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A Semantic-Based Framework for Verbal Autopsy to Identify the Cause of Maternal Death

Muhammad I. A. Durrani[1] Tabbasum Naz[1] Muhammad Atif[1] Numra Khalid[1] Alessia Amelio[2]

[1] Department of Computer Science & IT, The University of Lahore, Lahore, Pakistan
[2] Independent Researcher, Cosenza (CS), Italy

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Address for correspondence Muhammad I. A. Durrani, PhD Scholar, Computer Science Department, University of Lahore, 1-KM Defence Road, Lahore 54000, Pakistan (e-mail: 70038354@student.uol.edu.pk).

Abstract

Objective Verbal autopsy is a technique used to collect information about a decedent from his/her family members using questionnaires, conducting interviews, making observations, and sampling. In substantial parts of the world, particularly in Africa and Asia, many deaths are unrecorded. In 2017, globally pregnant women were dying daily around 810 and 295,000 in a year because of pregnancy-related problems, pointed out by World Health Organization. Identifying the cause of a death is a complex process which requires in-depth medical knowledge and practical experience. Generally, medical practitioners possess different knowledge levels, set of abilities, and problem-solving skills. Additionally, the medical negligence plays a significant part in further worsening the situation. Accurate identification of the cause of death can help a government to take strategic measures to focus on, particularly increasing the death rate in a specific region.

Methods This research provides a solution by introducing a semantic-based verbal autopsy framework for maternal death (SVAF-MD) to identify the cause of death. The proposed framework consists of four main components as follows: (1) clinical practice guidelines, (2) knowledge collection, (3) knowledge modeling, and (4) knowledge codification. Maternal ontology for the framework is developed using Protégé knowledge editor. Resource description framework application programming interface (API) for PHP (RAP) is used as a Semantic Web toolkit along with Simple Protocol and RDF Query Language (SPARQL) is used for querying with ontology to retrieve data.

Results The results show that 92% of maternal causes of deaths assigned using SVAF-MD correctly matched manual reports already prepared by gynecologists.

Conclusion SVAF-MD, a semantic-based framework for the verbal autopsy of maternal deaths, assigns the cause of death with minimum involvement of medical practitioners. This research helps the government to ease down the verbal autopsy process, overcome the delays in reporting, and facilitate in terms of accurate results to devise the policies to reduce the maternal mortality.

Keywords
- clinical decision support system
- expert system
- knowledge modeling and representation
- ontology
- semantic-based verbal autopsy framework for maternal death (SVAF-MD)

Background and Significance

Verbal autopsy (VA) helps determine probable causes of a death where no medical record is available or no formal medical attention is given.[1] VA is a technique used to collect information about a decedent from his/her family members using questionnaires, conducting interviews, making

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observations, and sampling. This information contains signs, symptoms, demographic characteristics, or events that occurred before and at the time of death.

The thrust of the World Health Organization (WHO) is on sustainable development goals (SDGs) for the reduction in neonatal and maternal mortality. The SDGs comprise a set of 17 "Global Goals" with 169 targets which cover a broad range of sustainable development issues. Alkema et al[2] explored the progress of the Millennium Development Goals (MDGs) till 2015 and stated SDG projections till 2030. SDG-3 is for the reduction of maternal death and, as per target, the death toll should be less than 70 per 100,000 live births by 2030. The vision of the United Nations and WHO, through SDG, is to have a safer world by 2030 with respect to neonatal and maternal life expectancy. The patterns of people's death are tremendously vital for understanding the disease and desperate condition of the world population. In substantial parts of the world, particularly in Africa and Asia, many deaths are unrecorded, whereas the unavailability of data further creates a bigger hurdle in planning for health services. In 2016, globally 50% of deaths and their causes were not formally recorded as reported by WHO.[3] In 2017, globally around 810 pregnant women were dying every day[4] and consequently, it was estimated that around 295,000 pregnant women were dying in a year because of pregnancy-related problems, pointed out by WHO.[5] The death rate of patients is high due to the absence of appropriate and timely treatment. Manzoor et al[6] observed that the greater part of the deaths occurred due to fundamental complications which were not handled timely. These complications can easily be addressed once the reasons are analyzed. This is a noteworthy issue for understanding the world's medical problems and designing their best possible solutions.

Identifying the cause of a death is a complex process, as it requires in-depth medical knowledge and practical experience. Generally, medical practitioners possess different knowledge levels, sets of abilities, and problem-solving skills. Additionally, the shortage of expert medical doctors around the world is a bigger challenge and plays a significant part in further worsening the situation. So, a semantic-based clinical decision support system (CDSS) overcomes these gaps and provides the best ecosystem to address issues of shortage of doctors and variance in expertise. The knowledge base should be a part of CDSS, it can play the role of back bone in the identification of the cause of maternal death because VA data contain the heterogeneous information. In ontology, we can easily define the relationships of classes and their entities.

The VA process currently in practice worldwide is:

- Conduct an interview with some relatives of a decedent.
- Review the verbal autopsy information by a team of doctors.
- Review patient history (if available).
- Assign the cause of death (CoD).

The above procedure takes a long time, whereas the CDSS predicts CoD quickly and is cost-effective as well. Low-income countries, like Pakistan, have geographical pockets with high heterogeneity for causes of maternal mortality. In addition, the manual verbal autopsy process has flaws, biases, and many layers of processes that put a question mark on the accuracy of the results. The current VA tools[7] provide a general scope to identify the CoD, but they are unable to predict or extend knowledge if heterogeneous data are available in their datasets.

With the help of semantic technologies, these gaps can be overcome by the utilization of an ontology-based CDSS. Furthermore, the semantic-based knowledge system intelligently predicts the solution with heterogeneous data and can effectively create additional knowledge. Ontologies are utilized as a basic element to enable ability inside the Semantic Web. Ontology is an information and representation structure that can be utilized to share and reuse knowledge.

The proposed system, semantic-based verbal autopsy framework for maternal death (SVAF-MD), is a semantic-based framework for verbal autopsy where the ontology and semantic reasoning play key roles. The framework automatically identifies the CoD for maternal mortality using multidisciplinary knowledge and, moreover, applies inference and reasoning techniques. The framework depends on production rules which are given by the domain experts (doctors) and it produces a set of suggestions that help to identify the CoD. This research helps a government to ease down the verbal autopsy process, overcomes the delays in reporting, and facilitates in terms of accurate results to devise the policies to reduce the maternal mortality.

Literature Review

This section is divided into four subcategories, that is, "Medical Error," "Clinical Decision Support System (CDSS)," "Statistical Verbal Autopsy Tools," and "Semantic-Based Solution." Each category is described in detail hereinafter.

Medical Error

Abas et al[8] described the following three common errors made by clinicians: (1) they neglect to meet standard rules, (2) they are not up to date on daily basis knowledge, and (3) they do not know about their duties. Every medical practitioner has a different level of knowledge, ability, and problem-solving approach, even experienced practitioners might have the possibility of giving an incorrect diagnosis.[9] Shiwani and Gadit stated that medical negligence or malpractice is a serious mistake by medical practitioners toward illegal and irresponsible behavior. Especially in Pakistan, medical malpractice is seeing significant growth, particularly in the last couple of decades. In general, malpractices include incomplete medical knowledge, wrong diagnoses, using expired medicines, and applying the wrong techniques in operations.[10] The development of SVAF-MD involves domain experts with their best theoretical and practical knowledge. This approach reduces human error in the medical domain.

Clinical Decision Support System

CDSS plays a vital role in improving the quality of medical services.[11] Lam et al[12] propose an architecture for CDSS in the domain of high-risk pregnancy. The architecture contains seven components as follows: (1) knowledge base, (2) inference engine, (3) machine learning, (4) case database, (5) electronic medical record (EMR), (6) query engine, and (7) user interface (UI). They use case-based reasoning (CBR) and the Bayesian Network approach to find an optimum solution. According to Dinevski et al,[13] a CDSS can be categorized as knowledge-based and nonknowledge-based tool. Knowledge-based CDSS contains expert clinical knowledge with concrete facts and nonknowledge-based CDSS contains the practical experience of medical doctors. Furthermore, Skjelvik divided knowledge-based CDSS into three main components, that is, (1) knowledge base, (2) inference engine, and (3) UI.[14] Our proposed SVAF-MD adopts both approaches of knowledge-based and nonknowledge–based CDSS to optimize the solution.

Statistical Verbal Autopsy Tools

This section contains a discussion about statistical-based tools to identify the CoD, that is, Interpreting verbal autopsy (InterVA), InSilicoVA, and SmartVA. To the best of our knowledge, a semantic-based VA tool does not exist that can automatically identify the maternal CoD.

InterVA[15,16] tool assigns a death across a predefined dataset of causes. It uses the information provided by the physicians from VA data (signs and symptoms). Clark et al.[17] described theoretical problems with the InterVA tool. McCormick et al[18] stated the following three issues of InterVA.

1. InterVA follows Bayes' rule; the algorithm does not determine comparable probabilities between individuals.
2. Output of InterVA is person dependent that means it varies from person to person.
3. The scope of information that is fed to InterVA is limited, as it does not incorporate other potential informative sources, it does not follow the gold standard.

According to Li et al,[19] InterVA contains the following ambiguous points:

- InterVA-4 was developed in FoxPro and its code is not promptly accessible.
- The criteria for dropping out unlikely causes or symptoms is suspicious.
- Some steps are not explained properly, including undocumented changes of index, and CoD is not normalized in the final output.

InSilicoVA is a statistical model (Bayesian Network) and computational algorithm to automatically assign the CoD for verbal autopsy. The importance of the InSilicoVA framework is in sharing information between individual and population cause distribution.[17] This model has a fixed probability of data as its limitation. SmartVA is an application that implements the Tariff 2.0 method. Tariffs are specific normalized endorsement rates to CoD for each symptom reported in the Population Health Metrics Research Consortium (PHMRC) gold-standard dataset. It takes VA electronic data as input and estimates the CoD at the individual and population levels.[20,21] Our proposed SVAF-MD uses the inference and reasoning approach of the Semantic Web to anticipate the solution. These approaches are very easy and provide the optimum solution to predict heterogeneous information into knowledge because the information is increasing with every passing second.

Semantic-Based Solution

Semantic Web technology is a promising solution for knowledge representation and reasoning. An ontology defines the formal structure and representation of data by specifying entities and their relationships.[22] Ontology supports the reasoning, but traditional databases do not support reasoning to infer the result. Manzoor et al[6] proposed an ontology-based CDSS for high-risk pregnant women. This ontology refers the high-risk women to doctors for timely treatment. In this ontology, the Waikato Environment for Knowledge Analysis (Weka) helps extract the rules from the dataset of a pregnant woman. Alharbi et al et al[23] proposed an ontology-based CDSS for diabetes diagnostics. The system collects the patient information in terms of signs, symptoms, risk factors, and laboratory tests, and then it proposes the treatment plan according to diabetes type under the supervision of clinical guidelines. Sanchez et al[24] presented a diagnosis supporting a tool of knowledge-based reasoning for Alzheimer's disease (AD) which was developed with the help of ontology and semantic reasoning. This tool gives support to physicians for early detection of AD by using knowledge gathered from different disciplines. The proposed solution comprises the Semantic Web Applications in Neuromedicine (SWAN), systematized nomenclature of medicine clinical terms (SNOMED CT), and medical investigation of neurodevelopmental disorders (MIND) ontologies. Wang and Uz Tansel[25] propose a framework using CBR. CBR methodology is structured with an ontological knowledge model using not only the real data but also the human significant experience.

Farinelli et al[26] developed an ontology, OntONeo, to represent electronic health record (EHR) data for pregnant women and their babies from fetus to toddler stages. The proposed ontology creates a vocabulary to give a portrayal of the information from EHRs. Third el at[27] proposed a hybrid-based framework of the Semantic Web and Quantified Self (QS) technologies. QS is the idea that people can use modern technology to better track themselves. The proposed framework enables clinical risk predictions based on QS data.

Methodology

We introduce a semantic-based framework, SVAF-MD, to identify the cause of maternal death based on verbal autopsy data. The framework contains three main modules which are given below:

1. Requirement elicitation and data collection.
2. Knowledge engineering/knowledge design.
3. Identification of CoD.

►Fig. 1 gives an overview of our proposed semantic-based framework for verbal autopsy which is applied to maternal death.

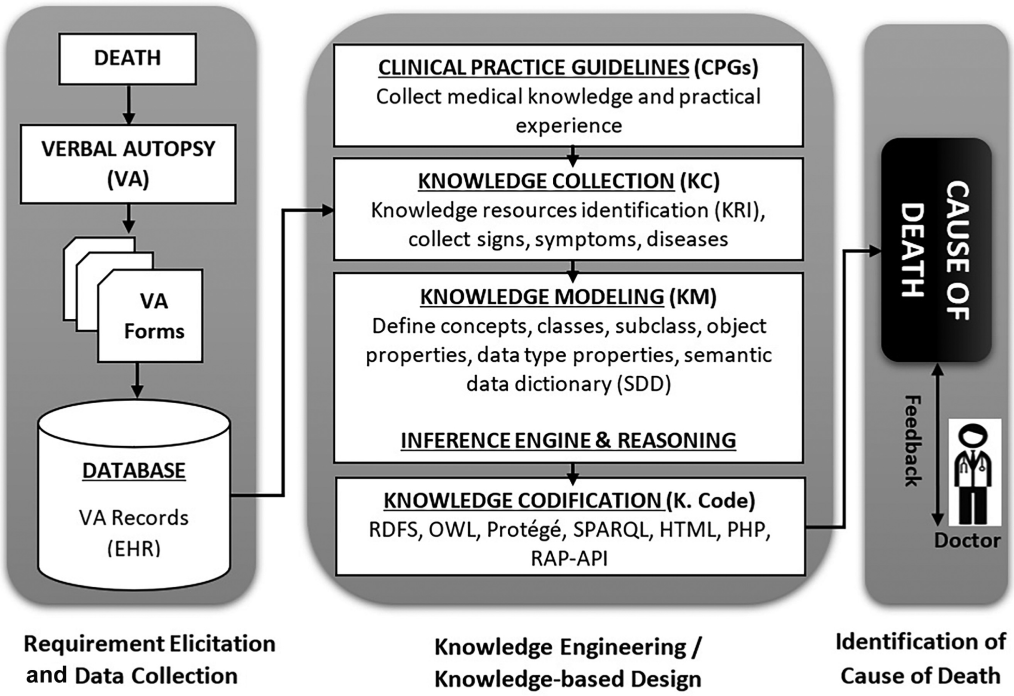


Fig. 1 Overall scheme of semantic-based verbal autopsy framework for maternal death (SVAF-MD). EHR, electronic health record.

Requirement Elicitation and Data Collection

There are various methods to determine requirements. As per scope, we have applied interview sessions, brainstorming, surveys and questionnaires, domain-expert analysis, and prototype design. It is an iterative process to gather information from stakeholders and domain experts. We introduced a neonatal, infant, and maternal death system (NIMDS)[28] to collect real-time data through user-centered design (UCD) and ethnographic techniques. The death report comes through in the form of a mobile text message (SMS). The Lady Health Supervisor (LHS) sends an SMS from her registered mobile number with predefined keywords to the system. The system cannot save the data in the database until the correct information is received from the LHS. ►Fig. 2 shows the complete flow of NIMDS data collection.

Our scope-related VA form contains eight sections (A–H) (see ►Fig. 4; ►Appendix A). Few sections (B and C) contain information about decedents' particulars. Sections D and E are of high importance, as they contain information about decedents' symptoms, complications, and pregnancy conditions. Below, an overview of VA form has been given.

- Section A: contains the detail of the person filing the VA form.
  – Form filled by (Name), designation, date, village name, etc.
- Section B: contains the particulars about a decedent.
  – Maternal name, age, date of death, etc.
- Section C: contains the medical history of a decedent.
  – Number of pregnancies, the total number of live children, nature of delivery, etc.
- Sections D and E: contain the information about the pregnancy condition, its complications, and symptoms.
  – Anemia diagnosed (Yes/No), bleeding before death (Yes/No), foul-smelling discharge (Yes/No), etc.
- Section F: provides the information about the hospital where the delivery case was conducted (if available).
  – Hospital name, any delay in hospital (Yes/No), doctor available (Yes/No), etc.
- Section G: shows some information about the availability of a death certificate.
  – Death certificate available (Yes/No), if yes, what is the cause of death according to the certificate?
- Section H: records the CoD given by a doctor.
  – Obvious cause of death, the underlying cause of death, if any, etc.

Knowledge Engineering/Knowledge Design

Ontology development or ontology engineering undergoes many phases and according to G. Antonio et al,[29] the major phases are determined scope, consider reuse, enumerate terms, define taxonomy, define properties, define facets, define instances, and check for anomalies. All the steps have been taken after discussion with subject matter experts (SMEs), carefully considering the VA forms and literature in the domain of verbal autopsy.

The semantic-based CDSS empowers a real quality of information with accuracy, timeliness, and a paperless environment. It helps to identify the causes of maternal mortality. The various local-level demographic pockets are identified with respect to mortality causes. In recent years, researchers have been developing ontologies in different domains[30] but an ontology to identify the cause of maternal death is not available. Our proposed SVAF-MD facilitates the VA process and helps identify the causes of maternal death.

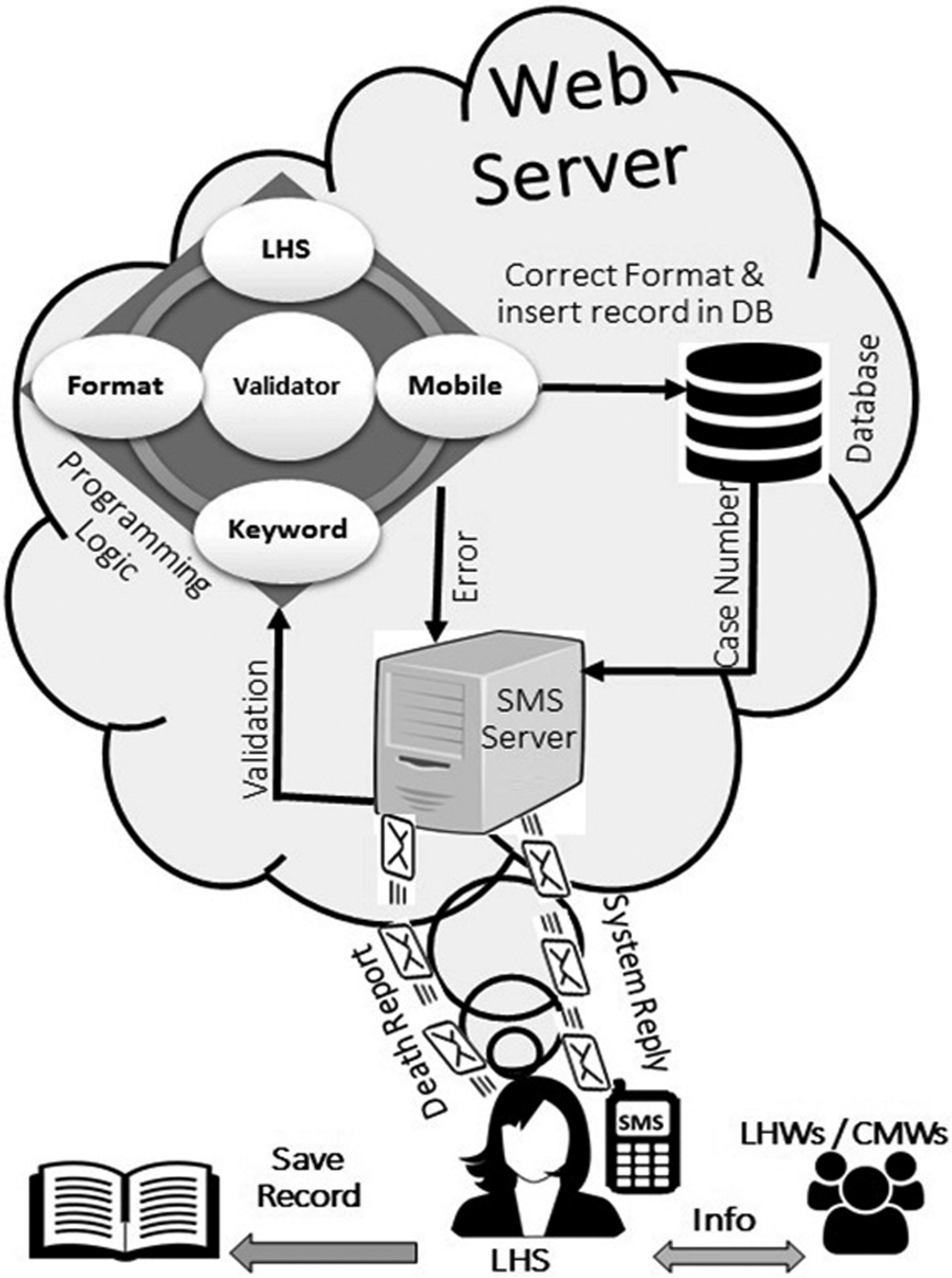


Fig. 2 NIMDS reporting system for data collection. CMW, community mid wife; DB, database; LHS, lady health supervisor; LSW, lady health worker.

The proposed knowledge design, from text to data bits and data bits to knowledge bytes is explained below in four phases.

1. Clinical practice guidelines (CPGs).
2. Knowledge collection (KC).
3. Knowledge modeling (KM).
4. Knowledge codification (K Code).

Clinical Practice Guidelines

Our research scope is related to gynecology, so domain experts or subject matter experts (SMEs) in our case are gynecologists and doctors. Therefore, to acquire theoretical knowledge and practical experience, we have conducted multiple interview sessions with two gynecologists and a general doctor. Furthermore, this knowledge also helps define concepts, properties, verbs, terminology, rules, and procedures. An example of terms with mapping to corresponding concepts or their synonyms is shown in ►Table 1.

Knowledge Collection

In addition to interview sessions, VA knowledge is also collected through domain knowledge (basic medical information related to verbal autopsy), scope-related data (decedent complete medical history),[28] clinical observations (practical experience of gynecologist), and WHO

Table 1 Term mapping to synonyms/symptoms

Term	Synonym/symptoms
PPH	Postpartum hemorrhage
Bleeding	Vaginal bleeding
Minor hemorrhage	Blood loss less than 50 mL
Major hemorrhage	Blood loss 50–1,000 mL without signs of circulatory shock
Massive hemorrhage	Greater than 1,000 mL with or without signs of circulatory shock

guidelines.[31] The domain knowledge covers the concept of cause identification and recommendation. To diagnose a VA cause, the complete verbal autopsy information of the decedent is needed. This information includes the risk factors, signs, and symptoms of the decedent.

Knowledge Modeling

Domain ontology comprises a set of classes, subclasses, object properties, and data-type properties. The relationship between classes is defined through object properties and data-type properties containing the data. The knowledge acquired from the previous phase (KC) is used for knowledge modeling.

Semantic Data Dictionary

Semantic data dictionary (SDD) is a standard approach for presenting dataset as machine readable.[32] It contains the specifications of a dataset, that is, content and its description. In our scenario, the SDD contains the classes, concepts, verbs, data properties, object properties, and synonyms.

Concepts

A class is a method of defining groups, according to their meaningful resources. We defined the classes and subclasses of maternal ontology, and a few of them are shown in ►Fig. 3.

- "Attendant" contains the subclasses information of the person who conducted the delivery, that is, "Doctor," "Community Mid Wife (CMW)," "Lady Health Visitor (LHV)," "Lady Health Worker (LHW)" and "Nurse."
- "CausesOfDeath" contains two subclasses, that is, "DirectObstetric" and "IndirectObstetric."
  - "DirectObstetric" contains the subclasses, that is, "Abortion," "Eclampsia," "Haemorrhage," "ObstructedLabor" and "Sepsis." "Sepsis" consists of three types, and these are "SepticShock," "SevereAbdominalPain," and "SevereAnemia."
  - "IndirectObstetric" contains the subclasses, that is, "AcuteHeartFailure," "ANN," "Anemia," "AntiPartumHaemorrhage," "Asthma," "BrainHaemorrhage," "CardiacDisorder," "CardiopulmonaryArrest," "ChronicRespiratoryStress," "CVA," "Dehydration," "Diabetes," "DisseminatedIntravasularCoagulation," "DUT," "EclampticFits," "EPH," "Fits," "HaemorrhageAnemia," "Hdp," "HeartFailure," "HELLPSyndrome," "HighBloodPressure," "Hypertension," "Hypovolumia," "Meningitis," "Myocardial Infunction," "PIH," "PostPartumHaemorrhage," "Preeclampsia," "ProlongedLabour," "PulmonaryEmboli," "RenalFailure," "Septicemia," "Shock," "StruckedBreach," and "UterineRupture."
- "DeliveryTypes" contains the subclasses information about delivery types, that is, "C-Section," "ForsepsDelivery," "Normal," "VacuumExtraction," and "VaginalBirthAfterCesarian."
- "OtherFactors" contains the subclasses information, that is, "AnyHistoryOfTrauma," "BloodGroupOfHusband," "CauseOfCSection," "ConditionOfPreviousBabyBorn," "DelayInDelivery," "DelayInHospital," "DurationOfLabour," "GapBetweenPreviousAndPresentPregnancy," "HealthStatusOfPatient," "Height," "HistoryOfAnyDischargeDuring Pregnancy," "HistoryOfBleedingDuringPregnancy," "HistoryOfFeverDuringPregnancy," "ModeOfDelivery," "PreviousCSectionOrNormalDelivery," "PreviousPregnancyDiseases," "PreviousPregnancyOutcome," and "TwinPregnancy."

Data-Type Properties

A relationship between classes and data are established in ontology through data-type properties. Data type properties contain the value in the form of text, a string, or an integer. The defined data type properties of the semantic-based framework SVAF-MD are as given below.

- "anemiaDuringANC" describes whether a patient is anemic during antenatal care (ANC).

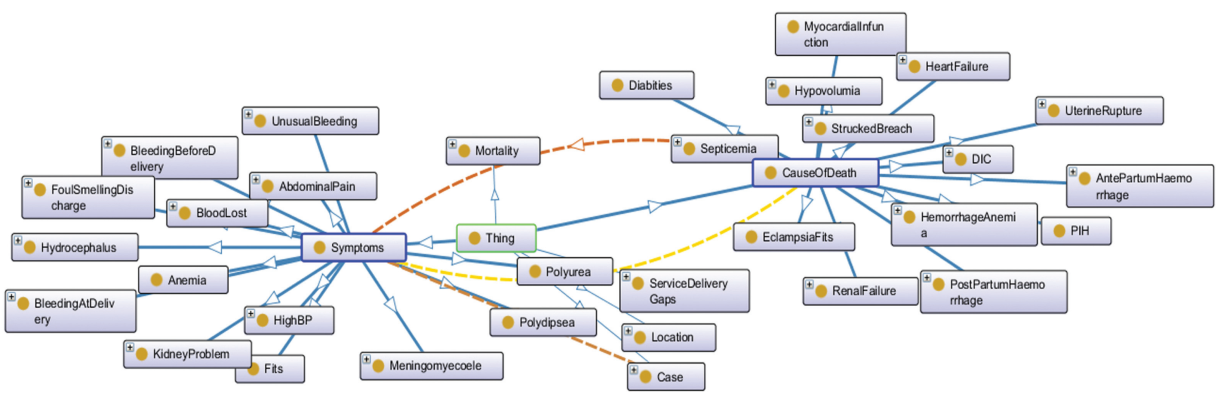


Fig. 3 Ontology classes and subclasses relationship (Protégé view). BP, blood pressure; DIC, disseminated intravascular coagulation; PIH, pregnancy-induced hypertension.

- “anteNatalCareVisits” identifies the ANC visits information.
- “complicationsBeforeThisPregnancy” identifies any complications before this delivery.
- “cSectionBeforeDelivery” identifies any C-section conducted before this delivery.
- “diedDuringTravel” identifies the death during travel.
- “durationOfLastPregnancy” identifies the duration of the last pregnancy.
- “firstPregnancy” identifies the first pregnancy.
- “gapBetweenPregnancyInMonths” finds the gap between pregnancies in months.
- “gapBetweenPregnancyInYears” finds the gap between pregnancies in years.
- “hasAbortions” identifies any abortion before this delivery.
- “hasDelayInReachingHospital” identifies any delay in reaching the hospital.
- “hasDescription” contains a description of a case.
- “hasHospitalName” identifies the hospital name.
- “hasLiveBirths” identifies the number of live births.
- “hasNoOfANCVisits” identifies how many ANC visits were conducted.
- “hasReference” identifies the reference, if any.
- “hasStillBirths” identifies the still births/dead babies.
- “isDeathCertificateAvailable” identifies any death certificate available.
- “lhwOrCmwVisitInLastPregnancy” identifies LHW or CMW visit in last pregnancy.
- “lhwRefferedForDeliveryToHospitalOrClinic” identifies LHW referral for delivery to hospital or clinic.
- “liveNoOfBoys” identifies the number of live boys.
- “liveNoOfGirls” identifies the number of live girls.
- “reasonOfDelayInReachingHospital” identifies the reason for delay in hospital.
- “timeOfDeath” identifies the time of death.
- “treatementGiven” identifies the treatment.
- “treatementSatisfactory” identifies a satisfactory response.
- “ttInjectedDuringPregnancy” identifies whether a TT injection was applied during pregnancy.
- “wasAttendantAvailable” identifies the staff available in hospital.

Object-Type Properties

It represents the relationship among classes. The defined object properties of the SVAF-MD are as given below.

ancPerformedBy	*belongsToMortality*	*caseHasDistrict*
deliveryConductedBy	*districtHasCity*	*hasAge*
hasCauseOfDeath OnBirthCertificate	*hasComplication*	*hasDeliveryType*
hasDisease	*hasExternalFactor*	*hasLocation*
hasPreviousPregnancy Result	*hasPlaceOfDelivery*	*natureOfDelivery*
hasSymptom	*lastPregnancy Outcome*	*hasPlaceOfDeath*

Restrictions in Ontology

One of the advantages of web ontology language (OWL) is that we can apply restrictions on properties. In the following resource description framework schema (RDFS), owl: Restriction for “hasSymptom” is provided. We have applied restriction on the following symptoms that become the cause of AcuteHeartFailure.

Resource Description Framework Schema (RDFS)

```
<owl:Classrdf:about=“AcuteHeartFailure”>
<rdfs:subClassOfrdf:resource=“IndirectObstetric”/>
<rdfs:subClassOf>
  <owl:Restriction>
    <owl:onPropertyrdf:resource=“hasSymptom”/>
    <owl:someValuesFromrdf:resource=“PerfuseSweating”/>
  </owl:Restriction>
</rdfs:subClassOf>
<rdfs:subClassOf>
  <owl:Restriction>
    <owl:onPropertyrdf:resource=“hasSymptom”/>
    <owl:someValuesFromrdf:resource=“LegOedema”/>
  </owl:Restriction>
</rdfs:subClassOf>
<rdfs:subClassOf>
  <owl:Restriction>
    <owl:onPropertyrdf:resource=“hasSymptom”/>
    <owl:someValuesFromrdf:resource=“ChestPain”/>
  </owl:Restriction>
</rdfs:subClassOf>
<rdfs:subClassOf>
  <owl:Restriction>
    <owl:onPropertyrdf:resource=“hasSymptom”/>
    <owl:someValuesFromrdf:resource=“ShortnessOfBreath”/>
  </owl:Restriction>
</rdfs:subClassOf>
<synonym>AnemiaCardiacIssue</synonym>
<synonym>HeartAttack</synonym>
<synonym>AcuteMyocardialInfarction</synonym>
<synonym>DilatedCardiomyopathy</synonym>
<synonym>CardiacFailure</synonym>
</owl:Class>
```

Knowledge Codification

In the development of our SVAF-MD, Protégé knowledge editor is used for ontology design. Protégé is a common software used to develop the ontology in the Semantic Web. HTML is used for the UI design, UI is an interaction layer between the user and the system. PHP programming language (server scripting language) is used for developing dynamic web pages, XAMPP Server (PHP and MySQL database development environment) is used for local server setup and resource description framework API for PHP (RAP) is used for interaction between ontology and application. The property of RAP is for querying, parsing, storing, and serializing RDF graphs. Simple protocol and RDF query language (SPARQL) are used for querying with ontology to retrieve the data from the OWL.

Identification of Cause of Death

Next, there are some competency questions to check the working of semantic framework accuracy. Multiple SPARQL queries are provided to show how the CoD is identified through symptoms. For example, we can ask the knowledge base what could be the reason of death if a woman dies

Table 2 Result of competency question query-1

Causes of death	Symptoms
Prolonged labor	IdentifiedCause some meningomyecoele
Struck breech	IdentifiedCause some meningomyecoele
Struck breech	IdentifiedCause some hydrocephalus
Prolonged labor	IdentifiedCause some hydrocephalus

Table 3 Result of competency question query-2

Symptoms	Cause of death
Bleeding before delivery	hasDisease some antepartum hemorrhage

because of hydrocephalus and meningomyelocele symptoms or another query could be what are the symptoms of antepartum hemorrhage (APH)?

Query-1: Identity the CoD in a Woman Having Symptoms of Hydrocephalus and Meningomyelocele
We assume that the decedent has symptoms of "Meningomyelocele" and "Hydrocephalus," assign these symptoms to SVAF-MD, a SPARQL query run at the back end and produces the result that "Meningomyelocele" and "Hydrocephalus" can be causes of "prolonged labor" or "struck breech," which can ultimately be the CoD. The result of competency question Query-1 is shown in ►Table 2.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX vo: <http://www.semanticweb.org/durrani/ontologies/2020/11/
SemanticFrameworkForVerbalAutopsy#>
SELECT distinct ?CausesOfDeath ?Symptoms WHERE {
{
?CausesOfDeath rdfs:subClassOf ?Symptoms.
?s owl:onProperty vo:hasSymptom.
?Symptoms owl:someValuesFrom vo: Meningomyelocele.
} union{
?CausesOfDeath rdfs:subClassOf ?Symptoms.
?s owl:onProperty vo:hasSymptom.
?Symptoms owl:someValuesFrom vo:Hydrocephalus.
}
}
```

Query-2: Identify the Symptoms of specific CoD, i.e., Antepartum Hemorrhage
Here, we assume that the patient died due to "Antepartum Hemorrhage (APH)," and we want to identify the symptoms of "APH." ►Table 3 shows the result of SVAF-MD that symptoms of "APH" is "Bleeding before delivery." The result of competency question Query-2 is shown in ►Table 3.

```
SELECT distinct ?Symptoms ?Disease WHERE {
{
?Symptoms rdfs:subClassOf ?Disease.
?s owl:onProperty vo:hasDisease.
?Disease owl:someValuesFrom vo:
AntepartumHemorrhage.
}
}
```

Table 4 Result of competency question query-3

Symptoms	Causes of death
Anemia cardiac issue	Acute heart failure
Heart attack	Acute heart failure
Acute myocardial infarction	Acute heart failure
Dilated cardiomyopathy	Acute heart failure
Cardiac failure	Acute heart failure

Query-3: What Are the Synonyms of Acute Heart Failure?
In this case, we assume that the death is due to "acute heart failure (AHF)" and we want to find out the terms used for "AHF." The result in ►Table 4 shows that "AcuteMyocardiaIInfection," "AHF," "AnemiaCardiacIssue," "HeartAttack," and "DilatedCardiomyopathy" are the multiple terms/synonyms of "AcuteHeartFailure." The result of competency question Query-3 is shown in ►Table 4.

```
SELECT ?o
WHERE {
vo:AcuteHeartFailure vo:synonym ?o.
}
```

Results

►Table 5 shows the identification of CoD by semantic-based framework and gynecologist. Columns 2 and 3 show the symptoms which are taken from the verbal autopsy dataset. Column 4 shows the CoD identified by the gynecologist/doctor (maternally) and column 5 proposes the CoD by the semantic-based framework. ►Table 6 shows the sample size, selected maternal cases, and framework accuracy. Initially, we have selected 100 maternal death (VA) cases from the dataset. Furthermore, 76 cases are selected based on the completeness of data, whereas 24 cases are dropped because they contain incomplete information. The CoD of 70 cases are correctly diagnosed by the SVAF-MD when compared with the reports prepared manually by gynecologists. The accuracy of the semantic-based framework is 92%.

Discussion

The 21st century is considered the information technology era based on electronic information. The heart of electronic information is knowledge management which enables it to a useful entity in our day-to-day business. The amount of information is increasing with every second; however, less

Table 5 Cause of death comparison by SVAF-MD and gynecologist

Sr. no.	Symptom-1	Symptom-2	Causes assign by gynecologist on maternal form (manual)	Causes assign by semantic-based framework (automatic)
1	Bleeding after delivery	Hypertension	Primary postpartum hemorrhage	PPH or postpartum hemorrhage, uterine tony, eclampsia, eclamptic fits, brain hemorrhage, CVA, myocardial infarction, severe headache, vomiting
2	Cardiac disorder	Swelling	Heart failure, myocardial infection,	Myocardial infection
3	Bleeding before delivery	Fever	Antepartum hemorrhage	Ante partum hemorrhage, sepsis, septic miscarriage
4	Abdominal pain		Uterine rupture	Uterine rupture, abortion
5	Fits	Hypertension	Eclampsia	Eclampsia, eclamptic fits
6	Infection	Fever	Sepsis, septicemia	Sepsis
7	Fits	Hypertension, abdominal pain	Uterine rupture, eclamptic fits	Uterine rupture, abortion, eclampsia, eclamptic fits
8	High blood pressure or hypertension	Cardiac disorder	Eclampsia	Eclampsia, eclamptic fits, brain hemorrhage, CVA, myocardial infarction, severe headache, myocardial infarction
9	Fits	Seizures	Eclampsia	Eclampsia, eclamptic fits
10	Infection	Fever	Sepsis, septicemia	Sepsis
11	Foul smelling discharge		Sepsis or septicemia	Sepsis, septic miscarriage

Abbreviation: SVAF-MD, semantic-based verbal autopsy framework for maternal death.

Table 6 Data samples and result accuracy

Data evaluation	
Total Number of maternal forms	100
Number of forms with incomplete information	24
Number of selected maternal forms for evaluation	76
Number of cause of deaths (CoDs) correctly identified by the framework	70
Number of CoDs correctly identified by the framework	06
Semantic-based framework result accuracy	92%

efforts and resources are diverted to transform this information into knowledge. Clinical diagnosis is a complex process and requires in-depth medical knowledge. Every clinical professional has a distinct degree of knowledge to diagnose the probable cause of a maternal death after studying complete medical history. Once the medical practitioners gain some medical knowledge, they have limited memory to recall. So, a semantic-based CDSS overcomes such gaps and provides the best ecosystem to address issues of variance in expertise. It is preferred that doctors stay more focused on their patient's treatment in hospitals instead of manually finding the CoD of people who already expired.

Testing and Accuracy

This section describes how testing was performed and how VA cases were selected. Out of these 100 cases, 76 were shortlisted by a team of gynecologists based on the completeness of data and these selected cases were given to SVAF-MD to infer the cause of a death automatically. We found that 70 cases were completely matched with the existing results while the other 6 could not succeed due to the limited knowledge base at that moment. On adding classes with respect to these six cases in the knowledge base, our results for all the 76 cases were fully matched with the existing record. We can conclude that increasing the knowledge base is a continuous process directly proportional to more success.

Conclusion

SVAF-MD is a semantic-based framework for the VA to assign the cause of a maternal death with minimum involvement of medical practitioners. This research helps a government to ease down the verbal autopsy process, overcomes the delays in reporting, and facilitates in terms of accurate results to devise the policies to reduce the maternal mortality. Identification of the CoD by our framework (SVAF-MD) will help a government to identify the CoD in the region and achieve the SDG-3 target. Based on the results, the government can take appropriate action and make policies to reduce the CoD in specific regions.

Future Work

The future work will be based on to identify the cause of death for infant and neonatal death including maternal death.

Clinical Relevance Statement

The semantic-based verbal autopsy framework for maternal death (SVAF-MD) in the domain of verbal autopsy to identify the cause of maternal death with minimum involvement of medical practitioners. This research helps a government to ease down the verbal autopsy process, overcomes the delays in reporting, and facilitates in terms of accurate results to devise the policies that how to reduce the maternal mortality. It is preferred that doctors stay more focused on their

A

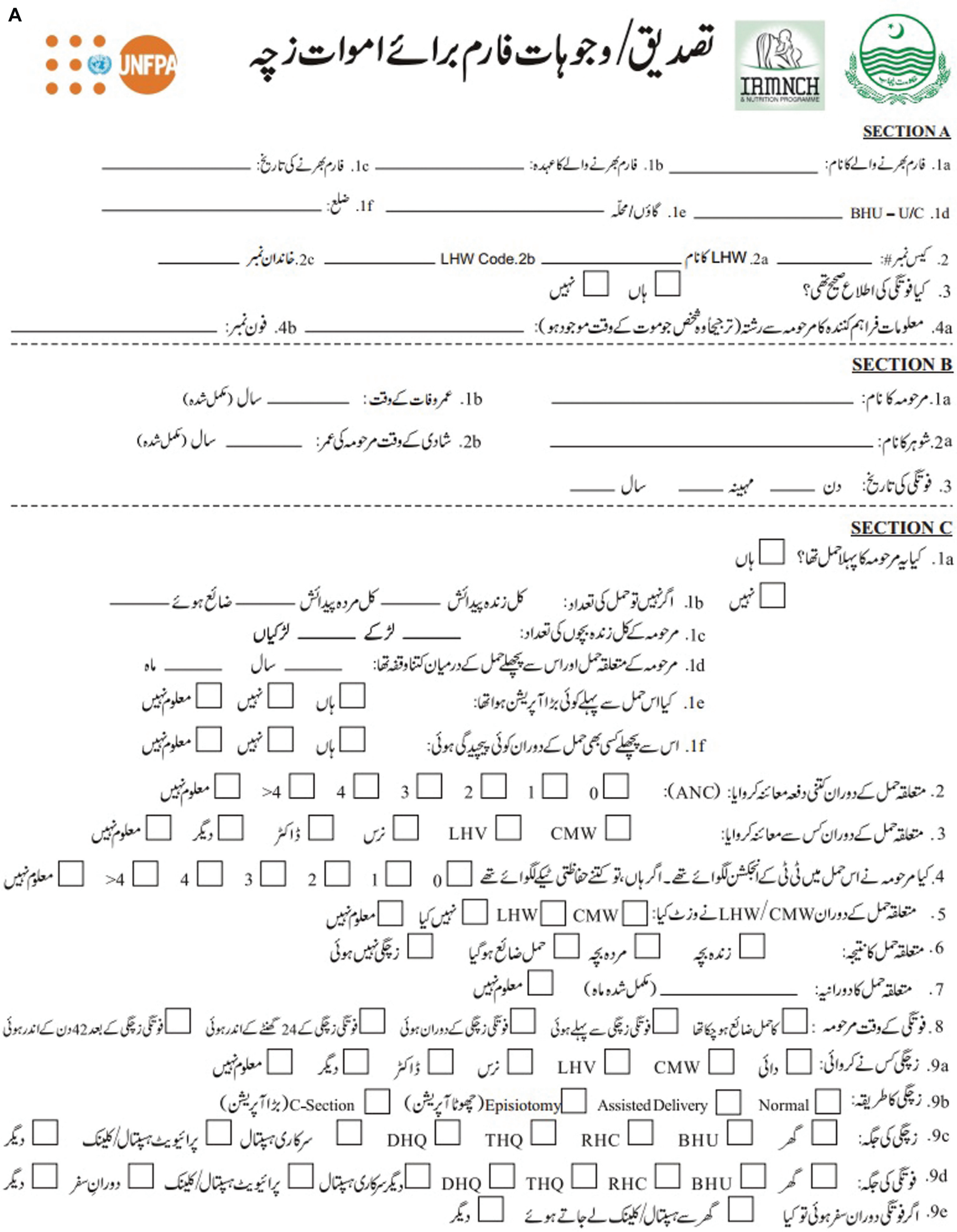
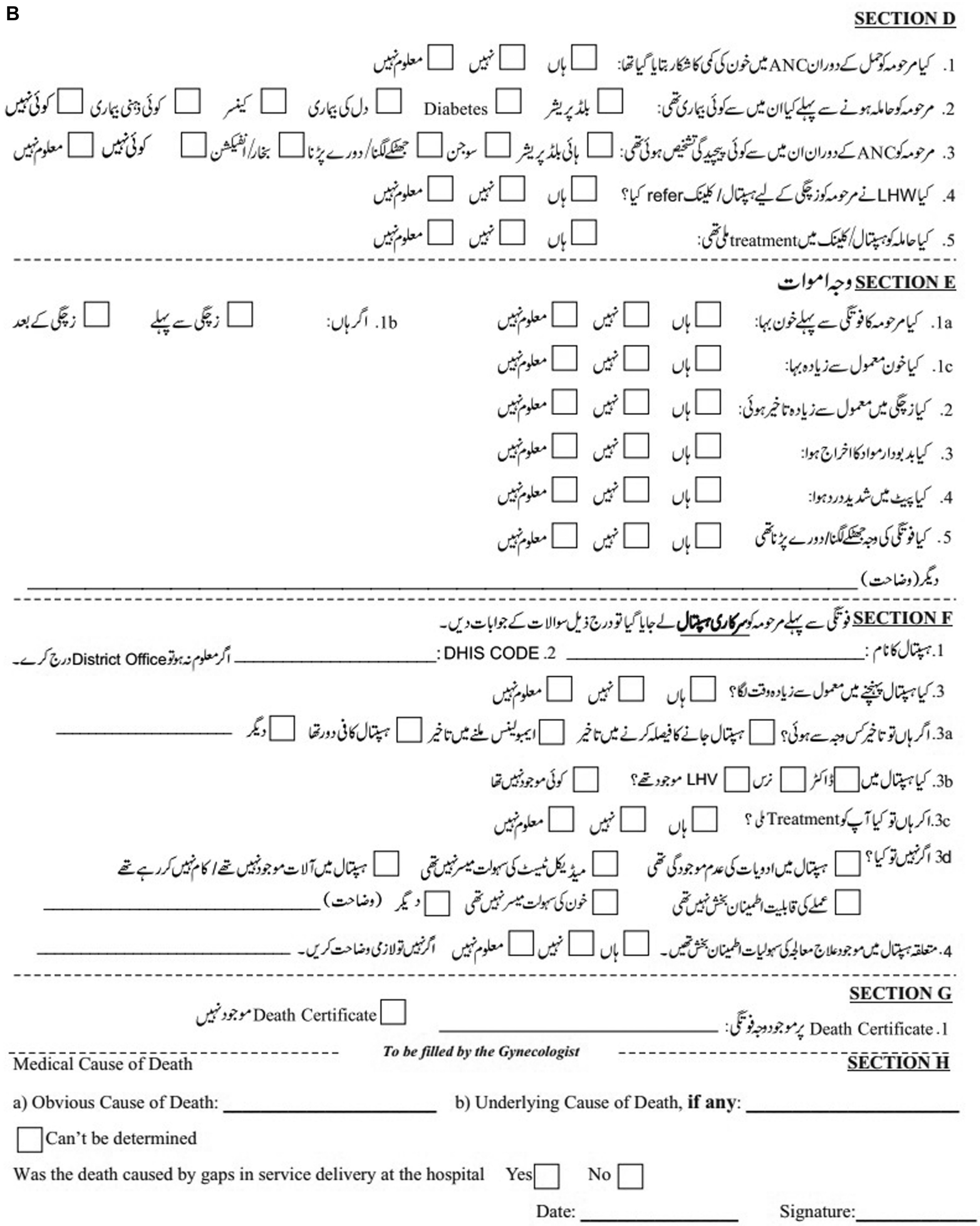


Fig. 4 (A) Verbal autopsy form for maternal death (Urdu format).


B

SECTION D

1. کیا مرحومہ کو حمل کے دوران ANC میں خون کی کمی کا شکار بتایا گیا تھا: ☐ ہاں ☐ نہیں ☐ معلوم نہیں
2. مرحومہ کو حاملہ ہونے سے پہلے کیا ان میں سے کوئی بیماری تھی: ☐ بلڈ پریشر ☐ Diabetes ☐ دل کی بیماری ☐ کینسر ☐ کوئی ذہنی بیماری ☐ کوئی نہیں
3. مرحومہ کو ANC کے دوران ان میں سے کوئی پیچیدگی تشخیص ہوئی تھی: ☐ ہائی بلڈ پریشر ☐ سوجن ☐ جھٹکے لگنا/ دورے پڑنا ☐ بخار/انفیکشن ☐ کوئی نہیں ☐ معلوم نہیں
4. کیا LHW نے مرحومہ کو زچگی کے لیے ہسپتال/ کلینک refer کیا؟ ☐ ہاں ☐ نہیں ☐ معلوم نہیں
5. کیا حاملہ کو ہسپتال/کلینک میں treatment ملی تھی: ☐ ہاں ☐ نہیں ☐ معلوم نہیں

SECTION E وجہ اموات

1a. کیا مرحومہ کا فوتگی سے پہلے خون بہا: ☐ ہاں ☐ نہیں ☐ معلوم نہیں 1b. اگر ہاں: ☐ زچگی سے پہلے ☐ زچگی کے بعد
1c. کیا خون معمول سے زیادہ بہا: ☐ ہاں ☐ نہیں ☐ معلوم نہیں
2. کیا زچگی میں معمول سے زیادہ تاخیر ہوئی: ☐ ہاں ☐ نہیں ☐ معلوم نہیں
3. کیا بدبودار مواد کا اخراج ہوا: ☐ ہاں ☐ نہیں ☐ معلوم نہیں
4. کیا پیٹ میں شدید درد ہوا: ☐ ہاں ☐ نہیں ☐ معلوم نہیں
5. کیا فوتگی کی وجہ جھٹکے لگنا/دورے پڑنا تھی ☐ ہاں ☐ نہیں ☐ معلوم نہیں
دیگر (وضاحت) ____________________

SECTION F فوتگی سے پہلے مرحومہ کو **سرکاری ہسپتال** لے جایا گیا تو درج ذیل سوالات کے جوابات دیں۔

1. ہسپتال کا نام: ____________ 2. DHIS CODE: ____________ اگر معلوم نہ ہو تو District Office درج کریں۔
3. کیا ہسپتال پہنچنے میں معمول سے زیادہ وقت لگا؟ ☐ ہاں ☐ نہیں ☐ معلوم نہیں
3a. اگر ہاں تو تاخیر کس وجہ سے ہوئی؟ ☐ ہسپتال جانے کا فیصلہ کرنے میں تاخیر ☐ ایمبولینس ملنے میں تاخیر ☐ ہسپتال کافی دور تھا ☐ دیگر ____________
3b. کیا ہسپتال میں ☐ ڈاکٹر ☐ نرس ☐ LHV موجود تھے؟ ☐ کوئی موجود نہیں تھا
3c. اگر ہاں تو کیا آپ کو Treatment ملی؟ ☐ ہاں ☐ نہیں ☐ معلوم نہیں
3d. اگر نہیں تو کیا؟ ☐ ہسپتال میں ادویات کی عدم موجودگی تھی ☐ میڈیکل ٹیسٹ کی سہولت میسر نہیں تھی ☐ ہسپتال میں آلات موجود نہیں تھے / کام نہیں کر رہے تھے
☐ عملے کی قابلیت اطمینان بخش نہیں تھی ☐ خون کی سہولت میسر نہیں تھی ☐ دیگر (وضاحت) ____________
4. متعلقہ ہسپتال میں موجود علاج معالجے کی سہولیات اطمینان بخش تھیں۔ ☐ ہاں ☐ نہیں ☐ معلوم نہیں اگر نہیں تو لازمی وضاحت کریں۔ ____________

SECTION G

1. Death Certificate پر موجود وجہ فوتگی: ____________ ☐ Death Certificate موجود نہیں

To be filled by the Gynecologist

SECTION H

Medical Cause of Death

a) Obvious Cause of Death: ____________ b) Underlying Cause of Death, **if any**: ____________

☐ Can't be determined

Was the death caused by gaps in service delivery at the hospital Yes ☐ No ☐

Date: ____________ Signature: ____________

Fig. 4 *(Continued)* (B) Verbal autopsy form for maternal death (Urdu format).

patient's treatment in hospitals instead of manually finding the cause of death of people who already expired. So, a semantic-based clinical decision support system (CDSS) overcomes such gaps, provides the best ecosystem to address issues of variance in expertise, and helps a government to achieve the sustainable development goals (SDG)-3 target.

Multiple Choice Questions

1. What is the purpose of semantic-based verbal autopsy framework for maternal death (SVAF-MD)?
   a. To identify the cause of neonatal death
   b. To identify the cause of infant death

c. To identify the cause of maternal death
All of above

Correct Answer: The correct answer is option c. The scope of the proposed SVAF-MD is to identify the cause of maternal death.

2. Who is our semantic-based verbal autopsy framework for maternal death (SVAF-MD) subject matter expert (SME)?
   a. General doctor
   b. Gynecologist
   c. Decedent
   d. Family member

Correct Answer: The correct answer is option b. Our SVAF-MD SME is gynecologist.

Data Availability

The data used to support the findings of this study are available from the corresponding author on request and data will be provided after departmental permission.

Protection of Human and Animal Subjects

This article does not contain any dangerous studies with human participants or animals performed by any of the authors.

Conflict of Interest

M.I.A.D. declares that he has no conflict of interest. T.N. declares that she has no conflict of interest. Author A.C. declares that he has no conflict of interest. N.K. declares that she has no conflict of interest. A.A. declares that she has no conflict of interest.

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Appendix A

A Key Terms

Community Midwife (CMW): is specially trained skilled birth attendant who is equipped to conduct a normal home delivery under safe and clean conditions.

Hypertext Markup Language (HTML): is used to design a web page and its content.

Lady Health Worker (LHW): is responsible for delivering community level primary healthcare, focusing on rural and urban slum populations.

Lady Health Supervisor (LHS): is responsible for administrative and supportive supervision of Maternal Mortality: is around 1:25 and this ratio may be change with respect to dynamic requirements based on landscape and demography.

Maternal Mortality: it is defined as death of women while pregnant or within 42 days of termination of pregnancy.

PHP (Hypertext Preprocessor): it is an open-source scripting language that are executed on the server side.

Resource Description Framework (RDF): is a standard model for data interchange on the web.

RAP: RDF framework API for PHP (RAP) is a software package for parsing, querying, manipulating, serializing, and serving RDF models.

Simple Protocol and RDF (Resource Description Framework) Query Language (SPARQL): is a semantic query language for databases.

Cross-platform, Apache, MySQL, PHP, and Perl (XAMPP): it allows to build site offline, a local web server on your computer.

Verbal Autopsy Form for Maternal Death

The scope related Verbal Autopsy form in Urdu format for maternal death (►**Fig. 4A** and **B**).

