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A Holistic Framework for Crime Prevention, Response, and Analysis With Emphasis on Women Safety Using Technology and Societal Participation

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ABSTRACT Ensuring women's safety in smart cities is a need of the hour. Even though several legal and technological steps are adopted worldwide, women's safety continues to be an international concern. Criminal records are maintained by law enforcement agencies and are most often not available to the public in an easily comprehensible form. While some wearable devices and mobile applications are available which are touted to aid in ensuring women's safety, they utilize limited societal intervention and are not very efficient in ensuring the safety of the women as and when required. Most often the crime response, crime analysis, and crime prevention schemes are not integrated, leading to gaps in ensuring women's safety. Our major contribution is in developing a holistic system encompassing the three crucial aspects, i.e crime analysis and mapping, crime prevention, and emergency response by leveraging societal participation for women safety management. This work applies the Geographic Information System (GIS) for the identification of hotspots and patterns of crime. The proposed system uses data generated from the mobile application and/or wearable gadget prototyped as a part of this work along with the criminal history records for crime response, analysis, and prevention. The system for the hotspot identification is demonstrated for the Pilani town in the Jhunjhunu district in the state of Rajasthan, India, and can be easily scaled up geographically and utilized as a safety strategy for smart cities. While the common man is provided a cost-effective solution via the developed mobile application or wearable gadget, the various components are integrated into a website for supervisory management and can be utilized by law enforcement agencies.

INDEX TERMS Smart cities, geographic information system (GIS), crime analysis, crime response, women safety, mobile application, wearable device.

I. INTRODUCTION

Gender-based disparities are one of the major issues of the current century. Even though constitutional rights have vouched for gender equality, it is a reality that gender-based disparity exists in several sections of societies across the world. The 21st-century women have to a certain extent succeeded in contributing to society and working shoulder to shoulder with men in several fields. However, violence against women is being increasingly reported in recent times across the world. According to António Guterres, the ninth Secretary-General of the United Nations, violence and abuse against women are among the world's most horrific human rights violations, affecting 1 in every 3 women in the world [1]. Gender equality is the prerequisite for a better world. Gender-based violence on females limits women's participation in decision making leading to a decline in life quality. Women's equal participation is vital to stability, to prevent conflict, and to promote inclusive and sustainable development.

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Though the intensity of violence against women may vary, no country has remained unaffected and there is a need to understand the root cause behind the crimes and find solutions. Today, the crime mapping and crime response remain majorly a responsibility of law enforcement agencies. Crime record data is maintained by law enforcement agencies and is most often not available to the public in an easily comprehensible form to take necessary precautions. Even though crime prevention is a major concern of the police force, since the human resource capacity of the police force is small relative to the population, their services sometimes tend to get limited to crime response than crime prevention. Some wearable devices and mobile applications are developed over the years towards ensuring women's safety. However, most of these applications and wearables either raise an alarm in the form of visual or audio cues or sent messages to the contacts (guardians) or law enforcement agencies. If a woman moves out of the city or away from their guardians these systems do not serve the purpose. These systems utilize limited societal intervention and are not very efficient in ensuring the safety of the women as and when required. Most often the crime response, crime analysis, and crime prevention schemes are not integrated leading to gaps in ensuring women's safety.

In this paper, we present a holistic framework encompassing the three crucial aspects, i.e crime analysis and mapping, crime prevention, and prompt emergency response leveraging community participation. Geographic Information System (GIS) techniques are utilized in the proposed system to identify hotspots and patterns of crime by integrating socio-economic attributes of the area along with the criminal history. Using the information generated regarding the crime statistics using the GIS techniques, the user can take necessary preventive measures before visiting an area. A prototype of a wearable device and mobile application is developed. The mobile application and the wearable gadget can be used to trigger a panic signal to alert the volunteers in proximity, in addition to the contacts and law enforcement agencies. The mobile application and gadget allows tracking of the person/volunteer and generates data for further crime analysis. This caters to the prompt crime response as societal participation is also leveraged. An interactive website is developed for the visualization of GIS analysis, and data generated through wearable and mobile applications. Through this website, the administrator (law enforcement agencies) can track the movement of victims and nearby volunteers in real-time and assist both in an emergency. The administrator can also update the database of criminal records regularly and the crime hotspot analysis will be updated automatically. The prototype of the framework developed for crime mapping, prevention, and crime response can be easily scaled up geographically and updated easily as a safety strategy in smart cities. The novelty, detailed design, implementation of the proposed system is described in detail in the subsequent sections.

II. RELATED WORK & RATIONALE OF THE PROPOSED WORK

Women's safety has been one of the top priorities for law enforcement agencies for several decades. Police departments around the world are facing demands to adopt newer solutions to handle the concern of women's safety. Various measures have been undertaken even in the past by police and public, through initiatives such as the starting of the dedicated police wings for woman safety, numerous mobile applications, severe punishments for offenders, etc. Other than dialing the police control room, the mechanisms available for women to seek help can be classified into two categories- smartphone assisted 'app' based mechanisms & dedicated gadget based mechanisms. In this section, we discuss popular mobile applications and wearables that are available for women's safety and analyze the possible technological interventions to improve women's safety. With the advancements in GIS techniques, it is possible to design proactive measures whereby which the hotspots of crime can be identified and preventive actions can be planned. In this section, we also discuss the notable works in analyzing occurrence of crime using GIS technologies.

A. MOBILE APPLICATIONS FOR WOMEN SAFETY

Some of the popular mobile applications available for women safety are summarized in Table 1. Most of these applications are reactive, i.e. can raise an alert when the user is in danger. These applications provide a means to contact the police, selected contact persons, or guardians when triggered. If the user goes to a distant location away from the contacts, only the police force will be available for help, and sending alerts to contacts at a distant place may be of limited use. Most of the applications do not offer assistance in warning women about a danger prone area. My SafetiPin app classifies a public area as 'unsafe' or 'safe' at night, based on parameters such as lighting conditions, openness, visibility, number of people in the vicinity, number of police stations, walking path, etc [2]. However, the reliability of the warnings generated by this application is mostly limited by the perceived data as entered by other users and not based on criminal history records from reliable sources. Also, higher number of people of the opposite sex in an area or poor visibility or lighting conditions may not necessarily indicate that the area is unsafe for women. It has to be noted that the safety of women is compromised even within house premises. These factors thus cause limited use of the available applications in ensuring women's safety.

B. WEARABLE DEVICES FOR WOMEN SAFETY

As mentioned in Table 1, several mobile applications are available, which lets the user alert the contacts in case of perceived danger. However, during an emergency, it may not be always possible to access the phone, unlock it, open an app, and trigger the alert. Wearables are developed to address this scenario. Some of the popular commercially available wearable devices are listed in Table 2. Some of the wearables

TABLE 1. List of popular mobile applications available for women safety.

Application	Main functionality on activation
Eyewatch SOS [2]	Captures audio & video of the user's surroundings and sends SMS or call guardian
iGoSafely [2]	Sends messages every 2 mins, optionally sends 30sec video on shaking phone
CitizenCop [2]	Crime reporting to police and supports live tracking, emergency calls and SOS alerts to guardians
Chilla [2]	On shouting, sends an alert message/call to the guardian. Send alert to contacts on pressing the power button 5 times
Suraksha [2]	Integrated to Police Computer Aided Dispatch System, sends 10 seconds video clip to the police
Himmat [2]	Captures live location & surrounding audio-visual information and transmit to the Delhi Police Control Room
Trakie [2]	Send real-time location, speed of travel, phone battery percentage and mobile network signal strength to selected numbers
Smart 24x7 [3]	Calls police/selected contact. Also allows to click photos and records audio-video of the surroundings
bSafe [3]	Records audio & video of the surrounding areas, track the user
Shake2Safety [3]	Send picture of surroundings, location information as text message to selected numbers
My SafetiPin [3]	On entering an unsafe location, gives alerts and invite family/friends to track the user

TABLE 2. List of popular wearable devices for women safety.

Name	Communication	Worn as	Action on Activation
Safelet [4]	Bluetooth	Bracelet	Alerts selected contacts and sends audio-video data
SpotnSave Feel Secure [5]	Bluetooth	Band/Keychain /Neckpiece	Sends a text with a link to the location to selected contacts every two minutes
Siren [6]	-	Ring	Emits a 110+ decibel alarm on activation
ATHENA [7]	Bluetooth	Magnetic clip attachment	Pressing Athena will immediately send SMS alerts with live GPS position information
Stilleto [8]	Bluetooth	Charm	Alerts friends, family members, police
Sonata ACT [9]	Bluetooth	Watch	Sends emergency alerts to a network of pre-set recipients
SAFER [10]	Bluetooth	Bracelet/Necklace	Pairs with mobile phone app to contact stored
REVOLAR [11]	-	Keychain	Sends message to contacts when pressed twice or thrice
Sound Grenede [12]	-	Wristlet	120 decibel alarm is activated

(eg: Siren or Sound Grenade) are standalone, which does not pair with a smartphone, and will generate high decibel sound on triggering thus alerting people in the near vicinity. However, this might also put the woman at risk as this might cause the pervert to attack the woman in an attempt to save himself. Other wearables as mentioned in Table 2, are not standalone. They pair with a mobile application on a smartphone using Bluetooth technology and then use the smartphone features to send alerts to pre-configured contacts, police, etc. 'Safelet', has two buttons on the side that can be pressed to send a distress message to selected contact numbers. The 'Stiletto' charm pairs with the mobile app and transmits a voice-assisted alert to selected contacts when triggered. The Sonata watch 'ACT' paired with a smartphone can send out panic messages to a set of contact numbers. If the phone is lost, thrown away by the attacker, or if phone is out of charge then the wearable will not serve its purpose.

Current solutions focus on limited crowd sourcing and are insufficient in ensuring the safety of the women as and when required. With the advancements in GIS, it is possible to design proactive response measures whereby the hotspots of crime can be identified and preventive actions can be planned [13].

C. GIS FOR CRIME ANALYSIS

This section provides a brief review of the notable works reported for crime analysis and hotspot mapping based on GIS techniques. Reference [14] analyses crime against women in Chandigarh, India using GIS Analysis. It is a preliminary work that involves the mapping of crime data and police stations in the area. The study reveals that crime against women is lesser in areas closer to the police station. As a part of the 'Free to Be' project, in the year 2018, young women were enabled to travel to popular cities across different countries to identify and share public spaces that make them feel uneasy and scared, or happy and safe [15]. Those women were asked to identify their experiences based on perceived safety. The identified points were tagged to a precise geographical location and a visual representation was derived in which the aggregated perceived level of safety was marked using color-coding. The visual representation was then made available to the public through a website. However, the data used for the visualization is based on data collected in 2018, and the hotspot identification is based on the perceived level of safety and not based on actual crime history. As very limited work is available in the literature regarding the application of GIS techniques for analysis of crime specifically against women we also reviewed the works on crime analysis in general.

Reference [16] paper presents a data-driven approach for the prediction of the number of crimes in the city of Chicago. The identification of crime dense regions or hotspots was performed on the real-world data set available for the area of Chicago. Once the hotspots were identified, the number of crimes reported in hotspots were extracted and a time series prediction technique was used for the prediction of the number of crimes in each hotspot. The dataset included information such as the type of crime, location, date, community area, etc. For the identification of hotspot, Density-based Spatial Clustering of Applications with Noise (DBSCAN) based clustering technique was utilized. Given a set of points in space, DBSCAN groups together points that are closely packed together leaving out the outliers. The objective behind hotspot identification in this work was to only identify and limit the further study to the hotspot areas and hence clustering technique was utilized. Identification of hotspot shifting or investigation of factors leading to the crime was not included in the scope of the work.

References [17]–[19] highlighted the potential of GIS techniques in identifying crime prone sites and then mapping them. Creating a database with relevant crime information and associated spatial data is a crucial aspect. The type of additional non-spatial information included in the database such as population, gender, etc varies across the different applications. Byungyun Yang identified crime prone areas based on the Kernel Density Estimation (KDE) technique [19]. In this work, the crime datasets (crime type along with the location coordinates) were saved in the CSV file format. Grubesic et al. in their work identified crime hotspots using the clustering technique [20]. The author highlighted that additional research work to reduce its complexity in addressing hotspot detection is required for its application to practical scenarios. Mitchell and Minami [21] in their paper discussed the various factors influencing the increase in crime rates over the last few decades in the United States. The author identified several socio-economic variables such as household income, educational achievement, employment status, and poverty status. The authors applied multiple regression analysis to depict the relationships between socio-economic/demographic variables and crime variables in the crime hotspots of Pittsburgh. The scope of the work was to identify the factors affecting the crime rather than identifying hotspots of crime.

Popular techniques for the hotspot mapping are discrete point mapping, choropleth mapping, grid mapping, spatial ellipse mapping, and kernel density mapping [22]. In choropleth mapping, the study area is divided into various geographic units and each unit is shaded based on the number of crimes reported within it. The geographic units can be of different sizes and shapes. In grid mapping, grids of uniform size and shape are generated across the study area and shaded depending on the number of crimes reported within each of them. In spatial ellipse hotspot mapping method, points are grouped into clusters based on their proximity, and a standard deviational ellipse is fitted to each cluster to indicate the dispersion of points in the cluster through the ellipse's size and alignment. Density mapping is probably the most commonly used hotspot mapping technique. The point density, line density, or kernel density can be mapped [23]. In a point (or line density) calculation, the magnitude-per-unit area from point features (or polyline features) that fall within a neighborhood around each raster cell is calculated. Kernel density mapping calculates a magnitude-per-unit area from the point or polyline features using a kernel function to fit a smoothly tapered surface to each point or line. However, the smoothing can also lead to inaccuracies especially in applications such as crime monitoring when the amount of data available may be very less when compared to the geographic area or the population of the area.

WebGIS is an advanced GIS system available on the web platform. This facilitates the users to browse the spatial data, generate or view thematic maps on the WebGIS site. The major components of a WebGIS system are GIS software, associated database and server (integrated database and server systems are also referred to as database server), web server, and the web client [22]. Zhou *et al.* demonstrated five hotspot mapping techniques, i.e., discrete point mapping, choropleth mapping, grid mapping, spatial ellipse mapping, and density mapping for crime analysis on a WebGIS system [22]. The database server used in the work is 'PostgreSQL', which stores crime data. The 'PostGIS' software is used in this work. PostGIS is a free and open-source GIS software that supports various types of operating systems such as Windows, Linux, iOS, etc. The web client is installed with Adobe Flash Player and accesses the web resources through the webserver ('Tomcat') and GIS functionalities through the 'PostgreSQL' server. Reference [24] presents another WebGIS system in which 'GeoServer' GIS software is used along with ''MySQL geospatial database'. It publishes Open Geospatial Consortium (OGC) services through the spatial database engine. They have utilized HyperText Markup Language (HTML), Asynchronous JavaScript and XML (AJAX) based web client and 'Tomcat' webserver. Reference [25] utilized a virtual machine with 2GB of RAM imaged with Microsoft Windows Server hosting SQL Database, ArcGIS software, ArcGIS database server, and Javascript-based web application. References [27], [28] provides a comparison of the features of notable GIS software, their supported data server, and the web clients.

D. RATIONALE OF THE PROPOSED WORK

Building safer cities for women will be effective only with (1) understanding of various socio-economic factors that lead to violence against women so that effective measures for social reforms can be designed, (2) crime analysis and mapping to identify hotspots of crime and hotspot shifting, (3) effective use of technology through which a woman can raise alerts in case of danger (4) prompt emergency response leveraging community participation, all of which are addressed in the proposed solution. Even though some prior work is available in each of these areas, a holistic system encompassing crime prevention, crime analysis, and crime response is not available. We propose a holistic framework leveraging societal participation and four major components as described below and depicted in Fig. 1.

1) Mobile application
2) Prototype of the wearable device
3) GIS analysis for the identification of hotspots of crime
4) Website for integrated crime monitoring, response, and analysis

Each city is unique and hence we propose that the safety of the women can be best addressed by leveraging societal

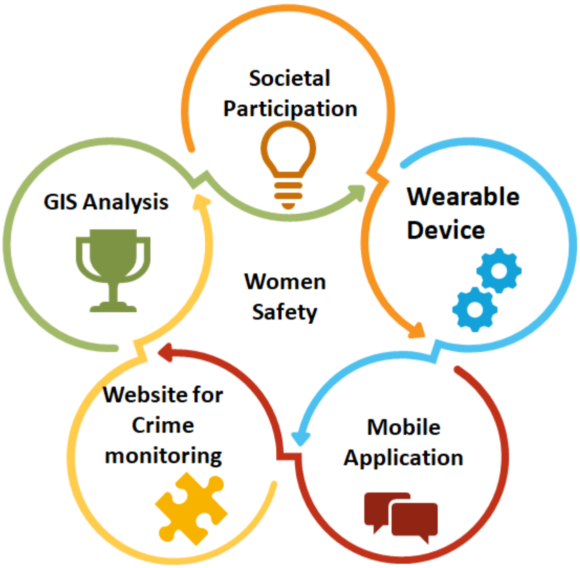


FIGURE 1. Proposed system for crime monitoring.

participation rather than completely relying on law enforcement agencies. Through our system, the users are provided with a cost-effective wearable gadget and a mobile application to raise an alert when they are in danger. The crime response is leveraged through community participation. The volunteers who are in the vicinity of the person in danger will receive notifications regarding the users in danger and can track the person in danger and assist her in addition to the police or guardian. The use of wearable gadget is optional. Wearable gadget designed in the system can be utilized as a standalone device and hence, can be used to trigger alerts even when the smartphone is not active. In case if the user do not want to invest on buying the wearable, the mobile application can be used for raising the alert. The website developed acts as an integrator between several components of the system such as mobile application, wearable device, and GIS-based hotspot visualization. The GIS visualization of hotspots of crime will help the user to identify possible threats in a locality and take necessary precautions. The supervisory management of the website can be done by the law enforcement agencies. The system is designed in such a way that the website administrators can update the crime records from time to time and the hotspots of crime will be updated in the website accordingly. The website administrators or law enforcing agencies can monitor the users in danger and responses of volunteers to the alert.

The design of the proposed system is explained in detail in the subsequent section.

III. PROPOSED CRIME MONITORING, RESPONSE AND ANALYSIS SYSTEM

In this section, the holistic framework developed for crime prevention, crime response, and analysis are presented. The design of four major components of the framework, i.e the mobile application, GIS analysis for identification of hotspots of crime, the wearable device, and website for crime monitoring are explained in this section.

A. MOBILE APPLICATION -"SpotHer"

A unique feature of the mobile application which is developed, i.e "SpotHer" is that the emergency crime response is supported by societal participation in addition to the response from law enforcement agencies and local guardians. To ensure societal participation, a network of authorized volunteers is created to assist the needy. The background/history of volunteers can be subjected to verification. "SpotHer" application supports interfaces for registration of users using phone number and One Time Password (OTP) based verification. The user can be either a victim or a volunteer. On registration, the user also gets registered as a volunteer. The user and volunteer activities are summarized using a use case diagram as shown in Fig. 2. Application is meant for crime response initiation triggered by a specific event, particularly-pressing of 'Save our Souls (SOS)' button on the application by the person in danger and acceptance of SoS notification by a volunteer.

The application supports the following features for victim monitoring :

- On logging in with the credentials, the user will be directed to a home page which displays the current location of the user along with the other users within a configurable radius on a map. Save Our Souls (SOS) button on the page can be pressed by the user in the case of an emergency event.
- When the SOS is pressed, a notification is sent to the registered users within a configurable radius (default configuration is 2kms). The notification can be also sent to the police and selected contact numbers/guardians. Once the SOS is pressed, the latitude and longitude coordinates are recorded and transmitted to the realtime NoSQL cloud firebase database at the interval of every 30 seconds. This information will be further displayed on the website designed for crime analysis.
- On receiving an SOS notification from the victims, a volunteer can click on the notification to help the victim. On selecting the notification, the volunteer will be redirected to another page containing Google maps. The volunteer can navigate to the user by clicking on the navigate button embedded in the Google maps.
- Once the user is safe, she can mark herself safe by pressing a 'Mark yourself safe' button of the application.
- Once the victim marks her 'safe', all the notified volunteers will be again notified of the safety status.

The various user and volunteer screens are shown in Fig. 3. and Fig. 4. respectively.

SQLite library which implements SQL relational database management engine is used for storing the application data including the user name and password on the phone. As the requirement of local data storage is minimal, this lightweight relational database is an ideal candidate for the application.

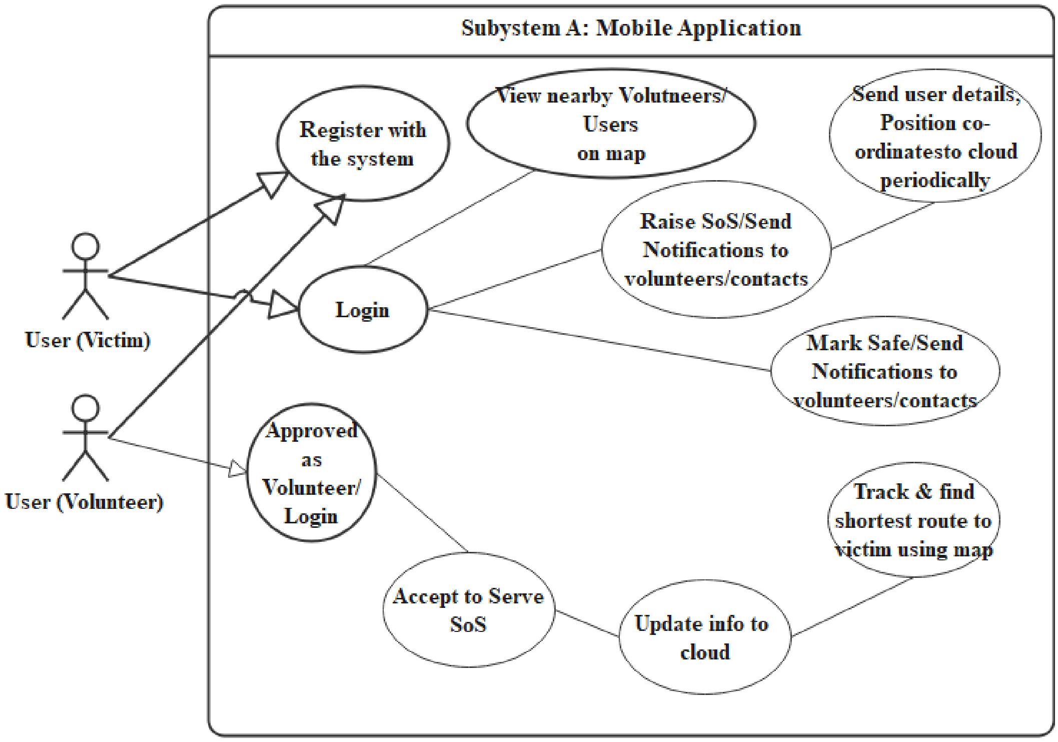


FIGURE 2. Use cases for mobile Application-'SpotHer'.

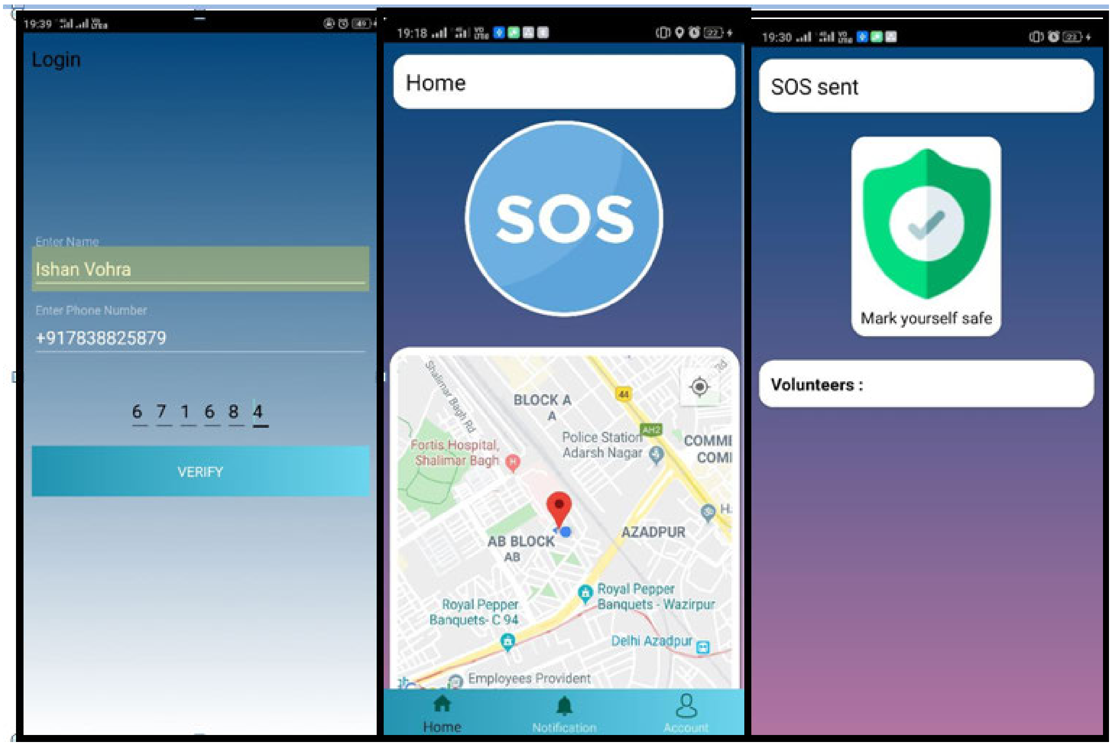


FIGURE 3. Various page views of SpotHer app for user (victim).

1) CLOUD DATABASE FOR STORING DATA FROM MOBILE APPLICATION & WEARABLE DEVICE

This section provides a brief description of the cloud data storage of the data collected from the "SpotHer" application and the wearable device. The database used for storing and manipulating data is the real-time NoSQL firebase cloud database. Data is stored in the firebase cloud in JSON format and is synchronized in realtime to every connected client.

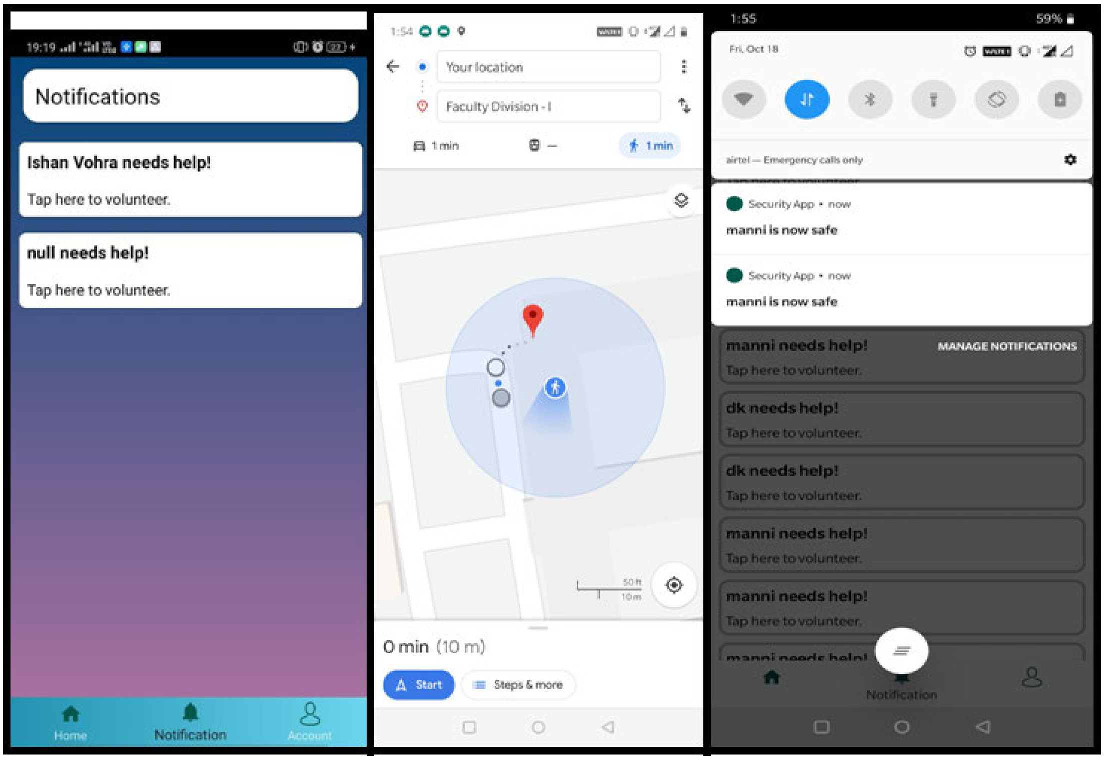


FIGURE 4. **Various pages of SpotHer app for volunteer.**

The same database can be utilized even if we plan to develop the application for iOS users as well. Firebase applications remain responsive even when offline because it persists the data to disk. Once connectivity is reestablished, the client device receives the missed data if any, and synchronizes with the current server state.

The structure of the real-time database was designed to have the following fields:

- User login details- named as 'users' in database: This field stores the information of the users registered with the app, such as the name, registered phone number, emergency contact numbers and the automatically generated unique ID (foreign key)
- User location details- named as 'userLocation' in database: This field stores the information such as the latitude and longitude coordinates of the user.
- SOS details-named as 'sosDetails' in database: This field stores information such as the ID of the user who triggered the SOS, latest SOS timestamp along with the user's location coordinates, if any volunteer has accepted the notification for service or not, and if the user is marked 'safe' or 'unsafe'. This field also stores the information about the volunteers such as the user ID of the volunteer who accepted the notification to offer help, timestamp and location coordinates. The structure of the database is shown in Fig. 5. Once SOS is raised by the user, the app automatically generates SOS at an interval of 30s till the user is marked safe.

The data from the wearable device or the mobile application is treated in identically.

A single database instance of firebase supports up to 200,000 simultaneous connections. Each instance of a firebase database caters to a specific region. In the current implementation, the database serves the region 'asia-south1' covering India [29]. For service across the multiple regions, we will include multiple database instances catering to different regions in the same firebase project such that each database caters to a specific region. This design will ensure the load-balancing of data. When the utilization within a region may expand beyond the limit of 200,000 simultaneous connections and 1,000 write operations/second, sharding of data will be done across multiple databases [29]. The above-mentioned features can be included as per the pricing policies of the real-time database and can be made available to the users as an updated version of the application.

We have customized a set of features of firebase, i.e authentication, authorization, and role-based access control to ensure that the data is stored securely in the firebase. Firebase supports a set of authentication mechanisms such as drop-in authentication, federated identity provider integration, custom authentication integration, and anonymous authorization of the device [30]. We have utilized phone number based authentication of the device which sends data to the cloud. After authentication of the user, we control the user's access to data (authorize user) in the database using firebase rules. Separate rules are defined for the users and

FIGURE 5. Structure of the cloud database for wearable and mobile application.

the administrators and then stored in firebase servers and is always enforced always automatically [31]. We have used 'read ' and 'write' rules to ensure conditional 'read' and 'write' access to files by users and administrators. The read and write rules were defined to decide if a user can access the data and also when the data can be accessed. To ensure the integrity of data collected at the firebase, we have utilized the 'validate' rules to enforce type checking of the type of data entered by the user such as contact number and names of the guardians provided by the user, etc. In addition to this, the firebase services also encrypt the data at rest and encrypt data in transit using HTTPS. As the number of users increases, the query response mechanism can degrade. Hence, 'indexOn' rules are used to improve the performance of queries [31].

B. WEARABLE DEVICE

In an emergency, it may not be always possible for the user to access the phone, unlock it, open the application, and trigger an alert. Wearables are developed to address this scenario so that the alert can be generated as soon as possible without accessing the phone. From Table 2, it can be observed that the wearable devices which do not have a communication facility, just produce a loud sound when triggered thus alerting the people in the nearby area. Other devices with communication capability are not standalone devices. They can function only when paired with a smartphone. Unlike the wearables mentioned in Table 2, the proposed wearable is a standalone device. Hence, it will be able to trigger SOS and trigger crime response even if the smartphone is thrown away or tampered by the attacker or if the mobile phone is out of battery. The device also can optionally pair with the smartphone. In addition to the power supply and clocking elements, the wearable device has a micro-controller, Wi-Fi, Bluetooth, GPS receiver, GSM/GPRS support, and a touch screen interface.

In the current work, we intended to do quick prototyping and hence have utilized Custom of the Shelf components (COTS). After careful analysis of the available COTS components, we selected the ESP32 microcontroller board with integrated Wi-Fi and Bluetooth connectivity support [32]. ESP32 includes dual-core Tensilica LX6 MCU as the computing element and includes ESP32-WROOM-32SE module for connectivity support. ESP32 is an ultra-low-power consuming module suitable for wearable electronics and Internet-of-Things (IoT) applications. ESP32-WROOM-32SE is a low form-factor module which also includes Microchip's ATECC608A crypto authentication for enhanced security to connect to IoT cloud services and TLS based secure communication. The connection diagram for the wearable module is shown in Fig. 6.

We have utilized the LoNET808 module for the GPS/GSM/GPRS connectivity [33]. The board has a SIM808 module, which supports GSM/GPRS Quad-Band network along with GPS technology for navigation. A unique feature of this module is that it supports the Assisted-GPS (A-GPS) module which can be used for positioning in indoor environments in addition to the outdoors. The A-GPS takes assistance from mobile towers to fix positions. The GPS receiver is highly sensitive with 22 tracking and 66 acquisition channels and provides positional accuracy of approximately 2.5m. Hence, women can report crimes and request for help even while indoors. The available wearable devices will report the position with reasonable accuracy only in outdoor environments. The LoNET808 module supports NMEA protocol for GPS. The module has a current consumption of 24mA while in continuous tracking mode and has a position update rate of 5Hz. The module also has an onboard battery charging circuit that can be used with Lithium Polymer batteries. The LoNET808 module also has a microphone that can be used to make voice calls and collect speech data around the module.

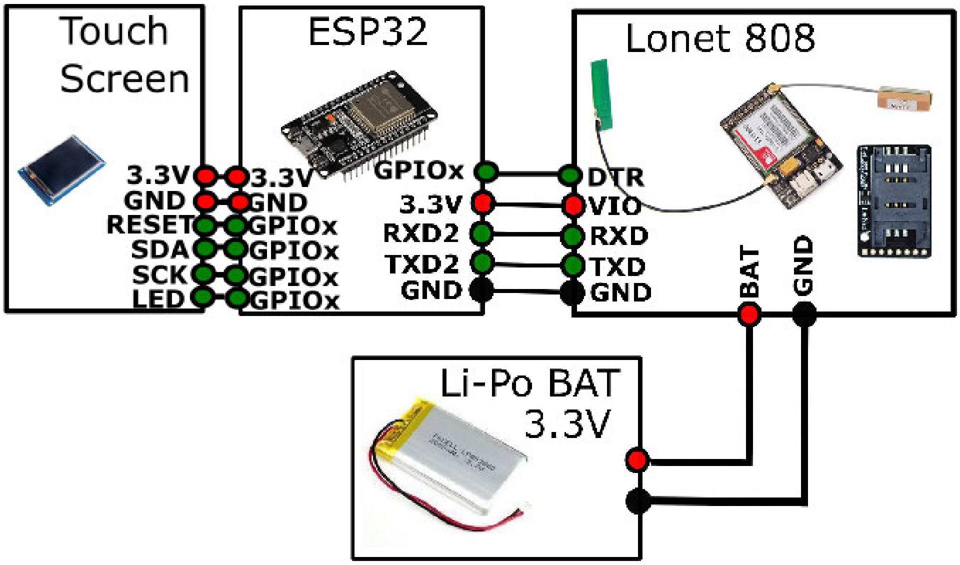


FIGURE 6. Interfacing diagram for the wearable prototype.

The module supports two modes of operation- LOCAL & REMOTE. In LOCAL mode, the user can trigger the SOS as and when required using the touch interface. The data from the wearable will be treated in the same manner as the data from the mobile application by the cloud database. When the guardian sends an SMS message to the wearable to obtain the location coordinates of the user, the module switches to REMOTE mode. Following this, the wearable module will initiate a call with the user so that the user is heard continuously by the guardian and the guardian can record the data at his/her end. In both modes, when triggered, the wearable will send position updates to the cloud database at an interval of 30seconds. In the LOCAL mode, once triggered, the position updates will be transmitted till the user is marked safe or till the module is restarted. In REMOTE mode the position updates will be sent continuously for 2 minutes after which the wearable module can be pinged again if required. The module can also be switched into low power mode of operation to save power consumption. The various use cases for wearable device is indicated in Fig. 7.

The prototype of the wearable is shown in Fig. 8.a, Fig. 8.b, Fig. 9.a and the data collection at the firebase cloud is shown in Fig. 9.b. The prototype is designed using the COTS components for the testing of the holistic system. For the product version, a dedicated circuit board will be designed and the size of the device will be similar to that of a watch. It may be noted that same microcontroller chip, GPS/GSM/GPRS system and touch screen controller as used in the prototype will be utilized in the final system. However instead of having the three systems on three different boards as is while using the COTS components, a single printed circuit board will accommodate the three chips along with the power supply and clocking modules. The device can be powered using a 3.3V, 2000mAH battery Li-Po battery. The battery can be charged similar to a mobile charging process. The device can be either worn on hand as a band or bracelet.

C. DATA COLLECTION FOR CRIME MONITORING & ANALYSIS

The data collection for developing the GIS-based crime monitoring and analysis system was completed using fieldwork in the town of Pilani. Pilani is a small town situated in the Shekhawati region of Rajasthan, India, and is a part of the Jhunjhunu district. As of the 2011 Census of India, Pilani has a population of 29,741 of which 51% are males and 49% females. The average literacy rate is 72%. Male literacy is 80% and female literacy is 63%. 12% of the population is under 6 years of age. The next census is due in the year 2021. The criminal records for the years 2016-2019 were collected from the Pilani police station. The data was not available in any digital repository and the field investigator collected the relevant and available data from the police record books. The crime against women under the following Indian Penal Code (IPC) sections were reported in the station.

- IPC 498-A: Husband or relative of husband of a woman subjecting her to cruelty
- IPC 376: Rape
- IPC 354: Assault or criminal force to woman with intent to outrage her modesty
- IPC 363 Kidnapping
- IPC 364: Kidnapping or abducting to murder
- IPC 365:Kidnapping or abducting with intent to secretly and wrongfully confine a person
- IPC 366: Kidnapping, abducting or inducing woman to compel her for marriage, etc.

The collected data were tabulated and segregated based on the year and IPC of the specific crime. The other attributes of the data are date/month of the incidence, address (information

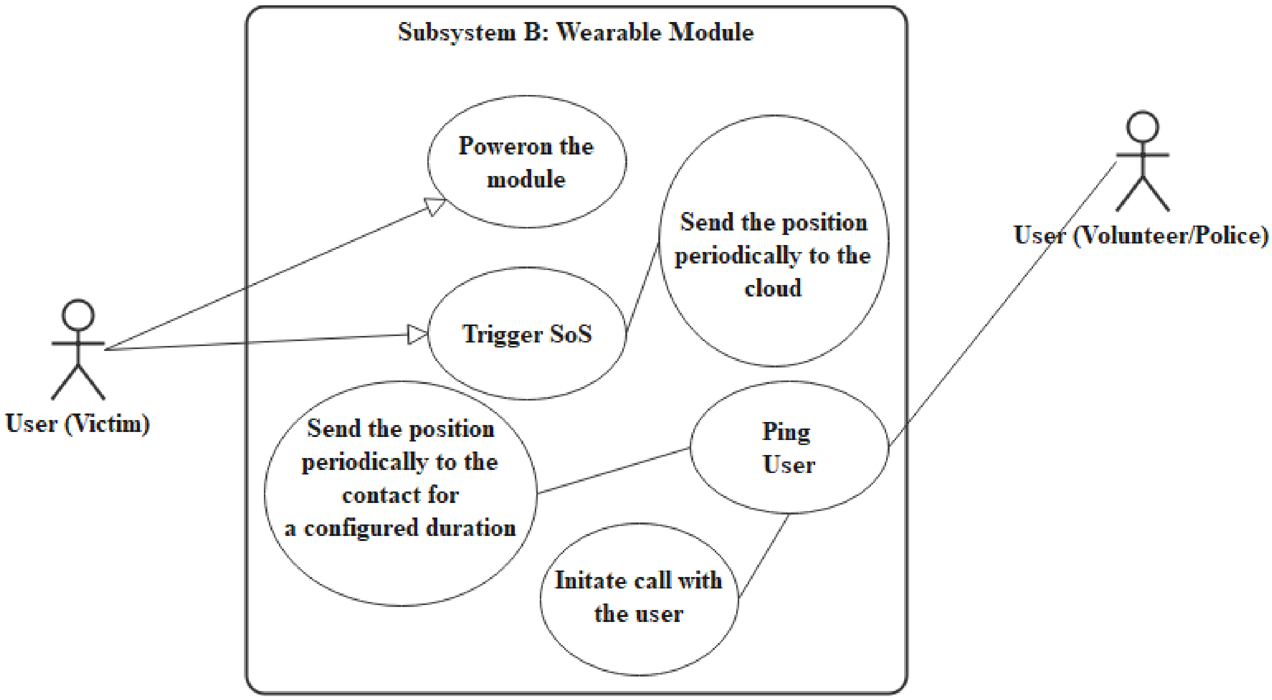


FIGURE 7. Use cases for wearable device.

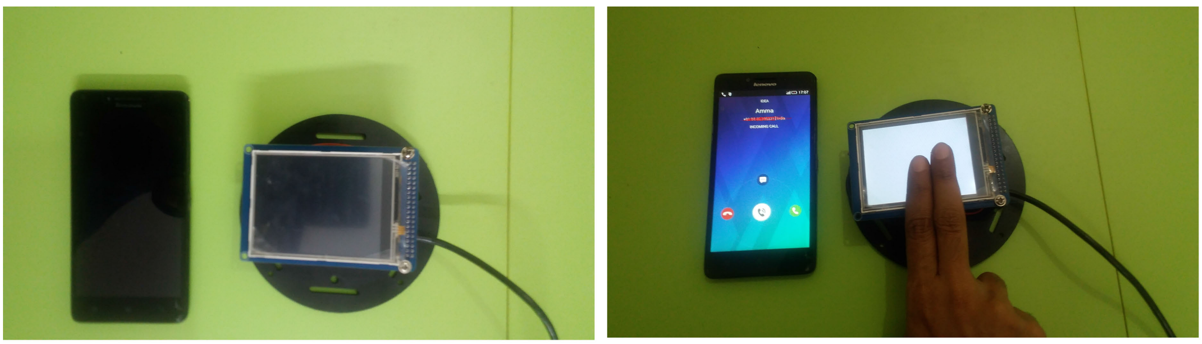


FIGURE 8. a. Top view of prototype when not triggered. b. Top view of the prototype when triggered.

regarding the location of crime such as the name of the village, direction, and distance to the police station). The data had to be georeferenced using latitude and longitude values for further plotting and visualization of this data on a map. With the help of the satellite geolocation feature provided by Google Earth, the precise latitude and longitude values (X, Y) for each location were also calculated for data. Fig. 10. represents the data after georeferencing.

The data about the population statistics and the socio-economic factors that affect crime was also collected to analyze the trends in crime and the identification of hotspots of crime. The analysis of socio-economic causes is crucial because it helps in the prediction of the probability of the occurrence of crime at a place. The socio-economic factors identified for this work are illiteracy, unemployment, and sex ratio. The socio-economic factors were selected based on a previous study conducted on identifying the major factors affecting the occurrence of crime [18]. The Census Organization of India conducts the census every 10 years and collects various demographic and socio-economic data. The latest census in India was conducted in 2011.

From the census records, information about the population, employment, sex ratio, and literacy were extracted and were used to analyze the literacy rate, unemployment rate and population density in the area for which crime data was available. The data for the different cities in the district of Jhunjhunu, Rajasthan was obtained and was used to infer the effect of various socio-economic factors on the probability of occurrence of crime. The number of crimes reported in the Pilani police station for the years 2016, 2017, 2018, and 2019 are 79, 67, 66, and 73 respectively. In the latest census records, socio-economic data for 30 points are available

FIGURE 9. a. Side view of the prototype b. Wearable data recorded in the database when triggered.

IPC	Month-Year	Address	Lat X	Lon Y
498-A	Jan-19	Dev road, Dakshin 8km from the station	28.3084	75.6292
498-A	Jan-19	Kasva, Pilani,5km north from station	28.4067	75.6135
498-A	Feb-19	Dev road,Moja Dev road, 8km from south	28.3041	75.6315
498-A	Feb-19	Moja Dhijka,8km east	28.3582	75.6925
498-A	Feb-19	8km , north east of station	28.4045	75.6812
498-A	Feb-19	Kasva, Pilani,2km north from station	28.3781	75.6109
498-A	Feb-19	Kasva, Pilani,2km north-west from station	28.3735	75.5957
498-A	Mar-19	Garinda, Pilani, 7km west	28.3784	75.5328

FIGURE 10. Sample record of crime data represented after georeferencing.

for the Jhunjunu district in Rajasthan and were utilized for our work. The socio-economic causes are represented as additional attributes in the data and the data was stored in the geospatial database created for GIS analysis. Crime spot analysis using ArcGIS is elaborated in the next section.

D. CRIME HOTSPOT IDENTIFICATION USING ArcGIS

The data collected from the fieldwork was processed as mentioned in this section for crime hotspot analysis. We have utilized ArcGIS 10.2 version for the work. The data was pre-processed as follows.

- Once the data was tabulated as shown in Fig.10., the data was classified and segregated into different tables based on the year of occurrence of the crime and the IPC number violated in the respective crime. This segregation is a very important step in the analysis of crime for a better understanding of trend, co-relationship, and probability of the crime occurrence. The crime spots were marked on the map as different point features in the map using the ArcMap software.
- To understand the dependency of the probability of crime on each of the socio-economic factor which was considered for the crime analysis, tabulation of the socio-economic data for every city in the district of Jhunjhunu, Rajasthan was performed. The socio-economic data is not generally made available or reported for every geo-coordinate location on the map, but for a region. For the given region, the maximum and minimum value corresponding to a socio-economic factor was available from census report. Hence, the available socio-economic data was assigned to relevant points on the map, and for the other places, the values were interpolated using the IDW (Inverse Distance Weighted) method of spatial interpolation. The general equation for IDW is given by

$$z_p = \frac{\sum_i^n \frac{z_i}{d_i^k}}{\sum_i^n \frac{1}{d_i^k}} \tag{1}$$

where ‘z_p’ is the estimated value at point ‘p’, ‘z_i’ is the z value at known point ‘i’, d_i is the distance between point ‘i’ and point ‘0’, ‘n’ is the number of known points used in estimation, and ‘k’ is the specified power. The power ‘k’ controls the degree of local influence [34]. A power of 1.0 means a constant rate of change in value between points (linear interpolation). A power of 2.0 or higher suggests that the rate of change in values is higher near a known point and levels off away from it. In our application, we have utilized linear interpolation. The IDW was selected as the suitable spatial interpolation technique

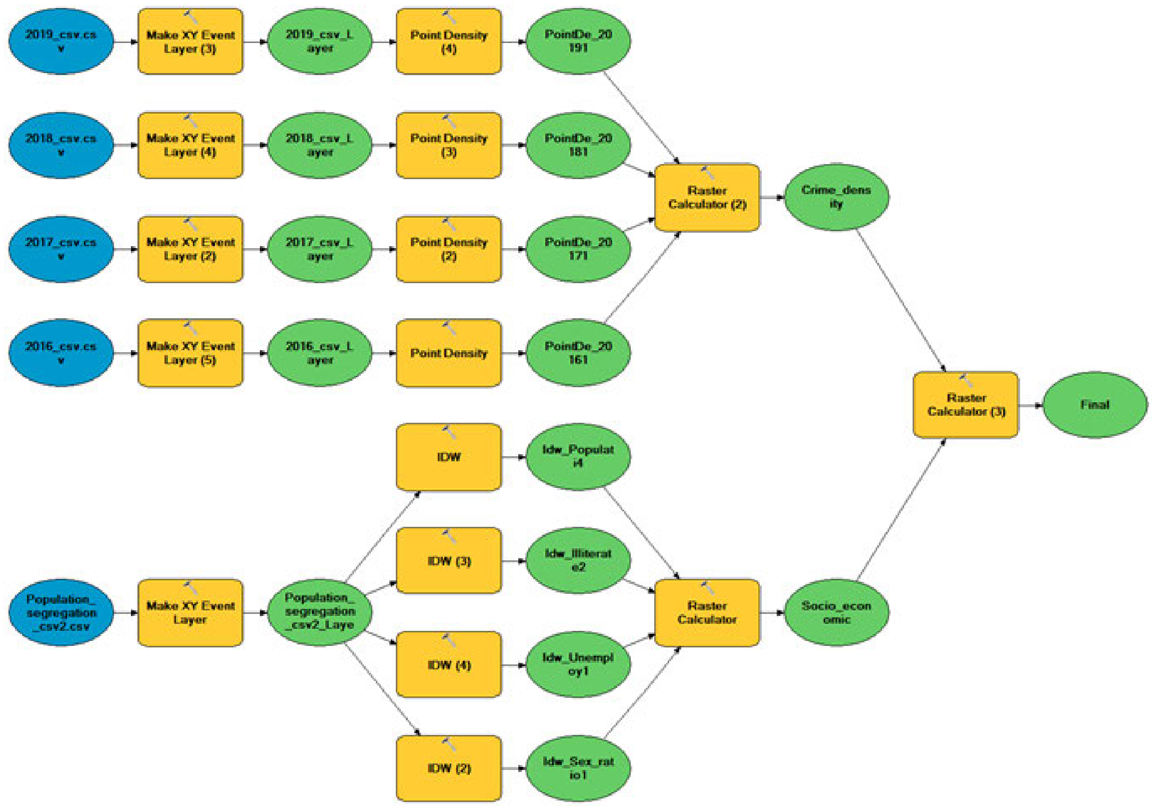


FIGURE 11. **Model generated using ArcGIS for hotspot mapping.**

for thematic mapping of socio-economic causes of crime after a comparative study of the various spatial interpolation techniques [35]. Once this procedure was carried out for every village considered in the area of analysis, the latitude and longitude for these points were obtained from Google maps.

- A table was prepared with the geo-coordinate points at which crime was reported and their socio-economic attribute data. The population of each city was obtained from the Census report and was used to calculate the population density in that area. In order to obtain the probability value for crime occurrence, the data obtained was normalized to a value between 0 and 1 to obtain the value of probabilities [36]. The population values were normalized to obtain probability values to identify the dependence of population density on the occurrence of crime in that area [13]. Similarly, the literacy rate was normalized to obtain the probability values. Before normalization, the literacy data was multiplied with the population density to obtain weighted values of literacy because the effect of literacy rate on occurrence of crime is affected by the population density in that place. Unemployment percentage was obtained by dividing the number of non-workers by the total population in the area. It was also multiplied with the population density at that spot and then normalized to obtain the probability values. Finally, the sex ratio was also multiplied with population density and then normalized to obtain the probability values.

The output of the preprocessing stage is a set of five files -named Population_segregation_csv2.csv and the crime records data for four years, x_csv.csv where x can be any year from 2016 to 2019. The five files were fed into ArcGIS 'Model Builder' as separate input files. The input files were then fed into the "Make XY Event Layer" data management tool of ArcGIS to create layers for individual input files. From the layer, a raster surface was interpolated using the IDW technique. The output of this step is fed into the 'Point Density tool' of ArcGIS which calculates the magnitude per unit area from point features within a neighborhood. Raster calculator was used to generate the overlay graphs from crime data and socio-economic data which were then again passed through another raster layer to generate the final overlay as shown in the Fig. 11. The overlay generated for socio-economic data, crime data and the final overlay which indicate the probability of crime (or the hotspots of crime against women) is shown in Fig. 12.a, Fig. 12.b and Fig. 12.c respectively. The base map of Pilani used for the analysis is shown in Fig. 12.d.

This generated model (or the python script extracted using the Model Builder) can be run on other platforms which support GIS libraries [37]. The final overlay files generated

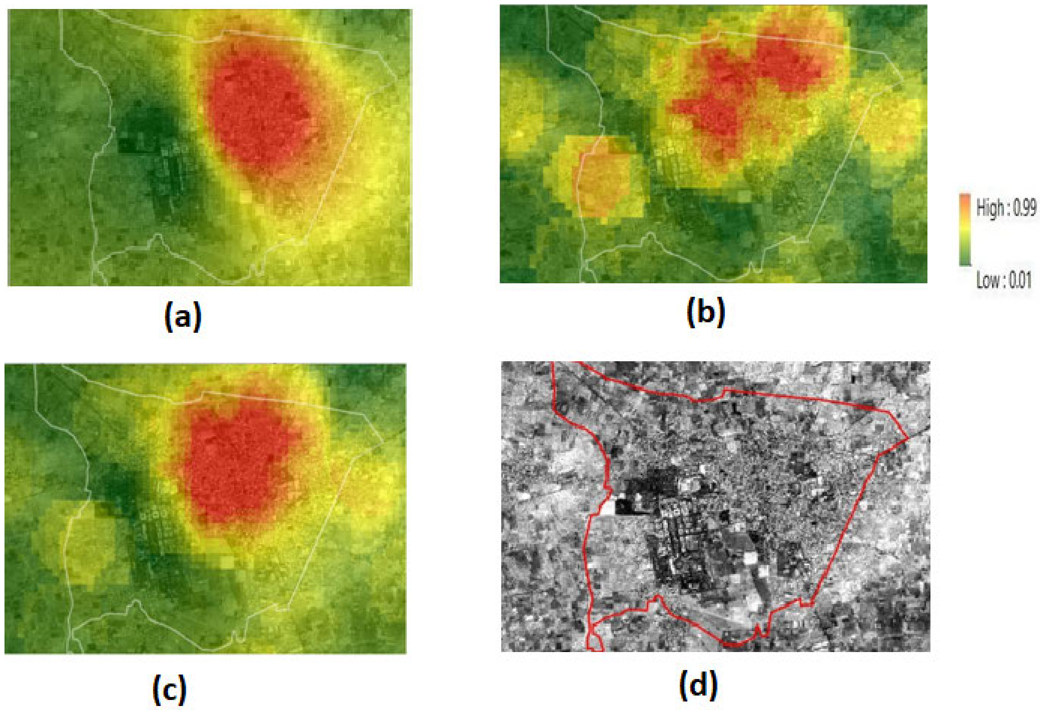


FIGURE 12. a. Overlay of the socio-economic data. b. Overlay of Crime data. c. Final overlay indicating crime-prone areas (Hotspots) in Jhunjhunu. d. Base map of Pilani used for the analysis.

by ArcGIS tool and the other layer files generated at intermediate steps can be uploaded on a website for public access. As data in the input files change or data for subsequent years are to be added, the model can be rerun to generate the final overlay graphs. However, rerunning the model (or running.py) file will require ArcGIS licensing and ArcGIS libraries [38]. Hence, we also performed the hotspot analysis using PostGIS- an open source GIS software, so that the data can be uploaded on a website without any licensing issues as in ArcGIS. This process is explained in the next section.

E. DEVELOPMENT OF A WebGIS SYSTEM FOR CRIME SPOT ANALYSIS

WebGIS is an advanced GIS system available on the web platform. GIS system acts as the server (which has a Uniform Resource Locator (URL)) and the web browser, mobile or desktop application acts as the client. We have developed a WebGIS application based on PostGIS. PostGIS is an open source software program that adds support for geographic objects to the PostgreSQL object-relational database [39]. PostGIS follows the SQL specification from the Open Geospatial Consortium (OGC). PostgreSQL database is used to store geographic data and 'Leaflet' is used to display that data on a map. Leaflet is a light-weight (approximately 38KB) open-source JavaScript library for interactive maps which can be extended with plugins.

We have utilized the PostGIS version 2.5.0 for this work. The WebGIS user interface developed by us mainly comprises of mainly two webpages. The first page presents the visualization of the crime spots and their corresponding socio-economic scores as shown in Fig. 13. The four checkboxes can be used to visualize the crime spots for the last four years and the fifth checkbox can be used to view the socio-economic score for the crime spots. The overall architecture of the WebGIS system implemented in this work is represented in Fig. 14. When the client checks the boxes, via Asynchronous JavaScript And XML (AJAX) call to the database, it gets routed through the PHP pages designated to communicate to the server (Fig. 14.). In response, a layer corresponding to the checked box is added to the WebGIS interface. AJAX supports the transmission and reception of information in various formats, such as text files, JavaScript Object Notation (JSON), Extensible Markup Language (XML), and Hypertext Markup Language (HTML). In similar manner, when the user clicks on the 'View Crime Probability Map', the crime hotspots will be displayed. The technique used for crime hotspot mapping is same as described in Section III.D. AJAX calls are 'asynchronous' and hence allows communication with the server, exchange of data, and updation of the page without having to refresh the page.

The client side is programmed using the HTML, Cascading Style Sheets (CSS) and Javascript. HTML5, the new version of the language HTML, with advanced elements, attributes, and behaviors, can also be used. The hot spot crime probability map of the region obtained using PostGIS is shown in Fig. 15. The second page of the WebGIS interface is an admin page through which an administrator can update the

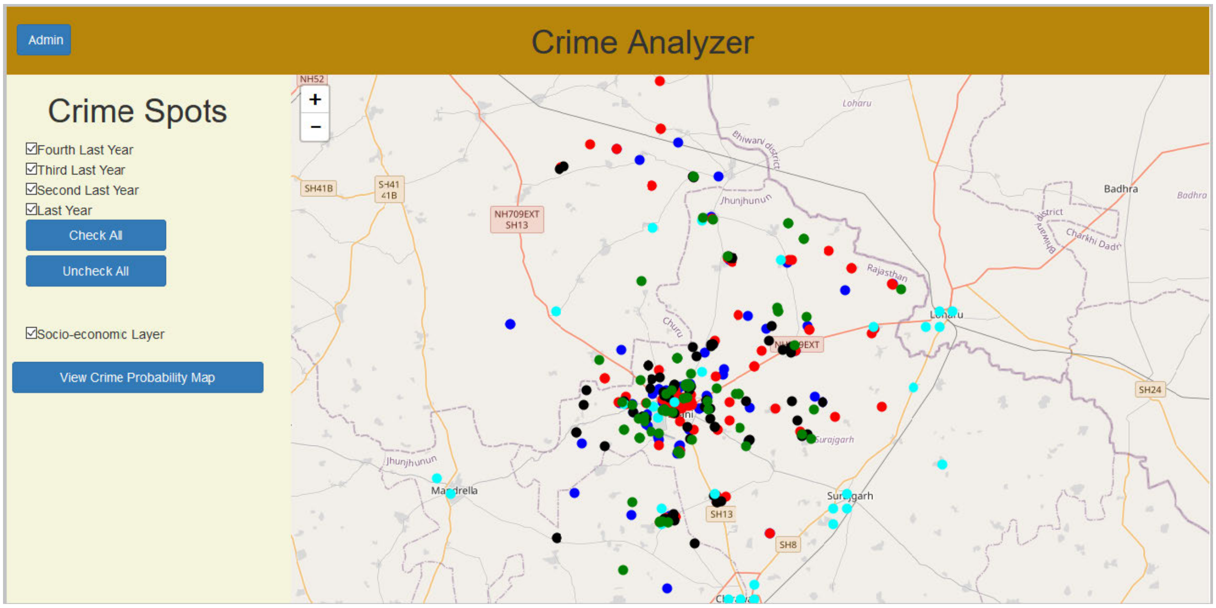


FIGURE 13. WebGIS interface developed for visualization of crimespots and socio-economic factors.

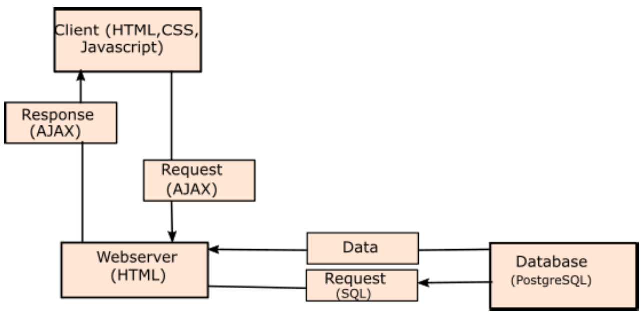


FIGURE 14. Overall architecture of the WebGIS system implementation.

data in the form of the GeoJSON file(s). The input file(s) can be derived based on the criminal history record as described in Section III.C. An admin button is given on the top of the first page which lets the administrator of the website to navigate to the admin page. On inputting the new data, the hotspot analysis will be updated. Admin page is shown in Fig. 16. To upload the latest crime records, an upload file button is provided at the top right corner of the admin page. On updation of data, the hotspot analysis will be updated automatically.

F. WEBSITE FOR HOTSPOT MONITORING AND CRIME ANALYSIS

The website acts as an integrator for the various components developed such as 'SpotHer' mobile application, wearable device, and WebGIS visualization. GIS can be used to analyze and visualize the crime trends with a locational aspect in a better way enabling the police to work in a preventive mode.

HyperText Markup Language (HTML) is the most basic building block of the website. It defines the meaning and structure of web content. Other technologies described below were used to change the appearance/presentation or functionality/behavior of the website. Following are the major programming languages and various front-end and back-end components used for developing the website.

- Python - used for running the entire website architecture and it also acts as a skeleton for the entire website. The version used for developing the website code is 2.7. The code is tested for compatibility till Python.3.6. PyCharm integrated development environment was utilized for Python interpretation. Python code is used for initiating the retrieval of the user data from the wearable device and the mobile application stored in the firebase database.
- Django - is used for creating connection to database and also for viewing /modifying the database contents. When a request comes to a web server, it's passed to Django which interprets the request. Along with Python 2.7, Django 1.11 was used.
- Java - used for creating block spaces for username and passwords, decoding the foreign key generated from firebase, etc.
- jQuery - This javascript library was used for creating animations, AJAX calls, adding plugins, for navigating through the content.
- AngularJs framework- is used to build frontend interface along with HTML to create dynamic components of the website such as handling text entry. HTML can be used only to create static components of the front-end.
- Cascading Style Sheets (CSS) - is a sheet style language for adding style elements such as colors, fonts and spacing to document written in a markup language such

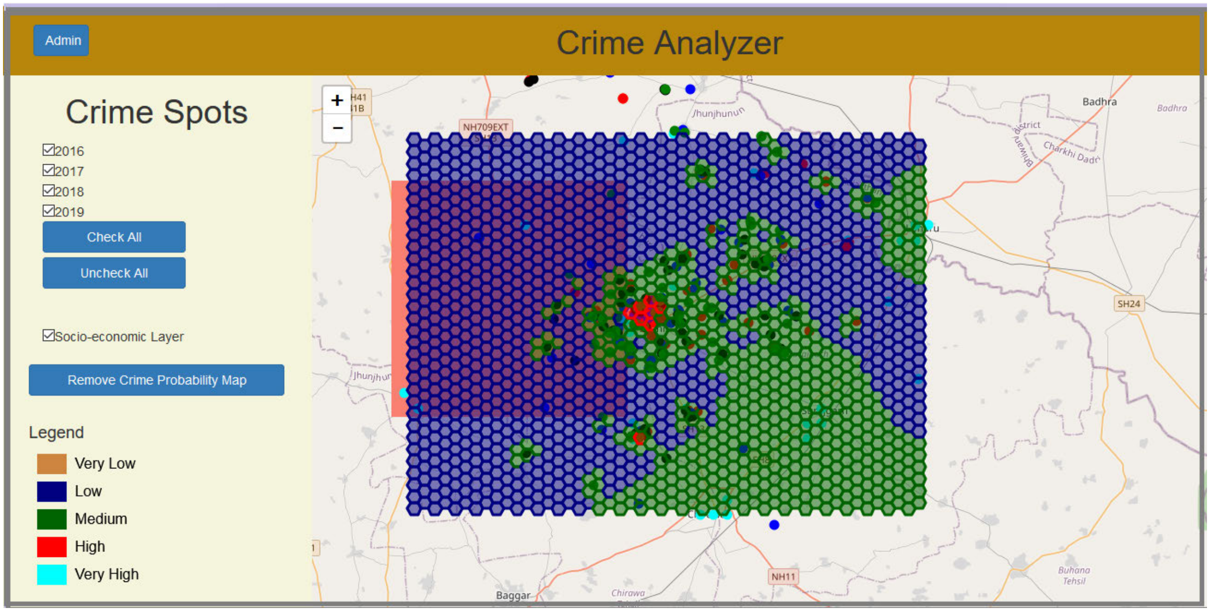


FIGURE 15. Crime Hotspot map of the Pilani area as calculated in PoSTGIS.

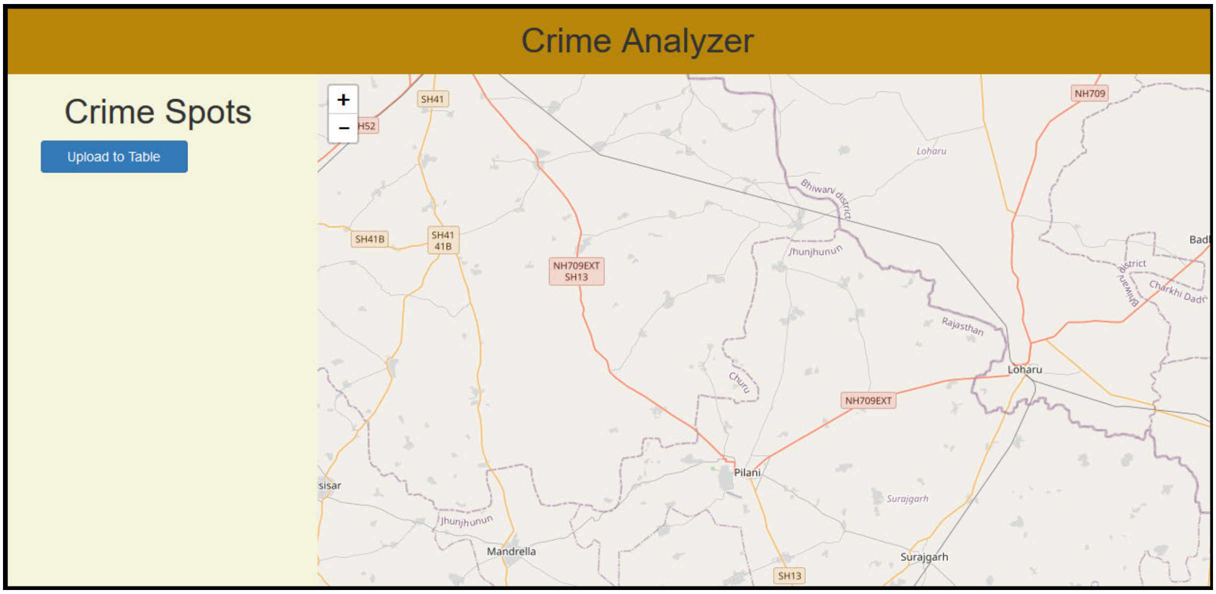


FIGURE 16. Admin page for uploading the new dataset.

as HTML. CSS is used for creating tables required for display of user data for supervisory management.

- Visual Studio - used for running the entire code in back-end and also for pushing the project onto webpage from local host.

The website has to be loaded on a web server. We have utilized 'PythonAnywhere' server for this implementation. 'PythonAnywhere' is a python based web hosting service and is based on 'servers in the cloud' concept [40]. The website is hosted on world wide web using 'pythonanywhere.com' service. The back-end components of a website consists of a PythonAnywhere' server, Python based application, and 'SQLite' database. Reference [40] describes the steps involved in deploying the website code on the webserver.

The website provides visualization for the data collected from the mobile application, wearable device, geospatial server and the crime records. The interaction of the website with the above mentioned components is depicted as a use case diagram as shown in Fig. 17. The data from the wearable device and the mobile application is updated in the firebase cloud. The main page of the website is shown in Fig. 18. User

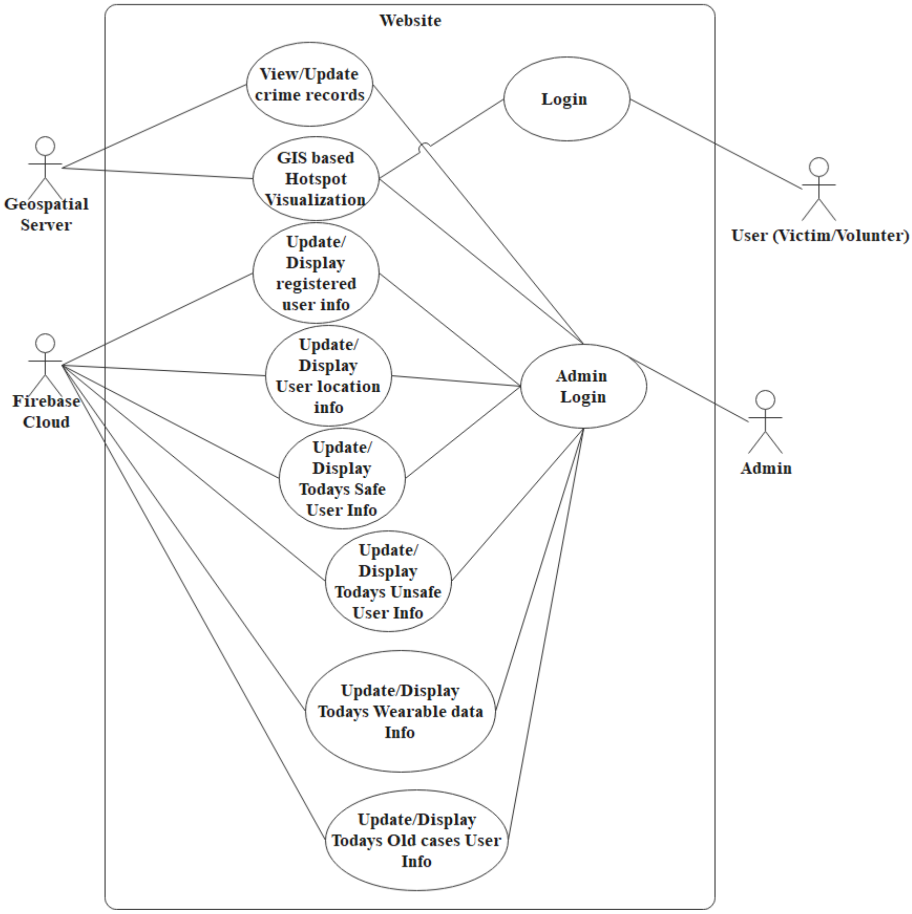


FIGURE 17. Use cases for website.

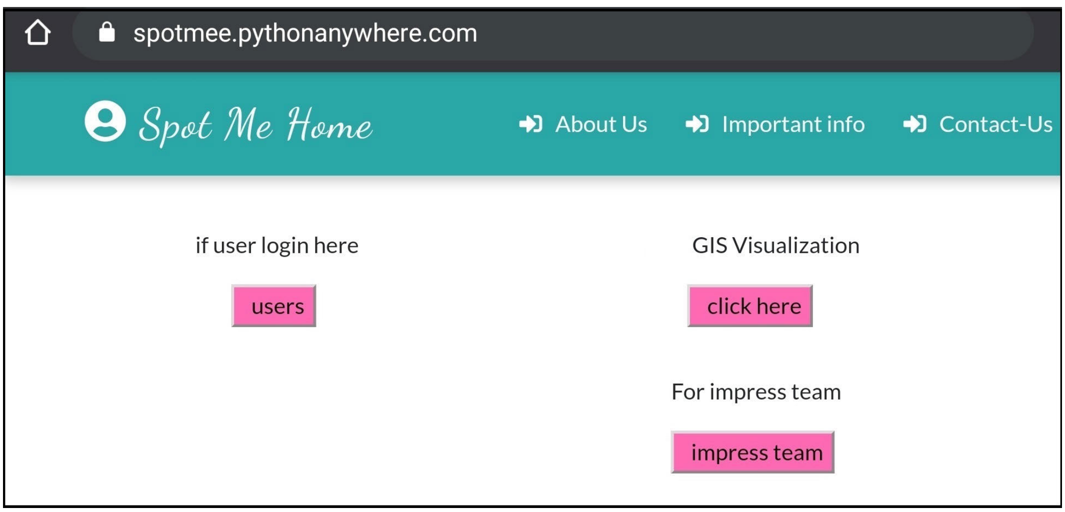


FIGURE 18. Home page of the website.

and administrator (also referred to as impress team) logins are available. The administrator account can be shared with the law enforcement agencies for hotpot analysis and also for monitoring the safe/unsafe status of users. GIS visualization can be accessed without logging in or registering with the system. On clicking on the 'GIS Visualization tab', as shown in Fig.18, the user will be redirected to the WebGIS interface as shown in Fig. 13, through which the Hotspots of crime can be monitored. On login, the administrator can view the page as shown in Fig. 19.

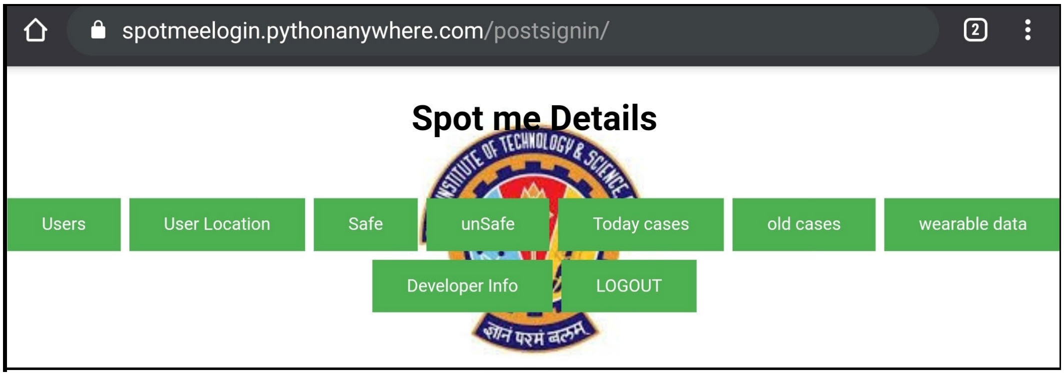
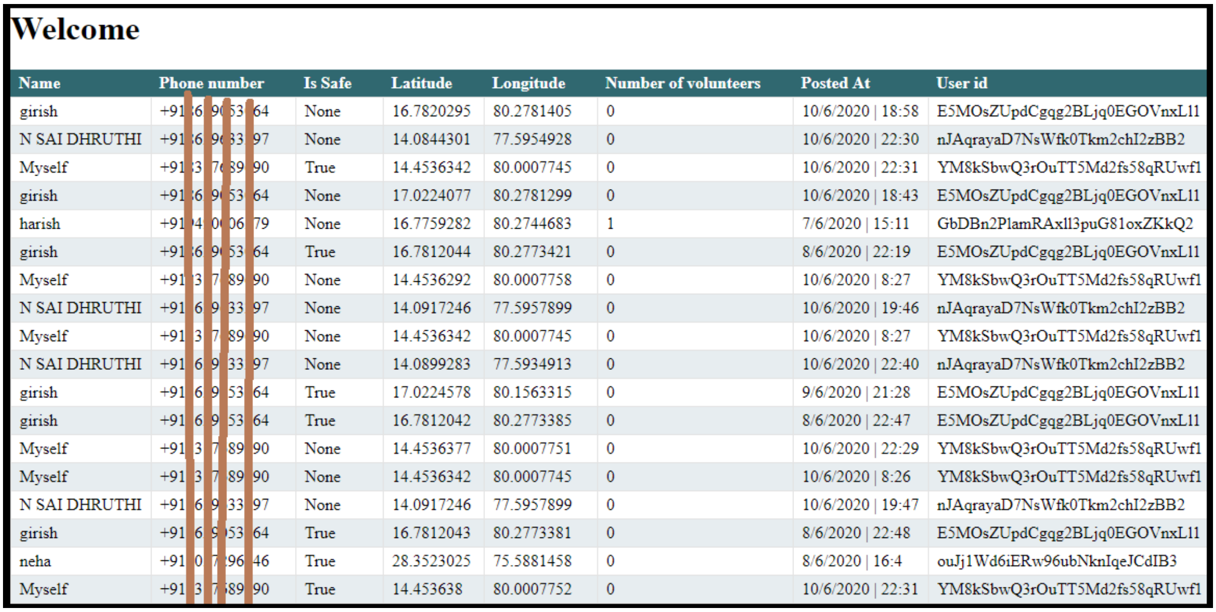


FIGURE 19. Webpage as seen by the administrator.



Welcome

Name	Phone number	Is Safe	Latitude	Longitude	Number of volunteers	Posted At	User id
girish	+91[redacted]6[redacted]9[redacted]53[redacted]64	None	16.7820295	80.2781405	0	10/6/2020 | 18:58	E5MOsZUpdCgqg2BLjq0EGOVnxL11
N SAI DHRUTHI	+91[redacted]6[redacted]9[redacted]33[redacted]97	None	14.0844301	77.5954928	0	10/6/2020 | 22:30	nJAqrayaD7NsWfk0Tkm2chI2zBB2
Myself	+91[redacted]3[redacted]7[redacted]89[redacted]90	True	14.4536342	80.0007745	0	10/6/2020 | 22:31	YM8kSbwQ3rOuTT5Md2fs58qRUwf1
girish	+91[redacted]6[redacted]9[redacted]53[redacted]64	None	17.0224077	80.2781299	0	10/6/2020 | 18:43	E5MOsZUpdCgqg2BLjq0EGOVnxL11
harish	+91[redacted]4[redacted]0[redacted]06[redacted]79	None	16.7759282	80.2744683	1	7/6/2020 | 15:11	GbDBn2PlamRAxll3puG81oxZKkQ2
girish	+91[redacted]6[redacted]9[redacted]53[redacted]64	True	16.7812044	80.2773421	0	8/6/2020 | 22:19	E5MOsZUpdCgqg2BLjq0EGOVnxL11
Myself	+91[redacted]3[redacted]7[redacted]89[redacted]90	None	14.4536292	80.0007758	0	10/6/2020 | 8:27	YM8kSbwQ3rOuTT5Md2fs58qRUwf1
N SAI DHRUTHI	+91[redacted]6[redacted]9[redacted]33[redacted]97	None	14.0917246	77.5957899	0	10/6/2020 | 19:46	nJAqrayaD7NsWfk0Tkm2chI2zBB2
Myself	+91[redacted]3[redacted]7[redacted]89[redacted]90	None	14.4536342	80.0007745	0	10/6/2020 | 8:27	YM8kSbwQ3rOuTT5Md2fs58qRUwf1
N SAI DHRUTHI	+91[redacted]6[redacted]9[redacted]33[redacted]97	None	14.0899283	77.5934913	0	10/6/2020 | 22:40	nJAqrayaD7NsWfk0Tkm2chI2zBB2
girish	+91[redacted]6[redacted]9[redacted]53[redacted]64	True	17.0224578	80.1563315	0	9/6/2020 | 21:28	E5MOsZUpdCgqg2BLjq0EGOVnxL11
girish	+91[redacted]6[redacted]9[redacted]53[redacted]64	True	16.7812042	80.2773385	0	8/6/2020 | 22:47	E5MOsZUpdCgqg2BLjq0EGOVnxL11
Myself	+91[redacted]3[redacted]7[redacted]89[redacted]90	None	14.4536377	80.0007751	0	10/6/2020 | 22:29	YM8kSbwQ3rOuTT5Md2fs58qRUwf1
Myself	+91[redacted]3[redacted]7[redacted]89[redacted]90	None	14.4536342	80.0007745	0	10/6/2020 | 8:26	YM8kSbwQ3rOuTT5Md2fs58qRUwf1
N SAI DHRUTHI	+91[redacted]6[redacted]9[redacted]33[redacted]97	None	14.0917246	77.5957899	0	10/6/2020 | 19:47	nJAqrayaD7NsWfk0Tkm2chI2zBB2
girish	+91[redacted]6[redacted]9[redacted]53[redacted]64	True	16.7812043	80.2773381	0	8/6/2020 | 22:48	E5MOsZUpdCgqg2BLjq0EGOVnxL11
neha	+91[redacted]0[redacted]7[redacted]96[redacted]46	True	28.3523025	75.5881458	0	8/6/2020 | 16:4	ouJj1Wd6iERw96ubNknIqeJCdIB3
Myself	+91[redacted]3[redacted]7[redacted]89[redacted]90	True	14.453638	80.0007752	0	10/6/2020 | 22:31	YM8kSbwQ3rOuTT5Md2fs58qRUwf1

FIGURE 20. Data collected by website in old cases section.

The webpage allows the administrator to view registered user details (registered via the Mobile Application), the last active location of user (once SOS is pressed) or volunteer (if SOS notification is accepted), details of users who have raised the SOS and are currently 'Safe' and 'Unsafe' and history of SOS raised and serviced. The administrator can also update the crime data to the geospatial server through the link made available on the website. The testing of the integrated system combining the mobile application, wearable device, GIS visualization and website was performed by allowing the 'SpotHer' to be utilized by a set of students, faculty members and research scholars on campus. One of the user was also given the wearable device. A snippet of data as saved in the oldcases section is shown in Fig. 20. As shown in the Fig. 20, the website allows to view important information such as the real time location of the user, safety status of the user, number of volunteers responded to an SOS, personal details of the user such as name, phone number and emergency contacts etc. It is thus possible to design proactive response measures whereby which the hotspots of crime can be identified, users in danger can be tracked and preventive actions can be planned. The website can be shared with the law enforcement organizations for crime prevention planning.

IV. TESTING AND VALIDATION

The testing of the integrated system consisting of the mobile application, wearable device, WebGIS based visualization, and website was performed over one month. The 'SpotHer' application was allowed to be utilized by 20 users including a set of students, faculty members, and research scholars. One of the users was also given a wearable device. The mobile application was installed and tested on heterogeneous types of mobile phones. The functionality of the mobile application, the wearable device, and the website was tested thoroughly during the process. The holistic system was also subjected to a concurrency test. The mobile application and the wearable device was found to enable real-time SoS notification and user tracking. The user can also view GIS visualization in real-time. The sample data recorded in the firebase database from mobile and wearable devices and retrieved through the website in the old cases section of the webpage is demonstrated in Fig. 20.

The main performance metric of the mobile application and the website is the 'loading' time. The website was utilized by the users and based on the user report and the report obtained from popular website speed testing sites such as 'GTmetrix' and 'webpagetest', the average loading time was not later than 1.1 seconds under various network conditions. During the development, the performance of mobile application such as peak CPU utilization, memory churn, memory leaks, energy usage, etc was monitored using the 'Android Profiler' available with 'Android Studio' integrated development environment, and required code optimizations were performed. The storage utilization of the mobile application is 4.8MB. On a Samsung M30 phone, the average RAM utilization was observed to be around 6MB during the testing. Utilization of battery for around 6 minutes, with 3 minutes of active time and 3 minutes of background time is 0.3%. We have customized a set of features of firebase, i.e authentication, authorization, and role-based access control to ensure that the data is stored securely in the firebase database.

The GIS technique for spatial interpolation for thematic mapping of socio-economic causes of crime, i.e the Inverse Distance Weighted was selected after a comparative study of the various spatial interpolation techniques which are briefly described in Section III, Subsection D and is elaborated at depth in our prior work [35]. The comparison was done with three popular techniques, i.e Kringing, IDW, and Spline interpolation techniques. First, the overlay analysis of all socio-economic factors and the crime density was performed separately using each technique. The overlay analysis was done by taking the weighted average of each attribute using the Raster Calculator tool in the ArcToolbox as mentioned in Section III, Subsection D. The comparison of each interpolation method is done by taking the absolute difference between the thematic map generated using the interpolation technique and the thematic map of the past crime data using the 'Raster Calculator tool' and 'Minus' tool in the ArcToolbox. The mean and standard deviation values of the differences (errors) were used to determine the interpolation method gives us the result most similar to past crime data. The mean (μ) and standard deviation (σ) were calculated for IDW technique, Kringing, and Spline technique and the values calculated were as follows- IDW ($\mu = 0.20$, $\sigma = 0.06$), Kringing ($\mu = 0.42$, $\sigma = 0.11$) and Spline ($\mu = 0.19$, $\sigma = 0.11$). Based on this IDW was selected as a suitable interpolation technique.

The holistic framework for crime response, analysis, and prevention is designed and tested for functional reliability and also usability as per the requirements. However, the system will still be subjected to continuous testing for security and stress testing in the subsequent months before final deployment for the public. The database shall get more enriched and extensive with time leading to increased accuracy and reliability in crime hotspot detection in the future. Our validation shall evolve in real-time with enriched crime and socio-economic data set in the future.

The proposed system performs effective crime analysis and generation of information to plan preventive measures against crime. The success of community assisted crime response will depend upon the network availability, volunteer availability and reachability, response reaction time of the volunteers, area/ zone characteristics of the crime, etc.

V. CONCLUSION

Building safer cities for women requires holistic measures for crime prevention, analysis, and response. This will be effective only with the understanding of various socio-economic factors that lead to violence against women so that effective measures for social reforms can be designed. Also, technological interventions will not be effective in providing timely help if only law enforcement agencies or personal contacts are involved in rescue and response. The work presented in this paper describes the holistic framework for crime prevention, response, and analysis with emphasis on women safety using technology and societal participation. The Integrated system offers the components - (1) WebGIS, including the geospatial database storing criminal records and for hotspot generation, analysis, and visualization. (2) Mobile Application for raising alerts and enabling tracking of the person in danger, viewing the crime hotspots in the locality to enable taking precautionary measures. The mobile application is designed to ensure that the registered users receive alerts about the person in danger in the locality. The user can commit to approaching the person in danger after which both the user and person in danger can be recorded and monitored by the system administrator. (3) A cost-effective wearable gadget with GPS/GSM/GPRS for raising alerts and can be used as a standalone device even when the smartphone is not active. (4) Website which acts as an integrator for the various components developed such as 'SpotHer' mobile application, wearable device, and WebGIS system. The website provides visualization for the data collected from the mobile application, wearable device, geospatial server, and criminal records. The administrator can also update the crime data to the geospatial database through the website. The website allows viewing of important information such as the real-time location of the user, safety status of the user, the number of volunteers who responded to an SOS, details of the user such as name, phone number and emergency contacts, etc. It is thus possible to design proactive response measures whereby which the hotspots of crime can be identified, users in danger can be tracked and preventive actions can be planned. The supervisory management of the website will be done by law enforcement agencies. Societal participation, in addition to providing immediate relief to the victims, can also create awareness in society regarding crime against women and indulge a sense of shared responsibility towards ensuring the safety of women.

The data collection for developing the GIS-based crime monitoring and analysis system was completed using fieldwork in the town of Pilani town in Rajasthan, India. Based on the analysis, Inverse Distance Weighted was selected as a suitable interpolation technique for the thematic mapping of socio-economic causes of crime. This paper describes the system design process in detail, including system components, functional design, architectural choices, and experimental testing. The system will be subjected to continuous stress testing in the subsequent months before final deployment. The framework developed for crime analysis, prevention, and response can be easily scaled up geographically and can be used for safety in smart cities.

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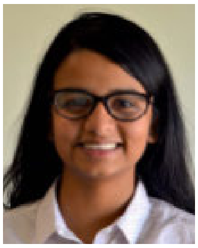

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