Assessing Environmental Hazards in Mina's Built Environments Using 3D GIS

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ABSTRACT

Mina (near Makkah, Saudi Arabia) is a city of tents that accommodates around two million pilgrims during the season of Hajj (Islamic pilgrimage). Mina's built environment has special characteristics, as it is mainly composed of light structured housing units (tents) in a valley surrounded by huge mountains. These characteristics make this built environment very vulnerable to natural hazards, such as falling rocks and floods from rain. A 3D GIS (Three Dimensional Geographic Information System) was constructed to understand and analyze the locations, types, and sizes of the possible natural risks in Mina. The 3D GIS can be used analyze slopes and investigate water drafting paths and the locations of possible falling rocks. The paper provides illustrations of possible areas of risk, using 2D and 3D visualizations and offers recommendations to avoid future environmental hazards. The paper also shows areas that are prime locations for future development and assesses their hazard-safety.

KEYWORDS

3D GIS, Urban Control, Environmental Hazards, Risk Planning, Hydrology, Mina, Hajj

1. INTRODUCTION

The Muslim pilgrimage (Hajj) to Makkah and the Holy Places near Makkah, Saudi Arabia, is one of the most important events in the world. The pilgrimage occurs annually and attracts more than two million people from all over the globe. According to Islamic literature, the Hajj is following the legacy of the prophet Abraham, who rebuilt the first House of God (Ka'ba), which is located in the center of the Holy Mosque, Makkah. The Hajj commences on the eighth day of Dhul-Hijja, the twelfth month of the loaner Calendar, and ends on the thirteenth of Dhul-Hijja. Pilgrims have to stay in different locations (such as Mina) during specific times within the five days. Space limitations and temporal constraints are major concerns for urban designers and planners. There are also some temporal constraints such as pilgrims have to spend at least two nights in Mina. The characteristics of Mina's natural and built environment also make Mina vulnerable to natural hazards, such as falling rocks and rain floods. The increasing number of pilgrims, as shown in Figure 1, further complicates the problem [1].

2. BACKGROUND

2.1 Natural Characteristics of Mina

Mina is located a distance of 6 km from Central Makkah and measures approximately 8.12 km2; 52% of Mina's area is flat land. The satellite image in Figure 2 shows the location of Makkah and Min. Mina is a ramped valley at about 300 meters above sea level. The valley is 3 km in length and 1.5 km in width.

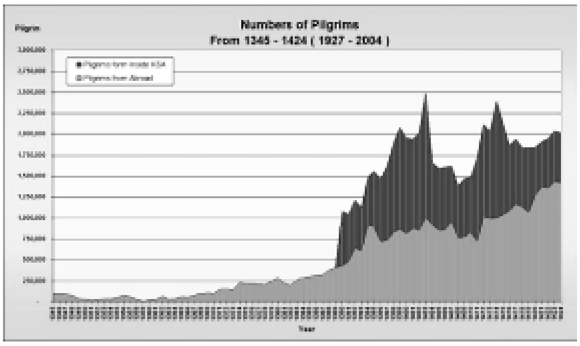

Figure (1): Number of pilgrims since 1927 to 2004
Source: Hajj Research Institute

Figure (2): A satellite image of Central Makkah and Mina
Source: Google Earth

Mina is a valley surrounded by two sets of mountains to the north and south. Figure 3 shows a satellite image of Mina's valley. The levels of the valley vary from 270 meters to 320 meters above sea level. Mountains rise in some of the surrounding area to 1000 m above sea level. The hilly parts of Mina are very steep slopes. Figure 4 is an aerial photo that shows part of the valley and also the surrounding mountains [2].

Figure (3) A satellite image of Mina's valley
Source: Google Earth

Figure (4): An aerial photo of Mina's Mountains
Source: Hajj Research Institute

In general, the Makkah zone is considered a dry zone. The average amount of received water during the last three decades has been about 100 mm. This average does not reflect the fact that there is a very serious times where the received amount of water can reach 250 mm. More than 110 floods were recorded over the last twenty years. In the 2005 flood, Mina received 10050000 m3 of water in just a few hours [3].

Urban development efforts cover almost every flat zone of Mina's valley. This development does not much space for natural life. In some of the hilly places, wild pigpen, hulks, and some natural shrubs have grown.

2.2 The Built Environment of Mina

Accommodating around two million pilgrims, Mina is considered the largest tent city in the world. Mina is a unique case, because of the several reasons: 1) Mina is used for only three days each year; 2) Mina has defined religious spatial and temporal limits; 3) No permanent buildings are allowed for housing within the limits of Mina.

Mina's built environment consists of: 1) housing tents, that are built of fabric and light structures that are fixed to concrete foundations. 2) Service buildings, such as public toilets, police stations and medical services built of concrete structures. 3) a utilities infrastructure, including water tanks and electric transformers. 4) a traffic network of roads and bridges. Figure 5 presents snapshots showing some characteristics of Mina's built environment.

Tent structures

Prefabricated water tanks

Steel and concrete bridges

Prefabricated toilets

Roads and tunnels

Light weight structured housing units

Figure (5) Snapshots of Mina's built environment

2.3 Mina's Environmental Hazards

The UN defines the major types of natural hazards as fires, floods, earthquakes, and volcanoes. The damage caused by these natural disasters can be staggering. In the first half of 2006 alone, the cost accrued by natural disasters worldwide has been US$ 24 billion, with over 60 million civilians affected by these disasters. The intensity of natural hazards, such as floods, is exacerbated by unsustainable environment and resource use practices, including deforestation, inappropriate land use, and poor management of natural resources [4].

Mina suffers from various types of life threatening hazards, including fires, floods, and falling rocks. After a major fire in 1976 (Figure 12), a new project was adopted to build fireproof tents that were structured with steel sections fixed to concrete foundations. Since the construction of that project, no major fire accidents have occurred . However, the Hajj commencing period shifted to the rainy season in Mina a few years ago. This change has resulted in floods during the hajj season and a lot of trouble for pilgrims. [5]

This paper focuses on studying such flood hazards and their effects on the fragile built environment of Mina. Figure 6 shows aftermath photos of the devastation in Mina's built environment that was caused by past natural hazards that occurred in previous years.

Damage to old tents suffers from a fire accident

Flood water covered entrances and cars

Paved roads suffered from negative impacts of floods

Concrete foundations washed away by running water

Floods brought mud and rocks into tents Steel structures did not withstand the floods

Figure (6): Aftermath photos of types of devastation in Mina's built environment that were caused by past natural hazards

3.HYDROLOGIC ANALYSIS OF MINA -- USING 3D GIS

3D GIS provides powerful tools for modeling and analyzing the hydrology of Mina's valley. This research project built a 3D GIS of Mina for this reason. The following sections describe the creation of the 3D GIS model of Mina and the Hydrologic analysis then performed using that model.

3.1 Building a 3D GIS of Mina

Different sources of information were used to build the 3D GIS Model, including:

- A 2D AutoCAD (a CAD Software) maps of the tents within the studied area provided by the Municipality of Makkah 1418 H (Loaner Calendar)
- A 2D contour map every 2 meters also provided by the Municipality of Makkah 1418
- The results of a services and infrastructure survey conducted by the Hajj Research Institute (HRI) during the Hajj of 1424 H [6, 7].
- 60 cm accuracy satellite images of Mina dated 1424 H, captured by the Quick Bird Satellite licensed to HRI through KACST
- A Civil Defense report about rains during the Hajj of 1424 H [8].

Using the above-mentioned sources, the analysis/research/study took specific steps to create the GIS 3D Model. First, an Auto-Lisp routine that can be run from within AutoCAD was developed to generate 3D contours from the given 2D contour maps by using the written values of the contour levels. Second, a 3D contour map was generated using the Auto-Lisp routine. Figures 19 shows the CAD model where contour lines are elevated and polygons for each building type are placed on a separate layer. Then, 2D polygons were created on a separate layer to represent each building type and the traffic network.

The next phase was to model the land surface (terrain) using the Triangulated Irregular Network (TIN), which is a GIS vector representation model for the contours created using the ArcGIS (a GIS Software) and an extension called 3D Analyst[9]. The software uses CAD contour lines to create the TIN. Figure 20 illustrates the TIN model of Mina. The white line on the TIN represents Mina's legitimate borders.

Figure (5): CAD 2D polygons and 3D contours for Mina

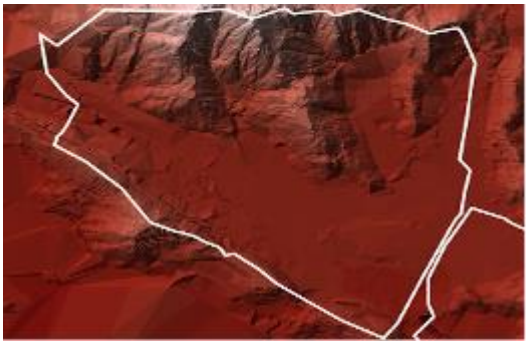

Figure (6): A TIN model of Mina with marked borders

After modeling the terrain, different features of the built environment (housing units, traffic network, service buildings) are represented as feature classes in the Geodatabase. Figure 21 illustrates a captured image of the feature classes of Mina's built environment elements. Using Arc-Scene 3D (part of 3D Analyst Extension), we created a 3D representation of all features. These features were also elevated to their corresponding TIN elevation. Figures 22 shows a captured image from Arc-Scene for the 3D GIS model of the natural and built environments of Mina and its surroundings.

Figure (21): Top view of the 3D GIS model, representing the contours, tents, services, and traffic network of Mina

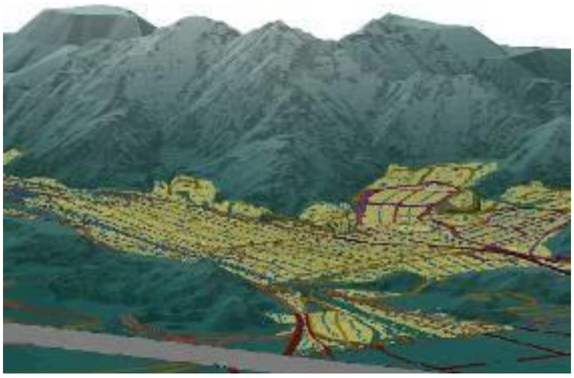

Figure (227): The perspective view of Mina's 3D GIS

3.2 HYDROLOGIC ANALYSIS

In this stage of the study, the rain drainage system was created and analysed, using an ArcGIS extension called ArcHydro. It is an extension that is specialized in performing hydrologic analysis [10]. First a Digital Elevation Model (DEM) of Mina was created. The DEM is a raster representation of the slopes, developed using the TIN [11]. Figure 23 shows the created (DEM) of Mina. The white line represents Mina's legitimate borders.

Using the ArcHydro GIS extension, the drainage patterns of the land-surface terrain were analyzed. Drainage areas were traced upstream and downstream by:

- Attaching drainage areas to the hydro network.

- Using area-to-area navigation.
- Identifying the region of hydrologic influence upstream and downstream from catchments or watershed.
- Generating water basins, water shades, water streams and catchment areas of the terrain surface, using Arc Hydro as illustrated in Figure 24.

Figure (8): Digital Elevation Model (DEM) of Mina with boundaries marked

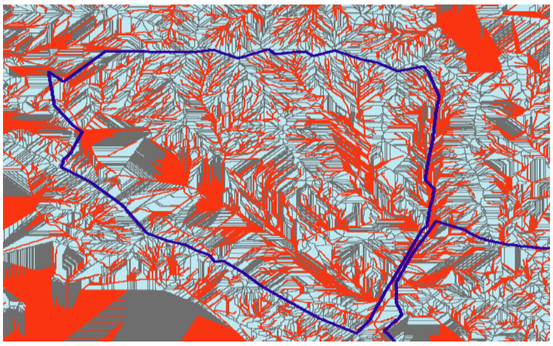

Figure (9): Catchments areas and water streams network

Figure 25 illustrates the water stream networks of Mina surface created using the ArcHydro GIS extension presented over the TIN. Figure 26 shows the TIN, the built environment, and the water streams. The data of recorded civil deafens reports were added to the map (blocks marked in yellow). In addition, all feature classes representing the built environment elements were added to the TIN and the rain water Hydro-Network. Figure 26 shows an exported image from ArcGIS to illustrate the Hydro-Network and the built environment as well as the devastated blocks marked in grey.

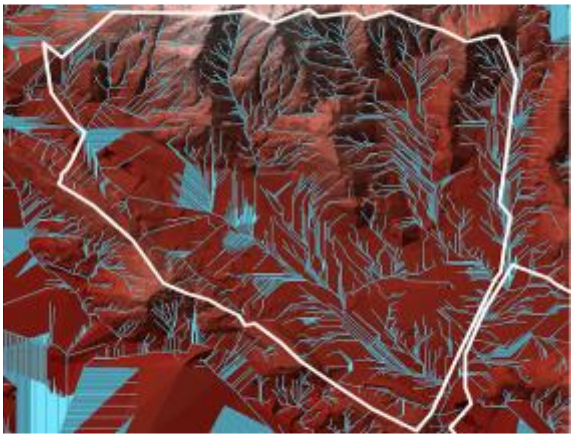

Figure (10): Water streams of Mina created using ArcHydro

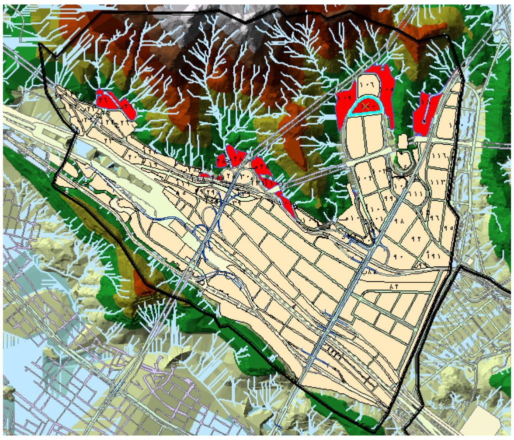

Figure (11): The TIN, built environment, and the water streams

4.DISCUSSION

From the above hydrologic analysis of Mina's natural and built environment, the following remarks can be made:

- The northern blocks of Mina's valley are the most vulnerable.
- Only blocks next to mountain areas (marked in grey) are affected by the rains.

- The northern mountains have the biggest heights and the sharpest overall slopes. This topography causes the water to run with great speed and force.
- At the Western branch of the valley, there is an island of tents that is not affected by the floods. Visiting this site, we was noticed that the tent level is higher than the surrounding streets.
- The Southern blocks were not affected for several reasons:
- Southern blocks are less vulnerable because the slopes go in the southern direction of the neighbouring valley or the Azzizyah area.

Areas suggested for near future development are the Northern parts of Mina, but only those with moderate slope. Using the previously created TIN, we executed a raster layer representing the slopes of Mina, using the 3D Analyst. Figure (27) shows the different slopes of Mina's areas. The light colour areas are flat areas while the dark areas are steeper. In Figure (28), undeveloped areas within the Northern mountains with a slope less than 60% were defined. Comparing Figures 26 and 28, it could be noticed that most of the suggested areas for future development are endangered areas. Developing such areas needs parallel coordinated projects for flood drainage to avoid future damaging floods [12]. In addition, future housing projects can be designed and planned to be in harmony with steep mountainous landscapes without damaging the natural environment of Mina.

Figure (27): The raster image represents Mina's different slopes

Figure (28): Areas with a slope of less than 60 degrees

5.CONCLUSIONS

3D GIS provides urban designers and planners with a useful tool to represent and picture mountainous urban areas for modeling and analysis. The tool can be utilized to estimate and calculate the slopes and flood stream networks of both natural and built areas. It could help as a decision support system for future urban development projects.

There is a need to build a more accurate and comprehensive 3D GIS for Mina. The far surrounding areas of Mina need to be captured for better estimate correlations with water drainage analysis. Future cut and fill work in Mina needs careful study to avoid unexpected future damage from unavoidable floods. It is important to elevate the base of tent camps to avoid future natural hazards caused by floods. There is also an essential need to evaluate and redesign Mina's drainage network to avoid future disasters. Future expansion projects within Mina should also coordinate with current and future water drainage projects.

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الملخص باللغة العربية

تستقبل مدينة الخيام بوادي منى إلى الغرب من مكة المكرمة خلال موسم الحج قرابة الاثنين مليون حاج ، وبذا يمكن اعتبارها أكبر مخيم سكني مؤقت في العالم. وللبيئة العمرانية بمنى خصائص مميزة جدا عن غيرها من البيئات العمرانية. حيث تتكون منشآتها بشكل أساسي من هياكل معدنية خفيفة وقواطيع خفيفة أو قماش (خيام). أم البيئة الطبيعية بها فقوية جدا حيث يحد وادي منى سلسلتين من الجبال الجرانيتية شمالا وجنوبا يصل ارتفاعها إلى ٦٠٠ متر. مثل هذه الظروف تجعل البيئة العمرانية بعناصرها المبنية ضعيفة جدا في مواجهة المخاطر الطبيعية المختلفة مثل السيول وتساقط الصخور والحرائق. وتهتم الدراسة بتحديد المناطق المبنية الأكثر تعرضا للمخاطر البيئية كما تهتم بتحديد المناطق القابلة للتطوير العمراني ومدى تعرض تلك المناطق للمخاطر البيئية المختلفة. ولتحقيق أهداف الدراسة تم إجراء الخطوات التالية:١) إنشاء نموذج نظام معلومات عمرانية ثلاثي الأبعاد يمثل كلا من عناصر البيئة المبنية والطبيعة الجبلية لكامل المنطقة. بحيث يساعد على التعرف على طبيعة تلك المناطق. ٢) تحليل ودراسة الميول المختلفة للمناطق الجبلية المحيطة بوادي منى وإنشاء شبكة تفصيلية لمجاري ومجاري مياه السيول واتجاهاتها باستخدام عدد من البرامج المتخصصة. ٣) تحديد المناطق المبنية الأكثر تعرضا للمخاطر البيئية. ٤) مطابقة النتائج بسجلات الحوادث لدى أجهزة الدفاع المدني. ٥) زيارة المنطقة على الطبيعة للتحقق من النتائج عمليا. كما تم استخدام نموذج المعومات العمرانية الثلاثي الأبعاد في تحديد المناطق القابلة للتطوير العمراني ومدى تعرض تلك المناطق للمخاطر البيئية. وتخلص الدراسة إلى عدد من النتائج العامة فيما يخص استخدام نظم المعلومات العمرانية ثلاثية الأبعاد كما تم التوصل إلى عدد من النتائج فيما يخص حماية عمليات التنمية العمرانية لوادي منى الحالية والمستقبلية.