Building a Historical GIS for the City of Makkah, Saudi Arabia

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Abstract

A Historical Geographic Information System (HGIS) is a way to create a time-variable spatial representation of geographic features, which is considered as a bridging technology between geography and history in a digital framework. The history of Makkah (Mecca), Saudi Arabia covers several thousand years, with numerous sites representing important historical landmarks. As Makkah is the most important city in Islamic history, developing a HGIS for it would have significant meaning for the more than a billion Muslims around the world. A state-of-the-art HGIS has been developed for Makkah through acquiring, integrating, manipulating, and analyzing an extensive collection of spatial and non-spatial datasets. This research has resulted in the publishing of a bi-lingual atlas of historical sites in Makkah that contains more than seventy historical locations and covers almost a thousand years (500s to 1500s). Work is underway to also build an online HGIS on the Harvard WorldMap platform, so that materials in the atlas and beyond will be made available for researchers and the general public from any part of the world through a web-based dynamic mapping site. Future work may propel the system into an augmented reality innovation. This paper introduces the background and historical-geographic materials, summarizes the technical challenges and solutions, and presents milestones and perspectives for this on-going effort.

Keywords: Geographic Information System (GIS), Historical GIS, Atlas, Makkah, Saudi Arabia, WorldMap

Introduction

The concept of documenting and mapping historical data is an old practice in geography and in field of mapping. Maps showing historical information are used in a simple manner for visualizing and even analyzing geographical data which refers to the past. There are many examples of printed atlases which have been developed representing the geographic patterns of specific events over space and time. Concerning Islam, several atlases have been published covering the geographic and historical expansion of the Islamic empire (e.g. Ruthven and Nanji...
However, such maps have certain limitations compared with modern day geographic information systems. For instance, due to the large extent of the subject in both geographic coverage (almost half of the world) and historical time span (about fourteen centuries), such atlases can only give a general picture of the subject. In addition presenting historical data on regular printed maps in a non-digital format, is restricted by map size, scale, and quality. In such an environment, combining and/or comparing different maps is not a simple task mainly due to the great variation in mathematical projection and spatial reference of the maps involved (Mirza 2013).

Geographic Information System (GIS) represent a computer-based technology for collecting, storing, archiving, queryng, analyzing, visualizing, and presenting large amounts of spatial and non-spatial data. GIS has been used in a wide range of applications world-wide, with the Kingdom of Saudi Arabia (KSA) being no exception. Some examples of GIS applications in KSA include urban growth monitoring (Al-Ghamdi et al. 2012), flood management (Dawod et al. 2011), soil management (El Bastawesy et al. 2012), and the spatial monitoring of disease (Khormi et al. 2012).

Historical Geographic Information System (HGIS) is a discipline within GIS which deals with historical events, data, and geographic locations (Bol, 2013). HGIS provides a new approach for studying history that allows for spatial historical analysis and the linking of historical data to specific geographical locations (Schlichting, 2008). HGIS can be considered a potentially revolutionary approach linking both geography and history together to study patterns of changes over space and time (Bailey and Schlick, 2009). A major application of HGIS is urban history analysis in an integrated digital framework that comprises heterogeneous data sources (Raymond 2011). HGIS has many merits such as the spatial-referencing of all data which allows for rapid map production, and the ability to perform geographic analysis of past events (DeBats and Gregory, 2011).

HGIS is utilized in a wide range of applications. For example, at the city or local level, Ayhan and Cubukcu (2010) applied a 4D spatial analysis to explore urban changes of the city of Izmer, Turkey based on the historical distribution of mosques. HGIS was also utilized in the construction of a historical heterogeneous database for Macedonia, Northern Greece for the purpose of locating hundreds of unknown buried ancient constructions (Kaimarisa et al., 2011). Another HGIS has investigated historical spatial occurrences of soil liquefaction as a measure for earthquake hazards in Greece since 1509, which could be valuable for urban planners (Papathanassiou and Pavlides, 2011). Additionally, HGIS can be used as a platform for public participation in historical site usage and preservation, and offers new understandings of the landscape of such historical locations (Algeo et al., 2011). A unique HGIS has been utilized to analyze visitation patterns for commercial hotels in three small places in central Pennsylvania, USA during the late 19th century (Fyfe et al., 2009). Moreover, HGIS has been used for modeling drought and population change in Canada (McLeman et al., 2010).
Several national HGIS projects have been carried out in the last years or decade. Some of them are available online. Examples of such activities include the US national historical GIS (https://www.nhgis.org/), the Canadian national historical sites (http://www.pc.gc.ca/eng/index.aspx), the US national register of historical places (http://www.nps.gov/nr/), the Great Britain HGIS (http://www.port.ac.uk/research/ghgis/), and the China historical GIS developed by Harvard University (http://www.fas.harvard.edu/~chgis/). Other HGIS projects have been established at smaller scales, state or county for instance, such as the one for the Goodhue county of Minnesota, USA (http://maps.co.goodhue.mn.us/historicplaces/), and the Ohio state online historical mapping system (http://www.ohiohistory.org/ohio-historic-preservation-office/online-mapping-system).

This research aims to use GIS to integrate several data types (maps, aerial photographs, satellite imageries, and non-spatial data) within a framework representing the geographic locations of historical events in Makkah city. The first product of the study will be an atlas of historical locations within Makkah. Work is underway to also build an online HGIS on the WorldMap platform, so that materials in the atlas and beyond will be made available for researchers and the general public from any part of the world through a web-based dynamic mapping site. Future work may propel the system into an augmented reality implementation (Elzahrany and Mirza, 2011).

**Study Area**

The city of Makkah (Mecca) is located in the southwest of KSA, about 80 km east of the Red Sea (Fig. 1). It extends from longitudes 39° 35’ E to 40° 02’ E, and from latitudes 21° 09’ N to 21° 37’ N. Makkah is a unique city for Muslims around the world, since it contains the holy mosque. From a religious point of view, a Muslim should perform a pilgrimage (called Hajj, which means visiting Makkah during the 8th - 12th days of the 12th month in the Lunar year) once in his/her life. Thus, hundreds of thousands Muslims gather in Makkah yearly. Also, Muslims perform a religious journey, called Omrah, to Makkah year-round. From an Islamic perspective, Makkah is the first place created on the Earth’s surface and the holy mosque in Makkah is the first "God House" for worship on Earth. Thus, the history of Makkah has been unfolding even before the start of the Islam itself. However, the main historical event in Makkah was the commencement of the Islamic religion in year 610 AD. It is known that Prophet Muhammad stayed 13 years in Makkah trying to convert people to Islam before he was obligated to leave for Al-Madinah (about 400 kilometers north of Makkah). Even though the Prophet Muhammad established Makkah eight years later, Al-Madinah stood as the capital of the new Islamic state. However, Makkah has remained the religious capital of the Islamic world and the most-important city for Muslims throughout the last fourteen centuries.
It is amazing to know that there was an attempt to make historical maps two centuries ago. That was when the Turkish officer Ayoub Sabry, in his book "A Mirror of Makkah" in 1872, drew an imaginary sketch showing Makkah’s landscape in the pre-Islam period (i.e., before the 5th Georgian century), as seen in Fig. 2d. He constructed this 3D image based on the historical description of Makkah as set by Kosaii Ibn Kalab (the 5th grandfather of Prophet Muhammad) when he ordered residents to leave some open spaces around the holy Kaaba and regulated buildings to be in circles around it with some radial streets to ease the access to it (ibid).

Recently, several atlases have been published concerning the Islamic history including the city of Makkah. For example, Abu Khalil published an atlas regarding the geographic places mentioned in the teachings of Prophet Muhammad (2005a). He also produced another atlas about geographic sites mentioned in the holy Qur'an (2003). The nature of these two atlases is general, with no details about the geography of Makkah itself. Mirza and Shawoosh (2011) published an illustrated atlas for Makkah and its holy shrines.

GIS was utilized in Makkah as a platform for four dimensional analyses over time, which can be seen as a specific application of HGIS. For example, Shehata (2007) carried out a 4D GIS to investigate the urban and landscape changes in the central region of Makkah in the last three decades. Similarly, Al-Ghamdi et al. (2012) constructed a GIS to estimate the urban growth of Makkah, and the corresponding flood hazards, over the period of 1947-2010.

Additionally, a large amount of historical geographic information about Makkah can be found in literature. Such historical data describing geographic sites could be extremely valuable for developing an HGIS about the holy city. For example, Al-Azraqi wrote one of the most famous geographic books about Makkah in 864 (Al-Azraqi, 2003). The two-volume book dealt with both the history and geography of the holy city, with a detailed verbal description of the famous geographic sites. Similarly, Al-Mekki developed a six-volume book about the history, geography,
and people of Makkah (Al-Mekki, 2000). In addition, Snouck Hugronje published a two-volume book about Makkah in 1888 (that was translated into Arabic in 2012). Furthermore, many historical landmarks within Makkah have been also mentioned in the geographic encyclopedia by Yakoot Al-Hamoy in the early 1200s (Al-Hamoy 1977). The challenge is to convert these rich texts into digital structured spatiotemporal information.

Building the Historical Geodatabase

Developing a GIS-based atlas for historical sites within Makkah is the first step in building a HGIS for the city. The effort presents several technical challenges. The key issues are the availability of spatial and attribute data and the linkage between past and present. Much effort has been put into source data collection, including maps of different scales (some dated a few centuries ago), aerial photos (for many decades), and satellite imageries. Attribute data presenting textual descriptions about specific geographic locations in the past are also gathered. Such attribute tables could be helpful in positioning some historical sites in modern geographic coordinate systems. Additionally, historical attribute data, particularly historical textbooks,
provide "recent or known" names of some old geographic locations (gazetteers). For instance, Al-Hudaibia village in which the famous peace treaty was signed in year 628 is currently known as Al-Shemesy. Figure 3 depicts the input data types to the spatiotemporal database. In the current research study, the geographic experience (of the first author) played a vital role in matching past and present names of historical sites, and required much field geographic experience and historical knowledge. It is known that Makkah has been expanding rapidly in the last two or three decades. Prior to that period many historical sites still existed though they were known by different names. Thus, defining the geographic locations of historical landmarks depends heavily on geographic experience acquired from field study before the rapid expansion of the city.

Another technical challenge in building the HGIS is the georeferencing of some historical spatial data. Some valuable old maps may be available but we do not know their spatial reference or datum, thus they can only be georeferenced through spatial adjustment or rubber sheeting. Scanned historical maps were systematically georeferenced, and spatial features digitized from them in order to create vector GIS layers of the historical geo database. These were then used to produce the atlas (Fig. 4).

Figure 3: Utilized Input Data Types

Figure 4: Historical Geodatabase Construction Process

Designing the Historical Atlas

The design of the historical geodatabase supported the development of the atlas as the first product of this project. The atlas consists of two pages for each historical landmark. The first page comprises the attribute data of a location in both Arabic and English, including: Name, Type, Geographic location, Direction from holy Kaaba, Distance from holy Kaaba, Description, and Historical remarks. Since the Kaaba is the center of the holy mosque (the most important Islamic site in the world), the distances and directions of a specific site are measured from the
Kaaba to show the location of the landmark with respect to this central object. On the opposite page of a historical landmark, its geographic location is presented on both map and satellite images.

The resulting atlas of historical sites in Makkah city contains more than seventy locations. The locations are grouped into nine types:

- Holy Kaaba
- History of the holy mosque
- Holy shrines
- Historical mosques
- Historical locations
- Historical mountains
- Historical events
- Ancient sites
- Pilgrimage and Omrah mikats

The first chapter of the atlas presents the main features existing within the holy mosque, particularly the holy Kaaba, Ismail Hijr, and the Zamzam well. The second chapter depicts the historical expansions of the holy mosque over almost fourteen centuries (Fig. 5). The area of the holy mosque has been enlarged from 2061 square meters in the pre-Islamic period (the 5th Georgian century) to 9844 square meters by year 710, and would be 1,225,000 square meters after the completion of the undergoing expansion project. Such information could not be represented well without HGIS. The third chapter includes five sites belonging to the holy shrines in Makkah, while the forth chapter contains fifteen historical mosques. Another fifteen sites, mostly related to the Prophet Muhammad, are depicted in the fifth chapter of the atlas. The famous mountains, where famous historical events occurred, are presented in the sixth chapter. The seventh chapter includes geographic locations of some famous historical events, i.e. battles and peace treaties. The ancient sites, in the eighth chapter, contain some historical locations that are not exactly related to the life time of Prophet Muhammad. An example of these ancient sites is the dam constructed between 692 and 694 by Al-Hagag Al-Thakafy, the ruler of Makkah by that time, to protect the city from flood water. The last chapter presents the geographic locations of the so-called "mikats". From an Islamic point of view, a mikat is a geographic location from which pilgrims declare "the intention" to start pilgrimage or Omrah before entering Makkah city. There are 5 mikat locations surround Makkah from all directions. Examples of the published atlas pages are presented in Figures 6 to 8 in the appendix.
Creating the Online Historical GIS for Makkah on WorldMap

The demand in history and the humanities for searchable online maps, online mapping utilities, historical GIS, and user participation in mapping data has been evident for at least a decade. WorldMap (http://worldmap.harvard.edu) is an attempt to meet this demand. It is an open-source, web-based, map-centric data exploration and visualization platform (Guan et al, 2012). WorldMap is designed to be publicly accessible, simple to use for nontechnical scholars, fast in search and mapping, and rich in geographic content. It is being built by and hosted by the Center for Geographic Analysis at Harvard University and is open to users around the world for both viewing and editing data (Lewis and Guan 2011). The platform is particularly useful for technology-challenged humanities scholars for it lowers the cost of entry to the spatial humanities. WorldMap eliminates the wasteful duplication of efforts for elementary and routine spatial tasks such as finding a base map as locational reference or overlaying multiple layers of spatial data and examining their locational relationships. In providing a working platform for spatial investigation, WorldMap also grants a powerful new and permanent life to the spatial research of any scholar in the world who shares their data using the system. Rather than resting inertly and often forgotten on their computer’s hard drive once the research is published, the data shared on WorldMap becomes part of a global online library of new evidence and analyses. Through such a process, humanists are encouraged to follow the example of scientists in sharing their data and the interpretive thinking upon which their work is founded. In putting the tools developed by geographic information science in the service of the humanities, WorldMap makes it possible for historians and humanities scholars to develop multiple and competing spatial visualizations, to collaborate, and work cumulatively.

The historical geodatabase and historical atlas for Makkah lay a foundation for creating an online historical GIS for the city of Makkah on WorldMap.
This online dynamic map combines modern-day base maps with historical satellite images and aerial photos, historical topographic maps, historical GIS data layers, historical photos, and modern-day social media streams such as geo-tagged photos from Flickr, giving users the freedom to turn on or off any of these layers, zoom in or out at any scale, “drill down” to any spot to find out more information behind the visible map symbols, or even embed the interactive map in their own website such as personal blogs. As of October 2013, this Makkah Historical Map contains two dozen GIS data layers, many of them are first-hand datasets developed by the first author, such as wells in 1947, urban boundary in 1880 and 1947, building foot prints in 1880 and 1947, etc. This is a living map that is being edited and improved continuously, while viewable by the world (Fig. 6).

Conclusions

Historical GIS plays a primary role in connecting the history and geography of a particular location by introducing time as the fourth coordinate. Since Makkah is the most important and ancient city in the Islamic history, developing a HGIS for it is critically important for more than a billion Muslims. A comprehensive geodatabase of historical data has been acquired, scanned, digitized, and processed, including historical maps at different scales, aerial photos, and satellite imagery. Attribute datasets have been collected and organized in a HGIS framework, thus forming the first HGIS for Makkah. The first product of this HGIS is a bi-language atlas of historical sites that contains more than seventy historical locations within Makkah. The time span covered by this atlas is almost a thousand year (500s to 1500s). Work is underway to also build an online HGIS on the WorldMap platform, so that materials in the atlas and beyond will be made available for researchers and the general public from any part of the world through a web-based dynamic mapping site. Future work may propel the system into an augmented reality innovation.
References


### Figure A-1: Zamzam Well

<table>
<thead>
<tr>
<th>Name:</th>
<th>Zamzam Well</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>A water well</td>
</tr>
<tr>
<td>Geographic Location:</td>
<td>21° 25' 21&quot; North 39° 49' 35&quot; East</td>
</tr>
<tr>
<td>Direction from Holy Kaaba:</td>
<td>South East</td>
</tr>
<tr>
<td>Distance from Holy Kaaba:</td>
<td>30 Meters</td>
</tr>
<tr>
<td>Description:</td>
<td>It is located inside the Tawaf area within the holy mosque. Currently, it is covered to ease the Tawaf around the holy Kaaba. It is known that the water of Zamzam is the best water ever on the Earth.</td>
</tr>
<tr>
<td>Historical Remarks:</td>
<td>This well was first flowed to prophet Ismail, the son of prophet Abraham, and his mother. It has been filled up for several decades, until Abdel-Motalieb, the greatgrandfather of prophet Mohamed peace upon him, dig it again.</td>
</tr>
</tbody>
</table>


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**Appendix 1: Examples of the developed atlas pages**

![Zamzam Well Diagram](image-url)
Figure A-2: Mina Holy Shrine
Figure A-3: Heraa Mountain and Cave