IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received October 10, 2019, accepted October 26, 2019, date of publication November 5, 2019, date of current version November 15, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2951739

The Ubiquitous Healthcare Facility Framework: A Proposed System for Managing Rural Antenatal Care

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ABSTRACT Ubiquitous computing is playing a vital role in the provision of healthcare services through advanced technologies. The ubiquitous environment where resources can be accessed by anyone at anytime regardless of location have brought revolution in delivery and accessibility of healthcare services even in remote areas. Therefore, in recent years more research contributions can be seen to propose digitalized healthcare services in the form of mobile and eServices that are accessible through ubiquitous devices. To exploit the underlining potential of ubiquitous computing, in this research we have proposed a ubiquitous healthcare framework for provision of healthcare services in remote rural areas in province of Punjab, Pakistan. The research has employed a case study research approach to understand the phenomena in depth and in its real context. The unit of analysis is provision of antenatal and child healthcare services at basic health units in the selected region. The case study is constructed through field study by engaging healthcare professionals working at basic health units and data is collected through focus group interviews with healthcare professionals. A proof-of-the-concept ubiquitous framework is proposed as part of the case study by constructing various services to facilitate healthcare professionals in rural areas. To evaluate the proposed ubiquitous framework, an evaluation framework based on usability, information system and ISO models is constructed. Hypothesis are constructed to measure user satisfaction through twelve constructs of the evaluation framework that include availability, adaptability, memorability, effectiveness, responsiveness, cognitive load, error recovery, ease to understand, ease of learning, efficiency of use, navigation, and execution. The data is collected through field surveys by conducting walkthroughs with healthcare professionals in rural areas. The analysis of the data is carried out by employing structured equation modeling in SPSS. The results provide highly significant relationship between constructs and user satisfaction. The study findings show that the healthcare problem in rural areas could be addressed through ubiquitous solutions however, while designing, constructing and evaluating these solutions, the involvement of relevant community is crucial.

INDEX TERMS Ubiquitous computing, ubiquitous healthcare, pervasive healthcare, eServices, antenatal health, rural healthcare.

I. INTRODUCTION

Ubiquitous computing, also known as úbicomp' is a software engineering concept taken from the computer science literature that indicates a computing process where computing occurs in any format, any time, at any location and by using any device with capability of using wired or wireless network [1]–[4]. Ubiquitous technologies include handheld devices such as laptops, PDA's, mobile phones; wearable devices such as sensor based smart watches and other biosensors [5]–[7]; wireless communication mediums such as RFID, Bluetooth, WiFi, etc.; and information processing technologies such as database management, workflow management, eServices (electronic services), knowledge processing and decision support, data exchange, security and privacy protection [8].The main objective of ubiquitous computing is to propose smart solutions through technology to make communication and exchange of data efficient and accessible even

The associate editor coordinating the review of this manuscript and approving it for publication was Dian Tjondronegoro.

at distant locations [9]. The integration of ubiquitous computing within healthcare area has brought major innovative transformations [10] for provision of healthcare services by removing time and location constraints. It has also increased the quality and coverage of healthcare services [11]. The ubiquitous healthcare solutions are largely integrated with eServices concept to deliver healthcare services remotely. eServices, also known as electronic services are the services delivered to users through the Internet [12]. Thus, eServices along with ubiquitous technologies (also known as the Ubiquitous eService environment) allow healthcare professionals to deliver and patients' to access various healthcare services effectively and efficiently [13], [14].

Until now, various ubiquitous healthcare solutions are being proposed by research community that varies from collecting patient record to diagnose chronical diseases [15], [16]. These solutions largely involve patient monitoring & well-being (remote monitoring of chronically ill patients, physiological & vital sign, telemedicine in case of emergency and accidents, in-home monitoring of patients, etc.) [17]–[19], education & awareness applications (mobile based health games, videos, and trainings, etc.) [20]–[22], disease diagnosis & treatment (e.g cancer, diabetics, Alzheimer etc.) [23]–[25] and others.

These healthcare solutions also vary in different countries depending on the technological infrastructure and advancements made in healthcare sector. For instance, in countries such as Australia, Denmark, Finland, Germany, Norway, United Kingdom, and United States, Hospital Information Systems (HIS) and Decision Support Systems (DSS) have been introduced which allow exchange of clinical and patient's information among different hospital departments [26]–[31]. The services, especially, ubiquitous mobile-based services (mServices), are mostly used to search for health related information. In-home patient monitoring ubiquitous healthcare solutions are also implemented that involve physiological and vital signs monitoring, heart rate monitoring, gait and fall detection, and respiratory monitoring etc. [26], [32]–[35]. These 'ubiquitous patient-centric healthcare solutions' use sensors to detect the condition of the patient. For example, Byrne *et al.* proposed a project called UbiHeld (Ubiquitous Healthcare for Elderly), which uses ubiquitous mobile technology and Kinect sensor for gathering patients physiological data [32]; Griffiths *et al.* developed a mobile application called 'bant', along with a glucometer and a Bluetooth adapter to measure patients' blood glucose level for type 1 diabetes patients [33].

Germany, Norway, United Kingdom, and United States are developing the concept of digital hospitals through telemedicine technologies [33], [36], [37]. This would enable healthcare services to be delivered to elderly patients through medically equipped ambulances. This will also make these services accessible in remote areas. These countries are also making effort to train healthcare workers to use ubiquitous healthcare solutions, to improve delivery of healthcare services [10], [38].

However, this situation differs in developing countries such as Bangladesh, Brazil, Egypt, Ghana, Kenya, India, Laos, Pakistan and Peru, where ICT based healthcare reforms are still emerging [10], [39]–[46]. These countries are working on improving healthcare services in the areas of real-time fall and activity detection for the elderly [41]; heart rate (ECG) monitoring for chronically ill patients [43], [44]; enhancing patient well-being through patient social network [10] and telemedicine to remotely monitor breast cancer patients in rural areas where there is a lack of healthcare services [40], [47]. Health education & awareness program is also initiated in Tanzania where incentive based quizzes were designed in the form of mobile application named 'Text to Change' and were sent through SMS to educate women dealing with pregnancies [48]. In case of Pakistan, the developed solutions largely fall under the categories of telemedicine, and patient monitoring & well-being. These solutions are in their early stage and narrow in their coverage. Immediate digital healthcare reforms are required to address the needs of healthcare services in the country especially in rural areas where a large number of population is residing. According to world health organization (WHO), Pakistan is facing huge healthcare problems which are affecting the life expectancy of the people (in 2018 for females is 66.5 years and males is 65.7 years) [49]. Among these problems, women and child healthcare need immediate attention. The antenatal patients living in rural area suffer from problems which include and not limited to (i) limited access to healthcare services, (ii) increased mortality rates of both mother and child (iii) lack of knowledge and awareness of their hygiene [50], [51].

By considering healthcare problems in Pakistan especially, women and childcare, in this research, we adopt a case study based research approach to address the issue of antenatal healthcare through ubiquitous solution. The case study is constructed by considering basic health units (BHUs) of rural Punjab, Pakistan that directly deal with antenatal patients through healthcare professionals. A proof-of-the concept Ubiquitous Healthcare Facility framework (UHFF) is proposed and evaluated through healthcare professionals as part of the case study. To our knowledge, this is the first study where rural antenatal health care problem is addressed indepth by engaging healthcare professionals from the same areas for solution design and to evaluate the solution for its applicability in these areas. Instead of using 'toy' examples and conduct laboratory experiments, this study has involved multi-method approach by conducting field surveys, interviews and walkthroughs to understand the environment, work processes and practices of rural healthcare professionals. This makes the proposed solution context aware and user centered which are some of the challenges faced by ubiquitous healthcare research community.

This paper is organized as follows: section II provides details on the case study constructed on rural Punjab, Pakistan. In section III, proposed ubiquitous healthcare facility framework (UHFF) is discussed. In section IV,

evaluation process of UHF Framework is explained. Finally, in section V, conclusion is provided.

II. CASE STUDY: HEALTHCARE IN RURAL PUNJAB

In this section, the case study constructed on healthcare in rural Punjab is discussed in detail.

A. HEALTHCARE STRUCTURE IN RURAL PUNJAB

The provision of healthcare services in rural Punjab are delivered through a 3-tier structure, as shown in Figure 1. Level 1 (tier 1) is defined to provide primary healthcare services in rural areas. The primary healthcare facilities are provided through basic health units (BHUs) and rural health centres (RHC). Level 2 is defined to provide secondary healthcare services at tehsil and district level through hospitals that deal with both out-patient and in-patient. At level 3, government tertiary hospitals are established to provide low cost specialized healthcare facilities. The tertiary hospitals are situated in major cities and are typically affiliated with research and teaching organizations.

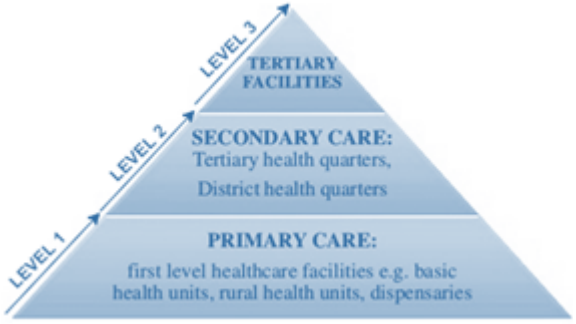

FIGURE 1. Three tier healthcare structure of Punjab.

The main focus of this case study is on BHUs as they provide first level healthcare facilities to rural population. Also they are the first point of contact to receive healthcare services in these areas. The rural areas are divided into districts and in each district there are 4-6 BHUs to cover a certain area of population. The healthcare services at BHUs are provided at primary level by healthcare professionals including medical officer (MO), lady health visitor (LHV) lady health supervisor (LHS), and lady health workers (LHW). Services provided at BHUs could be categorized as promotive, preventive, curative and referral. The healthcare services provided at BHUs include [52]:

- The basic treatment of common diseases (acute, semi-acute, and chronic) and injuries
- Immunization against infectious diseases
- Prevention and control of common diseases
- Antenatal and child healthcare
- Provision of essential medicines
- Water sanitation and nutritious food supply
- Health education and awareness

The healthcare services related to mother and child are an integral part of BHUs. To get an insight into how these services are provided by healthcare professionals at BHUs and to construct our 'case' particularly for antenatal healthcare services and child care, a field study is conducted. The details of field study are provided below.

B. FIELD STUDY

To get insight into the rural healthcare services particularly related to antenatal patient and childcare, a field study was conducted by engaging healthcare professional at BHUs in rural Punjab. Focus group interviews were conducted as part of the field study. A protocol was designed to conduct field study and details are provided below.

Purpose: The purpose of conducting focus group interviews was threefold: (i) to understand the process being adopted by healthcare professionals to provide healthcare services to antenatal patients (ii) to identify problems being faced by healthcare professionals during this process and (iii) to identify level of digital literacy among healthcare professionals and understand working environment to develop ubiquitous solution.

Population: The healthcare professionals involved in these focus group interviews were largely LHWs and LHW supervisors. For expert review, doctors at BHUs were also contacted to get further insight into the phenomena under discussion.

Location: BHUs throughout Punjab, were selected through convenience sampling. A total number of 72 BHUs were visited in 36 districts.The list of visited BHUs is available in Appendix A.

Focus Group Size: A group size of 10 participants was decided for each focus group discussion. Each group consisted of one LHS, one LHV, seven LHW, and one doctor.

Interviewers: The authors performed the role of the interviewer and role of moderator. The role of the interviewer was to engage participants in discussion and the role of the moderator was keep the conversation according to the schedule and within the context. The moderator also played the role of the recorder by taking notes during the session.

Session Length: The length of each session was one hour and 30 minutes. The time was kept under 02 hours to keep the discussion focused. Almost all sessions started at 09:00 am and completed around 10:30 am.

Language: The languages used during focus group sessions were Urdu, Punjabi and English. English was used for medical terminologies, as all the participants were more comfortable with it.

Data Gathering Technique: Data was gathered through informal discussions. To keep the discussion focused a semi-structured questionnaire was used. For data recording, audio recorders were used and notes were taken by the researchers.

Descriptive Statistics: A total of 648 healthcare professionals were involved in focus group sessions. Almost all of the participants were having experience of more than 15 years. The income of these participants was mostly less than PKR 40k and they were the key resource persons in

TABLE 1. Descriptive statistics of focus group participants.

Variable	Categories	Frequency (Count)	Frequency (%)
Age	<20	NA	NA
	21-25	NA	NA
	26-30	07	1.1%
	31-35	145	22.4%
	>35	496	76.5%
Experience (years)	<1	NA	NA
	1-5	NA	NA
	6-10	NA	NA
	11-15	01	0.2%
	>15	647	99.8%
Family income (pkr)	<20000	NA	NA
	20000-30000	483	74.5%
	30001-40000	149	23%
	40001-50000	16	2.5%
	>50000	NA	NA

TABLE 2. Digital literacy of focus group participants cont.

Variable		Categories	Frequency (Count)	Frequency (%)
Use of computer		No	639	98.6%
		Yes	09	1.4%
Computer usage		<1	NA	NA
experience		1-2	08	88.9%
		3-4	01	11.1%
		5-6	NA	NA
		>6	NA	NA
Internet Facility		No	NA	NA
with Computer		Yes	02	22.2%
Activities on computer	Messaging	No	NA	NA
	documenting	Yes	NA	NA
	Skype Calls	No	NA	NA
		Yes	02	22.2%
	Games	No	NA	NA
		Yes	02	22.2%
	Web searching	No	NA	NA
		Yes	02	22.2%
	Others	No	NA	NA
		Yes	NA	NA
Use of Cell Phone		No	NA	NA
		Yes	648	100%
Cell Phone Usage		<1	NA	NA
Experience (years)		1-2	NA	NA
		3-4	NA	NA
		5-6	NA	NA
		> 6	648	100%
Type of Mobile Phone		Mobile Phone	25	4%
		Smart Phone	623	96.1%
Mobile Phone		Keypad	25	3.9%
Input Structure		Touch Screen	623	96.1%
Internet Facility		No	NA	NA
with Mobile Phone		Yes	648	100%
Mobile Phone		Apple IOS	NA	NA
Software		Android	623	96.1%
		Windows	25	3.9%
		Other	NA	NA
Telecommunication		U-Fone	241	37.2%
Network		Mobillink/Warid	27	4.2%
		Telenor	278	42.9%
		Zong	102	15.7%

running their household. This information was important as their families are largely dependent on their income and to deliver healthcare services effectively and to continue their job, efficient techniques for healthcare service provision are required. The descriptive statistics of participants are provided in Table 1.

Digital Literacy: Regarding digital literacy of participants, information was collected related to their use of

TABLE 3. Digital literacy of focus group participants.

Variable		Categories	Frequency (Count)	Frequency (%)
Activities on mobile Phone	Messaging	No	NA	NA
		Yes	648	100%
	Voice Calls	No	NA	NA
		Yes	648	100%
	Games	No	503	77.6%
		Yes	145	22.4%
	Web searching	No	636	98.1%
		Yes	12	1.9%
	Others	No	NA	NA
		Yes	NA	NA
Self-Learning	Messaging	No	158	24.4%
		Yes	490	75.6%
	Voice Calls	No	23	3.5%
		Yes	625	96.5%
	Games	No	02	0.3%
		Yes	143	22.1%
	Web searching	No	04	0.6%
		Yes	08	1.2%
	Others	No	NA	NA
		Yes	NA	NA

computers, internet, and mobile phones. Only 09 participants knew how to use the computer. They used internet for playing games, make skype calls to relatives/family living abroad and to access latest news. In case of mobile phone usage, interestingly, all 648 participants were having their own mobile phones and using them for more than six years. 96% owned an Android smartphone with touchscreen, whereas the remaining 4% were using Windows smartphones. All of the participants had internet access on their mobiles. This was an important finding towards the formation of a ubiquitous solution. The availability of internet shows that ubiquitous healthcare services could be made available in the form of eService or mServices. The participants were using different telecommunication networks that include Telenor, Ufone, Zong, Warid and Mobilink. This shows that all representative and large telecommunication companies have their services available in these areas. Regarding utilization of mobile phones, it was found that all of the participants used their mobiles primarily for making calls and sending text messages. However, some participants 13.7% also used their phones for instant communication through the Internet such as Imo, WhatsApp and Viber; and watching online videos on YouTube. It was noted that no respondent needed help learning these applications, and managed to use them quite conveniently on their own. The digital literacy data collected from the participants is provided in Table 3.

Usage of Smart Healthcare Solutions: Participants were asked if they have any prior experience of using smart solutions for the provision of healthcare services at respective BHUs. The response was negative expect a few participants who had experience of using patient management system for antenatal patients. However, they found the application very complicated and stopped using that. Apart from that, the only automated system currently in place is the biometric attendance system for lady health supervisors and lady health workers mounted outside the medical officer's room in each BHU. The usage of biometric attendance system in BHUs implies that it is possible to introduce smart healthcare solutions in remote areas only if the needs of the healthcare professionals are considered and addressed through user centered design.

Usage of Smart Healthcare Solutions: The information collected from the healthcare professionals regarding their responsibilities, processes and challenges faced while providing healthcare services is provided below.

Medical Officer (MO): The medical officer is responsible for the provision of healthcare including preventive and curative services. The medical officers contacted during field survey of different BHUs were between the age of 25-35 years, had an MBBS (Bachelor of Medicine & Bachelor of Surgery) degree and were an immediate in charge of the BHU team. The MO has a government pay grade, grade 17 and is responsible for the provision of preventive and curative healthcare services. The MO works at the BHU in morning and evening shifts, however, she remains available 24 hours for emergency cases. The MO directly reports to the District Officer Health (DOH), who is the healthcare administrator. The MO is responsible for:

- providing patient checkup at the BHU.
- conducting visits to other BHU departments providing consultation services on gynecology and obstetrics related problem. The MO spends approximately 20% of her time visiting specific BHUs.
- providing technical support to LHWs alongside overseeing the quality of healthcare services provided to patients.
- ensure maintenance of the stock register by the concerned officials at the BHU and attached healthcare facilities.
- keeping all the forms, registers and patient records up to date for all the health related facilities

(clean environment and water supplies, care of patients during pregnancy and childbirth, family planning, nutrition, health education, immunization and early treatment of diseases).
- submitting information required by the higher echelon in the hierarchy on time.

Lady Health Visitor (LHV): The LHV is based at the BHU. She is responsible to promote community health by working with individuals, families, and communities, for the welfare of mother and children through Mother and Child Healthcare (MCH) services. At the BHU, the LHV conducts various pregnancy tests such as blood tests, urine tests, and weight tests. She is also responsible for pre, intra, and post-natal care to the antenatal patients including TT immunization, family planning methods, and health education including good breastfeeding practices, nutrition and growth monitoring, treatment of minor diseases, personal hygiene etc.

Lady Health Supervisor (LHS): The main responsibility of the LHS is to check the work of the LHW at the BHUs and meet with antenatal patients once a month. One LHS is responsible for the supervision of 25-30 LHWs in her allotted catchment population area. The LHS checks the reports provided by the LHWs and verifies at the end of every month before sending to the DOH.

Lady Health Worker (LHW): The working of LHW is quite tough. LHW is allotted around 100-300 homes per population area and is responsible for visiting at least 10-12 homes per week in their given population. Each LHW reports to her designated LHS. The LHW are responsible for the following tasks:
- Registration of all family members in the assigned population area, especially the patients who are expecting. They record the patients' basic information including the patients name, CNIC, age, home address, occupation, number of existing children, illnesses (if any), family diseases (if any), husbands name, husbands CNIC and a guardians contact number in case of emergency.
- Visiting antenatal patients once a week
- Provision of medicines and general health supplies to the patients every month or whenever needed.
- Educating antenatal patients regarding family planning, and other doorstep health education such as issues related to better hygiene, nutrition, sanitation, baby names, breastfeeding positions, etc. emphasizing their benefits towards improved quality of life.
- Facilitating antenatal patients in referrals to DHQ/THQ hospitals in case of emergency situations, after approval from the MO.
- Scheduling vaccinations for newborns.
- Participating in immunization campaigns, such as polio, dengue, measles, etc.
- Preparation of reports regarding antenatal patients' medical examinations and visits, getting them verified from their respective LHS and then submitting them to the MO to be sent to the DOH.

The problems and challenges faced by healthcare professionals at these BHUs were largely related to management, monitoring and availability of resources. The number of houses allocated to LHW are too many to visit in given time. The distances among houses consume time and resources of LHW. Further scrutinizing and reporting feedback sheets are manual and record entry consumes most of the time. Forms lack consistency and same information is repeated in multiple forms. Also, the content written on forms need to be clear, specific and with visible instructions. The schedules of visits and vaccinations are missed due to lack of notification and tracking. Moreover the dates of the supervisory visits conducted by LHSs are not conveyed timely. The medicines and general health supplies are not regular. Medicines are not provided on time and no data is recorded against medicines and supplies given to the patients. Training and education related to mother and child healthcare takes time and lack proper resources. Houses are at distance and time is spent on travelling which reduces time for visits and educating the patient. Salaries are low as compared to workload which is a factor that effects the efficiency of the professionals. Further lack of monitoring of LHW to ensure that all allocated houses are visited makes patients to suffer and delays their treatment. Preparation of all medical treatment data is recorded manually. The information of patients and healthcare professionals associated is transferred to DOH through forms to understand the situation at BHUs. This makes the whole process less efficient, error-prone and adds delays in addressing the needs of healthcare professionals at BHUs.

In the next section, the case of antenatal healthcare constructed through field study and secondary sources is discussed in detail.

C. THE CASE OF ANTENATAL AND CHILD HEALTHCARE

Mother and child healthcare services are provided at the BHUs, under the supervision of the MO. The LHWs are responsible for providing healthcare services to maternal women and children. LHWs are supervised by LHSs. The antenatal patient (expecting mother) comes to the BHU to get a pregnancy test done, which is carried out by the lady health visitor. The LHV enters the patients' basic information manually in a register. When a positive result arrives, the LHWs are sent to the patients' home in their locality, to register the patient in separate patient files. The patients expected delivery date (EDD) is calculated and entered in the patients file. According to EDD, the patient is classified into any of three trimesters. The trimesters have their own examination criteria and patient medical information in all these trimesters is recorded in the application. The trimesters and their examination details are provided as:
- **First Trimester (0-3 months):** pregnancy confirmation test (urine or blood hCG level), blood pressure, weight, pulse, routine ultrasounds, blood tests (hepatitis B, HIV, Rh factor, immunity to rubella).

- **Second Trimester (3-6 months):** routine blood and urine tests (glucose detection), blood pressure, weight, routine ultrasounds.
- **Third Trimester (6-9 months):** routine blood and urine tests, blood pressure, weight, routine ultrasounds.

The patient is regularly visited, or called at the BHU for trimester medical examinations. The results of the medical examinations are entered in the patient files. These medical examinations, carried out by the LHV include baby growth measurements through ultrasounds, blood pressure, pulse, temperature and weight. Medicines and general health supplies are provided to the patients every month. In case of emergency situations, the patients are referred to the nearby Secondary or Tertiary Health Units along with the patients' files. The referrals are carried out when patient need advance medical facilities that are not available in at BHU. The situations that come under referral are: abnormality in fetus, strong abdominal contractions, high BP greater than 140/90, severe headache or blurry vision, leakage of unusual fluid, water bag burst, bleeding or blood clots, lack of baby movements, baby heart beat less than 110 per min and greater than 160 per min, jaundice in newborn, and fits in newborn. At the time of delivery, various examinations are taken at different stages that include:

- **First stage of labour:** date & time, blood pressure, pulse, temperature, fetal heart rate, fetal movements, cervical dilation, membrane, amniotic fluid color.
- **Second stage of labour:** fetal heart rate.
- **Third stage of labour:** injection within 1 minute after birth (yes/no), placenta membrane delivered (yes/no), placenta intact complete (yes/no)

The physical examination of the patient after every 15 minutes of labour is also recorded in the patient files. The measurements monitored and taken are: pulse, blood pressure, temperature, bleeding and its cause, fundal height (cm), urine passed/not passed. After the birth of a newborn, the information of the newborn(s) is/are also entered into the patient files, along with their vaccination schedules. In case of maternal and newborn mortality, the deaths are also entered in the patients file.

In the next section the ubiquitous healthcare framework proposed in this research is discussed in detail.

III. UBIQUITOUS HEALTHCARE FACILITY FRAMEWORK (UHFF)

In this section, we formally define our proposed ubiquitous healthcare framework (UHF) constructed for the provision of healthcare services in rural areas. The UHF largely focuses on women and childcare health by providing features that could facilitate healthcare professionals in carrying out treatments, perform associated tasks, maintain patient and newborn information, establish data communication channels between healthcare professionals working in the field and those present at BHUs or at district health offices.

The UHF framework consists of services constructed in the form of mobile Services and eServices deployed on the AWS cloud platform (Amazon Web Service) and could be assessed through ubiquitous devices such as laptops, smartphones, and tablets etc. These ubiquitous computing devices allow information communication (data synchronization and data updations) through GPRS, Internet, WiFi, 3G, etc., which can be accessed, viewed, and updated by various healthcare professionals over the network. Healthcare professionals are the users of the system working at BHUs in particular LHWs, healthcare administrators, MO and also DOH who is monitoring the BHU working remotely. The implementation technologies used to develop the UHFF include: Android Studio and ASP.NET MVC-4. The database was implemented in SQL Server 2008 R2 and SQL Lite. The web services were developed using REST and JSON technologies. Retrofit REST client was used for data serialization and consume RESTFul web service in android application. The overall framework is shown in Figure 2.

The UHFF services include: (i) Patient Management (ii) Newborn Management (iii) LHW Management (iv) Medicine & Supplies Prescription (v) First Aid eToolkit (vi) Mortality Calculator, and (vii) Reports Generator. The features of these services are summarized in Figure3.

A. PATIENT MANAGEMENT

The purpose of patient management service is to facilitate LHW's in recording patient information. This includes first time patient registration of pregnant women and patient medical examination that includes trimester-wise medical readings along with labour readings before newborn delivery. This component also contains an expected delivery date (EDD) calculator that calculates the delivery date of the patient and automatically arranges the patients into her trimesters. The EDD is calculated using the formula: EDD = First date of last menstrual period + 9 months + 7 days

The LHW also receives weekly delivery reminders of patients. Referral of antenatal patients from BHUs to RHCs (rural health centres), secondary or tertiary hospitals in case of emergencies are also recorded by the LHW.

B. NEWBORN MANAGEMENT

This service facilitates both LHWs and healthcare administrators in managing information related to newborns of patients. When a newborn is delivered, his/her medical readings are taken and recorded against the patient's ID. Newborns vaccination is also scheduled under this service component.

C. MEDICAL & SUPPLIES PRESCRIPTIONS

This service is to keep track of the medicines & supplies given to a patient. This information is also used by MOs at the BHUs and other secondary / tertiary hospitals to see patients medication record.

D. LHW MANAGEMENT

The purpose of LHW management service is to facilitate healthcare administrators in managing and monitoring the working of LHWs. This includes features such as registration

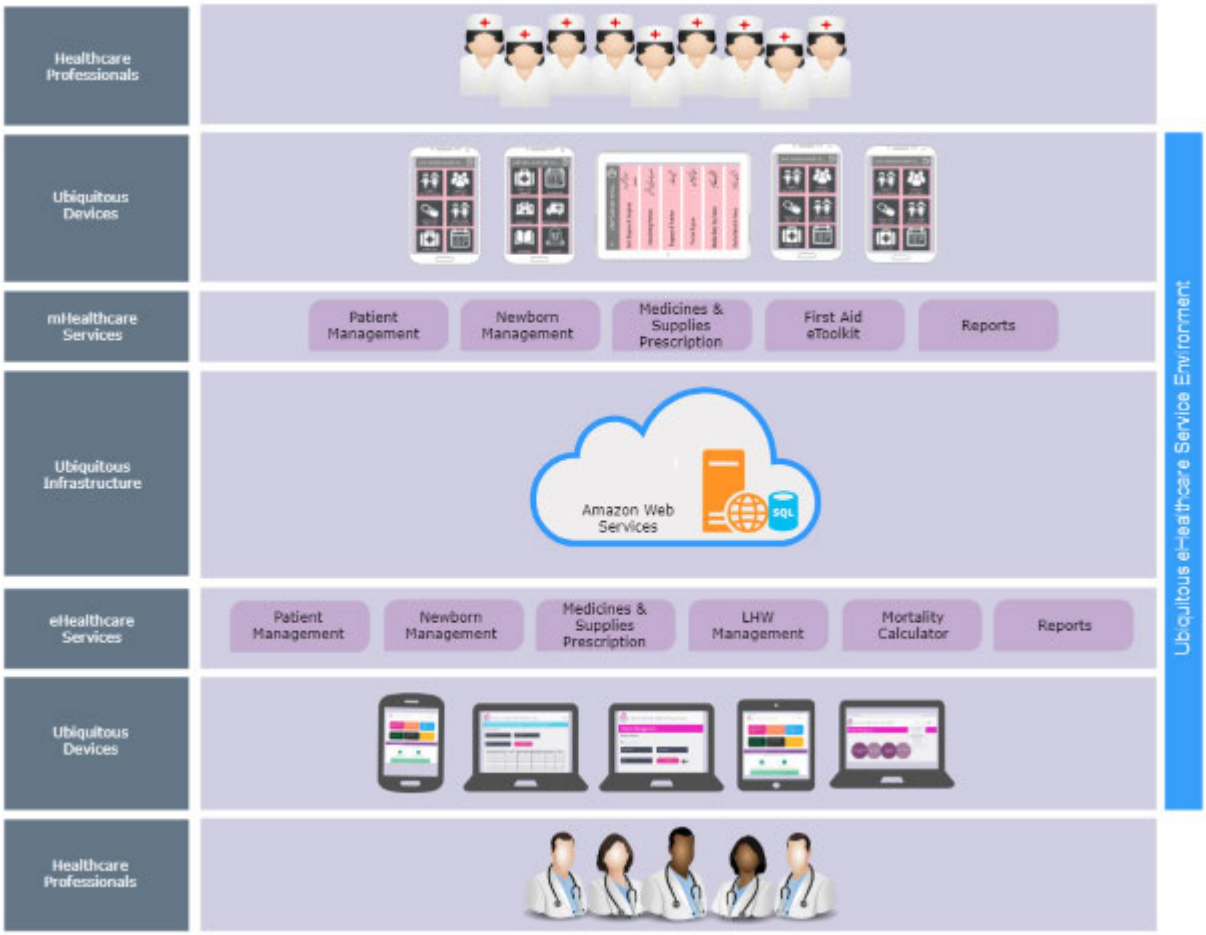

FIGURE 2. Ubiquitous healthcare facility framework.

of LHWs, assigning LHW's a unique username and password, allocation of homes to each LHW and scheduling their visits for each patient's home. This service component also allows the healthcare administrators to monitoring and track LHW visits through GPS tracking maps. A real time map will be displayed showing the current location of the LHW to ensure that timely visits are made.

E. FIRST AID eToolkit

This service is developed especially for LHW to facilitate her in accessing healthcare information required during her field visits. The first aid eToolkit consists of features such as early diagnosis and symptoms for expectant mothers, breastfeeding, pregnancy and nutrition, personal hygiene and baby names. These features are presented using images of various breastfeeding positions, nutrition charts, personal hygiene management, early pregnancy symptoms, etc. The purpose of adding these images is to help LHW's educate the patients at their doorsteps.

F. MORTALITY CALCULATOR

This service provides facility to healthcare professionals to view the mortality rate of patients and newborns in a particular BHU in a district. The mortality report is produced based on the patient and newborn data collected and available on the AWS cloud. The mortality rate is calculated using the following formula: Mortality rate = number of deaths/total population $\times 1000$.

G. REPORTS GENERATOR

In this service, various reports required by healthcare professionals are being provided for administrative and information purposes. These reports are based on the information recorded under the UHFF services mentioned above. These reports include: patient information and medical records, patient referrals, LHW records, medicines and supplies records, newborn medical and vaccination schedules, mortality report for each year.

The accessibility of these services by the users are shown in Table 4.

In the next section, UHFF evaluation is discussed in detail.

IV. UHFF EVALUATION

The evaluation of the proposed UHFF is carried out by constructing an evaluation process provided in Figure 4.

TABLE 4. Accessibility of UHFF services to healthcare professionals.

UHFF Healthcare Services		Healthcare Prof.		
		DOH	MO	LHW
Patient Management	Registration		✓	
	Medical Record	✓		✓
	Emergency Referrals	✓	✓	
	Reminders		✓	
Newborn Management	Registration			✓
	Medical Record	✓	✓	✓
	Vaccination Schedules	✓	✓	✓
Medicine Prescription	Patient Medicine Record	✓	✓	✓
First Aid eToolkit	Early Diagnosis & Symptoms		✓	
	Personal Hygiene		✓	
	Pregnancy & Nutrition		✓	
	Breastfeeding Positions		✓	
	Baby Names		✓	
LHW Management	Registration	✓		
	LHW Scheduling: Home Allocation	✓		
	LHW Scheduling: Weekly Visits	✓		
	LHW Location Tracking & Monitoring	✓		
Mortality Calculator	Maternal Mortality	✓		
	Newborn Mortality	✓		
Reports Generation	Patients Medical Examination Records	✓	✓	
	Emergency Referrals	✓	✓	
	LHW Records	✓		
	Medicines & Supplies Records	✓		
	Newborn Vaccination Schedules	✓		
	Total Mortality per Year	✓		

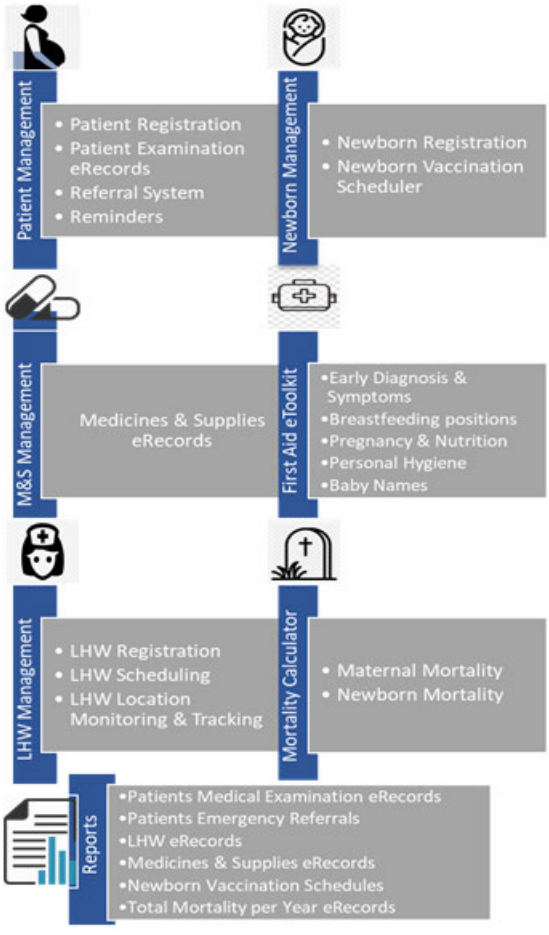

FIGURE 3. UHFF services and their features.

First, evaluation framework is developed by extracting features from models such as Nielsens' usability evaluation model [53], Information System model [54], [55] usability heuristics by Nielsen [56], HIMSS EHR (Healthcare Information and Management Systems Society Electronic Health Record) usability model [57], ISO (International Standard Organization) 9241 [58], and ISO 9126 [59]. Second, hypothesis are constructed based on proposed evaluation framework to evaluate user satisfaction towards proposed UHFF. A field survey was designed to evaluate proposed UHFF by engaging healthcare professionals working at BHUs. During field survey, Walkthroughs were conducted and data was collected through questionnaires. Statistical analysis was carried out by employing Structured Equation Modeling (SEM). The healthcare administrators were also engaged in evaluation of UHFF. The responses of conducting walkthroughs with healthcare administrators and doctors are discussed in relevant section. In next section, UHFF evaluation framework is discussed.

A. UHFF EVALUATION FRAMEWORK

The evaluation framework is constructed by employing thematic analysis on the constructs(attributes) of Models of usability, ISO Standards and Information system theory.

- **Nielsens Usability Evaluation Model:** The usability 93 model devised by Jakob Neilson is another broadly used model for usability evaluation. The model includes features such as learnability, efficiency, memorability, errors, and satisfaction.
- **DeLone and McLean's Model:** This model is one of the most influential and widely accepted theory mentioned in scientific papers across the world [49]. It introduces six critical dimensions with their sub features. These dimensions include information quality, system quality, service quality, system usage intentions, user satisfaction and net system benefits.

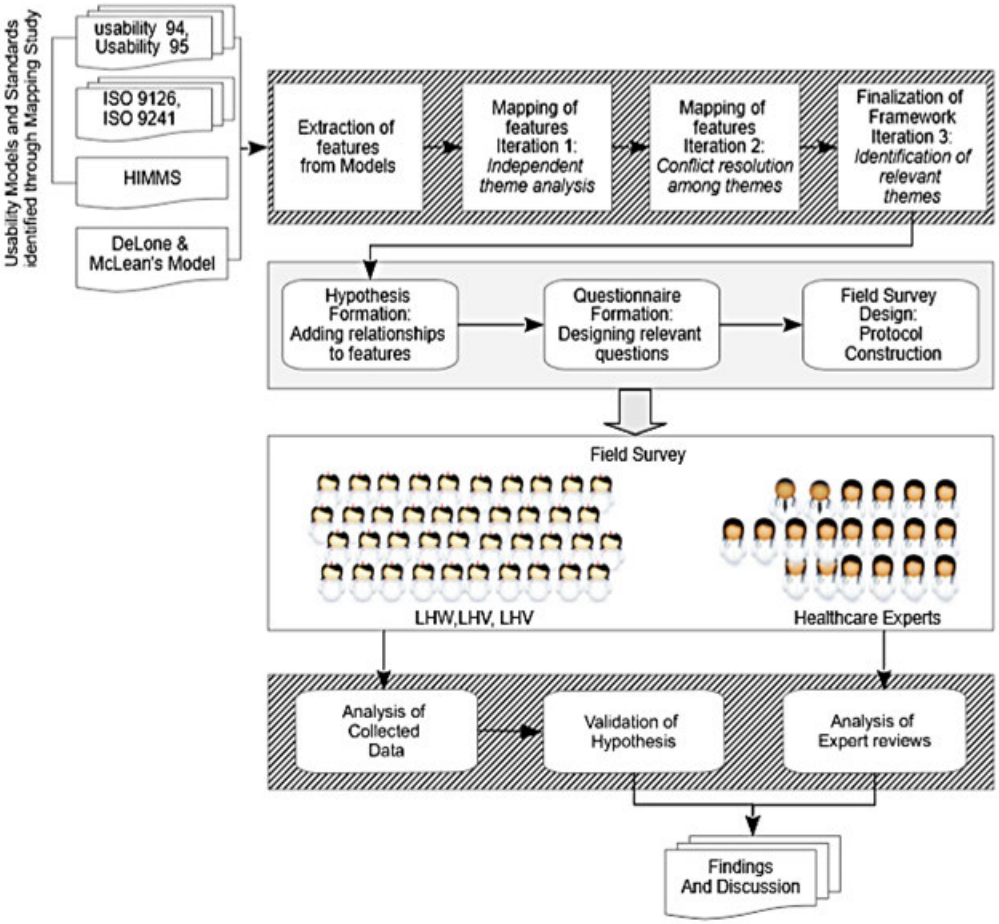

FIGURE 4. Evaluation process.

- **Jakob Nielsens 10 Heuristics:** This model offers ten usability heuristics that include visibility of system status, match between system and real world, user control and freedom, consistency and standards, error prevention, recognition of the system, efficiency of use, aesthetic and minimalist design, error recovery and help and documentation.
- **HIMMS:** HIMMS is a healthcare organization that provides healthcare solutions through Information Communication Technology. It has introduced usability evaluation model that includes features such as interactions, language, context, simplicity, naturalness, cognitive load, presentation, ease of learning and forgiveness and feedback.
- **ISO Model 9241:** This model is introduced by the International Standard Organization (ISO) to improve the ergonomics of human-computer interaction. This model introduces features such as effectiveness, satisfaction and efficiency.
- **ISO Model 9126:** ISO 9126 is another model by ISO that considers features such as functionality, reliability, usability, efficiency, maintainability, and portability.

The process of extracting features from the selected usability models and standards comprised of three iterations:

- Iteration 1: thematic analysis was carried out independently by two authors,
- Iteration 2: mapped features were reviewed by two analysts, and
- Iteration 3: repetitive features were removed and relevant features were included in framework.

The proposed evaluation framework is provided in Figure 5. The framework constructs include adaptability, availability, cognitive load, ease of learning, ease to understand, effectiveness, efficiency of use, error recovery, execution, memorability, navigation, and responsiveness. The dependent variable in this framework is user satisfaction.

B. RESEARCH HYPOTHESIS

The hypothesis formulated are based on the constructs mentioned in proposed evaluation framework and are provided below.

H1: The users will be more satisfied if the UHFF is available.

H2: Adaptability has a positive impact on the Satisfaction of using the UHFF.

FIGURE 5. Proposed evaluation framework.

H3: The greater the error recovery, the greater the Satisfaction of using the UHFF.

H4: Ease to understand is positively related to Satisfaction of using the UHFF.

H5: Ease of Learning positively impacts Satisfaction of using the UHFF.

H6: Execution while using the UHFF has a positive impact on satisfaction.

H7: Navigation in the UHFF positively affects Satisfaction.

H8: Minimum cognitive load has a positive impact on satisfaction.

H9: UHFF Satisfaction will be positively influenced by Efficiency of Use.

H10: Responsiveness will have a positive impact on Satisfaction of using the UHFF.

H11: Effectiveness will have a positive impact towards Satisfaction of using the UHFF.

H12: Memorability will have a positive impact towards Satisfaction of using the UHFF

The evaluation framework with associated hypothesis is provided in Figure 6.

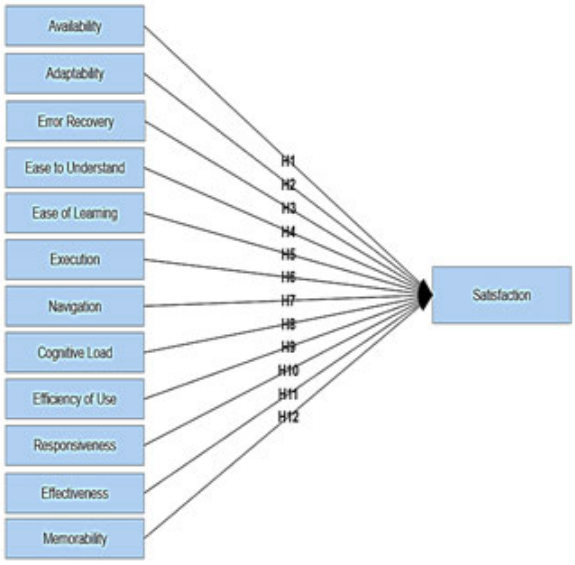

FIGURE 6. Proposed evaluation framework.

C. FIELD SURVEY

To evaluate the proposed UHFF, a field survey is conducted by engaging healthcare professionals working at thirty five BHUs in rural Punjab, Pakistan.A protocol was designed to conduct the field survey and is attached in Appendix A. The field survey session involved application demonstration, application walkthrough with healthcare professionals and data collection through questionnaire. The field survey procedure is discussed below.

- **Sample Size:** The responses collected during field study were 299 in total which shows a large sample size appropriate for best model fit [60].
- **Population:** The participants of the survey were healthcare professionals including lady health supervisors (females), and lady health workers (females). For expert review, doctors (male/female) at BHUs and healthcare administrators were contacted.
- **Location:** The Basic Health Units (BHUs) throughout province Punjab, Pakistan were selected through convenience sampling. A total of 35 BHUs were visited to collect data.
- **Participants Group:** The participants were divided into groups for each survey session. Each group consisted of 8-10 participants.
- **Session Length:** The survey session time was 03 hours for each participant group. However, during the survey, on the requests of the participants and their level of engagement, the time was exceeded to one hour.
- **Supporting Material:** Supporting material in the form of user manual was provided to participants to help them in using UHFF.

- **Session Structure:** The field survey was conducted according to the following procedure.
  - **Briefing:** The briefing was provided about the purpose of the field survey and the research authors are currently engaged in. Further, proposed UHFF was explained by relating its functionality with the work practices of participants. The briefing was to make participants engage in the evaluation process.
  - **Demonstration:** The UHFF developed application(s) were presented to participants. The various sections of these applications with associated features were further explained.
  - **Walkthrough and Discussion (Participant involvement in application use):** The participants were provided with user manual and asked them to use the application independently and thoroughly. The participants exhibited great interest in the application features and found them easy to use and relevant to their work. Where required, author(s) who was also moderating the session answered the participants queries related to UHFF features.
  - **Questionnaire (response collection):** After going through all the features of UHFF, the questionnaires were handed over to participants to collect their responses. The author(s) first explained the questionnaire to all participants and remain available to discuss any concern raised by the participants in completing the questionnaire.

D. DESCRIPTIVE STATISTICS

The descriptive statistics of field survey are provided in Table 5. As shown in Table, almost all participants were above 30 years old which implies that all these healthcare workers were mature people. There were 07 LHSs and 72 LHWs that fall in age group 31-35 years, in age group 36-40 there were 9 LHSs and 67 LHWs. In age group 41-45, there were 11 LHSs and 101 LHWs. For age over 45, there were 23 LHWs and 8 LHSs.

A significant number of respondents, which were mostly LHWs attained matriculation education. A considerable number of respondents consisting of LHSs, have intermediate level education, i.e. higher secondary school certificate. The LHVs were having bachelor's degree. The workload of the LHWs varies depending on the specific district the BHUs are located and based on the population size. 90 LHWs were allocated 100-200 homes/ population size of 900-1000 homes, whereas 210 LHWs were allocated 200-300 homes/ population size of 1000-1800 homes. Findings also show that 167 LHWs visit 7-9 homes per day. Whereas 127 LHWs visit 10-12 homes per day. Digital Literacy of participants was analysed through cell-phone ownership and utilization. All the healthcare practitioners at least have owned - and still own - a cell-phone for the past six years. 94% of the respondents owned a smartphone with touch screen, while only 6% owned a traditional QWERTY keypad cell-phone. The mobile phone model largely used was Samsung and QMobile.

TABLE 5. Descriptive statistics for evaluation survey.

Variable	Categories	Frequency (Count)	Frequency (%)
Age (Years)	<30	0	0%
	31-35	81	27.1%
	36-40	76	25.4%
	41-45	114	38.1%
	>45	29	9.7%
Experience (Years)	<1	0	0%
	1-5	11	3.7%
	6-10	72	24.1%
	11-15	86	28.8%
	>15	130	43.5%
Qualification	Matriculation	195	65.2%
	Intermediate	91	30.4%
	Bachelors	13	4.3%
	Masters	1	0.3%
	Other	0	0%
Houses Allotted (per population size)	Less than 100	0	0%
	101-200	90	30.1%
	201-300	210	70.2%
	301-400	0	0%
	Above 400	0	0%
Homes Visited (per day)	1-3	0	0%
	4-6	0	0%
	7-9	167	55.9%
	10-12	127	42.5%
	Above 12	0	0%
Mobile phone Usage	Yes	299	100%
	No	0	0%
Mobile phone Make and Model	Huawei	8	2.7%
	Nokia	9	3%
	Rivo	2	0.7%
	Samsung	162	54.2%
	QMobile	118	39.5%
Language used to interact on Mobile phone	English	299	100%
	Urdu	01	0.3%
	Local	00	0%
	Other	00	0%
Mobile phone Functions Used	Text	0	0%
	Voice	0	0%
	Both	299	10%
Work related applications on Mobile phone	SMS	299	100%
	Call	299	100%
	Skype	1	0.3%
	Whatsapp	184	61.5%
	Other	1	0.3%

The statistical analysis is carried out on the responses collected related to framework. In next section, statistical analysis is discussed in detail.

E. STATISTICAL ANALYSIS

The reliability of instrument, model fit measurement and hypothesis testing are discussed in this section.

- **Reliability of Survey Instrument:** To measure the reliability of survey instrument, Cronbach Alpha is calculated for each construct. The Cronbach Alpha values are shown in Table 6. These values are calculated through SPSS Statistical Software. The Alpha values are greater than 0.7 threshold and represent good internal consistency.
- **Model Fit Measurements:** The proposed model is evaluated by employing Confirmatory Factor Analysis CFA) because it measures the variables that cannot be assessed directly. The estimation of these variables is carried out through observed variables. Structured Equation Modeling (SEM) is employed to conduct CFA. For this purpose AMOS version 25 is used for modelling and analysis.The model fit measurements are shown in Table 7. The values represent a Good Fit Model.

TABLE 6. Internal consistency of constructs used in proposed model.

2*Construct	Cronbachś Alpha	Total Items	Reliability Level
Availability	0.971	3	Excellent
Adaptability	0.835	2	Good
Error Recovery	0.756	3	Good
Ease to Understand	0.870	5	Good
Ease of Learning	0.745	2	Good
Execution	0.859	4	Good
Navigation	0.951	8	Excellent
Minimum Cognitive Load	0.808	3	Good
Efficiency of Use	0.891	3	Good
Effectiveness	0.792	6	Good
Responsiveness	0.751	2	Good
Memorability	0.840	5	Good

TABLE 7. Model fit measurements.

2*Fit Index	2*Fit Index	Recommended cut of Value
Minimum Fit Index (X2) (CMIN)	2*1620.7 p = 0.000	3*Lower is better
Degree of Freedom (DF)	920	
X2/DF	1.762	<5
Goodness of Fit Index (GFI)	0.818	>0.80
Comparative Fit Index (CFI)	0.933	>0.90
Root Mean Square Error of Approximation (RMSEA)	0.51	<0.08
Tucker Lewis Index (TLI)	0.924	>0.90
Normed Fit Index (NFI)	0.858	>0.90

- **Hypothesis Testing** The hypothesis are tested against the data collected through field survey. The Table 8 provides beta values, t-values, p and significance level of each hypothesis. The significance of constructs is measured against p<.001, p<.01, p<.05 and ***.
  The test results mentioned in Table 8 show that all the hypothesis are found highly significant. There is slight variation in H5, however, the result is still significant. The hypothesis test results illustrate that participants were satisfied with the proposed UHFF. They found UHFF features easy to understand, navigate, learn and memories. Also, features such as availability, adaptability, error recovery, responsiveness of UHFF, and execution UHFF features gained high satisfaction from users. The participants also found UHFF features effective, efficient to use and having less cognitive load. Therefore, the results of these hypothesis are found highly significant.

In Figure 7, Fuzzy Cognitive Map associated with hypothesis is presented. The thickest line represent strong relationship with satisfaction. Therefore, Availability, Adaptability, Error recovery, Ease to Understand, Execution, Navigation, Minimum Cognitive Load, efficiency of Use, Effectiveness, Responsiveness and Memorability have strong effect on user satisfaction towards proposed UHFF. The moderately thick line between Ease of learning and satisfaction also show significant relationship between both. This slight effect could be participants' hesitation to move from their conventional working style towards use of technology. However, this effect could be ignored as the values shows that the participants were satisfied with UHFF.

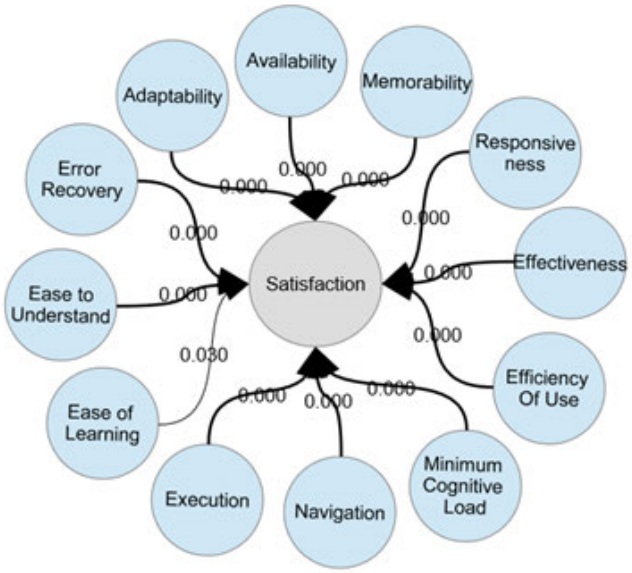

FIGURE 7. Fuzzy cognitive map.

F. DISCUSSION ON HYPOTHESIS

The result of each hypothesis is discussed below. The results are compared with core theories as literature lack evidences where these constructs are used for eHealth applications.

H1: The healthcare professionals will be more satisfied if the UHFF is available.

Availability is an important construct in UHFF as the purpose was to make it accessible in rural areas. Through availability, healthcare professionals can use the application from any location, anywhere and at any time, which removes the restriction to be in a specific place. In addition, data of respective BHU and their concerned healthcare professional is accessible irrespective of location. During field survey, healthcare professionals found no difficulty in accessing UHFF applications and their features. Therefore, this construct was found highly significant towards user satisfaction. Availability is a feature of system quality in DeLone & McLean Model. The result of this is consistent with the findings of [61] who evaluated system quality to measure user satisfaction.

H2: Adaptability has a positive impact on the Satisfaction of using the UHFF.

Adaptability (also referred to as the installability and portability) is the feature through which a system can be modified/installed for use in environments other than those for which it was specifically designed [62]. The UHFF was easily downloaded and installed by healthcare professionals on their own devices. Therefore, the results of this construct were also found highly significant towards user satisfaction. Adaptability is also a feature of system quality in DeLone & McLean Model. The result of this are consistent with findings of [61] where this relationship was found significant towards user satisfaction.

H3: The greater the error recovery, the greater the Satisfaction of using the UHFF.

TABLE 8. Significance level of hypothesis after testing.

2*Hypothesis	2*Path	Estimates (Beta Value)	C.R. (t-value)	2*P	2*Significance Level
H1	Availability → Satisfaction	.110	11.855	***	Highly Significant
H2	Adaptability → Satisfaction	.219	7.429	***	Highly Significant
H3	Error Recovery → Satisfaction	.053	7.846	***	Highly Significant
H4	Ease to Understand → Satisfaction	.066	8.990	***	Highly Significant
H5	Ease of Learning → Satisfaction	.010	2.164	.030	Significant
H6	Execution → Satisfaction	.064	7.106	***	Highly Significant
H7	Navigation → Satisfaction	.093	10.059	***	Highly Significant
H8	Cognitive Load → Satisfaction	.218	8.288	***	Highly Significant
H9	Efficiency of Use → Satisfaction	.309	9.663	***	Highly Significant
H10	Effectiveness → Satisfaction	.289	8.225	***	Highly Significant
H11	Responsiveness→ Satisfaction	.194	6.683	***	Highly Significant
H12	Memorability → Satisfaction	.216	8.265	***	Highly Significant

Error recovery is the ability of the UHFF to recover itself when the errors occur, also referred to as fault tolerance [63]. Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution. The UHFF displayed message in case of any error occurred. The participants did not need to worry about correcting the errors themselves as the UHFF has the feature of error handling. Therefore, this construct was found highly significant towards user satisfaction. Error recovery is a feature of usability which ensures reliability of the system. In DeLone & McLean Model, reliability is available under system quality. Therefore, this finding is found consistent with [61] evaluated results.

H4: Ease to understand is positively related to Satisfaction of using the UHFF.

Ease to understand is the degree to which the users understand the system [62]. The terminologies used in UHFF where relevant and related to the work practices of healthcare professionals. Therefore, this construct was found highly significant towards user satisfaction. Ease to understand is a feature of information quality in DeLone & McLean Model. Therefore, the findings of this hypothesis are found consistent with [61].

H5: Ease of Learning positively impact Satisfaction of using the UHFF.

Ease of learning is the time needed for a user of average knowledge to be able to configure, learn, and administer the system [63]. While developing a system, considering ease of learning attribute is very important since it contributes to the overall acceptance and satisfaction of the system. Healthcare professionals were able to use UHFF features through they had no prior experience of using any healthcare application. This construct was found significant towards user satisfaction. No prior experience of using application might have slight impact however, the result show that it was not a barrier for them to use application.

H6: Execution while using the UHFF has a positive impact on satisfaction.

The participants were comfortable and excited to use various features of UHFF. The features were easily and quickly available while tapping and clicking on the screen. They inserted and viewed the data to verify the functionality of the features. This gave them confidence and helped in establishing trust on the proposed UHFF. The execution was according to the procedure they require during the provision of healthcare services. Therefore, this construct was found highly significant towards user satisfaction.

H7: Navigation in the UHFF positively affects Satisfaction.

Navigation allows efficient and quick access to information. It includes sub attributes such as next and previous buttons, home button, scroll bars, etc. The navigation of the UHFF was found easy and order of the screen was relevant to its particular process. The participants faced no difficulty in moving around the application using its menus randomly. Therefore, this construct showed high significance towards user satisfaction. This finding of this hypothesis was found consistent with [Palmer, 2002] who associated navigation with higher perceived success of users.

H8: Minimum cognitive load has a positive impact on satisfaction.

To increase the performance of an information system, the cognitive load should be kept minimum. Cognitive load is increased if there are too many graphics, colors, and too much repetitive information is on the interface [64]. The design of the system must be such that it is easy to use and navigate through without creating much of a hassle. Since the aesthetics and design of the UHFF have been kept minimal, and there is consistency of colors and information on the interface, therefore the minimum cognitive load has a positive impact on healthcare professionals' satisfaction and found highly significant.

H9: UHFF Satisfaction will be positively influenced by Efficiency of Use.

Efficiency is the level of performance of the system resources used under given conditions [65]. A good information system reacts well to the users' needs and way of working and is quite customizable. Healthcare professionals were satisfied with performance of UHFF as they spent extensive time in exploring, and using the UHFF. They developed interest in the UHFF and enthusiastic that the UHFF will increase the productivity along with the efficiency in provision of healthcare services. Therefore, this construct was found highly significant towards user satisfaction.

H10: Responsiveness will have a positive impact on Satisfaction of using the UHFF.

TABLE 9. Expert review findings.

Availability	The availability of healthcare services on mobile and laptops was considered an important and significant feature of proposed UHFF. As it makes it easy for healthcare professionals to access services without any constraint of technology. As participant mentioned that *The healthcare facility can be accessed through mobile as well as laptop and is very convenient to use.* by Medical officer.
Completeness	The UHFF was designed by considering the needs and work practices of the health care professionals. For this, information was collected and verified through extensive field survey discussed in Chapter 4. Therefore, experts reviews shows that UHFF provides the complete functionality that is required in this particular case. As one of the respondents mentioned that:*All the healthcare services that we need are available to us on the healthcare facility.* by Medical Officer.
Easy to Understand, Memorability	The UHFF is constructed by focusing on the needs of its users especially level of digital literacy. Therefore, participants found it easy to understand and remember how to use its various features. One of the participants commented that *The healthcare facility is not difficult at all and is easy to remember where to find the desired content. The content is rich, however, in the long run, more features could be added, such as patient ultrasound images, etc. so the care could be provided to severely deprived areas also.* by Medical officer.
Simplicity, Visibility	The UHFF features are made visible through different color schemes which are consistent with their particular workflow. These features make UHFF simple, memorable and easy to use as mentioned by participants in following comments: *I like the design and visibility of the page, simple, catchy colors, and easy to use.* by Medical Officer. Another participants responded to UHFF as *I like that the healthcare facility is not complex, rather quick links are available. It is simple, and has only the content that is important. No extra information is present which is good.* by Medical Officer.
Navigation	The UHFF is constructed by grouping relevant information in respective sections. Which made access of relevant information easy for the users. Below are the comments from participants. *The features are easy to locate. The desired page is easily reached.* by Medical Officer. Another participant commented that *The interface of the healthcare facility is simple and easy to use. Colors are appealing. I can easily navigate through the facility and find my desired information.* by Medical officer.
Easy to Use	The UHFF features are made visible through large menus, interfaces were kept simple, and order of screens were made according to the workflow provided and discussed with healthcare professionals. This made the UHFF easy to use by the participants. One of the participant commented that *The healthcare facility is easy to use for a person like me who has not used technology so much. The facility is easy to use and navigate to obtain information required.* by Senior Medical Officer.
Comprehensive	The UHFF is deigned by focusing on the important and relevant aspects of the healthcare services provided by professionals. Extra and irrelevant information that might disrupt them from professional services was avoided. In this regard the participant highlighted that *I like that there are no pop-ups or ads on the healthcare facility.* by Medical Officer. Another participant commented that *I like that the healthcare facility is not complex, rather quick links are available. It is simple, and has only the content that is important. No extra information is present which is good.* by Medical Officer.
Decision Making	The UHFF features provides information which is relevant to the responsibilities of healthcare professionals. This make them to access information in timely manner and take appropriate decisions. The participants' responses are provided below: *The healthcare facility definitely saves time and helps in easy decision making.* by Medical Officer. Another participant commented that *Assisting healthcare professionals to access healthcare information is advantageous and enables us to make decisions in time.* by Medical Officer In addition, some participants commented that *Patient healthcare information is available to us which helps us in making decisions easily. Earlier, we had to ask the patient or the lady health worker who assisted the patient to discuss the patients' medical history with us which was very time consuming and sometimes the patients were unable to explain their condition or show us their reports which led to complications. I believe this healthcare facility will help us overcome the problems.* by Medical Officer.
Presentation	The UHFF module for administrative purpose was particularly designed by keeping color themes in consideration. This made easy for users to access relevant sections. Further, themes were added that reduce cognitive load on participants. *Graphical presentation of the healthcare facility is appealing.* by Medical Officer.
Information Quality	*The healthcare information and content provided is of quality. In healthcare units, often the information provided in patient files are forged. I believe that with the implementation of this healthcare facility, the quality of eHealthcare services throughout the province will be achieved.* by Medical Officer.
Effectiveness	The reporting feature is particularly introduced in UHFF as it was highlighted by administrators during field survey and constructing the case of rural healthcare services. This feature helps administrators to monitor the situation at various BHUs and make decisions accordingly. This feature was appreciated by participants and District health officer who needs this information the most, commented that: *I like the idea of giving us a report of the total mortality in a particular health unit.* by District Officer Health. *The feature of lady health worker tracking is really good. It will help us confirm their attendance.* by District Officer Health. Another respondent mentioned about mortality report that:*I believe that the mortality rate will reduce through this technological healthcare facility as information will be provided to us on time and patients can be treated effectively.* by Medical Officer.

Responsiveness is the immediate response of the system to a users' input. The faster the response, the more the users will be satisfied. The UHFF is able to work in offline mode as well as in online mode, and is very responsive to user input, therefore, this construct was found highly significant towards user satisfaction. Responsiveness is a feature of service quality in DeLone & McLean Model. The findings of this hypothesis were found consistent with [61].

H11: Effectiveness will have a positive impact towards Satisfaction of using the UHFF.

Effectiveness is the users' ability to achieve a desired goal using the system. The UHFF should be effective so that the healthcare professionals would be able to complete the task(s) with accuracy to achieve the goal. The healthcare professionals found the UHFF very effective and they were highly satisfied. Therefore, effectiveness has a positive impact on satisfaction.

H12: Memorability will have a positive impact towards Satisfaction of using the UHFF. Memorability is a measure of how easy an application, website or a software is to remember after a number of visits [66]. It will be easier to remember if features are grouped logically, conventional icons are used, and if a particular object is placed in a consistent location. The healthcare professionals were able to use the UHFF a second time because they found the application quite memorable due to well organized and grouped menus and features, and with less jargon. Therefore, this construct was found highly significant towards user satisfaction.

In the next section, expert review conducted as part of the field survey is explained in detail.

G. EXPERT REVIEW WITH HEALTHCARE PROFESSIONALS

To conduct expert review, same procedure was followed as discussed for field survey. The only change made was in time and group structure. Instead of 03 hours, time duration was reduced to one and half hour as per convenience of the expert. The second change made was instead of group, individual interviews were conducted with each expert. This change was made as their locations were very far from each other and it was difficult to arrange a combined setup. The expert review was qualitative in nature and purpose was to evaluate UHFF in a holistic way. The emphasis was more on administrative processes that include management, monitoring of LHW and reports associated with BHUs processes. In total twenty healthcare professionals were interviewed including two healthcare administrators, and fourteen medical doctors at BHUs (gynecologists), two medical doctors (general healthcare) at RHC and two medical doctors gynecologists) at tertiary hospitals. The healthcare administrators were male, and all other participants were females.

Despite of their designation, all the healthcare professionals were doctors and were enthusiastic about the potential of the UHFF to improve antenatal care services at rural areas of Punjab. Most of these healthcare professionals had a computer system with Internet/WiFi availability. The UHFF web application (hosted on Amazon Web Cloud Infrastructure), was opened on their screens by simply entering the web address in the web browsers address bar. The same questionnaire was used to structure the session and keep the discussion focused. Healthcare professionals were provided login details to use UHF application. Healthcare administrators and medical doctors were provided separate login details as the information displayed for healthcare administrators and medical officers was different. The expert reviews show that the proposed UHFF is suitable for rural environment and address the needs of the healthcare professionals. The participants emphasized on various features of the UHFF. The details are summarized in Table 9.

During walkthrough session, participants also suggested features that could be included in the proposed solution. These include images of patient condition and availability of chat with doctors working at BHUs.

The expert review sessions were useful to ensure that the processes and functionality provided in UHFF is according to the medical practices. Further, the UHFF is suitable in resource-constrained environment such as the one we discussed in this paper. Further, the reviews assured that the information used (content) was correct, and consistent with functionality. The UHFF features were aligned with the work practices of health professionals. This addresses the completeness and correctness of proposed UHF framework.

V. CONCLUSION

In this research a ubiquitous healthcare framework is proposed to facilitate healthcare professionals in provision of healthcare services in rural areas. To understand the problem in detail and in its real context, an evidence-based approach is employed by constructing a case study of a 'real case' instead of 'toy' examples. This study is different from previous studies as empirical investigation is carried out by engaging healthcare professionals to construct the 'case' which is focused on antenatal and child healthcare services. A focus group approach is adopted and an extensive field study is conducted to engage participants to identify the needs and understand the environment they are working in. The data collected through field study is used to construct proof-of-the concept ubiquitous healthcare framework. Then evaluate the framework by healthcare professionals working at BHUs. The collected data was analysed to measure user satisfaction towards proposed UHFF. The theoretical contribution of this research focuses on constructing a real case of healthcare services in rural areas particularly focusing on antenatal healthcare which is largely neglected in healthcare solution designs. The research further proposes a ubiquitous framework by considering the environment and work processes of healthcare professionals and engaging them in solution design and its validation. The practical contribution of this research is in the form of proof-of-the-concept implementation of proposed ubiquitous healthcare framework. It contributes by constructing healthcare services that could be deployed on the cloud and accessed in the form of mobile and eServices by healthcare professionals within their work practices and protocols. This not only addresses the issue of availability but also facilitates in providing solution for resource constrained environment.

The proposed solution is context specific, easy to use and involved user centered design. Therefore, this is to our knowledge first study that address the problem in such level of detail and engage relevant community throughout the process of problem identification to solution design and

TABLE 10. Basic health units (BHUs) visited during first field survey cont.

Division	Name of District	Region/Tehsil	BHU Name
Lahore division	Lahore	Lahore Cantt.	Halloki
		Raiwind	Niazbaig
	Sheikhupura	Ferozewala	Ferozwala Village
		Muridke	Chak No. 34
	Nankana Sahib	Nankana Sahib	Kot Hussain
		Shah Kot	Islamnagar
	Kasur	Chunian	Chak No. 18
		Pattoki	Dao Key
Rawalpindi division	Rawalpindi	Murree	Ghora Gali
		Rawalpindi	Chakri
	Attock	Attock	Bolianwal
		Attock	Kamra
	Jhelum	Jhelum	Darapur
		Pind Dadan Khan	Golpur
	Chakwal	Chakwal	Chakral
		Talagang	Sukka
Sargodha division	Sargodha	Bhalwal	Deowal
		Sargodha	Chak No. 30/SB
	Mianwali	Mianwali	Rokhri
		Mianwali	Muzafarpur
	Khushab	Khushab	Bijar
		Quaidabad	Bandial
	Bhakkar	Bhakkar	Muslim kot
		Darya Khan	Barkatwala
Gujranwala division	Gujranwala	Gujranwala	Dogranwala
		Kamoke	Dandian
	Gujrat	Gujrat	Behlpur
		Kharian	Amra kalan
	Hafizabad	Hafizabad	Chak Chatta
		Pindi Bhattian	Mattaki
	M.B.Din	M.B.Din	Chak No. 01
		Phalia	Ghanian
	Narowal	Narowal	Alipur syedan
		Zafarwal	Nonar
	Sialkot	Sialkot City	Muradpur
		Daska	Bonkan
Faisalabad division	Faisalabad	Faisalabad Sadar	Chak No. 6
		Jaranwala	Chak. No. 22
	Chiniot	Chiniot	Ahmadabad
		Lalian	Pir punja
	Jhang	Ahmadpur Sial	Sultan Bahoo
		Jhang	Kot esa shah
	T.T.Singh	T.T.Singh	Chak 149
		T.T.Singh	Chak 190
D.G. Khan	D.G. Khan	D.G. Khan	Gamoon wala
		Taunsa Sharif	Dona
	Layyah	Layyah	Chak No. 136
		Layyah	Chak No. 172
	Muzzaffargarh	Kot Adu	Budh
		Muzzaffargarh	Aliwala
	Rajanpur	Jampur	Burrewala
	Rajanpur	Wang	

TABLE 11. Basic health units (BHUs) visited during first field survey.

Division	Name of District	Region/Tehsil	BHU Name
Multan division	Multan	Multan Sadar	Shahpur
		Multan Sadar	Muzafarabad
	Lodhran	Duniapur	Chak No. 34
		Lodhran	Rukanpur
	Khanewal	Kabirwala	Maankot
		Khanewal	Behrowal
	Vehari	Burewala	Chak No. 425
		Vehari	Chak No. 1
Sahiwal division	Sahiwal	Sahiwal City	Chak Qutab khana
		Sahiwal City	Chak No. 100
	Pakpattan	Arifwala	Chak No. 26
		Pakpattan	Lakhwera
	Okara	Depal Pur	Raj Garh
		Okara	Fatehpur
Bahawalpur division	Bahawalpur	Hasilpur	Chak No. 15
		Yazman	Chak. No. 59
	Bahawalnagar	Bahawalnagar	Kot Ahmad Yaar
		Minchanabad	Said Ali
	R.Y.Khan	Khanpur	Chak No. 7
		Sadiqabad	Bhong

solution evaluation. The evaluation through field survey represent a high level of satisfaction towards the proposed UHFF by healthcare professionals working in rural areas.

TABLE 12. Basic health units (BHUs) visited during second field survey.

Division	District	Location	BHU Name
D.G. Khan	Layyah	Layyah	BHU Chak No. 136
		Layyah	BHU Chak No. 172
Faisalabad	Faisalabad	Sadar	BHU Chak No. 6
		Jaranwala	BHU Sultan Bahoo
	Jhang	Ahmad PurSial	BHU KotEsa Shah
		Jhang	BHU Chak No. 25
Sahiwal	Sahiwal	Sahiwal City	BHU ChakKutabShahana
		Sahiwal City	BHU Chak No. 100
	Okara	Depalpur	BHU PipliPahar
Bahawalpur	Bahawalpur	Hasilpur	BHU Chak No. 15
		Yazman	BHU Chal No. 59
	Bahawalnagar	Bahawalnagar	BHU Kot Ahmed Yar
		Minchanabad	BHU Said Ali
Multan	Multan	Sadar	BHU Shahpur
		Sadar	BHU Muzafarbaad
	Lodhran	Duniapur	BHU Chak No. 34
		Lodhran	BHU Rukanpur
Gujranwala	Gujranwala	Gujranwala	BHU Dogranwala
		Kamoke	BHU Dandian
	Hafizabad	Hafizabad	BHU ChakChattha
		PindiBhattian	BHU Mattaki
	Sialkot	Sialkot City	BHU Muradpur
		Daska	BHU Bonkan
Sargodha	Sargodha	Bhalwal	BHU Chak No. 2
		Sargodha	BHU Chak No. 99
Rawalpindi	Rawalpindi	Rawalpindi City	BHU Chakri
		Murree	BHU GhoraGali
	Chakwal	Chakwal City	BHU Chakral
		Talagang	BHU Sukka
Lahore	Lahore	Cantonement	BHU Halloki
		Raiwind	BHU Niazbaig
	Sheikhupura	Ferozawala	BHU Ferozawala Village
		Muridke	BHU Chak No. 34
	Kasur	Chunian	BHU Chak No. 18
		Pattoki	BHU Dev Sial

This research has employed a case study based research approach, therefore, the threats to validity could be associated with the generalization of the proposed solution which is also an implicit limitation of case study research. However, in our case the medical processes for antenatal healthcare are largely the same with slight variations in code of practice (depending on the region). The field survey conducted at more that 100 BHUs provide multiple cases withing the case study design and strengthen the findings of each other. Further, the rural healthcare structure at BHUs is almost the same in other provinces and is replicable in other regions. In next phase of this research, the ubiquitous healthcare monitoring devices will be integrated in the framework to capture the vital signs and other measurements to directly transfer data in patient records. Further, support of other languages will also be incorporated for education and awareness of antenatal and child healthcare. To our knowledge, this is the first study of this kind where antenatal problem in rural area is addressed to this depth and have employed a systematic process for problem analysis, solution design, provide proof-of the-concept implementation and evaluation by relevant healthcare community. Further, this study is unique as it has involved healthcare professionals from rural areas from identification of problem to solution design and its evaluation. Finally, the contribution made by this study could be used by healthcare professionals and practitioners in designing user centered ubiquitous solutions for the environment similar to the one discussed in this research.

APPENDIX A: BASIC HEALTH UNITS VISITED DURING FIRST FIELD SURVEY

The basic health units (BHUs) visted during field survey are provided in Table10 and Table11.

APPENDIX B: BASIC HEALTH UNITS VISITED DURING SECOND FIELD SURVEY

See Table 12.

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