Coupling of Population and Spatial Datasets for Flood Risk Impact Analysis

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Abstract
Due to the inadequacy of spatial themes for assessing flood risks, considerable attention was shifted towards models for addressing continental and global hazards. There was limited focus on the exposure and vulnerability components of flood risk assessments with more focus on the physical aspects of the assessment and little understanding of the specific impacts on people and the assets. GIS-based flood risk assessment model was adopted in this study for assessing flood risk and the impacts in the Sultanate of Oman. Images captured by Leica Geosystems were used to generate georectified images in NSA's office. Analysis of the georectified images revealed that people in the coastal tract were highly vulnerable to flooding during extreme weather events and sea-level-rise inundation. Impacts of flooding created nine classes of land use/land cover with a considerably extensive ground surface (221.28 km2) and limited land use areas for cropland (0.16 km2) and cultivation (0.20 km2), and built-up areas (21.57 km2). Impacts of flooding on roads and building infrastructures were significant. Hence, the rehabilitation approach involving the implementation of surface and underground water systems to mitigate impacts of flooding on people and the assets in the Sultanate of Oman was recommended.
Keywords: population, spatial datasets, flood risk, remote sensing.

Introduction

Spatial themes are not adequate for flood-risk assessments. Therefore, developing models for addressing continental and global hazards is gaining considerable attention [1]. Such models, combined with exposure and vulnerability datasets, can help to mitigate catastrophic flood events. Though flood-risk models have received significant attention, yet there is limited focus on the exposure and vulnerability components. There was more focus on physical/fieldwork scenarios [2] with little knowledge of the exact impacts on people and assets. However, robust GIS-based flood-risk assessment technology involving remote sensing has been implemented [3]; [4]; [5]. A similar GIS-based flood risk assessment approach was implemented in this research study.

Sultanate Oman is one of the countries which is located in an arid environment that is subject to flash flooding [6]. The main causes of floods in Manafwa River basin is due to land use changes and the increased frequency of floods in the basin due to global climate change and further points out that bad land management, population living and growing crops closer to the river each year is increasing the socio-economic damages of floods [7]; [8]. The expansion of urban built-up areas is one of the major reasons for the reduction in preamble land which in turn it increases surface floods [9]. Land Use is a by-product of human acts and deeds with the nature, which has resulted for dynamic usage of natural resources may paves way for irregular urbanization and causes flooding [6]. [10]; [11; [12] to trace the impact of land use change on discharge of water and floods.

The impact of flood is seen on nature, living and man-made features. Causing huge damages to normal life cycle that happens all over the world. While studying the impact of land use / land cover change due to floods in 1964 and 2003, in-spite of the same rainfall in the Madarsu Basin in Golestan province of Iran. It is pointed out that the expansion of urban built-up areas is one of the major reasons for the reduction in preamble land which in turn it increases surface floods [4].

Study Area

Sultanate of Oman is in the south-eastern part of the Arabian Peninsula surrounded by Sea of Oman in the northeast and Arabian sea in the southeast with a coastal length of 3165 km and an Area of 309,500 km^2. United Arab Emirates sited on the northwest and Saudi Arabia on the west while Yemen is on the southwest side of the Sultanate of Oman. The study area under Muscat Governate by Coastal tract named “Wadi Aday" with a geographical area of 128.12 sq. km. The study area has a geographical extent of 23º 37'2" N and 58º 29” 4’ E 23º 19”3’ N and 58º 19” 5’ E with a mean sea level of 7 meters. Wadi Aday is one of the largest wadies flows through Muscat. It drains some of 335km^2 watershed to the sea. The upper catchment consists of large gently sloping bowel named Al- Amerat bowel surrounded by mountainous range reaching at about 1500 meter above the sea level.

The Wadi Aday itself is formed by numerous tributaries flowing from mountains and heading to the northeast. the converge progressively to this in the entrance of narrow gorge where the Wadi cuts high limestone barriers. After 8 kilometers of winding flow, the powerful Wadi Aday comes out to the Qurum heights, runs throughout Qurum city center to reach finally the sea in the mangrove of Qurum natural reserve.

The lower course of Wadi Aday crosses densely inhibited Qurum areas. Houses and commercial buildings are packed along the wadi banks and some places they even encroach dangerously the rain wadi bed itself. Presently the upper Al Amerat bowel is more inhabited, it is one of the main suburbs of capital area with more than 20,000 new plots already distributed that would be led to increase in population reaching to more than 90,000 people and the number increased day by day due to huge development of the area and newly highway constructed which connect the area to other cities. [13].

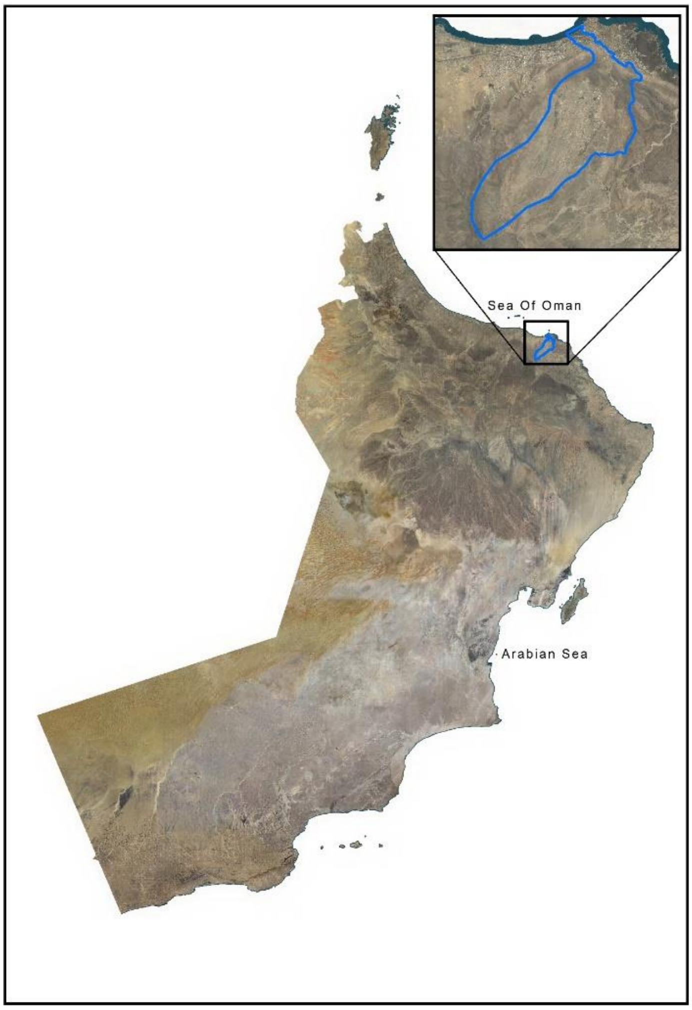

Figure 1. Study Area of Wadi Aday Basin

Materials and Methods

The imageries used to conduct the study are aerial images captured by Leica Geosystems which were used to produce spatial layers from ADS multispectral aerial photos after photogrammetric processing and using field survey techniques. The data which have been used dated 2012 due the national wide aerial photography project for the whole Sultanate of Oman. The project divides The Sultanate of Oman into 6 areas in which several blocks been defined. After subjecting the raw images to Aerial Triangulation, Pixel Factory software generated DTM was used to orthorectify them. They were assigned with Universal Transverse Mercator (UTM) projection and WGS 84 datum and registered with the National Survey Authority's (NSA) Control Points (GCPs), Sultanate of Oman. To ensure quality assurance, AT(aerial triangulation), DSM(Digital surface model), DTM (Digital Terrain Model), Orthophoto generation, colour balancing, and Pixel Factory processes were conducted in the NSA office. QC and stereo aerial image processing were carried out using ISAT by Intergraph and Microstation by Bentley software. Subsequently, the georectified images were extracted, overlaid, and analyzed by the ArcGIS software. The results helped to understand the flooding impact on the population distribution, neutral land cover, assets, and infrastructures in the study area.

Field data collection

Field data includes ground control points (GCP) and in-situ field observations for preparation and validation of thematic maps. GCP were collected using differential GPS system while other ground truth data were collected using calibrated Navmatica system. The ground control points have been used is part of the National wide aerial photography for the Sultanate of Oman and was done by Rolta ltd. and Navmatica Company for ground control points collection. The model of using temporary CORS network has been used and the Sultanate territory was divided to 6 main areas in each area there are blocks accordingly. The study area is in Area no (6) in blocks 10 & 11 (see Figure 2). Figure 2 shows area number 6, the blocks, the location of the ground points and the temporary CORS network. Sultanate of Oman has been divided to 6 areas and on each area, several blocks for the matter of CORS observation. GPS base stations establishment and surveying were deployed for the purpose of producing the maximum accuracy that can be achieved using Smoothed Best Estimate of Trajectory (SBET) which was used as one of the inputs of aerial triangulation in further steps. Trimble 5800 and 5700 was used as GPS receivers.

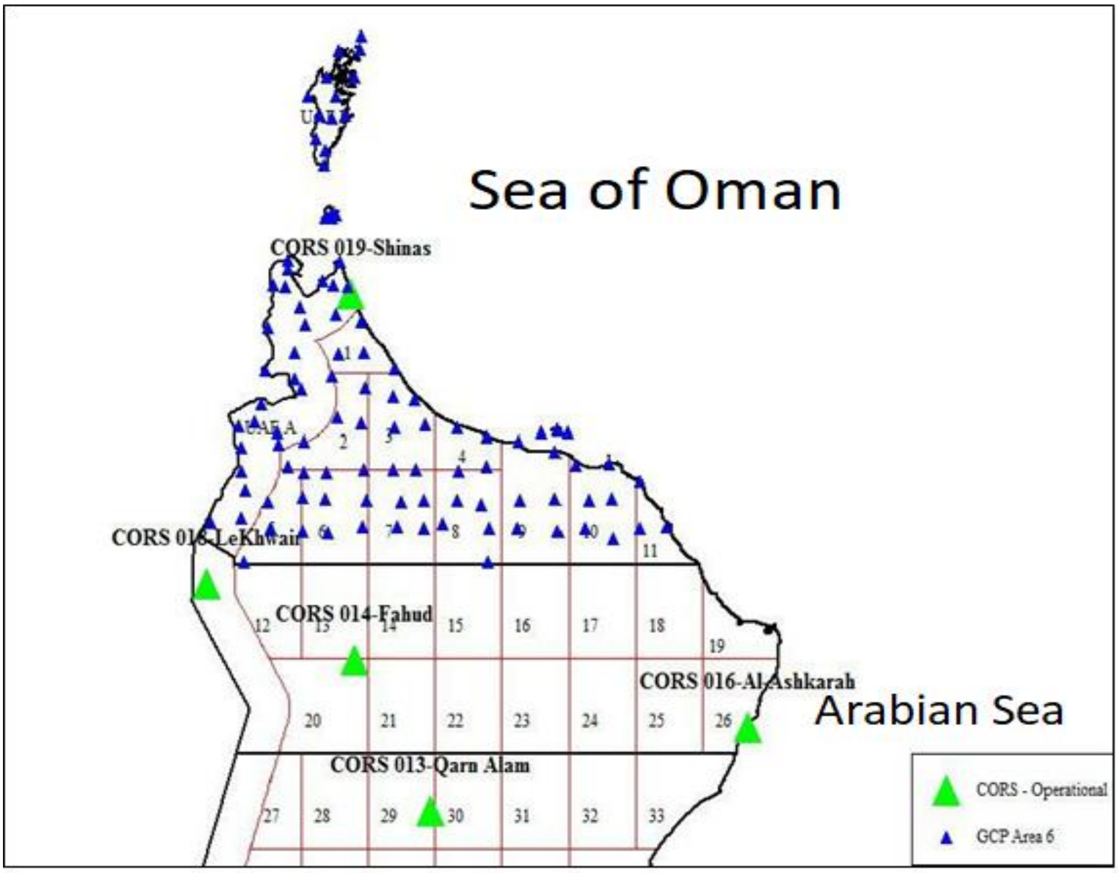

Figure 2: GCP and CORS points distribution in study area

Remote sensing data acquisition

ADS40 multispectral and stereo images were procured from Leica Geosystems for the study area. The ADS40 system is a line array system that employs a three-line scanning technique, in which multiple linear charge coupled device (CCD) arrays are situated on the focal plane within a single sensor head and view in the forward, nadir, and backward direction. The ADS40 uses large linear CCD arrays which yield wide cross-track image coverage per flight line. It has: 2 panchromatic CCD lines each 2* 12,000 pixels staggered by 3.25 µm, 6 multispectral CCD lines each 12,000 pixels, a pixel size of 6.5*6.5µm, swath angle of 64° and a focal length of 62.77mm as shown in table 1. (https://leica-geosystems.com/)

Table 1: Leica ADS 40 Specification

Electronic Characteristics				
• Dynamic range CCD chain	• 12-bit			
• Resolution A/D converter	• 14-bit			
• Data channel	• 16-bit			
• Data modes	• Raw data, compressed			
• Data compression factor	• 2.5x – 25x			
• Data normalization modes	• Linear, non-linear			
• Radiometric resolution of compressed data	• 8-bit			
• Recording interval per line	• ≥ 1.2 msec			
Spectral Range and Filters				
• Spectral range	• Panchromatic, RGB, Near Infrared			
•	• Band	•	(nm)	• = 50%)
• Spectral bands	• Panchromatic (trapezoidal) Red (rectangular) • Green (rectangular) Blue (rectangular) Near-infrared (rectangular)	• 465 – 680 (at 610 – 660 • 535 – 585 430 – 490 • 835 – 885		

Aerial triangulation

Aerial triangulation process was done automatically using Pixel Factory suite camera calibration report for ADS40 aerial camera with flight lines and flight reports. ADS40 aerial camera provides multispectral images with 50 cm spatial resolution. These images were extensively used for preparation of thematic maps. Similarly, ADS40 stereo images were used to generate 50cm resolution Digital Elevation Model (DEM) of 5 m spacing. The ADS40 aerial images were processed using the Pixel Factory tool of AIRBUS Software. The images have been used for the following purposes:

- Drainage layer extraction.

- Land use/Land cover layer extraction.
- Preparation of Drainage Density map.
- Preparation of Slope map.
- Extraction of Infrastructure layers (Buildings and Roads).
- Collection of Building footprints with height.

Images captured by Leica Geosystems were used to produce spatial layers from ADS multispectral aerial. After subjecting the raw images to Aerial Triangulation, Pixel Factory-generated DTM was used to orthorectify them. They were assigned with UTM projection and WGS 84 datum and registered with the National Survey Authority's (NSA) Control Points (GCPs), Sultanate of Oman. To ensure quality assurance, AT, DSM, DTM, Orthophoto generation, colour balancing, and Pixel Factory processes were conducted in the NSA office. QC and stereo aerial image processing were carried out using ISAT by Intergraph and Microstation by Bentley software. Subsequently, the georectified images were extracted, overlaid, and analyzed by the ArcGIS software. The results helped to understand the flooding impact on the population distribution, neutral land cover, assets, and infrastructures in the study area.

Geo-tagged population datasets were collected from the National Centre for Statistics and Information (NSCI) of Sultanate of Oman and a dot density population map was prepared for the study using ArcGIS tools. Population point layer was later overlaid on the land use/land cover and weighted overlay output. Building polygons were extracted from ADS40 image by using onscreen digitization technique. The building polygon layer was similarly overlaid on the weighted overlay output. Roads were also extracted from the image and draped on the weighted overlay output. The integration of population, land use/land cover and road layers with weighted overlay output has helped in understanding the impact flooding on population distribution, natural land cover, assets, and infrastructure.

Results and Discussion

Impact of flooding on population distribution

The National Centre for Statistics and Information (NSCI) of Sultanate Oman (http://ncsi.gov.om) stated that in year 2019, Wadi Aday basin has a total population of 72,325 out which 48,985 are Omanis and remaining 23,340 are non-Omanis. Nearly 33% of the total population inhabits in the coastal tract in which majority of the population corresponds to non-Omanis. This category of the population is at high risk as the entire coastal tract falls under very high and high flood risk categories as shown in the weighted overlay-based flood risk map shown in Figure 3. The outward flow from nearby hillocks towards the Seward side during rainstorms in peak monsoon or extreme weather events is one of the main reasons for flooding in the coastal tracts. On the other hand, the region also faces a threat of sea level rise-based land inundation. Although, there is not much impact of sea level rise up to 2m, anything beyond 2m increase would result in hazardous floods causing severe damages to people and properties. At 5m sea level rise, all the low-lying areas of the coastal tract will be submerged and at 10 m sea level rise, nearly 1/3 of the coastal tract is going to be inundated. Increase of sea level beyond 10 m is practically impossible, taking into consideration of the current global rate of sea level rise.

Overlay of population layer on weighted overlay output shows that majority of the overall population in the study area is distributed in the flat terrains surrounding the Wadi spread in the hinterland. The hinterland population is dominated by Omanis who are occupying the areas since centuries. There are the people who account for the lion share of the GDP of the nation through various means of employment, business and entrepreneurships. Most of hinterland population falls in the high flood risk category followed by the extremely high flood risk category as per the weighted overlay output. There is a minimal occupancy in the moderate category whereas low and very low categories contain negligible amount of occupancy. The study calls for localized flood risk mitigation action plans for costal tract and hinterland vulnerable zones with technology based participatory approach.

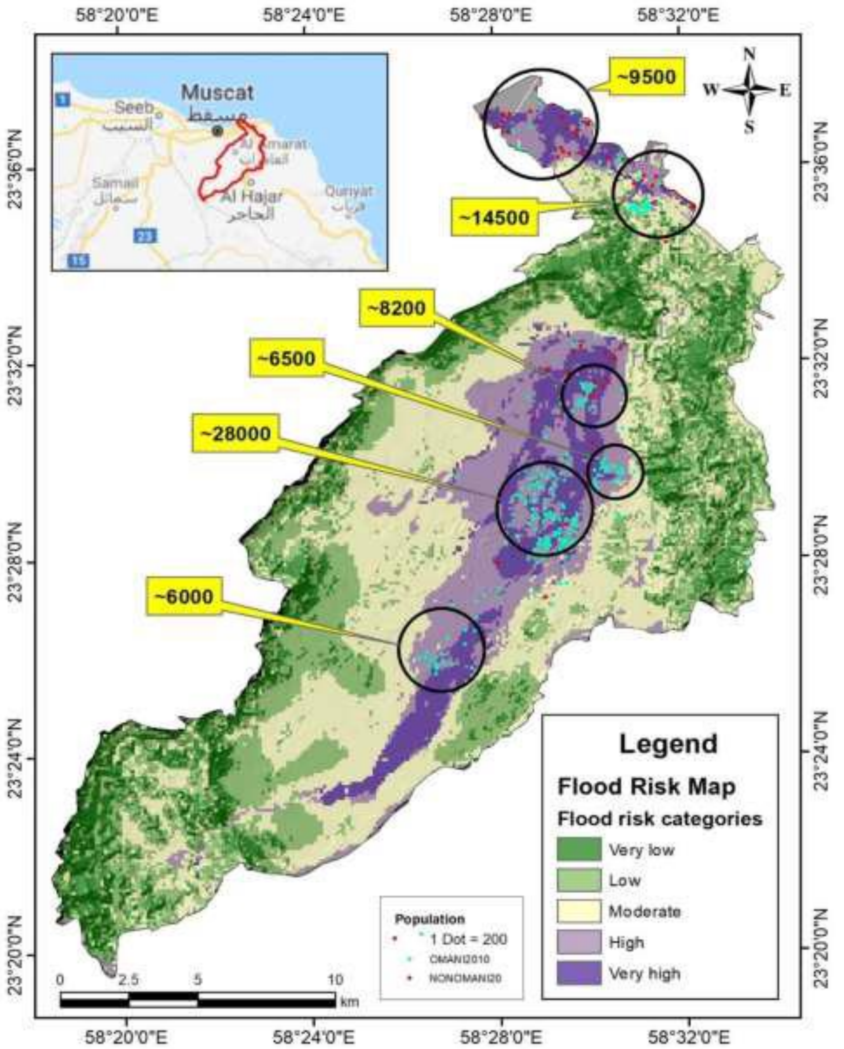

Figure 3. Population layer overlaid on weighted overlay flood risk map

The majority of the population in the flat terrains that surrounded the Wadi spread in the hinterland. Omanis dominated the hinterland population; they were at high flood risk; therefore, the region was moderately occupied (Figure 3).

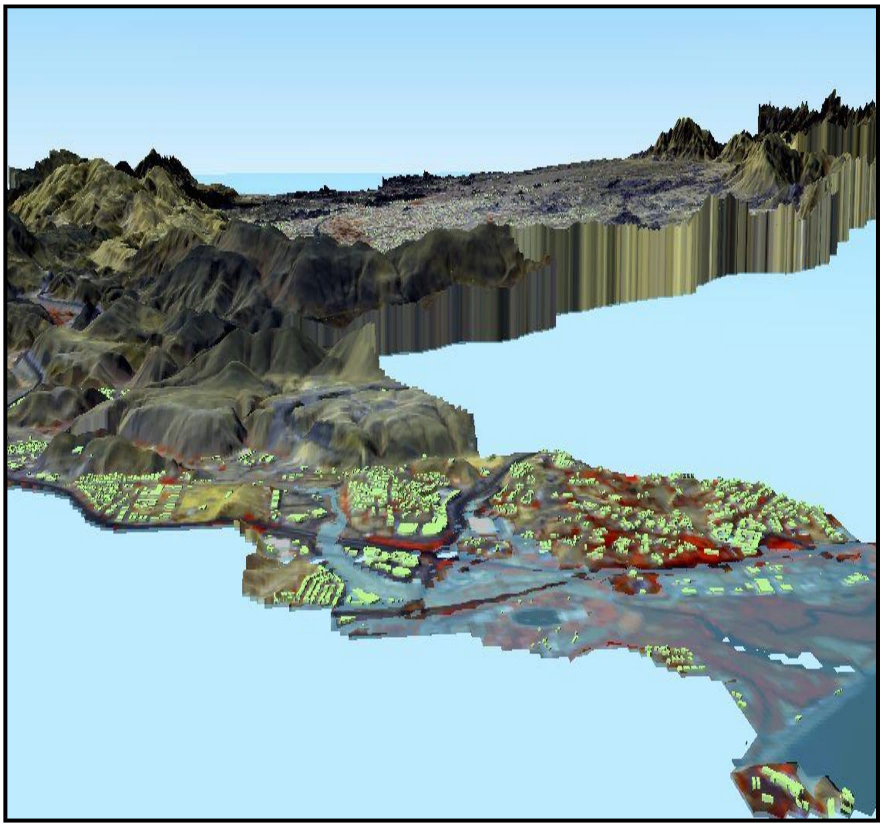

Figure 4: Inundation of the coastal tract at 10 m sea level rise

Impact of flood on land use and land cover

Land use and land cover changes affect both the probability of flood and its consequences in several ways. Land cover affects different elements of the water balance like evaporation, surface temperatures and interception [22]. In addition, they impact climate systems, and in turn, the frequency and characteristics of rainfall [11]; [7]; [18]. Moreover, there is a direct impact of Land use and land cover changes on the formation of runoff from a particular rainfall event [24]. Numerous studies have considered the general impact of land use/land cover change on flooding; however, there are fewer studies on the direct implications of flooding on existing land use/ land cover and rehabilitation approaches.

Nine divisions of land use/land cover, plantation (0.37 km^2), scattered trees (94.18 km^2), land with scrub (2.89 km^2), cropland (0.16 km^2), cultivation (0.20 km^2), grassland (0.55 km^2), ground surface (221.28 km^2), build-up land (21.57 km^2), and Wadi spread (12.87 km^2), were identified as Figure 5 and Table 2.

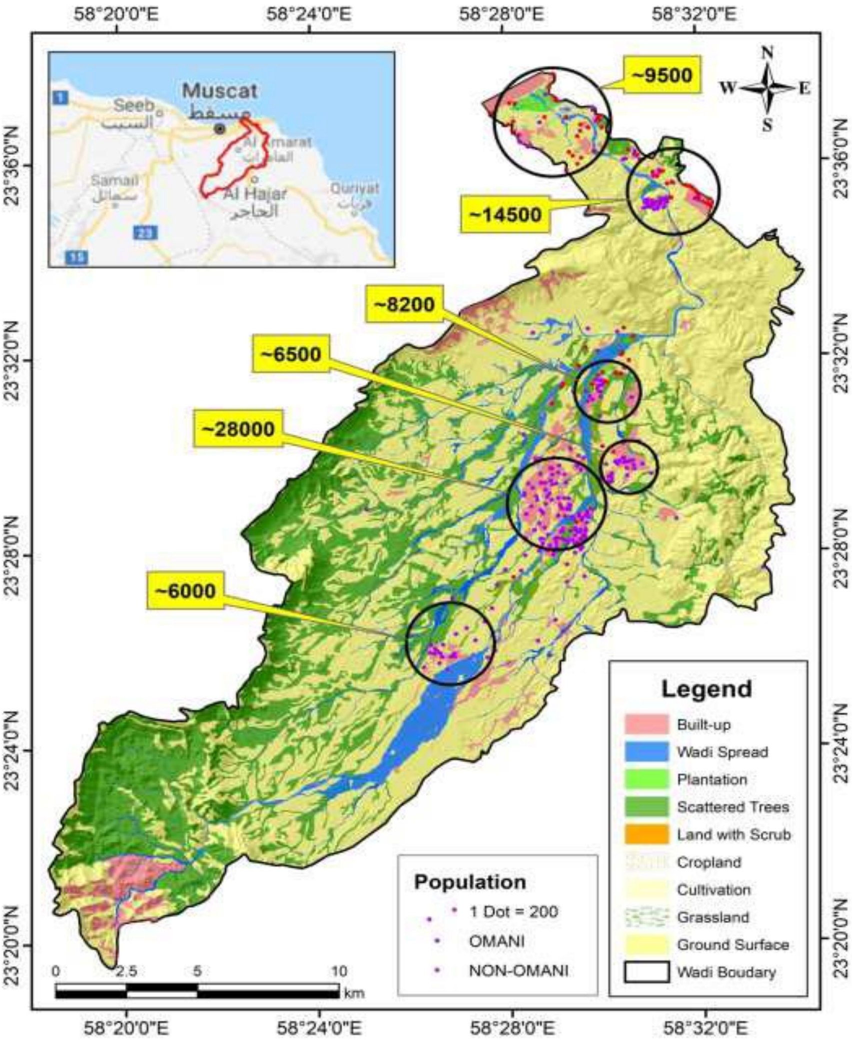

Figure 5. Land use/land cover map of the study area

The land use/ land cover of the study area is divided into 9 major classes as depicted in Figure 4 and Table 2.

Table 2. Land use/land cover classes with coverage in squared meter and percentages

LULC Class	Area (sq km)	Percentage of Class
Plantation	0.37	0.10
Scattered Trees	94.18	26.60
Land with Scrub	2.89	0.82
Cropland	0.16	0.04
Cultivation	0.20	0.06
Grassland	0.55	0.15
Ground Surface	221.28	62.50
Built-up land	21.57	6.09
Wadi Spread	12.87	3.64
Total	354.06	100.00

Major portion of the study area is covered by ground surface with sand deposits (62.5%). Built-up land which corresponds to about 6% of study area mainly falls under high-risk category in the hinterland and under very high flood risk category in the coastal tract. Plantations are mainly restricted to the coastal tracts and up-streams of Wadi spread which mostly fall in high-risk category. Scattered trees are evenly spread throughout the study area which account for 26.6% of the total land use/land cover. There is no significant effect of flooding on tree cover, unless there is a catastrophic flooding. Land with scrub is mostly restricted to the hill slopes. Cropping and cultivation practices are comparatively negligible in the study area. Grasslands are mainly restricted hill tops.

Impact of Flooding on Road Infrastructure

Several studies have assessed the consequences of past flood events on a road transport system. [14] have described how a 15 min journey turned into a two-hour reroute after the collapse of several bridges in Workington. [15] have analysed the cost of Storm Desmond to traffic disruption in Ireland to be € 3.8 million. These studies give a clear show that flooding can be catastrophic for transportation systems and their users. However, potential flood impacts on traffic systems have not been studied in detail in the past. [16] have opined that climate change could potentially double both travel time and travel distance, whereas [17] have considered traffic delays to be a more significant consequence than the longer distance. It is intuitive to expect that the urban environment has many rerouting options, so the travel distance should not be increased as much as the travel delays due to congestion. [18] have studies on the vulnerability and the robustness of the traffic system in York, UK. Nine roads were considered prone to flooding and were either closed for traffic or with reduced capacity. The vulnerability and robustness indices were calculated assuming each flooded street is independent. This rarely happens because usually, flooding affects larger areas than just one street. However, the research identified the most vulnerable streets and also suggested that traffic delays are the most significant impact. All three studies employ a macroscopic traffic model, which only poorly represents congestion or diversions. Furthermore, the information about flood hazard in these studies is coarse with no representation of drainage system, which is essential for a correct spatial description of urban floods [19];[20];[21].

The roads in the study area are divided mainly into 2 classes (Figure 5). The first class includes all highway roads, city roads, layout roads and other link roads. This class is mainly spread in the coastal tract and Wadi spread region. More than 80% of the above class falls either in high or very high flood risk category. The second class includes cart tracks. Majority of the cart tracks falls in moderate and low categories.

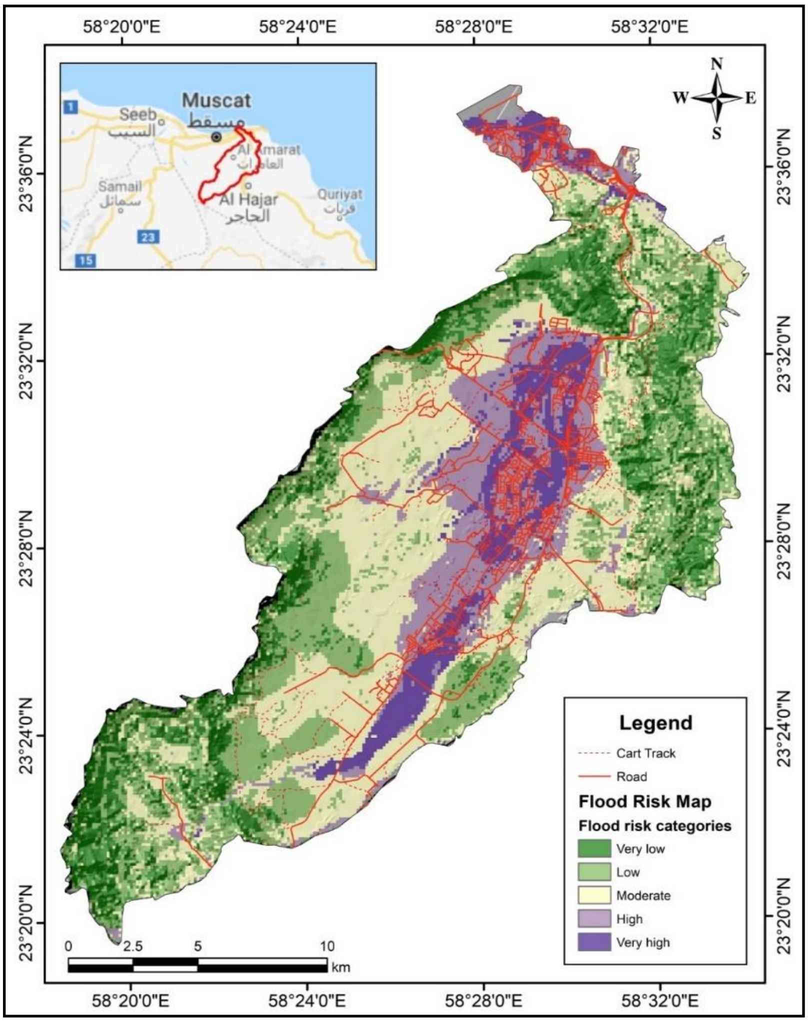

Figure 5. Road layer overlaid on Weighted overlay output

The present study clearly shows that both the coastal tract and the Wadi spread region have very poor natural drainage system due to flat topographical conditions as shown in Figure 6. Additionally, sufficient amount of clay present in the soils of coastal tract and Wadi spread resist the seepage and quick draining of water. Both the factors together cause enormous damages to road infrastructure during the unusual raining conditions. Implementation of adequate storm water drainage and underground draining systems will result in significantly reducing the flooding especially in and around the Wadi spread.

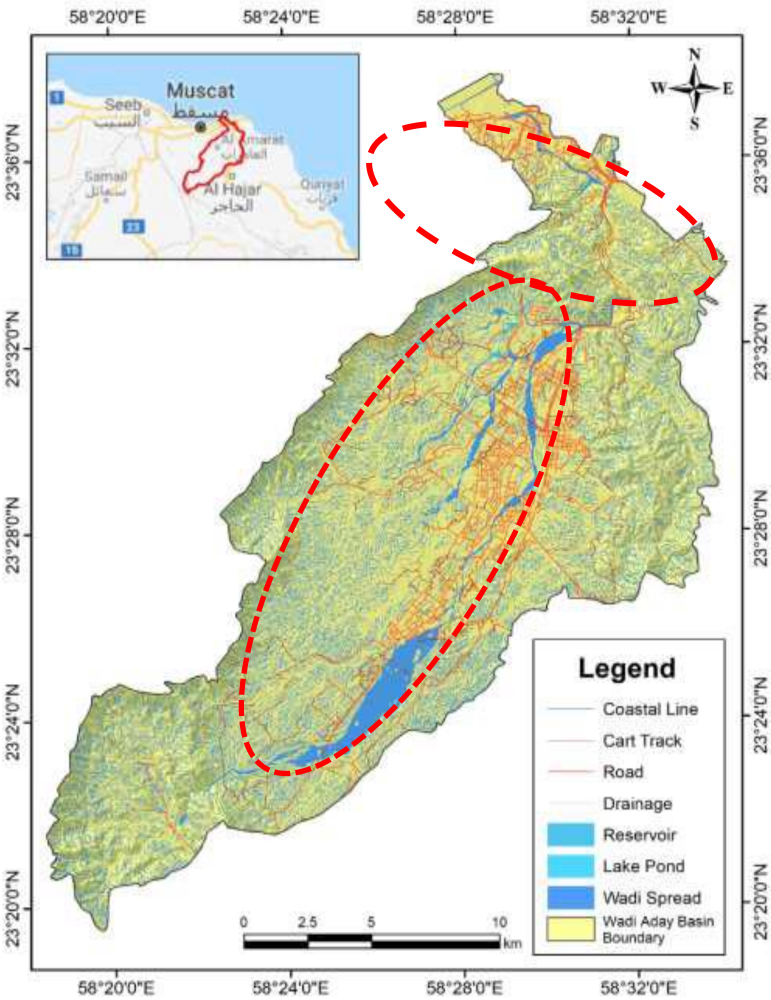

Figure 6. Natural drainage in coastal tract and Wadi spread area

Impact of Flooding on Building Infrastructure

Overlay of buildings layer on the weighted overlay output, clearly depicts that about 80% of the buildings falls either in high or very high flood risk category. The remaining 20% falls in the moderate category (Figure 8). Buildings in the coastal tract have dual risks of storm water and sea level rise flooding. However, the buildings in the mainland are prone to only storm water flooding. Majority of the buildings in the study area are of average height and are built strictly following the standard ground improvement techniques and structural design standards. This has drastically reduced their vulnerability to collapse during the flooding events.

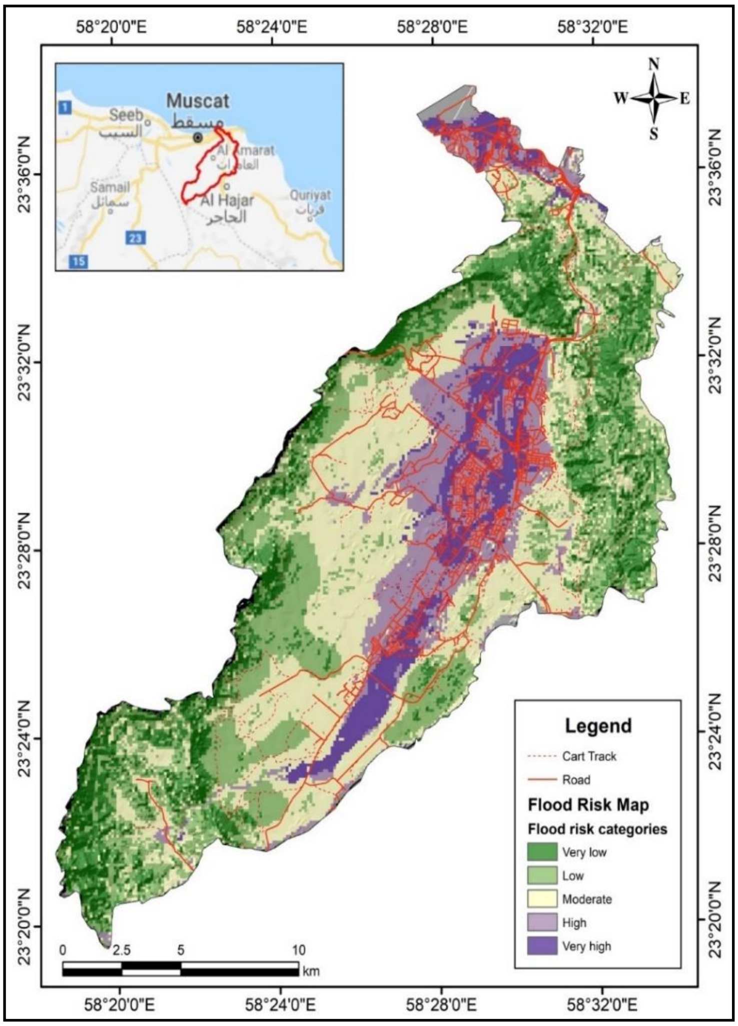

Figure 7. Road layer overlaid on Weighted overlay output

Overlay of population layer on weighted overlay output shows that majority of the overall population in the study area is distributed in the flat terrains surrounding the Wadi spread in the hinterland. The hinterland population is dominated by Omanis who are occupying the areas since centuries. There are the people who account for the lion share of the GDP of the nation through various means of employment, business and entrepreneurships. Most of hinterland population falls in the high flood risk category followed by the extremely high flood risk category as per the weighted overlay output. There is a minimal occupancy in the moderate category whereas low and very low categories contain negligible amount of occupancy. The study calls for localized flood risk mitigation action plans for costal tract and hinterland vulnerable zones with technology based participatory approach.

Many research studies investigated the impact of land use/land cover change on flooding. According to [22], land cover and land use influenced flooding probability and water balance elements, including surface temperatures, evaporation, and an interception. That impacts the climate systems, which resulted in significant impacts on rainfall [23]; [24]; [25]. [26] reported a direct effect of land use and land cover on rainfall surface runoff. However, fewer research studies similarly investigated the influence of flooding on the existing land use/land cover. This research study revealed nine main classes of land use/land cover caused by the impacts of flooding on the study area.

Other research studies similarly reported that flooding caused transport system disruptions and led to delay and rerouting and caused significantly increased travel time and travel distance [2]; [9]; [23]. [15] revealed that traffic disruption caused by Storm Desmond caused Ireland £3.8 million. Several research studies supported the findings from this research study that poor natural drainage and topography contributed to the effects of flooding [26].

Conclusion

This paper has presented how population and spatial datasets for flood impact analysis have been integrated with the weighted overlay output to understand the overall impact of the floods in the study area. Four(4) impacts of floods have been studied which are: on population distribution, on land use/ land cover, on road infrastructure and on buildings. The data that have been gathered from NCSI shows that the percentage of 67% Omani nationality and 33% no Omanis are still down in coastal area which was defined as a very high-risk zone as shown in the weighted overlay-based risk map. 9 classes of land-use land-cover have been depicted mostly ground surface with sand deposits which covers 60% of study area. The study area falls in high-risk category in the hinterland of wadi spread area and very high risk at tract region. Due to the topography of the area and the poor natural drainage, the roads infrastructure is at high-risk category of floods especially when up normal rainfall. Floods have the impact on building infrastructure because they fall in the high and very high zone of flood as shown in the maps created. Buildings in the coastal tract have dual risks of storm water and sea level rise flooding but the buildings in the mainland are mainly prone to rainstorm flooding.

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