Tom-Aba et al., 2018). The sustainability of these tools is a crucial indicator of successful development and implementation. The limitation to the sustainability of eHealth tools is characterized by the following; 1.) The lack of integration of standard frameworks during development, 2.) The inability to create a diverse pool of continuous donor support, and 3.) The generalized method of development without serving a targeted objective (AbouZahr C., Boerma T., 2005, Free C., Phillips G. et al., 2013, and Qiang CZ., Yamamichi M. et al., 2011). In the field of public health, funding and sustainability are crucial indicators for success, and many initiatives depend on scarce public resources. There are many eHealth tools developed and implemented in many countries, and, to assess which tool to use efficiently, many factors must be taken into account, including but not limited to; a.) The portfolio of functions; b.) The user-friendliness of the system and user acceptability and, c.) the sustainability and contribution to global goods.

The 2014/2015 Ebola Virus Disease (EVD) outbreak in West Africa exposed the innate weakness of the surveillance system in West Africa (Tom-Aba et al., 2018). However, the situation gave rise to several mHealth tools to be piloted and implemented across the region. The successful containment in Nigeria made the country a use case for other countries within the region. The national EVD team was made up of several experts, including epidemiologists, laboratory technicians, medical doctors, and IT informatics experts. They contributed to the successful containment of Ebola in 2014 (Faisal Shuaib et., al, 2015). The data team unit of the Ebola-Emergency Operation Center (EOC) developed a mobile application and deployed it for health workers and disease surveillance officers to collect real-time data. The teams were trained each day and given smartphones for reporting. The efficiency of daily situation reports increased from 50% to 100% in 24 hours and continued so until the end of the outbreak (Tom-Aba et al., 2015). The innovative mHealth approach that contributed to the containment of the Ebola outbreak in Nigeria (2014/2015) led to the development of Surveillance, Outbreak Response Management, and Analysis System (SORMAS).

1.1 Review of the use of open-source mobile health case detection and outbreak management systems for infectious disease control

Infectious disease containment is a critical factor in limiting the spread of the disease within a population. Rapid detection, identification and follow up of potential cases in real-time has become the game-changer in the last five years following the Ebola Virus Disease (EVD) outbreak in 2014/15 (Moyer D. et al. 2017). The outbreak identified gaps within the health structures in affected countries that bordered on delayed case detection, inefficient contact tracing, and follow up, laboratory data management, and real-time surveillance (Denecke, K. 2017). According to Dhillon et al. (2014), specific interventions are required for controlling major outbreaks that could result in pandemics. These
Interventions include community engagement, identification of contacts, monitoring of contacts for symptoms, rapid laboratory confirmation, isolation and treatment, and safe burials (Dhillon et al., 2014). The combination of these interventions can be harnessed to stop transmission and contain an outbreak (Dhillon et al., 2014). Real-time data for action, coordination of interventions, and strategy are important for dynamically changing epidemic patterns (Tom-Aba et al., 2018). There was a lack of an overview of what categories of tools were available and used during the EVD outbreak in 2014/15. It was important to identify the most promising approaches and tools guided for further development and work as a one-shop approach with several key functionalities, as explained by Dhillon et al. (2014) within one tool.

1.2 Integrated disease surveillance and response (IDSR) strategy

The Integrated Disease Surveillance and Response (IDSR) is a strategy that aims to strengthen surveillance and response at each stratum of the health system by building local capacities; leveraging strengths and expertise through partnerships and co-ordination in resource-poor settings (Phalkey, R.K., Yamamoto, S., et al., 2013). Vertical single disease surveillance strategies constitute a major challenge because they are designed to provide data to the national level where decisions are made with little or no coordination from the lowest reporting level (Franco et al. 2006). IDSR in West Africa aims to facilitate coordinated and harmonized strategies and methods. Usefulness and acceptability are among the most important attributes to take into account because it is the users who will do the work. Without them, no system can be successful (Wilkins, K., Nsubuga, P., et al., 2008). According to Klauck D.N. et al. (1988), a surveillance system evaluation should measure whether that system is helping a useful public health function and is meeting the system's objectives (Klaucke, D.N., Buehler, J.W., et al., 1988).

1.3 Challenges related to disease surveillance and outbreak response

In low and middle-income countries, weak health infrastructure, obsolete surveillance systems, and concepts, shortage of human, technical, and financial resources are major issues that impact effective disease surveillance (Hitchcock et al. 2007). An ideal surveillance department at any level requires trained staff, adequate transportation means, and logistics to function effectively (Dairo, M.D., et al., 2010). The training and follow up supportive supervision of health workers on mHealth solutions may have the capacity to reduce these challenges (Phalkey, R.K., Yamamoto, S., et al., 2013). In Nigeria, technological knowledge about mHealth surveillance systems among health workers is quite low, and as a result, they need to be trained and followed up before they can accept and use such a tool (Bawa, S.B. and Olumide, E.A., 2005).

1.4 Pilot implementation studies for surveillance and response software in developing countries

According to Adeoye O., Tom-Aba D. et al. (2017), involvement with the Nigeria EVD response in 2014 provided a framework for the tool design. The development of the tool from the initiation phase to piloting phase was eight months, and there was a collaborative effort of stakeholders in the design process with strict adherence to IDSR guidelines and International Health Regulations (IHR). IDSR was used as a reference for the data model. In a pilot implementation phase, the need for prior training and continuous supervisory availability on site should not be underestimated even for user-friendly tools (Adeoye O., Tom-Aba D., et al., 2017). The pilot was a success attributing to the fact that the development of the tool was user-centric in its methodology. The approach was a design-thinking
workshop with all potential users of the system and stakeholders. The outcome of the pilot showed increased acceptability and usefulness of the system during the pilot in Kano and Oyo states (Adeoye O., Tom-Aba D., et al., 2017).

1.5 Technical development of Surveillance Outbreak Response Management and Analysis System (SORMAS) for infectious disease control

The Helmholtz Centre for Infection Research (HZI), along with other key partners, developed SORMAS as an open-source mHealth and eHealth application software, to enable health workers to inform the public health departments about new cases of priority diseases and manage outbreak response at the same time. The HZI and partners developed SORMAS as a prototype Hana SAP platform in 2015 for a short field pilot during the EVD response in West Africa (Fähnrich C. et al., 2015). The first version of SORMAS was mainly developed for EVD and included Measles, Cholera, and Anthrax in its initial implementation. In 2016, The HZI, through the funding and assistance of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), fully migrated SORMAS to an open-source platform expanding its portfolio to 7 diseases including the laboratory data management component (Tom-Aba D. et al. 2018). In 2017, the monkeypox outbreak response in Nigeria initiated the pilot and Adhoc activation of SORMAS that expanded SORMAS to 10 diseases with further functional and technical characteristics (Silenou B.C, Tom-Aba D., et al., 2020). In 2018, The Nigeria Center for Disease Control (NCDC) initiated SORMAS rollout across 15 federal states within Nigeria while responding to simultaneous outbreaks. At this time, the number of diseases in SORMAS increased to 12 diseases, a French version of SORMAS, and additional technical features. In 2019, with the support of the Ghana Health Services (GHS) and the Ghana Community Network (GCNET), HZI deployed SORMAS as a pilot project in Ghana and included the clinical management module while completing 100% of the global goods maturity model (Tom-Aba et al., 2020). SORMAS is a process and user management system, which supports supervisors to validate cases and control the spread of disease. The objective of SORMAS is to improve infectious disease control and management by advocating control measures on time and verification of potential cases. SORMAS provides a framework for validated real-time surveillance data, which reduces the disease burden through enabled contact follow up and symptom detection during visits. SORMAS offers an easy to use, user-centric interface following international standards. SORMAS, as a multi-functional software, can be used for case surveillance, activity tracking, laboratory data management, contact tracing, and disease detection to prevent and manage outbreaks that may occur. SORMAS also uses a multi-directional information exchange synchronizing user requests as well as sending feedback to the different users within the existing surveillance system (Fähnrich C et al., 2015). SORMAS was specifically developed for resource-poor settings and is free of charge while adhering to the highest data protection standards, open access policy, and good scientific practice.

1.6 Systematic evaluation of public health surveillance systems

The systematic and continuous evaluation of disease surveillance systems is a proven process in ensuring an efficient capturing, analysis, and interpretation of data. The information generated is used for planning, implementation, and assessment of rapid response and action (Thacker, S.B. et al., 1988). The Center for Disease Control and Prevention (CDC) guidelines for evaluating public health surveillance, states that an established surveillance system within a country should be periodically reviewed based on their cost, usefulness, and quality (Thacker, S.B., Parrish, R.G. and Trowbridge, F.L., 1988). In assessing quality, evaluators should review the following seven attributes of a surveillance

1.7 Global goods maturity model assessments

Global agencies, policymakers, ministries of health came together to create guidelines to support these kinds of technologies, which are meant to assist Government agencies and stakeholders in launching and scaling up sustainable digital health innovations (Health Data Collaborative, 2017). The concept of the global goods maturity model (GGMM) for software development, implementation, and support stemmed from this collaborative effort. The main objective was to fast track development and scale-up of successful digital health solutions to campaign for improvements (Digital Impact Alliance (DIAL), 2017 and PATH. Digital Square 2017). Health strengthening through enhancing country information systems would contribute to better decision making and, ultimately, better health (Digital Impact Alliance (DIAL), 2017). Digital Square, which is an enterprise aimed at managing international efforts to develop and broadly share useful free and open-source digital tools, included 18 mHealth tools into the database of digital health software referred to as “Global goods software” Digital Square also included SORMAS as a global goods software (Digital Square (PATH). Global Goods Guidebook, 2019). We identified the GGMM to be an appropriate concept in assessing the maturity of SORMAS because; a.) GGMM has a particular focus on health software and those used in low resource settings; b.) the objectives of GGMM matches well with the mission of SORMAS; c.) the scope of most of the tools included in the GGMM guidebook fit to that of SORMAS. According to the GGMM, global utility, community support, and software maturity are the main concepts used to determine the maturity of global goods software. Hence, we applied the concepts to SORMAS to determine their maturity (Tom-Aba et al., 2020).

The objective of the thesis is to methodically assess SORMAS in comparison to other related tools in terms of functionality and technical characteristics, evaluate how end-user health workers in Nigeria perceive, accept, use it and to assess to what extent the tool is mature in the context of global goods
2 METHODS

2.1 A systematic review of mHealth apps for the management of the 2014/15 Ebola outbreak

During the Ebola outbreak in 2014, the use of different mobile apps for the outbreak raised a question to understand what tools exist which were developed and implemented for Ebola surveillance and outbreak response. We wanted to identify which tools could potentially be further scaled-up across Africa as a surveillance and outbreak response tool. We looked at the critical functionalities of the mobile health tools used with regards to four key features; (1) surveillance capability, (2) contact tracing, (3) case management, (4) laboratory data management (Tom-Aba, D. et al., 2018). We conducted a systematic search of articles published in Google Scholar, Medline, CAB abstracts, POPLINE, and Web of science. We limited our search from January 1, 2014, to December 31, 2015. We used the search criteria (“Outbreak” OR “Epidemic”) AND (“mobile phone” OR “smartphone” OR “tablet” OR “mHealth”) AND (“Ebola” OR “EVD” OR “VHF” OR “Ebola Virus Disease” OR “viral hemorrhagic fever”) AND (“2014” OR “2015”) (Tom-Aba, D. et al., 2018). The first step was to screen abstracts and journal titles. We threw out publications that were either editorials, summaries, commentaries, and videos. The next step was to identify those publications that described events that covered a mHealth tool and was used for the Ebola outbreak or other hemorrhagic fever outbreaks. The next step was to select the full articles, which reported about the characteristics of the tool itself. We then categorized each mHealth tool based on critical functionalities, technical features, and epidemiological characteristics (Tom-Aba, D. et al., 2018). The main aim was to generate an overview of mHealth tools that were developed from 2014 to 2015 to identify tools with the most promising portfolio of functionalities, which might build the basis for further mHealth developments for infectious disease surveillance and control (Tom-Aba, D. et al., 2018).

2.2 User evaluation of SORMAS after field deployment in Nigeria in 2015/2018 among hospital informants

In 2015, during the first pilot of SORMAS in Nigeria, the HZI with key partners deployed the prototype version of SORMAS (SORMAS-2015) in Kano state and Oyo state (Fähnrich, C. et al., 2015). We administered a user evaluation survey to measure the usefulness and acceptability of SORMAS-2015 among hospital informants (Tom-Aba et al., 2018). In response to the outcome of the user survey during the 3-month pilot, HZI re-developed SORMAS into an open-source platform (SORMAS-2018), including additional functionalities and a complete overhaul of the user interface and user experience in 2016 (Tom-Aba et al., 2018). Kano state re-deployed SORMAS-2018 among the same hospital informants, and we administered a user evaluation survey to them asking the same questions about the usefulness and acceptability of SORMAS-2018 to compare improvement with SORMAS-2015. We provided the health workers with 2.5-inch mobile smartphones with SORMAS-2015 installed compared to 7-inch smart tablets with SORMAS-2018 installed (Tom-Aba, D. et al., 2018). The login authentication protocol deployed in SORMAS-2015 was very complicated (network dependent 3-tier authentication protocol) for the hospital informants to access SORMAS-2015 compared to SORMAS-2018 that only required a one-time encrypted password stored on the device while creating a 4-digit pin to authenticate the app anytime it was being used with or without network availability. SORMAS-2018 was designed as a user-centric application by the end-users for the end-users. We conducted six different design-thinking workshops with a total of 65 clinicians, laboratory technicians, and
epidemiologists from Germany and eight other African countries. We generated disease-specific process models for Ebola, Cholera, Measles, Influenza from the design thinking workshop in 2015 for SORMAS-2015 while integrating additional process models for the following diseases such as Lassa fever, Monkeypox, Dengue fever, Yellow fever, Meningitis, and Plague into SORMAS-2018 (Tom-Aba D. et al., 2018). In 2015, the Kano and Oyo state government selected 31 hospital informants from private and public health facilities for the SORMAS-2015 pilot. The state epidemiologist for Kano and Oyo states made the selection based on previous reporting activities and incidence of the disease reported in those health facilities.

In 2018, the Kano state government deployed SORMAS-2018 in all private and public health facilities within two districts (Adeoye, O. et al., 2017). After a two-day training exercise, we deployed SORMAS-2015 for a five-week pilot from June 2015, administering a pre-implementation questionnaire, and in July 2015, after the pilot, administered a post-implementation survey (Adeoye, O. et al., 2017). For SORMAS-2018, 80 hospital informants from the two districts also attended a two-day training with one extra day for a refresher training. We administered a post-implementation questionnaire to the hospital informants in February 2018, two months after the deployment of SORMAS-2018, to compare post-user evaluation in 2015 and 2018. In both post-implementation questionnaires, we asked the hospital informants if they wanted to use SORMAS for their routine surveillance work (usefulness: yes/no), if they would recommend SORMAS to their colleagues (acceptability: yes/no), and whether the users had experienced login problems during use (login difficulty: yes/no). The post-implementation questionnaire for SORMAS-2015 was paper-based compared to an online questionnaire for SORMAS-2018. In the statistical analysis, we calculated comparison of respondent characteristics between 2015 and 2018 using the chi-square test and proportions. We obtained written consent from study participants was obtained from all respondents while keeping the responses pseudonymized. The principal investigator ensured that the Hannover Medical school ethics board approved the study, and the study was cleared by the Nigeria Centers for Disease Control (NCDC) (Tom-Aba D. et al., 2018).

2.3 Digital Health Global Goods Maturity Assessment of the Surveillance Outbreak Response Management & Analysis System (SORMAS)

We applied the global goods maturity model version 1.0 on SORMAS from November 2017 until October 2019 to assess the level of global good maturity that SORMAS has attained. The global goods maturity model contained 15 sub-indicators grouped into the following three core indicators: (1) global utility, (2) community support, and (3) software maturity. Each sub-indicator divides into three possible values from -1 for “low,” 0 for “medium,” and 1 for “high.” Each value contains a definition listed in table 1 (Tom-Aba D., 2020). Given that the GGMM scoring values range from negative to positive values, we applied the following transformation to allow percentage values for summary scores:

\[ MS = 5 \times [\text{MEAN} (S_i)] + 5 \]  \hspace{1cm} (1)

Where, MS = maturity score for each core indicator, \( S_i \) = vector containing scores of the sub-indicators, \( i = 1,\ldots, 5 \)

Periodically, the HZI and key partners assessed the completion of SORMAS in the 15 sub-indicators. Subsequently, HZI and software developers re-prioritized the software roadmap and the work plan of
SORMAS to dedicate resources and progress to those sub-indicators for which a full score had not yet been reached (Tom-Aba D. et al., 2020).

3 RESULTS

3.1 A systematic review of mHealth apps for the management of the 2014/15 Ebola and Viral hemorrhagic fevers (VHFs)

From the systematic review, we identified 1220 publications from Google Scholar, after extraction and selection, 79% (965 of 1220) were original publications of which 15%(145 of 965) addressed mHealth used during the 2014-15 EVD outbreak response and Viral hemorrhagic fevers (VHFs). Of the 145 publications that addressed mHealth tools, 53% (77 of 145) reported on 58 mHealth tools. The flowchart in figure 1 shows the number of papers retrieved, extracted, and selected following the Preferred Reporting Items for Systematic Reviews and Meta analysis approach (PRISMA (Tom-Aba D et al., 2018).
Figure 1. Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) method for the selection of publications on mHealth tools for the 2014-2015 Ebola virus disease outbreak. EVD: Ebola virus disease (Tom-Aba D. et al., 2018).

For the key functionalities, 62% (34/55) tools offered features for surveillance, 22% (10/45) for case-management, 18% (7/38) for contact-tracing, and 6% (3/51) for laboratory data management. For (3/58, 5%) tools, namely Community Care (CommCare), Sense Ebola Follow-up, and Surveillance and Outbreak Response Management and Analysis System (SORMAS) supported all four of these functionalities (Tom-Aba D. et al., 2018). For the technical characteristics of these tools, 27% (9/33) tools worked offline, and 63% (36/58) tools were open source. Table 3 in (Tom-Aba D. et al., 2018) shows more characteristics that are technical. For epidemiological characteristics of these tools, 9% (5/55) tools did not specify if they had outbreak management module, 18% (7/38) tools had event/rumor management, 60% (36/40) tools had completed a systematic evaluation, and 62% (26/42) were piloted or deployed in the outbreak regions. Table 4 in (Tom-Aba D. et al., 2018) shows the epidemiological characteristics. None of the 58 mHealth tools covered all four key functionalities, all seven technical features, and all ten epidemiological aspects (Tom-Aba D. et al., 2018). SORMAS included 20 functionalities and characteristics, the highest within one tool, 1 of its missing components being open source in 2015 (Tom-Aba D. et al., 2018).

3.2 User evaluation of SORMAS after field deployment in Nigeria in 2015/2018 among hospital informants

In 2015, all sampled 31/31(100%) hospital informants filled out the paper forms compared to 74/80 (93%) hospital informants that participated in the post-implementation survey in 2018. Of the 80 hospital informants that we recruited and trained, only 74 hospital informants used SORMAS for their daily work after the training in 2018. For comparison of survey respondents’ characteristics between 2015 and 2018, the average participant age was 40 years in 2015 compared to 36 years in 2018. There was no difference in the participant demographic characteristics (sex, facility type, and settlement) between both groups in both years. Using a chi-square test to check for differences between the groups in both years, 8(26%) of the 2015 participants were between 18-34 years compared to 33(45%) of the 2018 participants. For the participants within the age group of 35-54 years, 23(74%) were from 2015 compared to 41(55%) from 2018. The older population in 2015 was more than the older population in 2018. There was no significant difference in the ages between both groups [chi2 = 3.2, p-value = 0.072] (Tom-Aba D. et al., 2018).

For the gender of participants, 8(26%) of the 2015 participants were female compared to 12(16%) of the 2018 participants. For the participants who were male, 23(74%) were from 2015 and 62(84%) from 2018. There was no major difference in the gender between both groups [chi2 = 1.3, p-value = 0.254] (Tom-Aba D. et al., 2018). For the facility type of participants, 20(65%) of the 2015 participants were from public health facilities compared to 50(68%) of the 2018 participants. For the participants who were from private health facilities, 11(35%) were from 2015 and 24(32%) from 2018. There was no significant difference in the facility type between both groups [chi2 = 0.1, p-value = 0.762] (Tom-Aba et. al, 2018). For the type of settlement of participants, 16(52%) of the 2015 participants lived in urban areas compared to 54(73%) of the 2018 participants. For the participants who lived in rural areas, 15(48%) were from 2015 and 20(27%) from 2018. There was a major difference in the urban/rural settlements between both groups [chi2 = 4.5, p-value = 0.034] (Tom-Aba D. et. Al, 2018).
For comparison of survey respondents' assessment on usefulness, acceptance, and ease of login of SORMAS between 2015 and 2018 surveys, see table 2 below.

Table 2. Comparison of survey respondents' assessment on usefulness, acceptance, and ease of login between 2015 and 2018 surveys (Tom-Aba et al., 2018).

<table>
<thead>
<tr>
<th>Variable</th>
<th>2015 (N=31)</th>
<th>2018 (N=74)</th>
<th>Chi²</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n (%)</td>
<td>95% CI</td>
<td>n (%)</td>
<td>95% CI</td>
</tr>
<tr>
<td>Usefulness: would want to use SORMAS in surveillance work</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>23(74.2)</td>
<td>(58.8 - 89.6)</td>
<td>70(94.6)</td>
<td>(89.4 - 99.7)</td>
</tr>
<tr>
<td>No</td>
<td>8(25.8)</td>
<td>(10.4 - 41.2)</td>
<td>4(5.4)</td>
<td>(0.3 – 10.6)</td>
</tr>
<tr>
<td>Acceptability: would recommend SORMAS for their colleagues</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>28(90.3)</td>
<td>(79.9 - 100)</td>
<td>68(91.9)</td>
<td>(85.7 - 98.1)</td>
</tr>
<tr>
<td>No</td>
<td>3(9.7)</td>
<td>(0 - 20.1)</td>
<td>6(8.1)</td>
<td>(1.9 - 14.3)</td>
</tr>
<tr>
<td>Ease of login: encounter problems with SORMAS login</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>27(87.1)</td>
<td>(75.3 – 98.9)</td>
<td>14(18.9)</td>
<td>(10.0 – 27.8)</td>
</tr>
<tr>
<td>No</td>
<td>4(12.9)</td>
<td>(1.1 – 24.7)</td>
<td>60(81.1)</td>
<td>(72.2 - 90.0)</td>
</tr>
</tbody>
</table>

3.3 Digital health global goods maturity assessment of SORMAS

In November 2017, we migrated SORMAS from a tabletop pilot version to a real-life deployed open-source software and deployed in 8 federal states and 33 local government areas (LGA) during the monkeypox outbreak. By February 2018, the NCDC, through the support of HZI, deployed SORMAS in 3 additional federal states (71 LGAs) for meningitis outbreak. In March and April 2018, NCDC further deployed SORMAS in 3 additional states (49 LGAs, five health facilities) for the Lassa fever outbreak. As of October 2019, NCDC has fully established SORMAS for all epidemic-prone diseases in 15 federal states (including the federal capital), 287 local government areas, 37 health facilities, and approximately 700 users covering 75 million population. Through the use of SORMAS, health workers have been able to manage multiple outbreaks simultaneously across the country. The assessment of SORMAS applying the GGMMM showed that SORMAS had a ten out of ten point-score each in global utility, community support, and software maturity. (See table 3 in Tom-Aba D. et al., 2018 showing the three core indicators (global utility, community support, and software maturity) for SORMAS development from November 2017 to October 2019).
4 DISCUSSION

4.1 Systematic review, user evaluation, acceptance, and global goods assessment of SORMAS

Electronic and mobile digital health (eHealth, mHealth) have proven to be effective in providing a framework for real-time data and decision making to control infectious disease. Despite the limitations that exist with digital tools concerning weak resource areas, network challenges, training needs, and follow up, the ability of a tool to surmount these challenges depends on how the development and implementation of the tools address the user-driven needs. The systematic review of mHealth tools conducted by Tom-Aba D. et al. (2018) was supplemented in 2020 by another rapid review by Yavlinksky A. et al., (2020) from University College London (UCL) which expanded its purview beyond 2014-15 to 2020 and also included more diseases and technical functionalities in its search criteria. Yavlinksky A. et al. (2020) also came to the same conclusion that SORMAS was one of the most up-to-date and scientifically proven mHealth tools for disease detection, case surveillance and management, contact tracing and laboratory data management (Yavlinksky A. et al., 2020). The University College London (UCL) review strengthened Tom-Aba D et al. 2018 review even though they were not involved or affiliated with SORMAS; however, it concluded that SORMAS is the best for disease detection case surveillance, contact tracing, and laboratory data management. From personal communication with Yavlinksky A., UCL has decided to deploy SORMAS for Tanzania (personal communication). Embedding the technical characteristics and key functionalities of SORMAS with its user-centric methodology provides a framework for end-user acceptability and usefulness of SORMAS (Tom-Aba D et al., 2018). The sustainability of SORMAS has proven its use in Nigeria and Ghana as the primary surveillance and outbreak response tool for the national surveillance system in the country. Equipping health workers in Nigeria with the right user-centric software tools and efficiently following the up has provided a framework through SORMAS that produced high acceptance and intrinsically motivated them to use SORMAS for their daily work. This is a very crucial indicator for successful development and implementation. It is important to prioritize the further development and deployment of SORMAS with its function as a one-shop approach with several key functionalities within one tool. SORMAS, as a global goods software, has proven to be globally useful, acceptable to the community, and contains the ability to dynamically mature with the users’ perception and increasing needs.

4.2 Interpretation of findings

4.2.1 Interpretation of findings from a systematic review

The main objective of the systematic review of mHealth apps for the management of the 2014/15 Ebola outbreak was to produce a summary of mHealth tools that were developed from 2014 to 2015. The secondary objective was to ascertain which tools had the most promising set of functionalities that might construct the foundation for further mHealth developments for infectious disease surveillance and control. We observed from the review that many mHealth tools that we identified in the search results were developed for the 2014/2015 EVD outbreak and VHFs. The disparate nature of the functionality of each tool indicates a post-planned attempt to develop tools aimed at containing the EVD outbreak. However, only a few tools appear to have contained sufficient medical and public health expertise to address the procedural and technical needs (Tom-Aba D et al., 2018). For the critical functionalities of surveillance and outbreak management (surveillance capability, contact tracing, laboratory management, and case management), only three tools (SORMAS, COMMCARE, and Sense...
Ebola Follow up) had the overall capability and contain embedded functional requirements for data reporting and analytics through an integrated implementation of the surveillance guidelines and standards regarding functionality (Tom-Aba D et al., 2018). CommCare was used during the EVD outbreak in the endemic regions of EVD. CommCare technology was chosen to support the implementation of the Government Response Plan against EVD to obtain rapid and reliable information as well as facilitate contact tracing. CommCare was developed primarily for contact tracing and deployed in response to the Government response plan against EVD to get real-time data and information that was authentic, including an efficient contact tracing system. Open data kit (ODK) for CommCare was used as a mobile intervention in the field while synchronization its data with CommCare servers. Sense Ebola follow-up app was also deployed primarily for contact tracing and was used for real-time data capture, follow up of cases, and visits. It also had an automatic alert system for detecting temperature readings more than 38 degrees Celsius for contacts who became symptomatic. One tool that was closest in functionalities to the three tools identified, which was not designed to manage interventions as needed for infection control and outbreak response, was the District Health Information System 2 (DHIS2). DHIS2 has the advantage of being widespread in West Africa as a health management information system. Disease surveillance and outbreak response tool should be able to feed information into every task related to a particular officer and improve each task assigned to the officer (Tom-Aba D et al., 2018). SORMAS, CommCare, and Sense Ebola Follow mHealth tools supported all functions and tasks related to case management, surveillance, and contact tracing. SORMAS was piloted in the field during the Ebola outbreak after the epidemic in Nigeria, which was based on a practical EVD outbreak scenario (Tom-Aba D et al., 2018). Sense Ebola follow-up was developed and deployed during the Nigeria EVD outbreak (Tom-Aba et al., 2015). With the given nature of outbreaks, which tend to occur sporadically, the data processed during an outbreak is comparable to that handled for surveillance activities, it is, therefore, necessary to aim for a system that can function as a surveillance tool as well as an outbreak management tool (Tom-Aba et al., 2015).

4.2.2 Interpretation of findings from user evaluation

The objective of the user evaluation of SORMAS after field deployment in Nigeria in 2015/2018 among hospital informants was to compare post-implementation evaluation between hospital informants in 2015 and 2018 regarding the usefulness and acceptability of SORMAS-2015 and SORMAS-2018 respectively for the daily tasks. The post-implementation evaluation showed that there was significant improvement between the SORMAS-2015 and SORMAS-2018 versions regarding usefulness and ease of access. For the participant groups in both years, many of them consistently accepted the SORMAS application and stated that they would recommend their colleagues to use SORMAS. For the ease of access, it was evident that changing the authentication login protocol would improve access to the app. Sizeable 7.1-inch screen tablets were provided to the participants in 2018 compared to 2.5-inch smartphones, and that also contributed to the acceptability, ease of use for the SORMAS-2018 group. We have simplified the security architecture of the SORMAS-2018 version with a 4-pin authentication architecture. However, with increased data protection and security frameworks, we may be forced to build an encrypted security kernel on the tablets for the third layer of authentication, but this would not affect the users in any way (Dasgupta, D., Roy, A. and Nag, A., 2016). We observed an increased enthusiasm regarding the usefulness of SORMAS-2018. This improvement is most likely because SORMAS-2018 covered ten diseases compared to four in the SORMAS-2015 version and included the laboratory module and laboratory technicians as additional users in the persona (Tom-Aba et al.,
We also opined that mobile technology and information importance had also increased from 2015 to 2018. Many people would have imbibed these technologies and seen its usefulness for social life and business. Hence, the development of SORMAS since 2015, adding to this, could explain the usefulness rating stated by the participants. We also observed several limitations: The study populations were not precisely the same apart from the fact that they had the same demographic characteristics and worked in the same field and had similar educational backgrounds between 2015 and 2018. The type of survey instrument used between 2015 (paper-based) and 2018 (online based) limited comparability (Tom-Aba et al., 2018).

4.2.3 Interpretation of outcome of Global good maturity model (GGMM) assessment of SORMAS

The objective of the global good maturity model was to ascertain that SORMAS has completed the full score of the GGMM. The process from the decision to migrate a prototype based on an SAP proprietary technology stack to open-source software in 2016 until the accomplishment of the full score lasted three years. There is no registry or publicly available documentation of tools that have applied the GGMM assessment except District Health Information System 2. Of all the mHealth tools selected as global goods software listed in the GGMM guidebook, none has yet accomplished over 90% in the full score, nor are we aware of any other tool that has reached it. Thus, it appears very likely that SORMAS may be the first and so far only digital tool that has accomplished the full score of the GGMM. SORMAS has multiple revenue streams and funding mechanisms, which has enabled SORMAS development since 2016 to progress.

4.2.3.1 Short discussion on methodological limitations

For the systematic review, only a small percentage of the identified publications were found in peer-reviewed scientific publication databases like PubMed, although duplicates of the publications identified in Google Scholar. This was a major limitation of our approach. Health informatics systematic review methods are not well established in evidence-based medicine and may have little value for IT projects to publish findings in peer-reviewed scientific journals. Another limitation was the fact that we limited our scope to 2015 and Ebola and VHFs. Removing these filters would have resulted in a large output with a tremendously low positive predictive value that could not be managed properly, however, UCL review 2020 also opined and collaborated the fact that SORMAS is still the best for case detection, management, contact tracing, and laboratory data management.

The scoring model of the GGMM version 1.0 was straightforward to apply; however, there seem to exist some limitations in its use that concerned some of the criteria of the sub-indicators. Some definitions included the logical functions of “AND” or “OR” combinations that negated the overall criteria if one part of the criteria were fulfilled and the other not. Although the GGMM kept the calculation simple by introducing equal weights for all 30 sub-indicators, it may not be a perfect representation of the differences in importance for various indicators. Some indicators addressed two or more directional criteria in terms of progressive activities or increased number of events. The self-assessment nature of the GGMM could also introduce a certain degree of bias.
5 CONCLUSION/OUTLOOK

SORMAS has indeed proven to be highly accepted, perceived to be recommendable to users, and widely used for disease detection, outbreak control, and response while being one of the first mHealth tools to have scored 100% in the GGMM model in 2019. The unique technical and functional characteristics of SORMAS clearly showed that tools that combine these characteristics and functionalities within one system have a higher ability to be useful, acceptable and meet any global criteria concerning infectious disease control and response. SORMAS appears to be scientifically developed with a state of the art methodological framework and is currently the most advanced of its kind. The evidence has clearly been shown in the thesis. Additional studies are now ongoing for SORMAS within the HZI research and development framework while plans to roll out nationwide in Nigeria, increase deployments in Ghana and Tanzania and subsequently roll out a vaccine campaign module of SORMAS in Afghanistan are underway.

6 REFERENCES


7 RELEVANT ACHIEVEMENTS IN THE CONTEXT OF THESIS

7.1 Publications

7.1.1 Personal contribution to the development and implementation of SORMAS

I have been involved with the conceptualization, design and development of SORMAS from the beginning as a technical and content specialist in the project. My role was a business analyst and a liaison between the software developers and the epidemiologists. I translated processes and epidemiological principles and methods to software algorithms and process models for development. I have also been involved with conducting SORMAS server deployments, configuration, hardware set up, server releases, troubleshooting and installations.

7.1.2 First and co-authors publications directly related to SORMAS produced prior to the PhD program


### 7.1.3 Additional first and co-authors publications directly related to SORMAS produced during the PhD program


- Conceived and designed a systematic review
- Developed research question
- Collected and collated publications from review search
- Data cleaning and preparing
- Interpreting PRISMA results and evaluating publications on effectiveness
- Drafting the manuscript, revising the manuscript


- Searched literature
- Evaluating publications on effectiveness
- Drafting the manuscript and revising the manuscript


- Initiated manuscript concept
- Developed matrix of global goods tools
- Developed research question
- Collected and collated publications from review search
- Searched literature
- Data cleaning and preparing
- Interpreting results and evaluating publications on effectiveness
- Data cleaning and preparing
- Evaluating publications on effectiveness and following up on SORMAS updates for attaining 100% in the GGMM
- Drafting the manuscript, revising the manuscript

### 7.2 Presentations/Conference proceedings


8 ANNEX

8.1 Full-text publications relevant in the context of this thesis


**Abstract**

**Background:** The use of mobile phone information technology (IT) in the health sector has received much attention especially during the 2014-2015 Ebola virus disease (EVD) outbreak. mHealth can be attributed to a major improvement in EVD control, but these lacks an overview of what kind of tools were available and used based on the functionalities they offer.

**Objective:** We aimed to conduct a systematic review of mHealth tools in the context of the recent EVD outbreak to identify the most promising approaches and guide further mHealth developments for infectious disease control.

**Methods:** Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, we searched for all reports on mHealth tools developed in the context of the 2014-2015 EVD outbreak published between January 1, 2014 and December 31, 2015 on Google Scholar, MEDLINE, CABI Abstracts (Global Health), POPLINE, and Web of Science in any language using the search strategy: (“outbreak” OR “epidemie”) AND (“mobile phone” OR “smartphone” OR “smart phone” OR “mobile phone” OR “tablet” OR “mHealth”) AND (“Ebola” OR “EVD” OR “VHF” OR “Ebola virus disease” OR “viral hemorrhagic fever”) AND (“2014” OR “2015”). The relevant publications were selected by 2 independent reviewers and applied a standardized data extraction form on the tools’ functionalities.

**Results:** We identified 1220 publications through the search strategy, of which 6.31% (77/1220) were original publications reporting on 58 specific mHealth tools in the context of the EVD outbreak. Of those, 62% (49/80) offered functionalities for surveillance, 22% (10:45) for case management, 18% (7:58) for contact tracing, and 66 (3:51) for laboratory data management.

**Only 3 tools:** namely Community Care, Sense Ebola Followup, and Surveillance and Outbreak Response Management and Analysis System supported all four of these functionalities.

**Conclusions:** Among the 58 identified tools related to EVD management in 2014 and 2015, only 3 appeared to constitute all 4 key functionalities relevant for the response to EVD outbreaks and may be most promising for further development.

*(JMIR Public Health Surveillance 3011(4):e68)*

**KEYWORDS**
case management; contact tracing; Ebola virus disease; eHealth; mHealth; systematic review; West Africa
Introduction

Background
The 2014-2015 Ebola virus disease (EVD) outbreak caused almost 11,000 deaths and dramatically demonstrated the need for effective surveillance and outbreak management [1]. In the absence of established vaccines and specific pharmaceutical treatment, the main measure of containment for epidemics caused by emerging pathogens like Ebola virus is a rapid and efficient interruption of human-to-human transmission. Even for diseases for which vaccines or specific treatments are available, the epidemiological, nonpharmaceutical control measures are indispensable [2]. A particular challenge for EVD control is contact tracing, which assures that all persons who had contact with an EVD case are identified and monitored for the potential appearance of symptoms for 21 days after exposure to a patient with EVD [3].

Containment Strategy
Dhillon et al (2014) stated that for an epidemic such as Ebola virus to be controlled, complementary interventions are required, namely (1) community engagement; (2) identification of contacts; (3) contact monitoring for symptoms; (4) rapid lab confirmation of cases; (5) isolation and treatment of new cases; and (6) safe and dignified burials. Each activity is fundamentally complex, yet all need to be harmonized to stop transmission and control the outbreak [1]. Because of the dynamically changing nature of epidemics, it is important to have real-time data for action, strategy, and coordination of multiple efforts or interventions to ensure efficient execution of tasks and protocols and also a management platform that aligns, coordinates, and monitors all these measures and information resulting from them.

Integrated Disease and Surveillance Response
In 1998, the World Health Organization (WHO) African Regional Office established the resolution of the 48th assembly endorsing Integrated Disease Surveillance and Response (IDSR) for all member countries to adopt as the core strategy to strengthen national disease surveillance systems. The objective of the IDSR is to strengthen district-level surveillance and response for epidemic-prone diseases, integrating laboratory support for reference laboratories, reducing the duplication of reporting, and sharing resources among disease control programs, which in turn translates surveillance and laboratory data into timely public health actions [5]. The major setback with the IDSR since 1998 is that, in practice, it remains merely a paper-based system, collecting information from the periphery and transporting it in an aggregated manner, which results in considerable delay to the national level without implementing the notion of bidirectional information flow and even less that of integrated response [6].

mHealth Technology
The use of mobile phone information technology (IT) in the health sector (mobile health, mHealth) has received much attention, especially during the EVD outbreak and could in principle help implement the basic fundamentals of IDSR [7]. mHealth promises to overcome many of the communication and management hurdles and delays commonly experienced in countries with limited infrastructure in communication and transportation [8]. A study conducted in 2009 by WHO confirmed that majority of the WHO member states offer health call centers and toll-free emergency services using mobile communications, but these programs rarely used mHealth in surveillance, raising public awareness, and decision support systems [9]. These require enhanced capabilities and infrastructure to implement and therefore may not be a health priority in affiliate states with financial constraints. Evaluation is important to determine cost-effectiveness and involves educating the community about the benefits of mHealth, which leads to government policy. Despite the need for evaluation, the survey found that results-based evaluation of mHealth implementations is not routinely conducted, and only 12% of member states reported evaluating mHealth services [9].

Study Objective
The main objective of this study was to generate an overview of mHealth tools that were developed from 2011 to 2015 to identify tools with the most promising portfolio of functionalities, which might build the basis for further mHealth developments for infectious disease surveillance and control.

Methods
Identification Criteria
We conducted a systematic search for all articles published in any language indexed in Google Scholar, MEDLINE, CAB Abstracts (Global Health), POPLINE, and Web of Science with publication dates from January 1, 2014 to December 31, 2015 using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines [10].

Systematic Search and Selection
We used the following search strategy: ("Outbreak OR "Epidemic") AND ("mobile phone" OR "smartphone" OR "smartphone" OR "mobile phone" OR "tablet" OR "mHealth") AND ("Ebola" OR "EVD" OR "VHF" OR "Ebola Virus Disease" OR "viral hemorrhagic fever") AND ("2014" OR "2015").

The publications that were original, addressed mHealth in the context of the EVD outbreak, and reported on specific mHealth tools were independently selected by 2 authors (DTA and CCA). In case of discrepancy in assessment, both authors revised the findings and agreed on a joint assessment.

The first step was to screen titles and abstracts and discard any publication that was not original such as editorials, summaries, videos, and commentaries. The second step was to select those publications that, based on title or abstract, covered or dealt with an actual mHealth tool that runs on mobile phones and tablets and dealt with the management of EVD or other hemorrhagic fever outbreaks. The third step was to select those publications that, based on the full article, reported on or described 21 specific mHealth tool within the context defined above.
Categorization and Extraction
Each publication finally selected for review was categorized as one of the following: book chapter, scientific peer-reviewed journal article, or non-peer-reviewed Web article. To extract the content of these publications, we used a standardized extraction form assessing key functionalities, technical characteristics, and epidemiological capabilities of the respective mHealth tools.

Key Functionalities
The key functionalities included (1) surveillance capability (ability of the tool to cover surveillance tasks); (2) contact tracing (capacity of the tool to conduct contact interviews, take temperature, follow-up contacts for a certain number of days, and display results); (3) case management (ability of the tool to handle case management issues such as alert response for immediate suspect case evacuation, disinfection, and isolation as well as provide feedback for contact tracing and follow-up); and (4) laboratory data management (ability to integrate and update laboratory findings, an essential component of case verification).

Technical Characteristics
The technical characteristics included the following:
1. Offline capabilities: the ability of the tool to still function if there is no internet or data network and to send automatically stored data to the server once it connects again to a network.
2. Type of system: whether the tool was developed as an open or closed-source platform.
3. Server characteristics: the ability of the tool to function as a cloud network or client-side network, installation criteria regarding automatic updates, and user-friendly installation process.
4. Integrated data analytics: the capacity of the tool to analyze and generate reports for immediate action automatically.
5. Data migration: the capability of the tool to import and export data and its elements from 1 platform to the other.
6. Data security system: the security of the data system with respect to disaster recovery, data protection, and backups.
7. Bidirectional information flow: the data flow from the lowest level of data entry to the highest level of decision making and analysis with a standardized feedback mechanism back to the lowest level.

Epidemiological Characteristics
The epidemiological characteristics included the following:
1. Outbreak management unspecified: referring to tools that state the offering of functionalities but do not specify which ones and how.
2. Rumor management capability to capture rumors from the community via a hotline and real-time situational awareness to track the detection of diseases and spread.
3. National response management functionality to coordinate response measures at national level.
4. Regional response management functionality to coordinate response measures at regional or state level.
5. District response management functionality to coordinate response measures at the district level.
6. Performance of a systematic evaluation to evaluate the usefulness of the tool.
7. Piloted or deployed for use in the field via tool implementation in the field with real patients, at least for piloting.
8. Design based on IDSIR concepts and strategy used for health surveillance in Africa.
9. Design based on preexisting data models such as Centers for Disease Control and Prevention viral hemorrhagic fever case investigation form integration or Epi Info Viral Hemorrhagic Fever App [11].

Health facility notification, referring to health facilities using the tool to notify cases digitally.

Data Analysis
Data variable responses were categorized into yes (function available), no (function not available), or unknown (publication does not clearly reveal whether the tool offers the respective function or not). For computation of percentages, we used the sum of yes and no answers for each of the respective outcomes as the denominator.

Results
Identified Publications
We identified 1220 publications from the automatic search in Google Scholar. PubMed found 8 publications that were duplicates of those in Google Scholar, 4 of which were relevant to leptospirosis. We did not find any publications in CABI Abstracts (Global Health), POPLINE, or Web of Science using the same search string across the search engines. After manual selection, we identified 79.10% (965/1220) original publications of which 15.0% (145/965) addressed mHealth and EVD outbreak response. Among these 145 publications, 53.1% (77/145) reported on 58 specific mHealth tools. Figure 1 shows the flowchart of the number of publications initially retrieved and the proportion selected for extraction following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses approach.

Key Functionalities
With respect to the 4 key functionalities, 62% (34/55) out of the 55 tools offered functionalities for surveillance, 22% (10/45) for case management, 18% (7/38) for contact tracing, and 6% (3/51) for laboratory data management. Only 5 tools, namely Community Care (CommCare) [12], Sense Ebola Followup [13], and Surveillance and Outbreak Response Management and Analysis System (SORMAS) [14] supported all 4 of these functionalities (5/58, 5%). The detailed profile of key functionalities is displayed in Table 1.

Technical Characteristics
Table 2 displays the technical characteristics of the 58 identified tools. For 3% (2/58) of the tools, namely CommCare and Sense Ebola Followup, the publications indicated that they displayed all 7 technical characteristics.
Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses approach for the selection of publications on mHealth tools for the 2014-2015 Ebola virus disease outbreak. EVD: Ebola virus disease.

Table 1. Key functionalities for 53 mHealth Ebola virus disease tools, 2014-2015.

<table>
<thead>
<tr>
<th>Key functionalities</th>
<th>Yes, n</th>
<th>No, n</th>
<th>Unknown, n</th>
<th>Yes%, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surveillance capability</td>
<td>34</td>
<td>21</td>
<td>3</td>
<td>62</td>
</tr>
<tr>
<td>Contact tracing</td>
<td>7</td>
<td>31</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>Case management</td>
<td>10</td>
<td>35</td>
<td>13</td>
<td>22</td>
</tr>
<tr>
<td>Laboratory data management</td>
<td>3</td>
<td>48</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>

*The sum of yes and no answers for each of the respective functionalities was used as the denominator.*
Table 2. Technical characteristics for 58 mHealth Ebola virus disease tools, 2014-2015.

<table>
<thead>
<tr>
<th>Technical characteristics</th>
<th>Yes, n</th>
<th>No, n</th>
<th>Unknown, n</th>
<th>Yes*, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offline capabilities</td>
<td>9</td>
<td>24</td>
<td>25</td>
<td>57</td>
</tr>
<tr>
<td>Type of system (open source)</td>
<td>36</td>
<td>21</td>
<td>1</td>
<td>63</td>
</tr>
<tr>
<td>Server characteristics</td>
<td>43</td>
<td>15</td>
<td>0</td>
<td>74</td>
</tr>
<tr>
<td>Integrated data analytics</td>
<td>22</td>
<td>11</td>
<td>25</td>
<td>67</td>
</tr>
<tr>
<td>Data migration</td>
<td>40</td>
<td>18</td>
<td>0</td>
<td>69</td>
</tr>
<tr>
<td>Data security system</td>
<td>33</td>
<td>6</td>
<td>19</td>
<td>55</td>
</tr>
<tr>
<td>Bidirectional information flow</td>
<td>7</td>
<td>40</td>
<td>11</td>
<td>15</td>
</tr>
</tbody>
</table>

*The sum of yes and no answers for each of the respective characteristics was used as the denominator.


<table>
<thead>
<tr>
<th>Epidemiological characteristics</th>
<th>Yes, n</th>
<th>No, n</th>
<th>Unknown, n</th>
<th>Yes*, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outbreak management unspecified</td>
<td>5</td>
<td>50</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Rumor management</td>
<td>7</td>
<td>31</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>National response management</td>
<td>6</td>
<td>43</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Regional response management</td>
<td>8</td>
<td>42</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>District response management</td>
<td>8</td>
<td>42</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>Systematic evaluation</td>
<td>24</td>
<td>16</td>
<td>13</td>
<td>60</td>
</tr>
<tr>
<td>Printed or deployed</td>
<td>26</td>
<td>16</td>
<td>16</td>
<td>62</td>
</tr>
<tr>
<td>Design based on Integrated Disease and Surveillance Response concepts and strategy used for health surveillance in Africa</td>
<td>3</td>
<td>52</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Design based on existing data models such as Center for Disease Control and Prevention viral hemorrhagic fever case investigation form integrated of Epi Info Viral Hemorrhagic Fever Application</td>
<td>2</td>
<td>53</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Health facility notification</td>
<td>27</td>
<td>23</td>
<td>8</td>
<td>51</td>
</tr>
</tbody>
</table>

*The sum of yes and no answers for each of the respective outcomes was used as the denominator.

Epidemiological Characteristics

Table 3 contains the results of the epidemiological characteristics. All 10 epidemiological characteristics were present for 2% (1/58) of the tools, namely SORMAS.

Note of the 58 tools covered all 4 key functionalities, all 7 technical characteristics, and all 10 epidemiological characteristics. SORMAS covered 20 functionalities and characteristics, the highest within 1 tool, 1 of its missing characteristics being open source. Table 4 shows a breakdown of the 58 identified mHealth tools according to the key functionalities for EVD outbreak management.
Table 1. Characteristics of the 58 mHealth tools showing the key functionalities for Ebola virus disease outbreak management.

<table>
<thead>
<tr>
<th>Name of mHealth tool</th>
<th>Surveillance</th>
<th>Contact tracing</th>
<th>Case management</th>
<th>Laboratory data management</th>
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**Discussion**

**Principal Findings**

It is surprising that as many as 58 mHealth tools identified in our search addressed management of EVD (hemorrhagic fever) during the 2014-2015 outbreak. The vast difference in functionality indicates that during the wake of the tragic outbreaks and the urgency to stop the outbreak, many initiatives were started, which aimed and claimed to provide support for EVD outbreak response. However, only a few appear to have contained sufficient medical and public health expertise to actually address the procedural and technical needs. It is, therefore, needful to carefully assess the respective specifications and functionalities via a quality control system before deciding on one tool or another for deployment in such a situation. Only 3 tools have the overall capability for the key functionalities of surveillance and outbreak management (surveillance capability, contact tracing, and case management) and contain embedded functional requirements for data reporting and analytics through an integrated implementation of the surveillance guidelines and standards regarding functionality. Some tools, such as District Health Information System 2, had the advantage of being widespread in West Africa as a health management information system [15] yet it was not designed to manage interventions as needed for infection control and outbreak response by itself. Such a tool should feed information into every task related to a particular officer and improve each task assigned to the officer [16]. Ideally, it can be used as a real-time rumor management, surveillance system. The tool should include disease control management functionalities [17].

The tools CommCare, Sense Ebola Followup, and SORMAS supported all tasks and functions involving surveillance, contact tracing, and case management. CommCare and Sense Ebola Followup were used during the EVD outbreak. SORMAS was piloted in the field during the EVD outbreak after the epidemic in Nigeria and is therefore based on a practical EVD outbreak scenario. Additionally, it contains a function for rumor management, which was particularly important during the 2014-2015 Ebola outbreak [18]. Sense Ebola Followup was deployed during the EVD outbreak in Nigeria [19]. Since outbreaks only occur sporadically, and the information processed during an outbreak is comparable to that handled for surveillance purposes, it appears necessary to aim for a system that can function as a monitoring tool as well as an outbreak management tool [20]. Another factor that is likely to affect the acceptability of an mHealth tool is the independence from a specific provider. Tools based on open source platforms are more sustainable in this aspect and can potentially build a dynamic broader programming community for further developments and improvements. CommCare and Sense Ebola Followup were developed on an open source platform [21], SORMAS was originally programmed in platforms proprietary to Systems Applications and Products [22] but has now been developed on an open source platform (SORMAS-open) [23].

**CommCare Ebola Contact Tracking**

The cloud server open source Android app for contact tracking developed in 2014 was based on the CommCare development platform, which was designed to support Community Health Extension Workers acting in Guinea, and it has been promoted...
by the United Nations Population Fund, other United Nations agencies, and the actors involved in the fight against Ebola in Guinea [21]. CommCare technology was chosen to support the implementation of the Government Response Plan against EVD in order to obtain timely and reliable information as well as facilitate contact tracing. The Earth Institute at Columbia University (USA), United Nations Population Fund, and the Monitoring Cell of the National Coordination Against the Ebola Virus have promoted the idea. It requires a CommCare account and the Open Data Kit for Android to be deployed on an Android phone or tablet [24].

Sense Ebofa Followup App

The contact-tracing follow-up electronic health (eHealth) Sense app was developed in 2014 during the EVD outbreak in Nigeria. It is a mobile app for real-time data capture. The major technologies used were 2 Android-based apps, the Open Data Kit and Formhub [24]. Supporting technologies were dashboard technology and ArcGIS mapping. The contact listing form, contact follow-up form, laboratory investigation requests, and case investigation forms were created using extensible markup language and the eHealth Sense Ebola Android app [19] developed for 21-day follow-up. It has an automatic alert system for temperature readings ≥38°C for contacts that were under follow-up.

Surveillance and Outbreak Response Management and Analysis System

SORMAS is an open source Android and Web app, which was developed for case management, contact tracing, and surveillance with an equipped laboratory module for management of laboratory samples and tests [25]. SORMAS enables surveillance officers and epidemiologists to detect diseases based on real-time health facility data. Automatic notification validates rumors and notifications, and SORMAS enables decision makers to respond immediately to incoming information and to take adequate measures via the public health officers. Information about cases and contacts are made readily available for action, data quality assurance is performed for decontamination, and isolation tasks can be conducted.

Limitations

Only a fraction of the identified publications was found in conventional scientific literature databases, such as Medline and PubMed, all of which were duplicates, but 99% of the publications were found in Google Scholar. This may indicate a major limitation of our approach. The methodology of systematic reviews, being well established in evidence-based medicine, may be of limited value for health informatics because it may not be as common practice in the IT field to publish developments and findings in scientific journals, even less so in peer-reviewed ones. The urgency by which tools were developed in response to the EVD outbreak may even have accentuated this effect. Search criteria inputted to PubMed displayed only 5 results compared with 965 results in Google Scholar. An explanation might be that mHealth initiatives born out of urgent public health needs may not be accompanied by a systematic process of planning and evaluation and are thus not likely to be transferred into sustainable continuous implementation and even less likely to be published in scientific journals once the urgency of the need has diminished.

While it would have been valuable to conduct this review beyond the application of EVD and hemorrhagic fevers and beyond 2015, removing these selection criteria from the search strategy would have resulted in an unmanageably large output with an extremely low positive predictive value. Hence, we covered mHealth tools developed between 2014 and 2015. Taking into consideration the fact that we stopped data collection on December 31, 2015 on a topic that became relevant shortly before that, the delay in publication may have led to some tools not being captured in our analysis. There was a limited appearance of publications in established databases such as Medline, although Google Scholar will generate a very comprehensive, but also unspecified, output of search strategies that are not defined in a highly targeted way, especially if the period is increased beyond 2015.

Conclusion

Among a large number of reported tools developed in the context of the EVD outbreak response, it appears that only 3 of these tools contain the 3 key functionalities of outbreak management for EVD (surveillance capability, contact tracing, and case management) supported by tools developed from January 2014 to December 2015. These 3 tools, namely CommCare, Sense Ebola Followup, and SORMAS may serve as an orientation and reference for further developments of mHealth tools for infectious disease surveillance and outbreak management.

Acknowledgments

The authors wish to thank Salla E. Toikkanen, Prof Adeola Obayinna, Bernard Siencou Chawo, and Gabriele Poggesee.

Authors’ Contributions

DTA and CCA searched, selected, and extracted data based on criteria; DTA and GK conceptualized the study design and analyzed and interpreted the results of the data; GK initiated the study approach and supervised all steps of the study; PMN contributed to the manuscript confirming events and outcomes of software applications. All authors read and approved the final manuscript.

Conflicts of Interest

None declared.

References

Abbreviations

CommCare: Community Care open source mobile platform  
EVD: Ebola viral disease  
IDSR: Integrated Disease Surveillance and Response  
IT: Information Technology  
SORMAS: Surveillance and Outbreak Response Management and Analysis System  
WHO: World Health Organization

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User Evaluation Indicates High Quality of the Surveillance Outbreak Response Management and Analysis System (SORMAS) After Field Deployment in Nigeria in 2015 and 2018

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\textsuperscript{b} PhD Epidemiology Programme, Hannover Medical School (MHH), Hannover, Germany
\textsuperscript{c} Bernhard-Nocht Institute for Tropical Medicine, Hamburg, Germany
\textsuperscript{d} German Centre for Infection Research (DZIF), Braunschweig, Germany
\textsuperscript{e} Hannover Medical School (MHH), Hannover, Germany
\textsuperscript{f} Hasso-Plattner-Institute, Potsdam, Germany
\textsuperscript{g} Nigeria Centre for Disease Control (NCDC), Abuja, Nigeria
\textsuperscript{h} African Field Epidemiology Network (AFENET), Abuja, Nigeria
\textsuperscript{i} Robert Koch-Institute, Berlin, Germany
\textsuperscript{j} Max Delbrück Centre, Berlin, Germany

Abstract. During the West African Ebola virus disease outbreak in 2014–15, health agencies had severe challenges with case notification and contact tracing. To overcome these, we developed the Surveillance, Outbreak Response Management and Analysis System (SORMAS). The objective of this study was to measure perceived quality of SORMAS and its change over time. We ran a 4-week pilot and 8-week implementation of SORMAS among hospital informants in Kano state, Nigeria in 2015 and 2018 respectively. We carried out surveys after the pilot and implementation asking about usefulness and acceptability. We calculated the proportions of users per answer together with their 95\% confidence intervals (CI) and compared whether the 2015 response distributions differed from those from 2018. Total of 31 and 74 hospital informants participated in the survey in 2015 and 2018, respectively. In 2018, 94\% (CI: 89–100\%) of users indicated that the tool was useful, 92\% (CI: 86–98\%) would recommend SORMAS to colleagues and 18\% (CI: 10–28\%) had login difficulties. In 2015, the proportions were 74\% (CI: 59–90\%), 90\% (CI: 80–100\%), and 87\% (CI: 75–99\%) respectively. Results indicate high usefulness and acceptability of SORMAS. We recommend mHealth tools to be
evaluated to allow repeated measurements and comparisons between different versions and users.

Keywords. mHealth, eHealth, systematic evaluation, disease surveillance, outbreak response, open source, Africa, infectious disease, medical and health informatics

1. Introduction

During the West Africa Ebola virus disease (EVD) outbreak in 2014-15, it became very clear that response teams must be equipped with technologies enabling real-time digitalized reporting and response management in order to improve efficiency in outbreak containment [1]. This experience led to the development of the Surveillance, Outbreak Response Management and Analysis System (SORMAS). SORMAS is a mobile and web application that provides a platform to detect outbreaks, manage tasks, validate cases, coordinate with laboratories and perform contact tracing. SORMAS uses a bi-directional information exchange and feedback to the different users within the Integrated Disease Surveillance and Response System (IDSR), which defines the disease notification procedures, established in Africa. We piloted the first version of SORMAS in 2015 in the states of Kano and Oyo, in Nigeria and conducted a user evaluation on its usefulness and acceptability. In 2016 and 2017, we repackaged the system in a new platform and included additional functionalities. In December 2017, we initiated the deployment of the system with the new version (SORMAS 2017) in Kano State and conducted a new user evaluation in order to measure whether the usefulness and acceptability of the system had improved.

2. Methods

For SORMAS 2015, we used the In-Memory Database technology in the cloud-based SAP HANA platform [2] [3]. We programmed SORMAS 2017 based entirely on open source platforms using a PostgreSQL Relational Database Management System and VAADIN framework [4][5]. The hospital informants operated SORMAS with smartphones in 2015 and with tablets in 2017. In 2015 version, the login procedure was a 3-tier authentication protocol, whereas in the 2017 version user login required a one-time encrypted password stored on the device and a 4-digit pin to authenticate the app anytime it was in use. We conducted six design-thinking workshops with a total of 65 epidemiologists, clinicians, and laboratory experts from Germany and 8 African Countries. The team developed the disease specific process models for Ebola Virus Disease (EVD), Cholera, Measles and Highly Pathogenic Avian Influenza (HPAI) in SORMAS 2015 and additionally for Lassa fever, Monkeypox (MPX), Dengue fever, Yellow fever, Cerebrospinal Meningitis (CSM), and Plague in SORMAS 2017 [6, 7, 2, 8]. The tool contains user specific interfaces, including that for hospital informants who are in charge of reporting notifiable disease occurring in the health facilities, and for laboratory officers in charge of processing laboratory diagnosis. In 2015, we selected eight Local Government Areas (LGA) at random from both Oyo and Kano States to participate in the pilot [9]. Within these LGAs, the state epidemiologist selected 31 private and public health facilities based on previous reporting activities resulting in 31 participating hospital informants. In 2017, SORMAS was deployed in all private and
public health facilities of two LGAs [10]. After a two-day training, we conducted a five-week pilot in June 2015 [10]. For SORMAS 2017, all participants attended a two-day basic and a one-day refresher training. We implemented a post-pilot questionnaire in July 2015 after the hospital informants had used SORMAS 2015 for 5 weeks and post-implementation questionnaire in February 2018 two months after deployment of SORMAS 2017. We asked the users whether they would want to use the tool for their routine surveillance work (usefulness: yes/no), if they would also recommend the tool to their colleagues (acceptability: yes/no) and whether the users had experienced problems in the login (log-in difficulty yes/no). The 2015 questionnaire was paper based [11], while the 2018 questionnaire was administered electronically with SurveyCTO [12]. Questionnaires from both years contained questions on ‘age’, ‘sex’, and ‘type of facility and rural/urban settlement types’). We performed a comparison of the respondents’ characteristics between 2015 and 2018 using chi-squared test and calculated response proportions and their 95% confidence intervals (CI) using STATA version 14 [13]. We secured written consent from study participants and survey completion was anonymized. The study proposal was submitted to the ethics committee at the Hannover Medical School and cleared by the national agency in charge in Nigeria (NCDC).

3. Results

In 2015, 31 hospital informants (100%) that participated in the pilot submitted their responses. In 2017, 89 hospital informants were recruited and trained, out of which 74 (83%) participated in the post-implementation survey. The mean age in 2015 was 40.0 years (standard deviation=8.97) and 35.7 years in 2018 (standard deviation=8.27). See Table 1 for respondents’ distribution for age, sex, facility type and settlement. Table 2 demonstrates statistically significant improvements for usefulness, and ease of login and no significant differences with respect to acceptability, comparing 2015 and 2018.

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<td>0.1</td>
<td>0.762</td>
</tr>
<tr>
<td>Private</td>
<td>11 (35)</td>
<td>24 (32)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Settlement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>16 (32)</td>
<td>24 (33)</td>
<td>4.5</td>
<td>0.034</td>
</tr>
<tr>
<td>Rural</td>
<td>15 (48)</td>
<td>20 (27)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2: Comparison of survey respondents' assessment on usefulness, acceptability and ease of login between 2015 and 2018 surveys.

<table>
<thead>
<tr>
<th>Variable</th>
<th>2015 (N=31)</th>
<th>2018 (N=74)</th>
<th>Chi2</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n (%)</td>
<td>95% CI</td>
<td>n (%)</td>
<td>95% CI</td>
</tr>
<tr>
<td><strong>Usefulness: would want to use SORMAS in surveillance work</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>21(74.2)</td>
<td>(58.8 - 89.6)</td>
<td>70(94.6)</td>
<td>(89.4 - 99.7)</td>
</tr>
<tr>
<td>No</td>
<td>8(25.8)</td>
<td>(10.4 - 41.2)</td>
<td>4(5.4)</td>
<td>(0.3 - 10.6)</td>
</tr>
<tr>
<td><strong>Acceptability: would recommend SORMAS for their colleagues</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>24(90.3)</td>
<td>(79.9 - 100)</td>
<td>68(91.9)</td>
<td>(85.7 - 98.1)</td>
</tr>
<tr>
<td>No</td>
<td>3(9.7)</td>
<td>(0 - 20.1)</td>
<td>6(8.1)</td>
<td>(1.9 - 14.3)</td>
</tr>
<tr>
<td><strong>Ease of login: encounter problems with SORMAS login</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>27(87.1)</td>
<td>(75.3 - 98.9)</td>
<td>14(18.9)</td>
<td>(10.0 - 27.8)</td>
</tr>
<tr>
<td>No</td>
<td>4(12.9)</td>
<td>(1.1 - 24.7)</td>
<td>60(81.1)</td>
<td>(72.2 - 90.0)</td>
</tr>
</tbody>
</table>

4. Discussion

Overall, the user responses revealed significant improvement for usefulness and ease of login in the 2017 version of SORMAS compared to the 2015 version. In addition, in both surveys, a large majority of the respondents would recommend the tool to their colleagues. In 2015, the complex login process led to frequent typing errors and eventually caused the devices to be blocked. The changes in the login procedure alongside with the large screens of the mobile tablets enabled users to easily navigate through the app and most likely explain the improved user login experience of 2018 version. Even though we are now finding an improvement from the user perspective, demands on data security are increasing and may force developers to implement login procedures, which in the given setting lack practicability. In order to address this challenge, an enhancement of multi-factor authenticated key exchange protocols could be a solution [14]. The increase in usefulness in the 2018 survey is remarkable.

The following differences are likely to account for this improvement. SORMAS 2018 covers 10 disease instead of four in the 2015 version and includes the laboratories as additional users in the network. We believe that the major difference in usefulness rating results from multiple improvements of user interface design and user training and the fact that increased smartphone/tablet use in the country may also have contributed. However, this comparison also contains several limitations: The study populations are not identical, even if their demographic characteristics between the 2015 and the 2018 did not differ. Furthermore, improvements in the survey tool also limit comparability.

5. Conclusion

Hospital informants have repeatedly rated SORMAS very high on usefulness, acceptability, and reported clear improvement with respect to login procedures from the 2015 to the 2018 version. We will take the opportunity of continued SORMAS implementation in 2018 to analyze other data quality dimensions, such as completeness or timeliness.
6. Conflict of Interest

There is no conflict of interest.

7. Acknowledgment

We acknowledge the Federal Ministry of Education and Research (BMBF), German Centre for Infection Research (DZIF) and the German Corporation for International Cooperation (GIZ) for providing financial support for the SORMAS project.

References

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Digital Health Global Goods Maturity Assessment of the “Surveillance Outbreak Response Management and Analysis System”

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2 Hannover Medical School (MHH), Hannover, Germany
3 Digital Square, PATH, Chapel Hill, North Carolina, North Carolina, NC, United States
4 Symodo GmbH, Braunschweig, Germany
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Abstract
Background: Digital health is a dynamic field that has been generating a large number of tools; many of these tools do not have the level of maturity required to function in a sustainable model. It is in this context that the concept of global goods maturity is gaining importance. Digital Square developed a global goods maturity model (GGM) for digital health tools, which engages the digital health community to identify areas of investment for global goods. The Surveillance Outbreak Response Management and Analysis System (SORMAS) is an open-source mobile and web application software that we developed to enable health workers to notify health departments about new cases of epidemic-prone diseases, detect outbreaks, and simultaneously manage outbreak response.

Objective: The objective of this study was to evaluate the maturity of SORMAS using Digital Square’s GGM and to describe the applicability of the GGM on the use case of SORMAS and identify opportunities for system improvements.

Methods: We evaluated SORMAS using the GGM version 1.0 indicators to measure its development. SORMAS was scored based on all the GGM Indicator scores. We described how we used the GGM to guide the development of SORMAS during the study period. GGM contains 15 subindicators grouped into the following core indicators: (1) global utility, (2) community support, and (3) software maturity.

Results: The assessment of SORMAS through the GGM from November 2017 to October 2019 resulted in full completion of all subscores (10/30, (33%) in 2017; 21/30, (70%) in 2018; and 30/30, (100%) in 2019). SORMAS reached the full score of the GGM for digital health software tools by accomplishing all 10 points for each of the 3 indicators on global utility, community support, and software maturity.

Conclusions: To our knowledge, SORMAS is the first electronic health tool for disease surveillance, and also the first outbreak response management tool, that has achieved a 100% score. Although some conceptual changes would allow for further improvements to the system, the GGM already has a robust supportive effect on developing software toward global goods maturity.

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Introduction

Overview
Digital health is a dynamic field with a rapidly growing number of initiatives and tools, many of which operate in certain geographic areas and for a limited period [1]. This lack of sustainability may be due to a variety of reasons, including the lack of integration in standard frameworks, lack of diverse and continuous donor support, lack of serving the objectives, and limited generalizability of its application among others [2-4]. In the field of public health, funding for such initiatives relies mostly on scarce public resources. Many such parallel initiatives do not seem to be mature enough to survive their pilot phase, which makes it particularly unfortunate. It is in this context that the concept of global goods maturity is gaining importance [5,6].

Global Goods
The concept of global goods stems from guidelines influencing health policies to support technologies that are meant to assist government agencies and policy makers in launching, scaling, and sustaining digital health innovations [7]. Different ministries of health convened advisory committees, including members of the digital health ecosystem and new multi-stakeholder enterprises such as the Digital Impact Alliance and Digital Square [7]. These include global agencies, governments, philanthropies, funders, and academics to improve health data through shared investments in global goods and to fast-track the development and scale-up of successful digital health solutions to improve the environment for digital health [6,8]. To address the current lack of donor coordination, the committees created a framework to allow shared investments in specific countries and digital goods. Health strengthening through enhancing country information systems would contribute to better decision making and, ultimately, better health [9]. The digital investment principles state that the funding donors within countries who are looking to prioritize their needs to improve the health of populations should align their resources around scalable, sustainable, accessible, interoperable, and evidence-based digital health global goods [6].

Surveillance Outbreak Response Management and Analysis System
The Surveillance Outbreak Response Management and Analysis System (SORMAS) is an open-source mobile and web application software that we developed to enable health workers to notify health departments about new cases of epidemic-prone diseases, detect outbreaks, and manage outbreak response at the same time. SORMAS is a management process system that supports supervisors to validate cases and control the spread of disease. As a multifunctional software, it can be used for case surveillance, laboratory data management, contact tracing, and disease detection to prevent and manage outbreaks that may occur. SORMAS also uses a bidirectional information exchange synchronizing user requests as well as sending feedback to the different users within the existing surveillance system [9-11].

Digital Square Global Goods Maturity Model
Digital Square, which is an initiative aimed at coordinating international efforts to develop and broadly share useful, free, and open-source digital tools, included 18 mobile health (mHealth) tools into the database of digital health software referred to as “global goods software” [12,13]. Digital Square developed a global good maturity model (GGM) for digital health tools, which engages the digital health community to identify areas of investments for global goods [12,13]. We identified the GGM to be a suitable concept in assessing the maturity of SORMAS for the following reasons: (1) GGM has a particular focus on health software and on those being used in low-resource settings [12,13], (2) the objectives of GGM matches well with the mission of SORMAS [12,13], and (3) the scope of most of the tools included in the GGM guidebook fits that of SORMAS [12,13].

The following key concepts are prevalent throughout the study in determining the maturity of SORMAS according to the GGM: global utility, community support, and software maturity. The objective of this study was to assess the level of global goods maturity that SORMAS has attained using the GGM version 1.0.

Methods
We applied the GGM version 1.0 on SORMAS from November 2017 until October 2019 to assess the level of global goods maturity that it has attained [13]. The GGM contains 15 subindicators grouped into the following three core indicators: (1) global utility, (2) community support, and (3) software maturity. Each subindicator is divided into 3 possible values from “1” for “low” to “3” for “high.” Each value contains a definition that is listed in Table 1. Given that the GGM scoring values range from negative to positive values, we applied the following transformation to allow percentage values for summary scores, as shown in equation (1), where, $MS^i$ = maturity score for each core indicator, $S^i$ = vector containing scores of the subindicators, and $i = 1, ..., 5$:

$$MS^i = \frac{\text{MEAN}(S^i)}{5} + 5(1)$$

We put together a GGM assessment group consisting of a public health expert from the Nigerian Centre for Disease Control, a medical epidemiologist, an international health expert, an information technology specialist and a statistician from the Helmholtz Centre for Infections Research, and 2 software engineers from Syncera, a company for developing health software. This group periodically assessed the completion of SORMAS in the 15 subindicators. Subsequently, the software roadmap and the work plan of SORMAS was reprioritized to dedicate resources to and obtain progress in those subindicators that did not reach a full score. To reduce selection bias, as members of the assessment group were part of the development and deployment of SORMAS, and to reduce the potential
We also asked two external experts to review the findings made by the assessment group. These external experts had contributed to the development of the GGMM and were not involved in the development of SDERMAS.
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Global utility</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Country utilization</td>
<td>Less than two countries or states actively use the tool for use as part of their health information system</td>
<td>At least four countries or states actively use the tool for use as part of their health information system, with at least 20% of total nation-wide or state-wide target users routinely using product or service as intended</td>
<td>At least ten countries or states actively use the tool for use as part of their health information system, with at least 30% of total nation-wide or state-wide target users routinely using product or service as intended</td>
</tr>
<tr>
<td>Country strategy</td>
<td>Less than two countries or states have included the tool as part of their electronic health (eHealth) strategy or framework</td>
<td>At least four countries or states have included the tool as part of their eHealth strategy or framework</td>
<td>At least ten countries or states have included the tool as part of their eHealth strategy or framework</td>
</tr>
<tr>
<td>Digital health interventions</td>
<td>The tool does not meet digital functional requirements (as defined by World Health Organization's [WHO's] Classification of Digital Health Interventions) without significant customization or configuration</td>
<td>The tool does partially meet digital functional requirements (as defined by WHO's Classification of Digital Health Interventions) without significant customization or configuration</td>
<td>The tool does fully meet digital functional requirements (as defined by WHO's Classification of Digital Health Interventions) without significant customization or configuration</td>
</tr>
<tr>
<td>Source code accessibility</td>
<td>Source code not publicly available or not released under an open-source license</td>
<td>Source code exists on a publicly accessible repository and licensed under an open-source initiative approved license</td>
<td>Source code exists on a publicly accessible repository and licensed under an open-source initiative approved license</td>
</tr>
<tr>
<td>Funding and revenue</td>
<td>At most, two revenue streams exist. Revenue streams are largely dependent on time-bound project implementations</td>
<td>Multiple revenue streams/funders exist across project implementations</td>
<td>Multiple revenue streams and funding mechanisms exist, including at least one that provides for multi-year support of core software development, documentation, and other key artifacts</td>
</tr>
<tr>
<td>Community support</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developer, contributor, and implementer</td>
<td>Less than 10% of the estimated total of developers, contributors and implementers are on a communication platform</td>
<td>Up to 20% of the estimated total of developers, contributors, or implementers, including some country representation, are engaged on a communication platform</td>
<td>At least 30% of estimated total developers, contributors, and implementers are engaged on a communication platform. Community leadership includes representation from countries where the tool is deployed</td>
</tr>
<tr>
<td>Community governance</td>
<td>There is no community governance structure in place to direct continued development of the digital health tool</td>
<td>Some informal processes for community engagement exist to direct continued development of the digital health tool</td>
<td>Formal community structures (e.g., leadership, technical advisory group, and community representatives) exist and are practiced with documented roles and responsibilities in a transparent fashion and are used to direct continued development of the digital health tool</td>
</tr>
<tr>
<td>Software roadmap</td>
<td>No software roadmap exists, or there is no publicly accessible and routinely maintained platform for new feature requests</td>
<td>There is a publicly accessible and routinely maintained platform for new feature requests. A software roadmap exists describing currently planned and resourced development activities</td>
<td>New features and functionality are documented as part of a software roadmap as part of a release cycle. There are forums for community members to discuss new feature requests. A clear prioritization process exists and is utilized for the development of new features and functionality as part of a product backlog</td>
</tr>
<tr>
<td>Indicator</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>----------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>User documentation</td>
<td>No user documentation exists</td>
<td>Some user documentation exists (training manuals, dense videos) but only addresses a limited subset of common functionality</td>
<td>A full suite of user documentation exists, including training manuals, web-based courses, tutorials, and implementation guides addressing most of the common functionality. Documentation has been released under a Creative Commons license</td>
</tr>
<tr>
<td>Multilingual support</td>
<td>Limited or no support in the software for multiple languages. Multilingual documentation/user resources are practically nonexistent</td>
<td>Software has been internationalized to support multiple languages (though may not have been translated) for primary portions of the user interface. Some user documentation exists in more than one language</td>
<td>Software has been translated into multiple languages and fully supports internationalization requirements. There is an easy tool for new translations to be added. Significant parts of user and implementer documentation has been translated into at least one other language</td>
</tr>
<tr>
<td>Software maturity</td>
<td>No substantial documentation of the software exists</td>
<td>Some technical documentation exists of the source code, use cases, and functional requirements</td>
<td>Source code is documented to the point that new adopters can customize and add new functionality with relying on significant help from one of the core developers. Online courses or tutorials are available to address common development and deployment tasks. Core business workflows and functional requirements are fully documented using use cases, user stories, and other equivalent methodology</td>
</tr>
<tr>
<td>Software productization</td>
<td>No documentation available for deployment and configuration</td>
<td>Full documentation available for deployment and configuration. A new implementation does not require the involvement of the core development team</td>
<td>Software has been packaged for one or more common operating systems or platforms. Software upgrades can largely be achieved without manual intervention. Unit or integration testing is part of the release process</td>
</tr>
<tr>
<td>Interoperability and data accessibility</td>
<td>Extract or import data into the system usually requires looking at source code and/or directly accessing database</td>
<td>Some application programming interfaces (APIs) are available for accessing and managing data. There are user-facing interfaces to export core data and metadata in the system (e.g., in CSV format) for further analysis and data transfer purposes</td>
<td>A robust API is available for key data and metadata exchange needs for the primary business domain with functional requirements for the API having been developed in conjunction with appropriate country, regional, and global stakeholders. API endpoints exist for core data and metadata elements that adhere to standards developed by an appropriate Standards Development Organization relevant to the tools business domain. Standards-based API endpoints are used in at least four jurisdictions (e.g., countries or states)</td>
</tr>
<tr>
<td>Security</td>
<td>No security controls or implementation guidance is in place</td>
<td>Role-based authorization exists, if appropriate. All remote access (web interface and APIs) is encrypted by default using current best practices. An independent security audit of the software has taken place within the last 12 months</td>
<td>Role-based authorization exists, if appropriate. All remote access (web interface and APIs) is encrypted by default using current best practices. An independent security audit of the software has taken place within the last 12 months</td>
</tr>
</tbody>
</table>
Results

In November 2017, SORMAS had migrated from a tabletop pilot version to a real-life deployed open-source software and was deployed in 8 federal states and 33 local government areas (LGAs) during the monkeypox outbreak. From September 2016 until November 2017, SORMAS was piloted in 1 state in 2 LGAs and 85 health facilities [14,15]. By February 2018, SORMAS was deployed in 3 additional federal states (71 LGAs) for meningitis outbreak. In March and April 2018, SORMAS was further deployed in 3 additional states (49 LGAs; 5 health facilities) for the Lassa fever outbreak. As of October 2019, SORMAS has been fully established for all epidemic-prone diseases in 15 federal states (including the federal capital), 287 LGAs, 37 health facilities, and approximately 700 users covering a population of 75 million. SORMAS managed multiple outbreaks simultaneously across the country. The assessment of SORMAS applying the GMM showed that SORMAS had a 10-point score each in global utility, community support, and software maturity (see Table 2).
<table>
<thead>
<tr>
<th>Core indicator</th>
<th>Score 2017</th>
<th>Score 2018</th>
<th>Score 2019</th>
<th>Status of SORMAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global utility</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Country utilization</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Country strategy</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Digital health interventions</td>
<td>−1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Source code accessibility</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Funding and revenue</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Community</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developer, contributor, and implemen-</td>
<td>−1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>terer community engagement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Community governance</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Software roadmap</td>
<td>−1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>User documentation</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Multilingual support</td>
<td>−1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Software</td>
<td>1</td>
<td>5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Technical documentation</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

SORMAS has been fully established for all epidemic-prone diseases in 15 federal states (including the federal capital), 287 local government areas, 37 health facilities, and approximately 700 users covering 75 million population (November 2017).

SORMAS has now been fully integrated into the revised technical guidelines of the Integrated Disease Surveillance and Response strategy and eHealth framework (September 2019).

SORMAS can be configured and deployed without significant customizations or configuration (July 2019).

SORMAS has an open-source initiative approved license (GNU General Public License, Version 3, June 29, 2007) and is structured to allow local customizations and SORMAS is web-based and provides a relatively clear application programming interface (API) and database model. So, it is easy to build new modules and functionalities and host them on the same server (August 2019).

SORMAS is has been funded by the following partners: Commission for Intellectual Property Rights, Nigerian Foundation for the Promotion of Nigerian Health Care Provision Fund, and Centers for Disease Control and Prevention, Berlin, Zentrum für Infektionsforschung (IZIF). Funding sources for SORMAS increased from 1 in 2017, 3 in 2018, to 7 in 2019 (October 2019).

In Nigeria, the steering board consists of representatives of Helmholtz Centre for Infection Research (IZIF), Nigeria Centre for Disease Control, and in Ghana, the steering board includes Ghana Health Service, Ghana Community Network (Gcn), and IZIF. The steering board is furthermore supported by an international advisory board and an open-source clearinghouse (January 2018).

New features and functionalities are documented as part of the SORMAS roadmap and are also part of a biweekly release cycle (May 2019).

SORMAS currently has user guides and technical documentation in which the source codes, use cases, and functional requirements exist, including training videos that are available to address everyday deployment tasks (August 2018) [16].

SORMAS has a multi-lingual support mechanism for English and French on its platform. The language translation component in SORMAS is easy to configure by a non-technical person and can be adapted into by any language required (February 2019).

SORMAS has full documentation for deployment and configuration, which does not require the involvement of the core development team. The SORMAS mobile app has only been packaged for the smartphone version of the operation system and not yet packaged for the iOS operating system. The SORMAS web app has been packaged for Windows, Apple, and Linux operating systems (August 2018).
### Core indicators

<table>
<thead>
<tr>
<th>Core indicator</th>
<th>Score 2017</th>
<th>Score 2018</th>
<th>Score 2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software productization</td>
<td>-1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Interoperability and data accessibility</td>
<td>-1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Security</td>
<td>-1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Scalability</td>
<td>-1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

**SORMAS** has automatic software upgrades without the manual intervention of the developers and also has integrated unit testing as part of the release process (August 2019)

**API and post-transaction within SORMAS** for accessing and managing data, and SORMAS has user interfaces to export case data and metadata in the system (CSV format) for further analysis and data transfer purposes (August 2017)

**Role-based authorization exists within SORMAS and all remote access via the web interface and APIs are encrypted by default. SORMAS has undergone an independent security audit of the software, which has taken place within the past 12 months (May 2019)**

**We have deployed SORMAS in at least 30% of all entities, which are managed within the software. There has been a surge in the number of models and deployments across the country in the past year (Indicator 2, sub-indicator 5 criteria). For every SORMAS release, we evaluate the software performance and perform load testing and IT integrated testing (October 2019)**

**Total score, a (%)**

|                | 10 (33) | 21 (76) | 30 (100) | N/A |

*The global goodness model assigned scores for each sub-indicator as -1 for “low,” 0 for “medium,” and 1 for “high,” and computed average values for the 5 sub-indicators of each core indicator using the formula in equation (1). MS = 5 * (MEAN [Sij]) + 5, where, MS = Maturity score for each core indicator S, i = sub-indicator, j = 1,...,5 (vector containing score of the sub-indicators).*

**SORMAS:** Surveillance Outbreak Response Management and Analysis System

**N/A:** not applicable

### Discussion

**Principal Findings**

SORMAS has reached the full score of the GGMM. The process from the decision to migrate a prototype based on a System, Applications, and Products proprietary technology stack to open-source software in 2016 until the accomplishment of the full score listed 3 years [10]. There is no registry or publicly available documentation of tools that have applied the GGMM assessment except the District Health Information System 2 [17]. Of all the mHealth tools selected as global goods software listed in the GGMM guidebook, none have accomplished over 80% of the full score nor are we aware of any other tool that has obtained it [13]. Thus, it appears very likely that SORMAS may be the first and, so far, only digital tool that has reached the full score of the GGMM. SORMAS has multiple revenue streams and funding mechanisms that have been enabling progress in its development since 2016. SORMAS requires funding for software adaptations to country-specific requests, personnel for training, and supervision and maintenance of the tool.

The outline and the scoring principle of the GGMM version 1.0 was easy to apply. However, there were some limitations concerning the clarity of the definition of each of the 3 possible criteria of the sub-indicators. Many of those definitions contained a combination of several contextually independent items, for which the wording did not clearly distinguish between “AND” or “OR” combinations. Some definitions left room for interpretation, which may be necessary for some but also be too ambiguous in other situations. The 30 sub-indicators grouped into 3 core indicators all have equal weights keeping the model and its handling simple.

On the other hand, it may also not represent the difference in importance that different indicators may have. For example, it may be considered essential for global goods maturity to have repetitive external security tests implemented than multilingual. Once the full score has been accomplished, these differences are no longer relevant. However, as long as the total score is only partially completed, the quantitative value may be very misleading in the attempt to compare tools. A way to improve this dilemma would be to add weights to each indicator. A more natural way would be to discourage the computation of proportional completion and to categorically apply a dichotomous all-or-nothing principle, by which all requirements have been either fully fulfilled or not fulfilled [18]. Some indicators address items that may develop into two directions. For example, the number of countries using the tool may not always diminish but also increase, or an external penetration test may not be repeated as required. It may increase scaling if those sub-indicators that do require a regular renewal or update be explicitly highlighted to facilitate monitoring of the status. Another difficulty appeared with the sub-indicator for global utility, “Source Code Accessibility,” as it was not entirely clear what “new modules” and “functionality” meant in the context of this model. In contrast to modular systems, some mHealth apps are built specifically to deliver a ready-to-go solution for a specific task, and they are defined by external standards that govern how the internal processes of the end users work. In such a situation, the requirement for facilitating options for developing new modules and functionalities without prematurely forsaking the code may not be applicable.
For the time being, the GGMM serves as a self-assessment system. In that, the authors can confirm that is the ease of SORMAS, it has dramatically guided the prioritization and acceleration of its development. It appears to be the main objective of the model. On the other hand, self-assessment also allows for a certain degree of subjectivity or bias [19]. To reduce this risk, we contacted external experts who were not involved in the development and deployment of SORMAS but were instead instrumental in the development of the GGMM. Through this, we aimed to reduce conflicts of interest and maximize the expertise on SORMAS as well as on the interpretation of the GGMM. We believe that inviting independent external experts in reviewing this assessment may be a model for other projects and tools to apply the GGMM assessment. We do not entirely recommend an external assessment, as practiced in many accreditation procedures, because it carries the risk of creating a business that will only be able to draw resources needed for the actual development of the tools.

Conclusions
To our knowledge, SORMAS is the first electronic health tool for disease surveillance, and also the first outbreak response management tool, that has reached the full score (100%) of the GGMM. The GGMM is clear in most of its definitions and is easy to apply for self-assessment, although some indicators require more resources for completion than others. Some conceptual modifications would allow for further improvements to the system. Nevertheless, it already has a supportive effect on developing software toward global good maturity.

Acknowledgments
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Authors’ Contributions
DT, BS, and GK searched, selected, and extracted data based on the criteria. DT conceptualized the first draft and GK analyzed and interpreted the results of the data. DT, GK, BS, CA, and JD reviewed the GGMM criteria for SORMAS development. MW and MS contributed to the development of SORMAS software. CL and CF represented Digital Square in the initiative that convened the initial creation of the GGMM version 1.0 and assisted in the SORMAS GGMM assessment. GK initiated the study approach and supervised all steps of the study. All authors revised and contributed to the final manuscript.

Conflicts of Interest
None declared.

References


**Abbreviations**

GGMM: global good maturity model

LGA: local government area

mHealth: mobile health

SORMAS: Surveillance and Outbreak Response Management and Analysis System
8.3 Complete list of publications


8.4 MHH ethics clearance letter

[Image of an ethics clearance letter from Medizinische Hochschule Hannover]

Nr. 8578_BO_5_2019
User Evaluation of Surveillance Outbreak Response Management and analysis System (SORMAS) in Nigeria, West Africa

Beratungsergebnis: Ohne Bedenken, mit Hinweisen

Sehr geehrter Herr Kollege Krause,

die Mitglieder der Ethikkommission haben auf ihrer Sitzung am 14.08.2019 über o.g. Antrag beraten.

Die Ethikkommission hat keine Bedenken gegenüber der Durchführung des Studienvorhabens, erlaubt sich aber folgende Hinweise:

1. In der Teilnehmerinformation soll besser auf die Datenschutz eingegangen werden und die Rechte der Teilnehmer sollen entsprechend DSGVO sollen werden.
2. Die formulierten Forschungsfragen passen nicht zu den vier genannten Hypothesen.
3. Die Angaben zur Fallzahl basieren auf standardisierten Effektgrößen, die nicht weiter nachvollziehbar sind. Weiterhin fehlt ein t-Test-basierter Ansatz für die Auswertung mit logistischer Regression nicht weiter.

Der Antragsteller ist seiner berufsrechtlichen Pflicht entsprechend § 15(1) Berufsordnung für Ärzte in Niedersachsen nachzukommen. Eine Wiedervorlage wird erst bei Änderungen des Vorhabens nötig.

Das Beratungsverfahren ist hiermit abgeschlossen.

Die Ethikkommission weist darauf hin, dass die ärztliche und juristische Verantwortung bei den jeweiligen Pflichten verbleibt.
Datenenschutzechte Aspekte von Forschungsarbeiten werden durch die Ethikkommission grundsätzlich nicht kursorisch geprüft. Dieses Votum über diese Bewertung ersetzt mit Hinweis nicht die Konsultation des zuständigen Datenschutzbeauftragten.

Mit besten Grüßen

Prof. Dr. Stefan Engell
Vorsitzender

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Folgende Mitglieder haben an der Beratung des o.g. Antrages mitgewirkt:
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PD Dr. Urs-Volker Albrecht (stellv. Vorsitzender & geschäftsführender Arzt)
Stellv. Direktor des Peter-L. Reichertz Instituts für Medizinische Informatik, MHH
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Leiter der Pädiatrischen Stoffwechselmedizin, Klinik für Pädiatrische Innere-, Leber- und Stoffwechselkrankungen, MHH
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Arzt für Allgemeinmedizin
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Prof. Dr. Thomas K nig
Leiter der Hannover Riebberk (MHH) & Stellv. Direktor des Instituts für Humangenetik, MHH
8.5 Nigeria REC ethics clearance letter

[Image of document]

National Health Research Ethics Committee of Nigeria (NHREC)


Health Research Committee assigned number: NHREC/03/01/2007

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**Date of receipt of valid application:** 08/10/2019

**Date when final determination of research was made:** 14-01-2020

**Notice of Expedited Committee Review and Approval**

This is to inform you that the research described in the submitted protocol, the consent forms, advertisements and other participant information materials have been reviewed and given expedited committee approval by the National Health Research Ethics Committee.

This approval dates from 14/01/2020 to 13/01/2021. If there is delay in starting the research, please inform the HREC so that the dates of approval can be adjusted accordingly. Note that no participant accrual or activity related to this research may be conducted outside of these dates. All informed consent forms used in this study must carry the HREC assigned number and duration of HREC approval of the study. In multiyear research, endeavour to submit your annual report to the HREC early in order to obtain renewal of your approval and avoid disruption of your research.

The National Code for Health Research Ethics requires you to comply with all institutional guidelines, rules and regulations and with the tenets of the Code including ensuring that all adverse events are reported promptly to the HREC. No changes are permitted in the research without prior approval by the HREC except in circumstances outlined in the Code. The HREC reserves the right to conduct compliance visit to your research site without previous notification.

Signed

[Signature]

Professor Zubairu Illyasu MBBS (Unimaid), MPH (Glasg), PhD (Shef.), FWACP, FMCPH
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9 ACKNOWLEDGEMENT

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Finally, I would like to thank the EPID team of the Helmholtz Centre for Infection Research (HZI) for all the support, feedback, and constructive criticisms.

Now a famous Persian poem by Ibn Yamin

“One who knows and knows that he knows… His horse of wisdom will reach the skies. One who knows, but does not know that he knows… He is fast asleep, so you should wake him up! One who does not know, but knows that he does not know… His limping mule will eventually get him home. One who does not know and does not know that he does not know… He will be eternally lost in his hopeless oblivion!”
10 DECLARATION

Herewith, I confirm that I have written the present Ph.D. thesis myself and independently, in compliance with the “policy of Hannover Medical School on the safeguarding of good scientific practice and procedural rules for dealing with scientific misconduct” and that I have not submitted it at any other university worldwide. Herewith, I agree that MHH can check my thesis by plagiarism detection software as well as randomly check the primary data. I am aware that in case of suspicion, ombudsman proceedings according to § 9 of MHH ‘Guidelines of Hannover Medical School to guarantee good scientific practice and dealing with scientific fraud’ will be initiated. During such proceedings, the Ph.D. process is paused.

Hannover,

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Braunschweig, 22.03.2020