

Mobile Health for the Developing World: Review, Prospects, and A Case Study

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Abstract

Mobile Health (mHealth) is an emerging technology that has a tremendous potential to improve the public health across the globe. Mobile phones being the simplest and most affordable technology has fueled the rapid adoption and institutionalization of mHealth. This paper focuses on the developing countries as despite the tremendous potential mHealth has not been implemented in large scale and there is a lack of research explaining the cause. We present a comprehensive list of the challenges that are current roadblocks for successful implementation of mHealth in the developing countries. In particular, we present a case study of Pakistan—an large underdeveloped country in South Asia. We discuss the public health architecture of Pakistan and then consider how mHealth can be used to complement the public health services in Pakistan. Moreover, we present a number of future aspects that the implementation of mHealth is likely to encounter. This research is expected to guide the development of strategies and policies for an effective and sustainable adoption of mHealth in the developing countries.

I. INTRODUCTION

Mobile health or mHealth is a evolution of existing healthcare system built upon the highly portable mobile devices. The word mHealth is an umbrella term that encompasses a rich set of use cases in which innovative healthcare services are provided using mobile communication devices and information and communication technology (ICT). The proliferation of mobile phones has stimulated the application of mHealth globally, especially in the developing countries where there is a severe scarcity of healthcare infrastructure. The worldwide statistics reveal that there are 62.9% mobile users around the globe [1] and 80% of the Internet users own smart mobile phones [2]. Mobile phone penetration in the developing countries like Pakistan is even higher than the landline services, almost 90% of the population in Pakistan has a 2G coverage [3]. The use of mobile technologies, such as smartphones, tablets and other mobile devices by medical practitioners at point-of-care has transmuted various aspects of clinical practice and has the great potential to improve the public health system, and provide disease interventions, real-time monitoring, outbreak prediction, etc.

The modern smartphones incorporate a gamut of programmable sensors such as gyroscope, ambient light sensor, camera, proximity sensor, GPS, accelerometer, microphone, digital compass and touch screen interface. In addition, each smartphone vendor now offers a set of open software development kits (SDKs) allowing developers to design and develop new sets of applications (apps) [4]. There are more than 97000 health-related mobile applications or mHealth apps available on Google Play and Apple's App Store; and around 4 million downloads happen each day [5]. This shows the rising popularity of the mHealth industry. It is expected that 50% of the smartphone users will have downloaded mHealth apps by 2017 [6]. The mHealth apps are transforming the smartphones into medical kits that is changing the landscape of real-time health monitoring paradigm. Moreover, constant monitoring of a patient's activity increases the likelihood of an early detection of emergency states and provides a wide range of versatile, convenient and efficient healthcare services such as improved vaccination quality, disease screening, health education, improved medication adherence [7]. The mHealth is focusing to have an increased number of consumer-based mHealth apps to cope with different aspects of public health. People give value to their personal data and do not like to expose their personal sphere of life. In future, the ethics and mechanisms of sharing personal data will certainly evolve since sharing of personal data with trusted parties will be unavoidable for gaining access to quality health services.

Mobile phones are being used as a tool for gathering diverse kind of data, such as data from computerized physician order entry (CPOE), patients' data in electronic patient records (EPRs), mobile generated sensor data, social network posts, and blogs. This is resulting in an overwhelming amount of data that is rightfully termed as *big data* these days. The spread of big data analytics enables one to obtain insights from the sheer volume of data and provides clinical diagnostics and monitoring directly to a patient [8], [9]. Further, the advancement in mobile communication technologies, such as 3G and 4G, for data

transport enables fast and reliable interaction between medical staff and patients. A physician can easily access the health-related medical information anytime anywhere, thereby eliminating geographical barriers by remotely taking substantial decisions on the clinical care of patients. In an mHealth system, data is gathered by mobile devices which is then transmitted to a remote server from where it is available to physicians as depicted in Fig. 1.

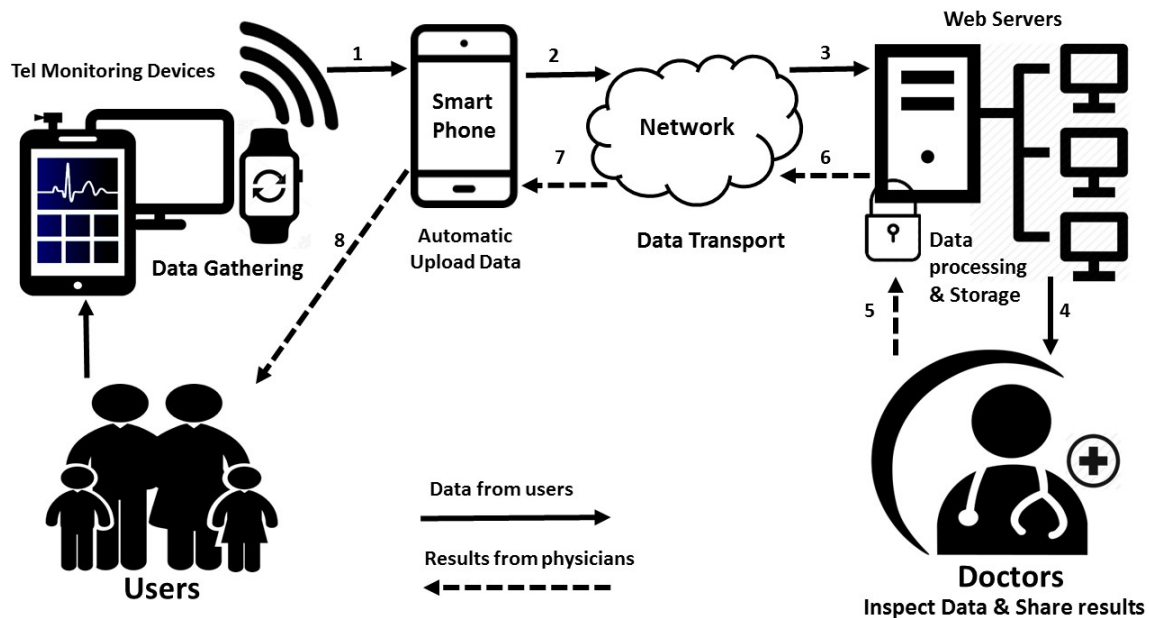


Fig. 1: Illustration of a typical mHealth architecture, data from various mobile devices pass through the network destined for remote servers for data analytics.

The mobile phone sensors along with the mHealth applications have enabled the real-time accumulation of health related data that holds the valuable indications for the treatment of various devastating diseases. Now, mobile phone sensors are being utilized in a variety of applications for the public health, such as stress sensing (microphone) [10], lungs function monitoring (microphone) [11], teeth health monitoring (microphone) [12], boredom detection (mobile usage) [13], mental disorder control (accelerometer, light sensors, temperature sensor, barometer, compass and microphone) [14]–[16], behavioral healthcare (accelerometer, light and proximity sensors, temperature sensor, barometer, compass and microphone), [15], [17], [18], surveillance and outbreak response management systems [19]–[21]. Table I also highlights some other common applications of sensors technology for public health.

The mHealth is the main attraction for the innovative research in the field of mobile computing for public health. It offers numerous possibilities to produce efficient mHealth applications for high-, middle-, and low-income countries, including the poor and rich living within the same country. Over the past 40 years, people have been trying to address vital public health problems throughout the globe, especially in the developing countries. The targets of these efforts have focused on reducing child mortality; meliorating maternal health; providing improved treatment of HIV/AIDS and malaria; and increasing access to safe drinking water in impassable and underprivileged areas [29]. More than any other advanced technology, mobile phones are notable for their ubiquitous deployment in emerging countries [30]. In the developing countries like Pakistan, most of the population resides in rural areas with insufficient health care facilities. Most of the people living in remote impoverished regions use low-cost basic cell phones. Even the most basic cellphones have three basic communicative features: short message service (SMS), multimedia message service (MMS) and voice call. These basic features have enabled various mHealth applications, such as toll-free call centres, text messaging campaigns, health promotion, emergency and disasters management systems, remote data collection, community mobilization, and medication compliance. The implementation of these mHealth applications has enabled an effortless communication among medical staff, researchers, and patients, which offer an effective way to support a healthy lifestyle, improve patients' access to the relevant information and provide better intervention for chronic diseases [31], [32].

Currently, the mHealth approaches are evolving as an emerging tool in providing easy access to healthcare services in a cost-effective way in the developing countries, by improving the quality and capacity healthcare systems. Consequently, mHealth has expanded in various types of healthcare initiatives, and it is projected to be a multibillion dollar industry by 2017 [33]. The current advancement in the Internet, mobile phones, and machine-to-machine communication can be realized as the initial phase of the Internet of Things (IoT) [34]. The mHealth together with IoT and big data can accelerate the diagnostics by

Sensors/Modules	Domain	Application
Camera	Capture photos and video	It is being used for tracking different diseases, to view surgical effects, remote diagnostics, incision monitoring, skin disease analysis [22], supervision of child health [23].
GPS	Location tracking	It gives access to track the vulnerable patients such as people with Alzheimer's disease [24] and Ebola [25] by using contact-tracing apps.
Electrocardiograph	Cardiovascular disease monitoring	Electrocardiograph enabled mobile phone are being used in underdeveloped areas in China for surveillance of heart diseases [26].
Bluetooth	Data sharing	It enables the short range data communication between mobile phone and various health monitoring devices and wearable sensors.
Microphone	Voice recording	It enables the communication with doctors regarding diagnostic and clinical support. It also provides capital for the audio analysis to access patient's feeling with different diseases such as myotonic syndrome [27].
Accelerometer	Measure linear acceleration	It helps to measure the device's orientation relative to the earth magnetic field. It can be implemented in various patients' activity monitoring techniques such as step-counting of a person and gait monitoring (which can help in early diagnosis of other diseases like Parkinson) [28].
Wi-Fi	Data transport	The Wi-Fi module empowers the mobile phone to communicate the health data to physician for diagnostics and treatments.
Accelerometer, GPS, compass, gyroscope, barometer,	Physical activities	The combined module of these sensors is being exploited for measuring the sedentary versus non-sedentary activities.
Microphone, accelerometer, GPS	Social engagement	This package enables the surveillance of mental health by monitoring the social encounters, conversationalist talks, anxiety, stress, depressive behaviors and crustal motion of patients [16].
Microphone, GPS, accelerometer, touch interface, light sensor	Tracking sleep patterns	This module provides the effective information of disrupted versus continuous sleep patterns of a patient [4].

TABLE I: Some famous smartphones' sensors and their application

changing the landscape of healthcare in terms of operational efficiency and accuracy [35], [36]. Healthcare providers are trying to make patients' medical data to be more intelligent and visible in real-time. RF identification (RFID) technology is now latest development of IoT in the healthcare system [37]. In the coming years, the IoT-based healthcare systems are anticipated to have intelligent sensors that can assist patients without their active involvement. The IoT-based healthcare market is believed to grow globally from \$32.47 billion in 2015 to \$163.24 billion by 2020. Similarly, IoT based connectivity in medical labs will increase diagnostic test by more than 3.02 billion in the next 5 year [38].

Despite the promising opportunities of mHealth in the developing countries, healthcare providers face various unique hurdles like low literacy, poor infrastructure, limited skilled professional and cultural issues. The challenges to adoption of mHealth include changing the behaviour of the people towards better health, nudging them with success stories, providing requisite education, furnishing them with essential infrastructure such as solar power units and mobile devices. The mHealth initiatives also have to protect the privacy of patients' personal information shared through mobile devices. They must also ensure the interoperability of mHealth with electronic health records (EHRs) and existing healthcare systems.

Although mHealth has proven a wonderful joyride for providing healthcare facilities in underdeveloped areas but its adoption is still very challenging. We have performed a case study on the health problems and scope of mHealth in Pakistan to find the variables that influence the adoption of mHealth among the population. In Pakistan, mHealth is still in its inception and demands voluminous research on its adoption process. Through case study, we have tried to highlight the potential benefit and the realization of mHealth in the developing countries that can attract the attention of the government and population towards the adoption of mHealth. Most importantly, we have proposed different insinuations for various hidden challenges that are still persisting in the developing countries like Pakistan. However, a very few to no studies present the realization of mHealth by highlighting the hidden problems that barricade the adoption of mHealth in the developing countries. These findings can be utilized by government authorities, policy makers, stakeholders, population, healthcare professionals, app developers, researchers, as well as by the mobile phone and telecommunication industries to increase the acceptance of mHealth in the developing countries. This paper also concludes several implications and research problems for future research.

This paper is organized as follows. In Section II, we introduce the applications of mHealth and its impact on public health. In Section III, we present the significance of mHealth for the developing countries followed by the challenges to address for the successful adaptation of mHealth in Section IV. In Section V, we discuss the current healthcare system of Pakistan, some prominent mHealth initiatives along with different existing challenges. In Section VI, we present the future aspect and the realization of mHealth for the developing countries and finally conclude in Section VII.

II. APPLICATIONS OF MHEALTH AND THEIR IMPACT ON PUBLIC HEALTH

There is a strong evidence that shows the millions of people suffer and eventually die from diseases for which there exist effective treatments. For example, each year 52% of children die around the World due to the diseases such as diarrhea,

pneumonia and malaria [39]. According to a World Bank report, for each and every disease there exists at least one effective prevention and intervention [40]. Healthcare systems in the developing countries are continually facing major challenges in providing affordable and better quality of care due to increase in both non-communicable chronic and communicable diseases [41]. A research at the University of Kentucky Center for Rural Health shows that in one year mHealth was able to reduce the cost of the healthcare system by over 80%, decrease hospitalizations by 92%, and reduce emergency center visits by 87% [42]. Further, researchers, policy-makers and private NGOs [43], [44] have started various mHealth programs in the developing countries and are seeking innovative approaches to improve the quality of life and elimination of the geographical and financial barriers to health. The mHealth addresses these challenges and offers some hope by providing high quality and financing of healthcare.

A. Education and Awareness

According to the World Health Organization (WHO) [29], 57 countries face severe shortages of healthcare workers and mostly communicable diseases continue to claim people's lives due to the lack of knowledge and limitation in medication. Lack of health and technological informatics of the public in the developing countries significantly hinders the innovative healthcare practice. Therefore, a strong training and education program is required to illuminate the health awareness in common people for smoothing the health informatics curve. Health education through mobile devices is a cost effective, efficient approach which can raise awareness about medical testing, management of diseases, interventions, drug interactions, treatments, dosage errors and suggestions of relevant professionals based on patients' electronic medical records (EMR). In real-time situations, there are various ways to design a mobile-based expert systems, e.g., a mobile phone coupled with a patient monitoring device like an ECG or a pulse oximeter that sends warnings or reminders to the patients or physicians in acute circumstances.

Text messaging (or SMS) is the most accessible and economical way to provide health-related education and interventions with a target of health improvement both domestically and internationally. Health awareness campaigns through SMS are equally popular in the first and third World countries (like India and Bangladesh) [45]. The mobile platform is being harnessed to spread health education and awareness on sexual health [32], HIV/AIDS [32], [46], women's pregnancy [47], [48], oral contraceptives [49], and smoking cessation [50]. Similarly, various SMS-based mHealth programs are reported in the developing countries. For example, a program text-to-change in Uganda aims to provide awareness on AIDS and HIV testing [51]. In this program a local mobile phone company together with the AIC (AIDS information center) uses bulk SMS messaging service to provide awareness on AIDS [18]. Project Masiluleke is a hugely successful initiative in South Africa, working to fight against the epidemics of HIV and TB. It allows the users to send an SMS of 120 spare characters (Please Call Me or PCM) messages from their mobile phones to receive required assistance about HIV/AIDS [52]. They receive prompt feedback from the local HIV/AIDS and TB call centers. Learning about living project functioning in Nigeria, provides awareness of AIDS through text messaging. In India, education on HIV/ AIDS is delivered by engaging the user in a mobile game [53].

Reminders of daily medication are very effective means of cure for diseases like TB, for example the SIMpill system in South Africa is designed to help ensure compliance. SIMpill consists of a pill bottle with a subscriber identity module (SIM) card and transmitter. When the patient opened the pill bottle, an SMS message is sent to a designated doctor. If the patient did not open the pill bottle when expected, the patient receives reminder to take his medication. Similarly, if the patient fails to take his medications, the doctor calls for a visit to encourage him to take his medication. The solution is now available worldwide [54], [55]. Fig. 2 displays the percentage of some prominent mHealth services which are being used globally as of 2011.

The mHealth educational initiatives have proven to be very effective to enhance health awareness and health outcomes in the developing countries. A risk-benefit analysis in Thailand proves mHealth reminders for the TB medication adherence to be very inexpensive compared to direct observational treatments [56]. In South Africa, SIMpill proved to be very effective and about 90% of patients complied with their medication, compared to 22% to 60% compliance without this system [54], [55]. A systematic review of randomized controlled trials (RCTs) on SMS based applications revealed that mHealth helped to reduce viral load amongst HIV patients and improved HIV anti-retroviral treatment (ART) adherence [57]. But SMS-based intervention failed to tackle the risky health behavior such as contracting HIV [58]. An SMS-based reminder system in Kenya proved to be very effective for the improvement in child vaccination rates [59], but a substantial proportion of women were not allowed to take part in this campaign by their husbands, thus proving as a major challenge to mHealth interventions. A survey of 223 midwives in Indonesia showed that the mobile phone based health information resources positively increased the health knowledge [60].

B. Decision Support Systems

In the developing World, remote data collection is particularly important since most of the population is barely able to visit a hospital, even in the cases of severe illness. Gathering of health informatics on a real-time is vital for effective clinical decision support and it is more accurate and reliable if conducted via smartphones, PDAs, EMRs, or mobile sensors rather than manual data entering of paper-based surveys. At the beginning the implementation of decision support systems was

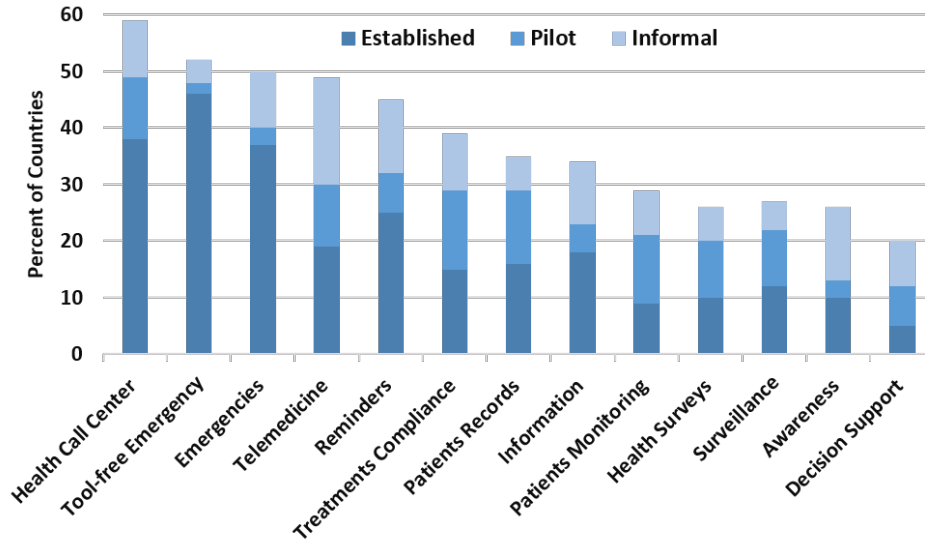


Fig. 2: The global distribution of established mHealth initiatives as of 2011. Data source: [45]

computer based and on a smaller scale across the globe [45]. Decision support systems are now emerging due to evolution in the field of smartphones and artificial intelligence techniques (e.g., machine learning). Patients can put their data on hospital servers remotely through mobile phones and receive health treatments, avoiding the expense of hospital visits. It can also be a software-based algorithm that can notify health professionals on clinical decisions related to patients by collecting the patients' data and medical information.

There are multiple clinical algorithms developed for the assessment and treatment of HIV/AIDS, diabetes, child health and reproductive health. Care-improving access [61] is an mHealth initiative to provide decision support in South Africa for the treatment of HIV/AIDS. People were screened through a handheld computer or mobile device for further treatment and it also maintains patients' records to overcome the limitations of doctors. Likewise, in India a medical equipment company Maestros Mediline Systems introduced an electrocardiograph (ECG) application in Mumbai, Nanavati Hospital, together with Vodafone for BlackBerry mobile phones. In this system, doctors can remotely access patients' ECG and heart reports [62]. Integrated Management of Childhood Illness (IMCI) provided by WHO and UNICEF [63]. This system offers simple and effective practices to prevent and control the major causes of serious sickness and mortality in children and provides evidence-based treatment and cost effective use of drugs. Future work includes integration of decision support algorithms into electronic health records (EHRs) to provide better point-of-care.

Decision support systems have been deployed in various developing countries, narrowing the information gap that currently exists between the patients data and healthcare professionals. A trial system established in Kenya for management of malarial treatment adherence in 107 rural health providers [64]. In this system, health workers received daily (except weekends) two SMS messages for six months, containing guidance about the outpatient management of malaria. Results proved that, the short-term treatment improved by 31.7% and long term treatment improved by 28.6%. St Gabriel's Hospital in Malawi used a pilot system to reduce avoidable visits of rural communities to hospitals. In this scheme 75 volunteers from respective villages, were provided mobile phones and guided how to use them in situations of communication with physicians. This intervention was aimed to reduce the barriers of poor doctor-patient ratio via community health workers (CHW) mediation. Overall results reported a saving of US \$2,750, mainly in terms of reduced fuel costs [65].

C. Epidemic Outbreak Tracking and Natural Disasters

Ignorance about communicable diseases such as cholera, TB, dengue fever and severe acute respiratory syndrome (SARS) can render these diseases into epidemics. Mobile devices can be used to monitor, capture and communicate statistics to responsible authorities on incidence of such diseases and hence preventing their outbreaks. Outbreak of infectious diseases is common phenomenon in the developing countries after natural disasters. For instance, diarrheal diseases outbreaked in Bangladesh after the 2004 floods. A similar outbreak occurred in Pakistan after the 2005 earthquake. On May 2008 a severe earthquake having the magnitude 8.0 struck the Sichuan province, China. More than 80000 people were died and around 5 million became dispossessed. A mobile phone based reporting system was deployed for the detection of epidemic-prone diseases to take quick actions for the prevention of outbreaks [21].

As per WHO, Polio is still endemic only in Pakistan and Afghanistan, which is causing outbreaks of vaccine-derived poliovirus in other countries such as Guinea, Madagascar and Ukraine and has vulnerable threat to the Syrian Arab Republic, Iraq and Israel. The major factors responsible for poor immunization are inadequacy of electronic records, poor security, insufficient vaccination coverage, and lack of education and awareness. The mHealth is playing a vital role to assist the polio eradication programme in such circumstances. In Pakistan, an SMS-based service was used in 2010 to enable the parents to report the national polio control program about the missed areas by the vaccination team. The polio vaccination team was dispatched to the reported areas shortly [66]. In Pakistan, dengue fever outbreaks have been cycling since 1994 and one of the major striking trend was reported in 2013 from the regions that were not in the conventional endemic belt of the country, such as the province of Balochistan and Khyber Pakhtunkhwa (KPK) [67]. The table II shows the overall number of dengue fever cases. In the rainy season of 2012, Punjab Information Technology Board (PITB) used smartphone-driven program in Lahore to stop flagitious effect of dengue virus. This initiative was proved largely successful, In 2012, the number of deaths in Lahore dropped to zero. In the next year (2013), there were 1511 death in the whole province of Punjab but in Lahore there were only 8 deaths that has proven the significance of mHealth services for the outbreak of diseases [68].

Dengue fever cases from Pakistan, 1994-2011		
Year	Suspected Cases	Number of Deaths
1994	145	1
1995	75	57
2003	3500	18
2004	25	0
2005	500	13
2006	4961	41
2007	2304	18
2008	2792	17
2009	1940	13
2010	15901	40
2011	252935	219

TABLE II: Dengue fever in Pakistan. Data Source: World Health Organization

Mobile phone based early warning systems for disease and epidemic outbreaks are being used in India, Peru and Rwanda, allowing healthcare professionals to track the spread of infectious diseases [69]. Similarly, various mHealth initiatives such as Ushahidi, FrontlineSMS and SamaSource focus on public help to respond in the situation of disasters like Indian Ocean tsunami in south-east, Haiti earthquake, and disease outbreaks [45]. UNICEF reported the effectiveness of their mHealth initiative called RapidSMS [70], which monitored the malnutrition rates by eliminating the delays of months usually incurred by the paper based surveys. The SMS-based program called Cam e-Warn initiated by Cambodia, together with the WHO, during the wake of the SARS crisis in 2003 for the surveillance of 12 reported diseases [45]. This project was implemented in 2008 and has detected various outbreaks such as watery diarrhea, influenza and dengue fever.

D. Crowdsourcing for Health

Crowdsourcing entails the participation of many people to solve a composite problem. Crowdsourcing for health involves inputs, ideas, products, capital, services and processes that ameliorate diagnosis, preventions, treatments and information. These offerings can come from researchers, employees, donors, specialized professionals and common citizens around the globe to solve complex, emerging and persistent troubles in the field of healthcare. The breakthrough of mobile phones along with the Internet has furnished promising opportunities for crowdsourcing in both developed and developing countries, because they are readily available at any time, mostly functional at remote areas and can be used at point-of-care [71].

As an industry, crowdsourcing shares about \$5.5 trillion or 8% of the global economy and it has one of the sumptuous human-based problem solving system [72]. There are various crowdsourcing projects in terms of innovative healthcare ideas, raising awareness, engaging patients and healthcare providers. The National Cancer Institute (NCI) office of Cancer Nanotechnology Research (OCNR) at the National Institute of Health (NIH)¹ used crowdsourcing to find the nano-materials and tools that transform the clinical oncology and research of cancer. They encouraged people to submit their ideas to make cancer treatment more efficient in terms of drug delivery, nano-informatics, metastasis and circulating tumor cells. The selected ideas were presented at a Strategic Workshop on Cancer Nanotechnology by OCNR [73].

BAYADA² Home Health Care aims to provide safe and healthy life for children and adults of all ages with comfort and dignity. In the fall of 2012, BAYADA used crowdsourcing to find an effective solution for public health with the help of IdeaScale³. They were able to attract over 400 users, and received 2000 votes, 110 ideas, and 730 comments. PatientsLikeMe⁴

¹<https://www.nih.gov>

²<https://www.bayada.com>

³<https://ideascale.com>

⁴<https://www.patientslikeme.com>

is another initiative of crowdsourcing for public health, it was launched on October 10, 2005 with the aim of connecting patients with one another to improve their lives and a real-time research. This innovative initiative helped more than 400,000 patients and improved the health of more than 2500 patients.

E. Remote Monitoring

All the major smartphone systems—including iOS, Android, Symbian, webOS, Blackberry and Windows Phone allow access to control interfaces such as dialog boxes, menus, calendar pickers, phone’s built-in sensors and other native applications such as a contact list, calendar, call logs, call duration and email. This enables the developers to easily create more sophisticated applications to monitor patient’s health and related activities [74]. For instance, monitoring the patients with chronic diseases such as diabetes, heart problem, hypertension and health-related vital signs like blood pressure, obesity, sugar level, and ECG can be measured using smartphone’s sensors and then transmitted to a central server through the mobile wireless network for further processing.

The remote monitoring enables one- or two-way communications between patients and caregivers to manage, monitor, and treat a patient’s illness by collecting data through sensors installed on the household mobile devices (e.g. laptop computers and PDAs) or in mobile phones. The patients with chronic diseases from AIDS to diabetes need strict adherence to a medication for effective results and informed diagnosis. Remote monitoring opens new opportunity for treating patients and improves survival rates dramatically in the developing countries where access to the hospital is difficult and clinics are limited [69]. In the developing countries, remote monitoring applications are being used on a relatively small scale, but they are gaining public interest in the developed countries, particularly for the diagnosis of chronic diseases. Patient monitoring initiatives were adopted in Europe (47%) and Americas (33%). In the growing world these initiatives are being used on limited scale, such as in Western Pacific (23%), Eastern Mediterranean (14%), and African (20%) [45]. Table III shows the famous mHealth initiatives being used in the developing countries.

The remote monitoring of patients using mobile phones and digital communication has improved health treatments and ameliorated the shortage of specialist physicians especially in the developing countries. A mobile phone based light microscopy has proved to be a cost effective and more adaptable technique in the diagnosis of infectious and hematological conditions [75]. In Egypt and Uganda the built-in camera of a mobile phone has been used to send the required photographs of the patient’s skin to expert dermatologists for the dermatological diagnosis. Result shows 73 – 77% successful teleconsultation [76], [77]. In Botswana, the mobile phone photography was used in the diagnosis of cervical-cancer-suspected women by sending images to the specialist gynecologists [78]. The results manifested that the combination of test with photography have a 70 – 81% accuracy as compared to visual diagnosis, reducing the referral delay, travel times and cost for patients. The Indian governmental Health Management and Research Institute launched a scheme in Andhra Pradesh in 2008 [79]. This scheme aimed to improve disease interventions by sending 475 mobile medical units (MMUs) to rural areas. This service was also able to provide the antenatal care to 1.26 million pregnant women, outpatient treatment (via mobile phone) to 600000 people and establish 10 million unique EHRs.

The analysis on the mHealth literature, it is posited that the rapid adoption of mHealth is mainly due to the affordability, availability, acceptability and accessibility of mobile phones. Mobile phones have proven as a major tool for health interventions. For example, in Nigeria a total of 1176 cancer patients were given contact numbers of the medical team for illness related necessary communication. After 24 months, only 19.2% (42 patients) of the non-mobile phone patients were able to maintain their appointments as compared to 97.6% (1132 individuals) patients with mobile phones [103]. This new paradigm of mHealth has a vast impact on public health that is also revolutionizing the healthcare industry. The mHealth market size is anticipated to achieve \$58.8 billion globally by 2020. Fig. 3 reveals the growth rate of mHealth market value from 2012 – 2020.

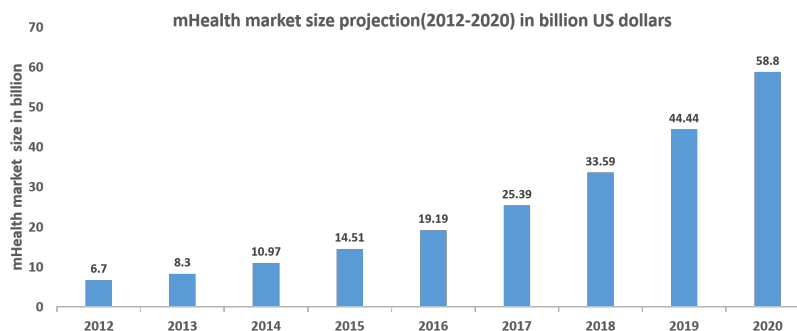


Fig. 3: mHealth market size projection from 2012 to 2020. Data source: Statista–The Statistics Portal

mHealth applications	Scope	Description
Chatbot [80]	Education and Awareness	Chatbot is a mobile app used in Pakistan to provide a counseling session based on a Balanced Counseling Strategy algorithm to promote family planning.
Pesinet [81]		A mobile application based pilot project launched in October 2009 in Mali, to reduce the child mortality by providing the easier access to early treatment.
Text me! Flash me! [82]		This project provides HIV/AIDS related information, referral and counseling services to individuals in Ghana. It uses mobile phones to provide a friendly and accessible informational and counseling services from a qualified counselor to encourage the population regarding self-care
ChidCount+ [81]		A SMS-based reporting and alert platform started in Kenya and Sauri, in July 2009, for the active monitoring of 9500+ children below the age of five.
Text4baby Russia [83]		Provides health and pregnancy related personalized information to women in accordance with their delivery date.
Mawana [84]		Project Mwana launched in Zambia and Malawi by using mobile technology to provides early-stage antenatal care for mothers and delivers HIV test through SMS.
Phones for Health [85]		This initiative aims to increase health awareness in Tanzania, using cell phones to promote a information flow between doctors and patients.
Mobiles4Health [86]		In Bangladesh, this program uses mobile technology to assist expectant women with information about the prenatal care, possible infant complexities, breast feeding practices and family planning.
The freedom HIV/AIDS games [62]		This program was launched in India (2005) that effectively increases awareness about HIV/AIDS.
mPedigree [81]	Decision Support	HP and mPedigree, offer an free SMS-based platform to stop the sales of counterfeit drugs in the developing countries. Patients in Nigeria, Ghana and Kenya can verify the authenticity of their medications free of charge.
CallDoc [87]		CallDoc is a 24/7 health line service in Pakistan, it provide consultancy and treatment to the patients in their villages and homes.
Phoned Pill [88]		In Philippines, a cell phone bases reminder system used for TB treatment. Patient were given mobile phones for maintaining health condition, appointments and receiving SMS reminders for daily medication.
eIMCI [89]		In Tanzania, electronic version of IMCI (eMCI) protocol was developed that run on PDAs for data collection. It provides full assessment of the children of ages between 2-59 months, and suggests medications.
Medicall [90]		Medicall offers a telephone consultations with medical practitioner to the remote populations in Mexico with the charges of flat USD 5 per month
TeleDoc [91]		It uses cell phones to connect health workers in remote area of India with physicians of cities for diagnosis and medications remotely.
MXit [92]		MXit is HIV content delivery Java application chat environment. It claims 1.2 million users from South Africa and Indonesia, where as over 11 million user globally.
eCompliance [93]	Remote Monitoring	A combination of mobile phone and biometric machine used for TB medication adherence in the illiterate urban areas of Delhi, India.
AutoCare [94]		A wearable sensor used in conjunction a mobile phone to provide remote monitoring for breast cancer in rural areas of Bangladesh.
Cell-Preven [95]		In this project health workers use cell phones to provide immediate reaction to untoward symptoms of sexually transmitted diseases including HIV
AED SATELLIFE [96]		In Uganda, this mHealth initiative uses wireless enabled PDAs along with the low earth orbit satellite for disease surveillance and health information collection.
Mobile Ultrasound Patrol [86]		This system uses smartphones and ultrasound machines to reduce the diagnostic time for pregnant mothers in Morocco.
Data gathering [69]		In the Amazonas state of Brazil, the Nokia data collection system was used for the fast essential data collection about the dengue virus.
Dokoza system [97]		This mHealth initiative is designed for the improvement of critical health services in South Africa. It is being used for the treatment of HIV/AIDS and TB.
EpiSurveyor [52]		EpiSurveyor is open source app for smartphones that allows health workers to collect and exchange health information. It is used in Kenya, Uganda, Zambia and sub Saharan Africa to track the immunization and to monitor stocks of vital drugs
EpiHandy [98]	It is a mobile phone based tool for data collection and handling of patients records. It has been proven effective in Uganda to reduce the error in data collection.	
SMS for life [99]	Epidemic Outbreak Tracking	SMS for Life is started in 2009 in Tanzania, to provide easy access to necessary treatment for malaria and to ensure supply of drugs in sufficient quantities for 888000 people.
TulaSalud [100]		TulaSalud uses ICT and mobile phones to to monitor disease outbreaks and to reduce the maternal mortality rate in the largest rural and remote area of Alta Verapaz, Guatemala
Alerta DISAMAR [101]		This system especially designed for the Peruvian Navy to provide the surveillance of the infectious diseases such as dengue, malaria and yellow fever. It provides a real-time data transmission by text message, Internet and mobile telephone.
Handhelds for Health [69]		In this system handheld devices or mobile phones are uses to collect health-related data for transmission to Health Information System Database in order to control and track disease and epidemic outbreaks in India.
Tamil Nadu health watch [102]		After the devastating 2004 tsunami in Tamil Nadu, a surveillance system based on the health watch was set up to instantly report disease incidence to health functionaries.

TABLE III: Some prominent mHealth initiatives being used in the developing countries.

A survey (2012) based results taken from Statista⁵ shows the optimism of patients about mHealth for the improvement of the overall healthcare system in term of cost, convenience and quality in next three years. Fig. 4 shows that the people in the developing World have more optimistic thought for mHealth than developed ones.

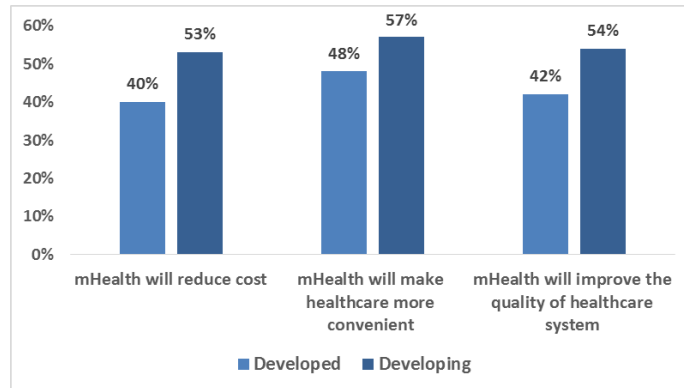


Fig. 4: Optimism of patients in the developing countries for mHealth. Data source: Statista–The Statistics Portal

III. WHY MHEALTH FOR THE DEVELOPING COUNTRIES

In underdeveloped countries, the prevalence of chronic and communicable diseases is continually growing. Moreover, in these areas people lack in major basic needs of life and have to face various unhealthy environmental conditions which are the major cause of various lethal diseases as depicted in Table IV. More than any other technological advancement, mobile phones are one of the most suitable technologies to tackle with the continued burden of health problems and diseases because they have become an integral part of the modern life. The ubiquitous nature of mobile phone along with the increased number of functionalities, lower acquisition and operating costs leads us to explore a new paradigm of public health. In the past few years, we have endorsed heighten rise in the mobile phone subscribers throughout the globe as shown in Fig. 5.

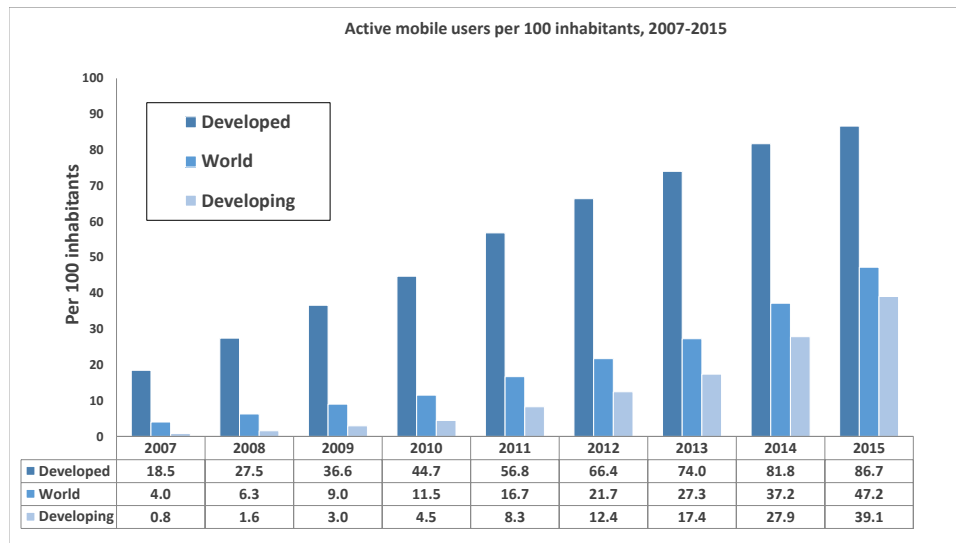


Fig. 5: Region wise active mobile users. Data source: ITU World Telecommunication

Moreover, the developments in mobile technology have made a great change in the antiquity of mobile phones to smartphones, by revolutionizing the large-sized mobile phones to more comfortable, slim and sleek smartphones. Now, it is common to carry smartphones everywhere, unlike desktop computers or even laptops, which is a substantial proof of the suitability of mobile phones for the interventions and prevention of various diseases. According to preparatory statistics from the International Data Corporation⁶ (IDC), mobile phone vendors exported a total of 399.5 million units during the fourth quarter of 2015, resulting in 45.7% growth as compared to the 377.8 million units shipped in the last quarter of 2014 [30]. These numbers manifest an increase in the production and sales of mobile phones all around the globe.

⁵<http://www.statista.com/>

⁶<https://www.idc.com/>

Causes	Facts
Unsafe drinking water	780 million people do not have access to healthy water: 31% of people lack safe drinking water in sub-Saharan Africa, 33% in Southern Asia and 65% in Eastern Asia [104]. Contaminated water causes the transmission of diseases such as cholera, diarrhea, dysentery, hepatitis A, typhoid and polio. In the developing countries, 50% of primary schools lack of safe drinking water and sanitation facilities [105], as much as 80% of diseases are due to poor water and sanitation conditions [106]. In the developing countries, an estimated 801000 children under the age of five died from diarrhea each year, due to the unsafe drinking water, insufficient water for hygiene, and lack of access to sanitation [107].
Indoor smoke	The use of solid fuels in domestic cooking and heating purpose kills an estimated 1.6 million people each year due to respiratory diseases [108].
Lead exposure	The lead exposure kills globally above 230,000 people each year and results in cognitive defects in one third of all children, more than 97% of those estimated in the developing World [109].
Poor hygiene	Poor hygiene such as poor irrigation, inadequate housing, inadequate waste management and loss of biodiversity give rise to the the most common diseases, including malaria, dengue and leishmaniasis. Malaria causes over 1.2 million deaths per year, most of them are African children under the age of five [110].
Unintentional poisonings	In the developing countries, the toxic effluents of industrial processes are emitted directly into the air, soil, and clean water. Acute poisoning kills annually 355000 people globally [110]. In the developing countries, two-thirds of these deaths occur due to excessive exposure and inappropriate use of toxic substances and pesticides available at occupational and domestic places [110]–[112].
Climate change	The risks of climate change are the heaviest among poor populations in the developing countries. The extreme weather conditions, changing patterns of disease affect the agricultural production, which cause over 150000 deaths per year [108].
Malnutrition	Malnutrition is a major health problem in the developing countries, particularly in sub-Saharan Africa and southern Asia [113]. The degree of malnutrition causes an estimated of 300000 deaths annually about half of deaths in young children [114].

TABLE IV: Some major environmental conditions in the developing countries that are claiming lives in remote areas [115].

The World Bank accounts that 50% of the economical development differentials of the developing and developed countries are due to inadequate health and low life expectancy. The healthier the inhabitant of a country, the more efficacious is its manpower. Majority of the population in the developing countries is poor and illiterate [116]. Poverty and ignorance creates ill-health as it causes people to live in unhealthy environments [117]. According to The United Nations Children’s Emergency Fund (UNICEF), poverty accounts for 22000 deaths of children each day in the developing World [118]. In the growing countries, a child is 33 times more likely to die under the age of five as compared to the industrialized countries [69].

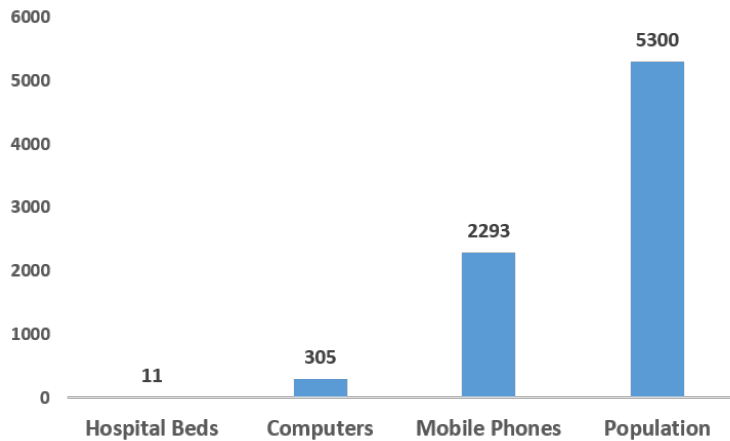


Fig. 6: Mobile technology and health-related infrastructure statistics of the developing countries (in millions). Source: [69].

The health services in the developing countries are very limited and mostly dysfunctional that make them mostly unresponsive to the needs of patients. The available health services are neither accessible nor affordable for the masses of these countries. Fig. 6 compares the mobile phones reach with other technology and health-related infrastructure in the developing countries. Thus, the delivery of the necessary care through mobile phones with limited resources is a rational approach. Because, the mHealth can cope with MOST limitations of health services in the developing World in a various ways by providing better quality of healthy life. Most common services provided by mHealth are described below.

1) *Emergency Response Medical Care During Disasters/Emergencies*: The developing countries do not have a viable infrastructure for early warnings in the situation of emergency and natural disasters. The limitations of roads, transportation, hospitals, and medical staff also increase the strain of people during natural disasters and emergencies. Because people in these

substations are unable to move to safer places. In this context the mHealth is a viable and cheap solution to serve the people by providing the right assistance to the right people at the right time.

2) *Cheap Low-Tech Indigenous Devices and Smart Ventilators*: The inhabitants of remote areas are mostly poor and are unable to afford the healthcare services. Only 5% of people in the developing World can afford and have access to health services, where as 43% of population own mobile phones [52]. Indeed, the mobile phones are cheaper and ultimate platform that have the potential to meet the unserved health needs of population in the developing countries.

3) *Telemedicine*: Mobile telemedicine is the use of ICT to provide healthcare facilities remotely. It eliminates the distance barrier and enables communication link between healthcare providers and patients through the built-in functionalities of mobile phones. The shortage of resources in health sector is a major problem in the emerging World and underserved areas of the developed World, patients in these areas do not have access to specialized care. Telemedicine can circumvent these challenges in various ways, such as consultation with experts over the Internet, medical kiosks, economical point-of-care diagnostics and reaching out to rural populations.

4) *Improving Current Healthcare Capabilities and Chronic Disease Management*: The people with chronic diseases can have a better life with proper disease management, which requires a long term nature of caring. Mobile phones or mHealth have potential to continuously monitor the vulnerable people with chronic diseases due to their popularity, portability, availability, and technological aspects. Embedded sensors and context awareness attributes of mobile phones have enabled the real-time information delivery to healthcare professionals, which have increased the adherence to chronic diseases around the globe.

5) *Utilizing Mobile/ SMS-based Technologies*: The SMS is the most basic property of every mobile phone, which is the most suitable technology for the developing countries to provide healthcare services. SMS-based technologies can help in various ways, such as increasing awareness and education of the diseases, providing aid in the situation of disaster, reminding them about the drug intake.

6) *Digital Epidemiology*: The idea of digital epidemiology is to access the public health through digital traces in real-time. In the developing nation the disease outbreaks are common, it is mostly due to the unawareness about the infectious diseases. The mHealth is playing a critical role in digital epidemiology for the monitoring and surveillance of infectious diseases and also helps to understand the attitudes of infectious diseases. This can help the health professionals to track and respond the victims more quickly and effectively with necessary medications to stop the epidemic.

7) *Home Healthcare Delivery*: Home healthcare delivery is committed to delivering individualized and comprehensive healthcare to the patients at their residence in the situation of illness or disability. The mHealth has enabled the assessment of healthcare services remotely in a cost effective and more convenient way. The patients can contact a specialist through the Internet at home and they can also share their personal data with physicians to seek health prognosis.

8) *Nudging People towards Better Health*: Nudge theory is a modern concept in behavioral science, political theory and economics to learn about the people's thinking process, decision making and behavior [119]. This theory claims that the positive reinforcement and indirect suggestion can influence the motives, incentives, thinking and decision making without imposition. Nudging through mobile phones is a softer approach that can encourage people to alter their decision, thinking towards better health and directs people to attain socially and individually optimum behavior.

IV. CURRENT ISSUES OF MHEALTH IN THE DEVELOPING COUNTRIES

The mHealth projects have potential to address the healthcare problems in many parts of the World including the developing World. The ubiquity of mobile phones in the developing countries has reduced the capital investment for healthcare facilities because inhabitant can use their own mobile phones. The successful implementation of each mHealth project has to deal with some common pitfalls such as inadequate health literacy, language barrier, lacking in skilled and professional medical staff and lack of infrastructure.

A. Inadequate Health Literacy

The degree to which individuals can understand the basic health information and health services for appropriate interventions is known as the health literacy [44], [120]. The inhabitants of the developing countries lack the basic literacy skills such as reading, writing, understanding the images, numeric concepts and interaction with mHealth devices which limits the quality of mHealth services and cause poor health outcomes [121], [122]. The individuals with inadequate health literacy have one-in-three chance of misunderstanding the prescribed medication [123]. According to the United Nations Educational, Scientific and Cultural Organization's (UNESCO) Institute of Statistics (UIS) approximately 776 million adults (16% of the world's adult population) lack basic health literacy skills and about two-third of which are women [124]. There is a clear correlation between inadequate health literacy and mortality rates as shown in [125], approximately 50% to 80% increased mortality risk for inhabitants with low health literacy. Moreover, the literacy levels of mothers have a direct impact on the child's growth with proper nutrition and better implementation of health practices that reduces the illness in children [126].

B. Language Barrier

The people in the developing countries with limited literacy cannot completely utilize the effectiveness of mHealth services. They are unable to follow instructions although they are written in the local language.

C. Lack of Skilled Professional Medical Staff

In most of the developing countries there is a serious shortage of healthcare professionals. There are 57 countries with critical limitations of medical staff, overall shortage of 2.4 million doctors and nurses; Africa has 2.3 medical professionals per 1000 population, while Americas have 24.8 per 1000 population [127]. In addition to this these health professionals might not have sufficient skills to operate the mHealth platform, which is a major barrier to the mHealth services in the developing countries.

D. Lack of Infrastructure

In the developing countries, there are also rural populations living in inaccessible areas due to the poor roads and limited public transportation. The spread of mobile technology is also covering the most remote areas of the World enabling communication to these populations. The Internet connectivity with mobile phones is the emerging capability of the mHealth applications. But most of the developing countries still lack in both mobile technology and Internet connectivity. Fig. 7 compares the availability of the Internet in the developing countries with developed one. According to the Mobile Economy 2015 [128], more than a half of the population in the developing countries do not have a mobile subscription, with the penetration rate of 44.6% at the end of 2014. Similarly, in sub-Saharan Africa, 200 million individuals were using the Internet through mobile devices by the mid of 2015, but still more than 60% of the population will lack Internet connectivity by the end of the decade.

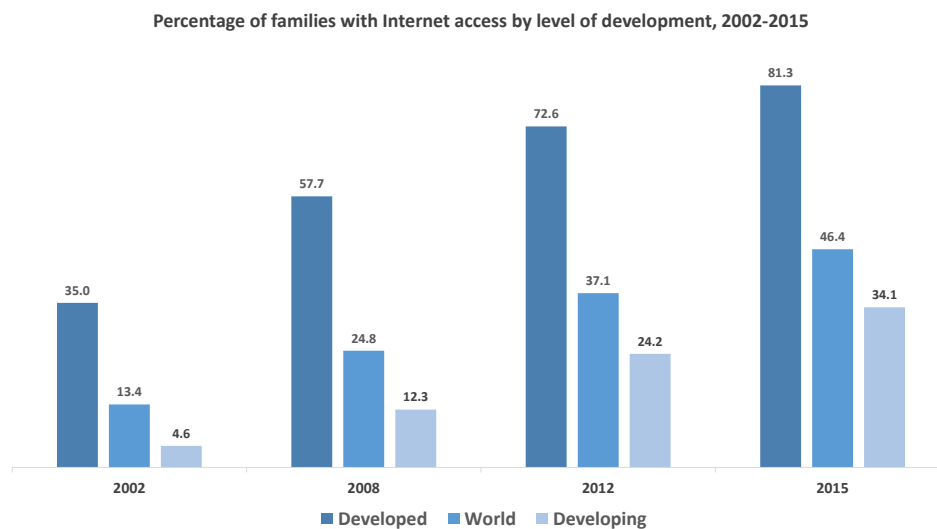


Fig. 7: Region wise comparison of the availability of Internet access. Data sources: ITU World Telecommunication /ICT Indicators database

E. Limitations for Crowdsourcing

Mobile phone based crowdsourcing offers a valuable tool for the improvement of healthcare system. There are various hidden challenges of time, travel, skills and cost creating obstacles for crowdsourcing. Additionally, in remote areas, crowdsourcing projects failed to find the active crowd due to the risk of being attacked, or captured. Moreover, the contributors also have the feeling of not being incentivized because these projects do not offer direct reputé or benefit [129].

V. CASE STUDY: MOBILE HEALTH FOR PAKISTAN

In this section we present the current healthcare system of Pakistan and its different components. We will motivate the use of mHealth that can be integrated in a complementary manner with the existing healthcare system in Pakistan. The mHealth solution in Pakistan will deploy descriptive, prescriptive and predictive analytics to diagnose, monitor and prognosis of the various chronic diseases such as cardiovascular disease, high/ low blood pressure, diabetes and cancer, etc. In Pakistan, most of the population lives in rural areas that face problems travelling to major cities for a better healthcare experience. The vision of a mHealth system in Pakistan must be to obviate the need for such expensive and hard visits and bring the relevant healthcare

information and services near to the actual patients. We will highlight opportunities, tools and techniques, envisioned goals, and most importantly hidden challenges. This case study will also provide deep insight into different existing common barriers to the adoption of mHealth in the developing countries. These findings will be utilized for the proposition of future dimensions required to design an efficient mHealth system in section VI.

A. Current Healthcare System in Pakistan

Pakistan has a three-tiered public healthcare delivery system: (i) the primary healthcare system includes *Basic Health Units (BHU)* and *Rural Health Units (RHUs)*; (ii) the secondary healthcare system includes referral facilities for acute diseases and comprises Tehsil (In Pakistan, a Tehsil is an administrative subdivision of a District) Headquarter Hospitals (THQs) and District Headquarter Hospitals (DHQs); and finally (iii) the tertiary healthcare system largely consists of teaching hospitals. There are also health workers at the community level that usually help run different health campaigns (e.g., polio vaccination etc.) [130]. This hierarchy can be seen in Fig. 8.

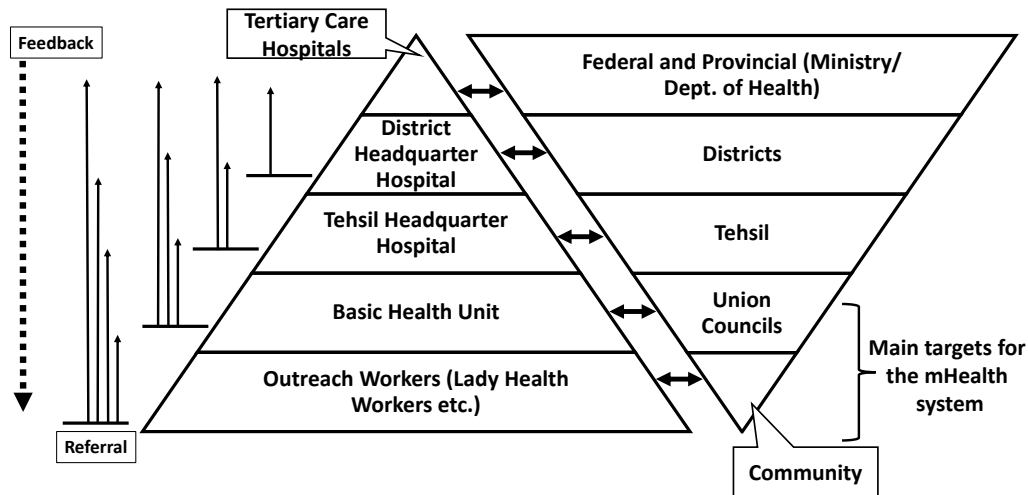


Fig. 8: Current structural organization of the Pakistan healthcare system and its interaction with the envisioned mHealth. Source: [130].

A mHealth system for Pakistan needs to be designed by taking into account the above structural organization. In particular, BHUs and RHUs and lower community levels need to be targeted so that people in the under-served areas get easy and affordable healthcare information and services. This would help people in the rural and remote areas avoid expensive journeys to the major cities to receive health services.

B. Current mHealth Initiatives in Pakistan

The Pakistan Information Technology Board has taken great initiatives to pilot/implement a number of mHealth systems mostly in the Punjab province. There are also research projects that have trialled mHealth systems. Recently, the most significant contribution of mHealth was in combating the dengue pandemic that started spreading in Punjab in 2011. This pandemic claimed many lives and resulted in tens of thousands of infectious cases. The PITB initiated a mHealth project ⁷ in 2012 that facilitated the recording of the Dengue larvae hotspots. With spatio-temporal analysis of this data, areas that were under potential threat were identified. This resulted in ever decreasing infectious cases through the following years. Some other mHealth systems initiated by PITB are as follows:

- 1) **Medicine Inventory Management System:** Automation of medicine purchase and inventory management. Automated facility of alerting the authorities to keep them informed of the stock status across the health facilities in Punjab, Pakistan [131].
- 2) **Disease Surveillance System:** Disease detection, registration, confirmation and supervision. Spatio-temporal mapping of diseases at various administrative resolutions (i.e., districts and thesils) [132].
- 3) **Drug Inspection, Monitoring and Evaluation System:** An application developed to keep a check on the drug stores and pharmacies. The provision of standard drugs is monitored and any contravention is recorded and reported by the

⁷<https://www.pitb.gov.pk/dats>

monitoring officers. All the information is geo-tagged that can be evaluated by the higher authorities to take the relevant preventive measures [133].

- 4) **HealthWatch:** An android-based smartphone application that is being used by health supervisors in different districts of Punjab. They health supervisors report any anomalies e.g., medicine stock shortages etc through this app. This data is then mapped geographically and presented to the higher stakeholders that can then intervene to take necessary measures to tackle the situation at hand [134].
- 5) **VET Inspect:** A monitoring application for veterinary facilities in the province. It works in much the same way as the above mentioned HealthWatch application [135].
- 6) **HospitalWatch:** A monitoring application designed that is aimed to achieve efficiency of the staff working in hospitals in different districts of the province. This application is used by the medical officers to monitor the activities of a hospital staff [136].
- 7) **Monitoring and Evaluation Assistants for Secondary Health:** An application to monitor the efficient monitoring of the hospital and the medical staff at the DHQs, THQs and DHQ teaching hospitals [137]. Also, Monitoring the Monitors (MM) program is step by the Government of the Punjab, it has replaced the paper-based monitoring with the smartphone app which collected data in a centralized server. It collects data on workers absence, facility usage and drugs availability [138].

Amongst the research projects a worth mentioning one is the TB screening using mobile phones in the city of Karachi in Pakistan by Khan et al. [139]. This study collected data using mobile phone-based crowdsourcing in the period of 2010-2011. Mobile phones were installed with a data collection application and were distributed among the community laypeople. The laypeople were encouraged to screen the TB cases in private clinics by giving them financial incentives. A notable increase in detected cases were observed (2.21 times, 95% confidence interval [CI] 1.93, 2.53) that fell in the intervention area as compared to the control area. This study highlights that the mobile phone-based technology could help in detecting cases in particular that can be a useful approach in remote areas.

Another project was by envisioned the Microsoft Research in the late 2000s to be used in rural Pakistan. In the rural areas the local community members known as *community health workers* are given basic training mostly for the maternal care and vaccination purposes. In order to strengthen the training of these health workers a toll-free voice response mechanisms was planned [140]. Using this system the health workers with limited training can get the instant access to the useful information that could be used by them to help the local patients in their communities.

The other worth mentioning project was the mobile-phone based system called *HeartFile Health Financing* [141] to ensure a fair and on-time funds delivery to the poorer population of a region. The mobile-phone based electronic interface was designed along with the provision of transferring health funds and a mechanism to validate poverty without delays. Keeping in view of mHealth stressfulness in Punjab, a new initiative Independent Monitoring Unit (IMU) is launched by KPK Government in Khyber Pakhtunkhwa. It aims to monitor all healthcare facilities through smartphones and Internet [142].

Most of the research projects above were implemented or tested in a small scale. However, with the establishment of PITB by the Government of Punjab, Pakistan is working more systematically to design and, in turn, implement technology-powered healthcare projects. It is expected that the projects started by PITB will soon be expanded to cover the whole of Pakistan.

C. mHealth Design Goals in Pakistan

The following two design goals are important to consider while designing an effective mHealth solutions for Pakistan. Here we should note that the guiding principles we discuss next are not entirely exclusive for Pakistan. These can be adopted to implement an mHealth solution in other parts of the world as well.

1) *Requirement Analysis for mHealth in Pakistan:* In order for an mHealth solution to penetrate in the Pakistan and work alongside the existing healthcare infrastructure and practices it is imperative that a requirement analysis is performed first. Such a requirement analysis, we believe, is going to be a non-trivial task since in this phase the local context, socioeconomic conditions, cultural norms and the geographical locations have to be corroborated in the design. Only this way a solution that is people-centric can be designed that stand a chance to be adopted by the common citizen of Pakistan and that can also work in unison with the existing health infrastructure.

2) *Technical Solution:* This goal is important in empowering the patients. In particular, this will further subsume two subgoals (i) mobile access to the relevant medical information and healthcare services and (ii) realization of the concept of personal health data or *myHealthData* in which the data will be curated and analyzed in a way to present an effective visual/audio report to the relevant patient.

D. mHealth Related Challenges in Pakistan

1) *Limited Literacy:* Presentation of the relevant healthcare information to the patients is of paramount importance in Pakistan. This is due to the fact that most of the population has limited literacy. Techniques from natural language processing (NLP) can be deployed to design an effective system that can well understand a patient's needs and demands and in turn produce a report (either auditory or visual) in a way that can be easily understood by the patient.

2) *Regional and Cultural issues*: Most of the women in Pakistan are relying on their male guardians for seeking healthcare facilities and have insufficient economic resources and bounded social support [143]. They have very limited otherwise restricted access to the outside World and their social lives are mainly limited to household chores [144]. This compounded with the underdeveloped nature of healthcare services, limited communication facilities and substandard transport systems cause rural women to lack in proper antenatal and postnatal healthcare which causes the high rates of maternal mortality and morbidity [145]. mHealth can be a great remedy to many of these problems, however, the challenge would be to get it to women subject to all these social and cultural constraints.

3) *Human Centered Design*: Any technical solution in Pakistan will need to be built in compliance with the cultural and social norms of the people of Pakistan. In particular, care must be taken to understand how an average users in Pakistan interacts with the relevant technology, in our case with mobile phones. This would reduce the possibility of false positives (more discussion on it in the Section: Challenges) and will accelerate the widespread adoption and penetration of an mHealth solution.

VI. FUTURE ASPECTS OF REALIZING MHEALTH IN THE DEVELOPING COUNTRIES

The mHealth projects are growing in the developing countries, but these projects still need to attain large-scale deployments. Individually, each mHealth project look very impressive, but they do not incorporate a significant rise in the adoption of mHealth. Reviewed literature on mHealth initiatives is still prevailed by the pilot projects that are implemented for a limited period of time to deal with specific disease or problem. Most of the projects are deserted after the pilot stage, due to the lack of upscale strategies and unendurable business. The governments of developing countries should place mHealth in national healthcare policies to envision the mHealth to achieve scale. Researchers should have imperative studies on larger-scale stationing of mHealth projects. The findings of such studies can be used by the policymakers and stakeholders in the whole healthcare ecosystem.

A. Behavioral Change

In the developing countries, mHealth has made some progress in behavioral change of people towards health but still healthcare organizations must alter the old practices to get involve inhabitants in the adoption of healthier behaviors for the optimal outcomes towards the causes of illness and death [146]. The behavioral sciences provide the emerging insights about the decisions making process of individuals that is affected by social norms, healthcare practices and cognitive biases. There are various behavioral theories that present different perspectives for the change in health behavior. According to the biomedical theories, patients are passive recipients of physicians' instructions and the non-adherence behavior is correlated with the patients' characteristics such as gender and age [147], [148]. The behavioral learning theory suggests the antecedents (internal thoughts or external environmental conditions) and consequences (punishments or rewards) have an influence on the behavior change [149]. Communication perspective suggests that clear and comprehensible patient-physician communication will increase adherence [147]. According to the cognitive theories the attitudes, beliefs and expectations for future positive outcomes are the prime determinants towards the change in health behavior [150], [151]. The protection-motivation theory postulates how the change in behavior is caused by an individual's fear [152]. Social-cognitive theory propose that a change in behavior is reciprocal to determinism, in which behavior, individual and environmental events are the interacting deterministic [153].

The Common issue for the mHealth initiatives is the lack of attention on the erudition of these theories that can help in the designing of optimal strategies for the change in health behavior at the personal, interpersonal, and community level in the developing countries. Instead, these initiatives are formulated based on the logical model and formative qualitative research [146]. The strategies for the effective change in the behavior of the population should focus to create a supportive ecosystem by utilizing the behavioral science theories and innovative techniques for the improvements in self-care, self-efficiency, lifestyle interventions and patient satisfaction.

B. Appropriate Technology

Every technology has its own limitations and the selection of most appropriate channel to address the population is very challenging. Text messaging has proven very effective and cost effective solution for some health problem, but it is not universal as some users also prefer to communicate over voice call, some want video conferencing, while others prefer in-person meeting. It is consented that the cheap and quick solution accepted gladly by population. Researchers should focus on designing such simple solutions that address most of the vital health problems by minimizing the technology gap to have long-term positive results in diverse populations.

C. Understanding of Population

Successful mHealth initiatives leverage the communication channels that are most suitable and compatible with the targeted population and available resources. The mHealth will be able to provide the most compelling and valuable services, if it has,

the clearer image of the audience and their most vital and basic needs. Healthcare providers can select an incentive-based initiative or use multiple channels to target the population for a single objective. Researcher and service providers should drill down deeper to identify the geographical location, level of education, cultural factors, ongoing conversations and social norms of aimed population and take appropriate actions after analyzing the results.

D. Data Fragmentation and Interoperability Issues

The digitization of healthcare system is generating a huge amount of data, that is too complex, large and difficult to manage with traditional software and hardware [9]. Health information in coming from various medical devices, clinical reports, EHR, medical correspondence and financial reports are typically fragmented or isolated within hospitals, and laboratories. The interoperability of this information with different organizations or healthcare providers is prohibited. This fragmented health information is not fully utilized to provide effective and efficient health care. In the developing countries, fragmentation and interoperability problem of health informatics in various overlapping health programs is a major impediment for the accurate diagnosis and ailments. Changes are required to create such an interoperable system that can solve the problem of fragmentation or isolation of health data. In South Africa, Zanzibar, Sierra Leone and Botswana different integrated approaches such as minimum essential data storage and single data warehouse for routine data storage are being used to resolve the inconsistencies between various data set [154]. Researchers, policy makers, political leaders and stakeholders should focus to provide such an interoperable platform that can make the patient-level health information available to medical practitioners at the regional or community level. Such integrated and interoperable system would speed up the diagnostic procedures and provide holistic treatment with a complete access to the patients' long-term history.

E. Ethical Issues

The collection of health information through mobile phones, wearable sensors and software apps from individuals is a prerequisite phenomenon of mHealth clinical support. In the developing countries, the data collections are fraught with the regulatory and ethical issues. These issues are more significant when the mHealth programs are brought by the scientists and agencies from developed countries. Thus, users enrolled in mHealth system do not have trust to share their personal information due to the risk of outflow of data [155]. The consequences of these challenges are less serious in the developed World due to their better legal accountability for digital agendas [156]. In the developing countries the risk and uncertainty is very high due to the lack of legalization, risk assessment, risk minimisation and necessary laws. Therefore the mHealth initiatives are less effective in the developing countries as compared to developed World [155]. The policy makers and political leaders of the developing countries should set national priorities for the provision of mHealth projects. They should establish independent research ethics committees for the justification and ethical review of outwardly sponsored and local projects. These committees also make sure the training in ethics for the researcher or professionals before the provision of mHealth projects.

F. Privacy and Security Issues

Health data are the most vulnerable and sensitive information related to individuals. The use of mobile phones for healthcare gives rise to privacy and confidentiality issues. Privacy and confidentiality in the provision of mHealth services are challenging, but it is essential to ensure that personal information is processed legitimately and legally. In 2014, the personal data of more than 5 million people were compromised in the healthcare system caused by privacy breaches [157], and each dossier with the worth of \$1,300 ended up in the black market [158]. The Health Insurance Portability and Accountability Act ⁸ aims to ensure reasonable measures to prevent any disclosures of personal and private health information. In the developed nation, security risk is very low due to strong legal traditions and technological agendas. In the developing World, people are vulnerable to misuse of their personal data due to poor privacy policies. These poor policies in such environment may make inhabitants even more vulnerable [159]. Therefore, mHealth services must be furnished through an environment which make sure transparency of identifiable health data in the context of social, gender and personal considerations.

Several concerns exist that need to be addressed regarding the administrative safeguard tools or privacy preserving protocols that are being used to protect the unwarranted access from the wireless networks and mobile devices. The National Institute of Standards and Technology specified Advanced Encryption Standard (AES) for generation of symmetric keys that replace old Data Encryption Standards (DES). Similarly, Sutherland proposed that the Elliptical Curve Cryptography (ECC) is the most powerful algorithm for public/private key encryption [160]. Therefore, the hybrid cryptographic scheme along with the public/private key encryption algorithm is the most suitable choice for wireless mobile devices in mHealth architecture. These concerns are particularly important in research to design such techniques that can extract information from personal raw data by protecting privacy.

⁸<http://www.hhs.gov/hipaa/>

G. Issues Related to Human Computer Interactions

The human-computer interaction or usability factors are a major challenge for the provision and adoption of new mHealth product or services in the developing countries. The health services through mobile devices are novel opportunities, but lack of holistic understanding of users also introduces errors and misinterpretations [161]. In the developing countries, mobile-based health services are intended to be used by all types of individuals, including literate and illiterate users, the elderly, and the people with permanent or temporary disability. To ameliorate the productivity of a service or product, the health service providers should focus to identify the specific problems with its working and interaction with users [162].

Smartphones are increasingly being used for monitoring and diagnostic purposes. Today in the market a large number of mobile phones exist with comparatively complex user interfaces, which requires complicated manual dexterity and visual acuity, which take longer time for their functions. There are some exceptions, such as the Jitterbug cell phones that provide the simplified user interface by reducing dexterity through brighter screen, and simpler input keypad [163]. But this is just the exception rather than the rule to provide user friendly usability of mobile phones for individuals. The human-computer interaction community should significantly need to provide interactive user-interface to embrace the cross-cultural development by considering the cultural cognitive models of underdeveloped areas and their education level.

H. Sustainability Issues

It is important for an mHealth project to provide the evidence of sustainability in terms of its scope and scalability, to attract the attention of individuals, professionals and policy makers. The sustainability of mHealth depends upon the implementation of interventions, their health outcomes and importantly on the trans-disciplinary approaches that engage the system design, professionals, and researchers together [164]. The mHealth researchers should focus on establishing the relationship between mHealth projects and their impact on health, by designing suitable tools for those vulnerable populations that cannot have access to technology and remain unaddressed due to social and economic drawbacks of poverty and illiteracy.

I. Need for a Unified Platform

The lack of operating system neutrality is another barrier to the development and adoption of mHealth applications. There are multiple operating systems (OS) for mobile phones such as Microsoft Windows, J2ME, Symbian, Palm OS, Blackberry, Linux, and the Android. The language used for the development of mHealth applications differs in each OS, and applications developed for one OS usually do not work in others. Currently, only voice call and SMS features of mobile phones are OS neutral, and all other applications are closed in nature. Thus, mHealth applications for specific diseases, developed for a particular OS, will operate only on a certain type of mobile phone. For mHealth to reach its full potential across all platforms that can provide healthcare services, it is necessary to envision a platform that can operate across the board i.e., on all the mobile phones.

J. Battery Life

The battery life is one of the major challenges for the mobile devices-based mHealth applications. Because these applications have to run complex programs to monitor health which consume too much battery. In the developing countries, longer battery life is very crucial for portable devices used by the medical practitioners, health workers and users, because most of these countries do not have continuous and guaranteed power supply. In this context, researchers and developers should need to build energy efficient devices and lightweight applications to provide the maximum flexibility and mobility for users and professionals.

K. The Wireless Network Environment

The pervasive nature of wireless technologies provides communications to mHealth applications without the portability and mobility issues of wired interfaces. Over the past few decades, the proliferation of radio frequency (RF) and microwave technologies has enabled multiple wireless solutions, including wireless personal area networks (WPANs), wireless metropolitan area networks (WMANs), wireless LANs (WLANs), cellular networks (2G, 3G, and 4G), wireless wide area networks (WWANs). Moreover, short range technologies such as Bluetooth, radio frequency identification (RFID), ZigBee, ultra-wideband, and Wi-Fi (IEEE 802.11a/b/g). The technological advancements in wireless communication help in the implementation of mHealth projects in rural and underdeveloped remote areas that lack the telecommunication access and cable wiring. Ubiquitous computing enables instantaneous health status reporting in conjunction with wireless sensor networks. In addition to the above mentioned advancements in wireless technology, there are also some barriers to the development of mHealth system such as electromagnetic interference, coexistence with the wireless technology, fluctuations in mobile network, resource management, location, and mobility [165]. The latency of wireless network can also affect the online medical assistance and treatment [166]. We need to focus on designing adaptive network protocol allowing the wireless network to tune the network parameters according to the changes. Such adaptability can provide convenient medical monitoring, consultation, treatment with optimized results to everyone, everywhere at the right time.

VII. CONCLUSION

This paper presents the feasibility of mHealth for improving public health delivery in the developing countries which have a serious shortage of health-care infrastructure. We describe the challenges that are constraining the widespread adoption of mHealth in the developing countries and project a comprehensive list of future aspects that need to be considered for an effective and sustainable adoption of mHealth. A case study on Pakistan validates our findings and reveals that some country-specific adjustments are necessary for an extensive adoption of mHealth in the developing countries.

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