

Assessment of Urban Flooding caused by Hurricane Gonu in the Seeb City using IKONOS Satellite Imagery

Ahmed Alnaabi, Mohamed Ait Belaid, and Ali Elbattay
Arabian Gulf University, College of Graduate Studies, Manama, Bahrain

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ABSTRACT

The aim of this study was to assess the effect of flooding on urban areas (both existing and planned) and to verify the degree of certainty of with the existing maps of floods risk at an extreme event such Hurricane Gonu; 2007. The Wilayat Seeb located in Sultanate of Oman was significantly affected by Guno hence it was chosen as case study. The methodology adopted is based on the use of (i) IKONOS Satellite Imagery, before and after the Hurricane, (ii) existing Flood Risk map for the region and (iii) the urban general plan for Wilayat Seeb in order to (1) determine affected areas by floods and to compare them with existing Flood Risk map and (2) to investigate the impact according to the urban general plan whether it has been implemented at the time of Guno or not. As for the first objective, the results shows that 54.9% of the selected area was flooded during Hurricane Guno, while the proportion of projected immersion for the same area according to the flood risk map was estimated at 39.1%. The comparison indicated that 72.4% of flood risk map matched with the affected area retrieved from IKONOS Imagery. Therefore, the percentage of affected area which did not correspond to the flood risk map was about 48.4% of the total area. For the second objective, the implemented urban plan was estimated at 26 sq km, while the non implemented urban plan was estimated at 18.5 sq km until 2007. The total area affected by the flood in the implemented urban plans was 21.7 sq km which represent 83.47% of its total area. The non implemented urban plan that would be affected was 15.4 sq km which represented 83.49% of its total area. The area of implemented urban plans expected to be effected according to existing flood risk map was 15 sq km which represented 58%, while the area of non implemented plan would be 8.1 sq km that represented 44.1%. The most affected area by the floods was North Al Mawaleh Town, while the least affected was South Maabela

Town. The study showed a significant difference between the maximum Flood Risk map and what happened during an extreme events such as the Hurricane Guno. The study suggests that the concerned authorities have to consider reviewing the flood risk maps.

INTRODUCTION

Sultanate of Oman is located on the southern part of the Arabian Peninsula (Longitude/Latitude: 51°50'-59°40'/16°40'-26°20') with a 3,200 Km of coasts. Due to its location facing the Indian ocean, the sultanate is among countries at risk of tropical storms and their extreme manifestation; Hurricane. In fact, Hurricane Guno hit Sultanate Oman on 5th of June 2007 and last for three days. Precipitations and wind speed reached 610 mm and 100 km/h respectively. This is considered the worst natural disaster affecting Sultanate of Oman in the last decades. The human toll reached 49 deaths (35 of them at Muscat Governorate), while the infrastructure damage was estimated at some 4 billion (U\$). Face to such devastation, and especially that urban areas was seriously affected many studies appeared trying to assess the flood risk, both before and aftermath, and understand why this occurred in such a brusque manner; (Scholz, 1980); Alkalbani, 2010; Wayne and David, 1986; Alrawas and Voleo, 2010; Saleh and Alhatrush, 2009). However, Remote Sensing based studies focused mainly to determine the affected area after Guno (e.g. Azaz, 2010; Alsaud, 2004; UNDP, 2010) but omitting the use of such outcome to test the response of existing flood risk maps in the event of such extreme calamity. Therefore, the targets of this study were to (1) use IKONOS satellite imagery with remote sensing techniques to evaluate the existing flood risk map generated by hydrological models for Wilayat Seeb, (2) Combine Remote Sensing techniques with GIS

tools to classify the 2003 urban general plan of Wilayat Seeb into implemented and unimplemented by the time of Guno and (3) Determine the affected areas in all eight administrative sectors of wilayat seeb using (ii) real flood maps obtained from IKONOS images and (ii) existing flood risk maps.

MATERIALS AND METHODS

Wilayat Seeb is on Muscat Bay within Muscat Governorate and located at Longitude/Latitude (57°40'-59°40'/22°40'-23°40'). It has an area of 480 sq Km with a population of more than three hundred thousand. It is town to major infrastructure at national level such as Muscat international airport, Sultan Qaboos University, Military facilities, shopping centers, etc. About 80% of its total area is mountainous leaving the main concentration of activities at the flat costal area. Figure 1 depicts the general location of the study area as well as the mosaicked set of Ikonos images before the Hurricane and after it.

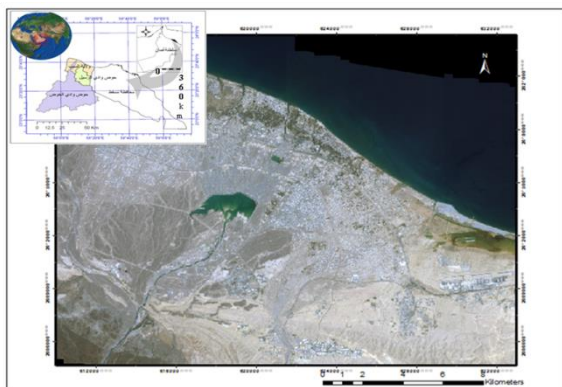


Figure 1: Mosaic of Ikonos Images over Wilayat Seeb Before Guno hurricane (June 2006)

In this study only the coastal area, where major activities are located, is used and it covers approximately 125 sq Km, and contain eight towns, namely: Alkhud, North Al Mawaleh, South Al Mawaleh, South Maabela, North Al Hil, South Al Hil, Alsharadi and Seeb Town.

The flowchart presented in figure 2 shows the general methodology followed in this study. It started with Satellite Imagery data consisting of one set of six IKONOS images that was acquired before Hurricane Guno in June 2006, and a second set covering the study area in 11 June 2007, days after Guno. The flood risk maps (FRM) at a scale of 1:1500, the General Urban Plan (GUP) for the Wilayat Seeb, and its administrative subdivision were all obtained from Oman Supreme Committee for Town Planning (OSCTP). All, IKONOS images

had gone through conventional preprocessing including the color balancing, mosaicking and subsetting. Although the images were already projected (UTM-WGS84, Zone 40), some of them needed an Auto-synchronization (using ERDAS 2011) to assure a good overlay between mosaics before and after Guno. The three bands (1,2,3) for both mosaics were undergone an image difference as change detection technique capable of showing differences due to flooding (Michener and Houhoulis, 1996; Bouazaoui et al., 2000). A simple unsupervised classification was then performed on the difference image to discriminate the flooded zones (both water and mud were considered as flood) and determine the Effective Flooded Zones Map (EFZM). GIS techniques were used to perform a raster to vector transformation, and then overlay EFZM with the Flood Risk Maps (FRM) obtained from OSCTP (risk map had three levels, the extreme was chosen). Areas of similarities and differences between EFZM and FRM were then calculated in sq Km and percentages.

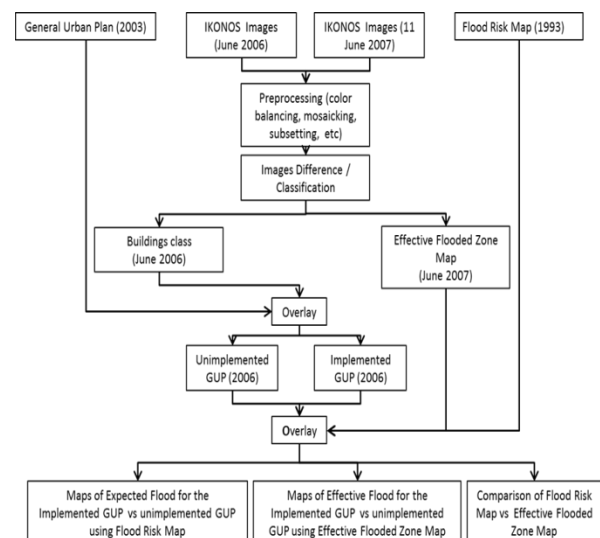


Figure 2: General Methodology Flowchart

Meanwhile, a separate unsupervised classification was conducted on the IKONOS 2006 image to retrieve buildings class only. The buildings class was isolated as a binary raster layer and then vectorized (as polygons), cleaning and correction were conducted in GIS environment and the IKONOS 2007 was used as support to adjust buildings (2007 is affected by mud and water and could not be used directly to achieve this task). An overlay between (i) the building class obtained from IKONOS 2006 image, and corrected to 2007, and (ii) the General Urban Plan, allows the determination of the extent of implementation of the plan as per the date of the first layer (2007). Finally, using the results from above mentioned,

and knowing the administrative boundaries of the eight towns in the Wilayat Seeb, it was possible to produce for the whole wilayat of Seeb as well as for each of its town the following maps: (1) Map of Effective Flood for the Implemented GUP vs unimplemented GUP using Effective Flooded Zone Map, and (2) Maps of Expected Flood for the Implemented GUP vs unimplemented GUP using Flood Risk Map. And intra and inter comparisons of all of this maps were then easily achievable.

RESULTS AND DISCUSSION

Applying the proposed methodology over IKONOS images before and after Guno Hurricane, it turned that the effective flooded zone (EFZ) was 68.6 sq Km of the study area (Figure 3.A). Accuracy was measured by using 200 random check points, 89% from them were classified correctly. Hence, 54.9% of the total area was affected by the flood. It is important to mention that during the transformation from raster to vector, a buffer of 5 meters was applied to get the effective flooded zone to compensate the four days delay between the end of the hurricane and the acquisition of the IKONOS image. Figure 3.B shows the flood risk map (FRM) for the same area, where 48.9 sq. Km (39.1%) of it is supposed to be flooded in extreme floods. It is clear that hurricane Guno has affected a much larger area than expected through FRM, where 54.9% of the study area was affected versus 39.1% expected. This significant difference is also observed spatially (Figure 3.C) where the red color represents areas where both EFZM and FRM are concordant (72.4% or 35.4 sq. Km of similarity with reference to FRM). The blue color shows zones where the FRM indicates a risk of flood while there was no flood during Guno, 27.6% or 13.5 sq. Km of dissimilarity with reference to FRM). The orange color represents the zones affected by Guno but not present in the FRM (48.4% of the total area covered by both EFZM and FRM).

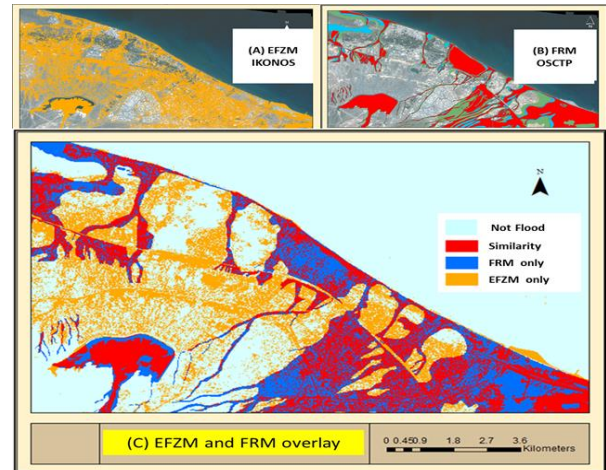


Figure 3: Comparison of Guno flooded zones (A) obtained via IKONOS images, (B) Flood Risk Maps from OSCTP and (C) overlay

For the second objective, figure 4 depicts results and steps to segregate the GUP into implemented versus unimplemented. As explained above in the methodology section, the first step was to isolate buildings class by conducting an unsupervised classification using IKONOS 2006 images (figure 4.A). Once done, the results were converted into a vector layer and overlaid with the GUP retaining only the intersection (Figure 4.B). IKONOS 2007 was used for accuracy assessment and to correct/adjust the final output as the GUP should be segregated to 2007. The orange color in figure 4.D represents the original GUP as per 2003, with a total area of 44.43 sq. Km. the red color in figure 4.E represents the unimplemented GUP by 2007 with a total area of 18.47 sq. Km while the implemented part (yellow color and dark grey) cover 25.96 sq. Km.

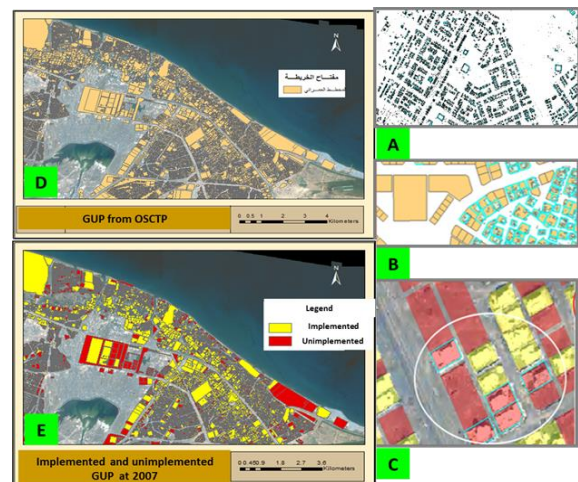


Figure 4: Implemented vs unimplemented GUP at 2007; (A) buildings class extracted from IKONOS 2006, (B) Vectorization and overlay with GU, (C) Correction using IKONOS 2007, (D) original GUP, (E) segregated GUP, background is IKONOS 2007 image

Figure 5 shows the result of overlay between the EFZM and the implemented and unimplemented GUP as per 2007. It turns that 21.67 sq. Km of the implemented GUP was affected by Guno (83.47% of its total area), while 15.42 sq Km (83.49%) of the unimplemented GUP would be affected by Guno. Yellow zones represent the limited area in the implemented GUP not affected by Guno (less than 17%) and so for the green area depicting the unimplemented GUP. It is clear that Hurricane Guno was of an extreme adversity and only 17% of both implemented and unimplemented GUP have escape its direct effects.

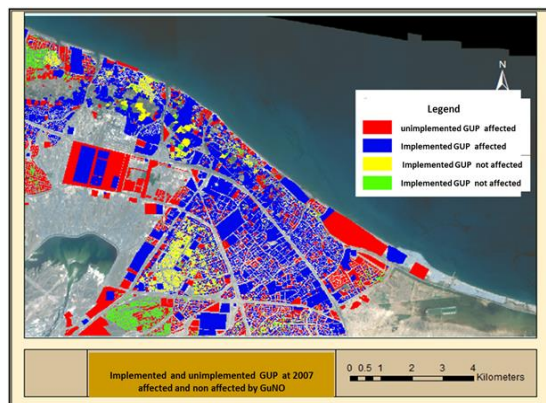


Figure 5: Implemented and unimplemented GUP at 2007 affected and not affected by Guno

The third and last objective of this study was to compare the EFZM and FRM at level Wilayat Seeb's towns. Table 1 shows the results obtained for the eight towns included in the study area. It is clear that North Al Mawaleh and South Al Mawaleh are the two towns that FRM predicted the biggest flooding percentage, 93.83% and 94.47% respectively. The EFZM confirmed that fact and effectively 98.77% and 91.30% of these two towns was affected by Guno. However, only 21.85% of Seeb town was predicted to be affected using FRM while EFZM indicates 84.31%. The same was observed for the South Maabela, which was the relatively the less affected by Guno with 66.35% of its area affected by Guno while only 27.88% was predicted by FRM. It is obvious that FRM had underestimated significantly the effect of Guno for all towns at Wilayat Seeb.

Town	Area of Implemented GUP (km ²)	Area within FRM (km ²)	Percentage	Area within EFZM (km ²)	%
North Al Mawaleh	0.81	0.76	93.83%	0.8	98.77%
South Al Mawaleh	2.53	2.39	94.47%	2.31	91.30%
North Al Hil	5.58	3.51	62.90%	4.44	79.57%
South Al Hil	3.87	2.92	75.45%	3.81	98.45%
Alkhud	6.17	2.83	45.87%	4.38	70.99%
Alsharadi	2.39	1.55	64.85%	2.23	93.31%
Seeb Town	3.57	0.78	21.85%	3.01	84.31%
South Maabela	1.04	0.29	27.88%	0.69	66.35%
Total	25.96	15.03	57.90%	21.67	83.47%

Table 1: Area of implemented GUP by towns at Wilayat Seeb affected by flood according to FRM and EFZM

CONCLUSIONS

This study is a relevant illustration of the role of geospatial techniques such as remote sensing and Geographic Information Systems in post-disaster assessment. Pan-sharpened IKONOS images (1 meter spatial resolution) acquired before and after hurricane Guno were very useful in the determination of effective flooded zones. Unsupervised classification was used to determine buildings class and combined with GIS techniques allowed to segregate the general urban plan for Wilayat Seeb into implemented and unimplemented by the date of Hurricane Guno (June 2007). The obtained results show clearly that the Flood Risk Map available before the hurricanes was not adequate to predict the vulnerable areas. In fact, according to this map 57% of the implemented GUP should be affected in the occurrence of such extreme event. However, it happened that 83% of the overall implemented GUP were affected by Guno. Furthermore, towns such Seeb Town and South Maabela were only expected to be affected at 21.85% and 27.88% respectively, while it turns to be affected at 84.31% and 66.35% respectively. It then highly recommended to review the existing flood risk maps for the region and to learn from the extreme event of Guno on the necessity to adopt new methodology of generating such maps and to study the unaffected areas as possible locations where shelter and emergency response might be arranged.

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AUTHOR BIOGRAPY

Ahmed ALNAABI: M.Sc Student, Arabian Gulf University, M. Ahmed got a Bachelor in Agriculture from Sultan Qaboos University, Sultanate of Oman, 2000. He then joined the Sultanate Government. In 2010 he joined as a postgraduate student at Arabian Gulf University- Desert and Arid Zone Program, GIS and Remote Sensing specialization. He got his Master degree in 2012.

Mohamed AIT BELAID: Professor, Geodetic Sciences and Remote Sensing, Arabian Gulf University, belaid@agu.edu.bh. He is graduated from Canada (Laval University) and Morocco (Agronomic Institute Hassan II) in the fields of Geomatic Sciences. Over 32 Years of experience, from which 13 years within the Ministry of Agriculture (Project Leader), 8 years at the Royal Center for Remote Sensing (Head of Department of Natural Resources and Environment) and 11 years at the Arabian Gulf University in Bahrain (Academic Chair of GIS). Organization of 6 Symposia, Vice-Chairman of the United Nations Committee of peaceful uses of outer space (COPUOS), Development of a new Higher Educational Program on GIS/RS, Expert to United Nations Organizations, Author & co-author of more than 60 Scientific Papers, 4 Books and 1 Arabic Encyclopedia.

Ali ELBATTAY: Assistant Professor-Remote Sensing, Arabian Gulf University, elbattay@yahoo.com. Dr. Ali Elbattay got his PhD (Environmental SAR specialization) from INRS-ete (Canada) in 2006. He joined Faculty of Geoinformation Science and Engineering at Universiti Teknologi Malaysia in 2007 as researcher then lecturer and subsequently senior lecturer. In 2011, Dr. Ali joined Arabian Gulf University as Assistant Professor (Remote Sensing and Geoinformatics) at College of Graduate Studies

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