Resilience Urban Planning from Climate Change Point of View: A Case Study for Qatar

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Abstract

Qatar is a Middle Eastern country characterised by an arid climate. Key challenges in urban planning in general are uncertainties of the future, *especially when it comes to water resources and specifically storm water.* While textbook of urban planning concentrates the most on social and economic factors that promote prosperity for the communities, in many arid areas the concept of planning from a climate change and specially storm water might be looked at as the least important in the priority list of criteria required for a successful and practical urban planning. This situation poses a challenge to urban planners in general, especially with limited available standards and criteria of planning from a storm water and climate change perspectives. This paper intends to shed some light on the above-mentioned challenges of planning from storm water perspective and provide a more practical approach to urban planning from climate change perspective, and aims at providing the urban planning community with the basics of optimizing the challenge of rainfall and possible flooding in such an arid area like Qatar.

Keywords: Climate change; Storm water; Sea level rise; Urban planning; Qatar

1 Introduction

Changes to climate change in terms of changes to rainwater intensity and the sea level rise, and the consequences of poor planning of flood mitigation measures are not uncommon in the arid region of Middle East. For example, a devastating flood in Nov 2009 in Jeddah, Saudi Arabia caused deaths of over 100 people and major destruction of urban infrastructure (Al-Saud, 2010). Furthermore, the Gulf countries including Qatar, experienced unusual rainfall events in 1995 causing severe flash floods (Membery, 1997). Heavy rainfall and major flooding were also reported in 2015 across the Gulf regions including Qatar, Oman and Saudi Arabia (Al Saud, 2010; Al-Shaqsi, 2010; Subyani, 2011; Al-Rawas & Valeo, 2015). In the most recent years, multiple unexpected rainfall events have been encountered in the State of Qatar. And although the investment in Infrastructure in the State of Qatar is unexceptional in magnitude, it is still challenged by dealing with rainfall events that exceed expectations and thus pose some risks specially in the built environment.

The main challenges in urban planning in arid regions from a storm water point of view include lack of recorded available watercourses, rainfall, infrequent occurrence of floods and lack of defined storm water catchment (Xao Lin, 1999; Vivoni et al., 2006; Sen, 2008; Morin et al., 2009). The accurate identification of historical water courses and proper characterization of storm water catchment, in addition to the set of available rainfall and flood data together with sea level - tidal station – data is an important first step for comprehensive watershed management.

A number of hydrological modelling approaches have been adopted to estimate design floods in arid regions (e.g., El-Hames & Richards, 1998; Jothityangkoon et al., 2001; Foody et al., 2004; Sevinç & Sen, 2007; Bracken et al., 2008). However, the calibration of rainfall runoff models in arid regions is problematic due to the lack of recorded rainfall and flood data, and simple empirical or semi-empirical models may perform equally well or even better than the complex modelling approaches (McIntyre et al., 2007). Numerous storm water and flood studies have been carried out in various parts of the world recently utilizing GIS based methods (e.g., Soussa et al., 2010; Metwaly et al., 2010; Fernandez & Lutz, 2010). These GIS based methods can also be applied to storm water management in the arid region of the Middle East.

This paper focuses on properly incorporating storm water into urban planning in Qatar. There have been limited holistic storm water studies in the Gulf region; in terms of storm water studies, there is no known significant rainwater study that linked its output with the urban planning community in Qatar until now. The Ministry of Municipality had carried out multiple studies related to rainfall and runoff, a national flood project, and an outfall assessment project in Qatar. The paper aims at providing the urban planning communities with some guidelines regarding better utilization of the outputs of the watershed and flood studies. In addition, introducing the major storm water watershed elements (including storm water catchments, major wadi lines, major natural depression areas), in addition to depth and risk of flood. Finally, it will also discuss the potential changes in rainfall intensity and possible location that might be affected by sea level rise from climate change point of view. Hence, provide a practical way to incorporate them into the urban planning, therefore providing a more climate change resilient planning for the built environment in general, coupled with added value planning from socioeconomic and environmental perspective to meet sustainability goals.

2 Study Area

The study area for this paper will focus on Qatar in general, (Figure 1) with an estimated area of 11,571 km^2, but will also include two pilot study areas with smaller size to better illustrate the objectives.

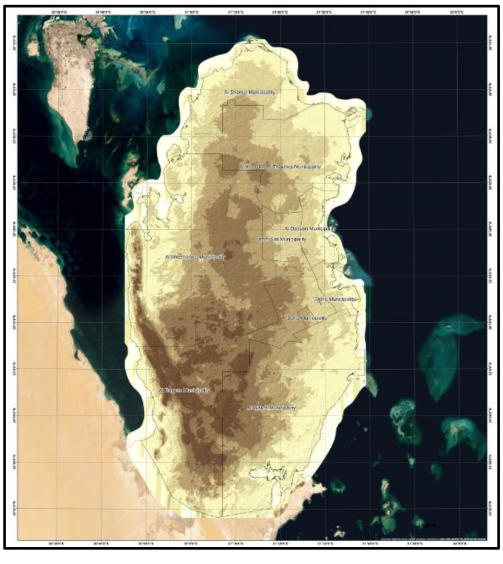

Fig. 1: Location map of Qatar

3 Data Collection and Assessment

Most of the data for this study were obtained from the Ministry of Municipality (MM), Qatar. An assessment was undertaken to identify any significant data gaps and to determine its implication on storm water modelling and mapping outcomes of this study. The objectives of data collection were to:

- Assess the level of detail and availability of existing topographic and bathymetric data to develop a Digital Elevation Model (DEM) of the study area.
- Collect and review available historical rainfall and flood data available, to calibrate and parametrize hydrologic model.
- Determine the availability and reliability of existing GIS information.

In relation to the most 2017-2018 current terrain data, the team has processed the DEM available to better fit the hydrological and watershed analysis. The study has also utilized the output of the Qatar flood study finalized by Ministry of Municipality together with available tidal station sea level rise analysis as part of a climate change analysis.

The rainfall runoff processes in arid regions are characterized by flat topography, poorly defined overland flow paths, poor vegetation and high transmission losses (Pilgrim et al., 2009).

The average annual rainfall in Qatar is 77.9 mm (Mamoon et. al 2016). The climate of Qatar is dominated by mild winters and very hot summers. Rainfall mainly occurs in the period from October to May, with significant inter-annual variability (Batanouny, 1981). Westerly disturbances are considered to be the main source of rainfall in Qatar.

4 Methodology

4.1 Overview of Methodology

The focus of this paper is to present the outputs of the watershed analysis and shed the lights on the importance of utilizing them in future urban planning efforts in general. The study will present the major water courses within the watershed under study, including main boundaries of catchment areas and the major Wadis within. In addition, it will present the natural depressed areas that would be potential storm water accumulation points, finally through incorporating the major areas of potential flood currently under future climate change scenarios, the paper will present the urban planning community with solid guidelines for better planning the future including the climate change scenario.

4.2 Model Setup

4.2.1 Preparing the Digital Terrain Model

The first step in carrying out an accurate watershed analysis is to prepare the topographical data, mainly the digital elevation model (DEM), by conducting a DTM analysis to produce the elevation topography model from LIDAR data set of 2017.

The available data was in point cloud format and further analysis is required to create the Digital Terrain Model (DTM). Accordingly, the team has carried out Post Data Processing phases by manipulating the LIDAR point cloud until creating seamless Digital Terrain Model (DTM) (Figure 2). An algorithm has been created to speed up the surfacing and interpolation analysis. The interpolated DTM is derived from the LIDAR point cloud in shapefile format and further involved mosaicking process which require approximately 13,152 tiles to create a seamless DTM for the whole Qatar. The team also generated two analyses from the DTM which are as follows (Figures 2 and 3).

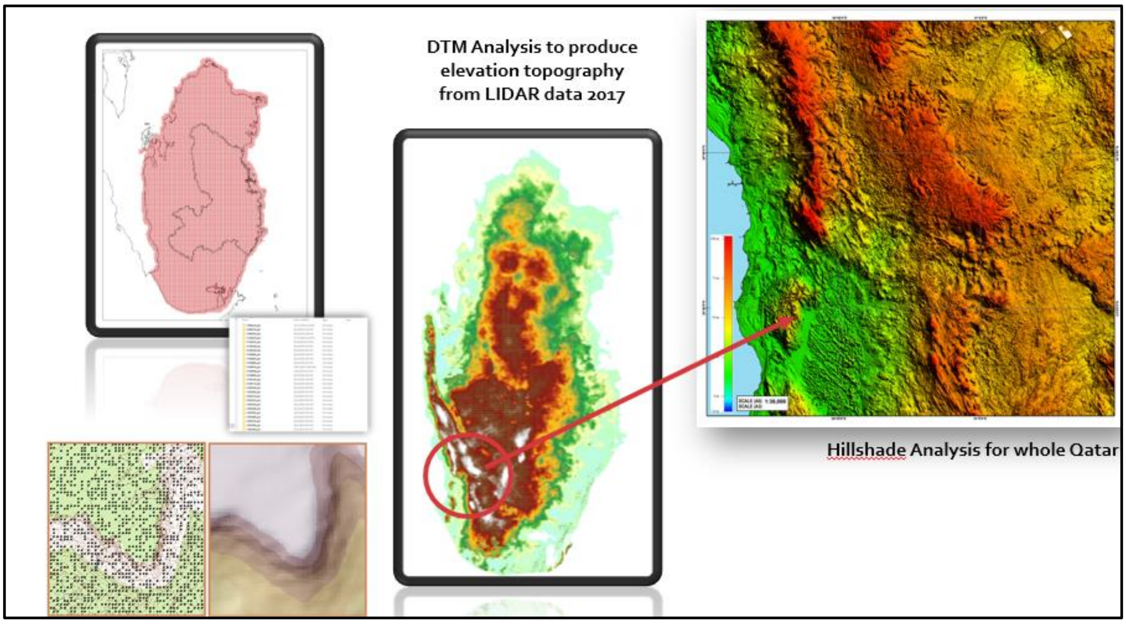

Fig. 2: Creating the digital Terrain model from Lidar Data set

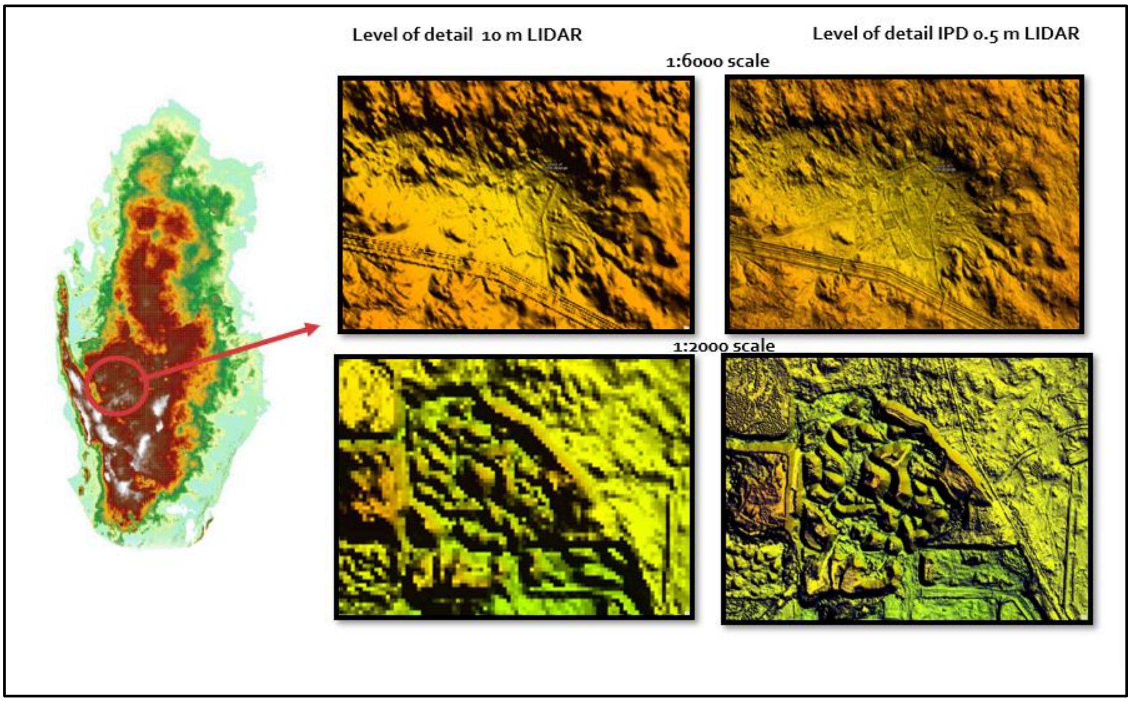

Fig. 3: Level of details after processing the elevation data

4.2.2 Conducting the Watershed Analysis

The second step in watershed analysis is to establish the main watershed and sub-catchments. Due to the flat nature of Qatar, the assessment considered various factors to design the hydrological level of the catchments to better suited the planning process. Figure 4 herein below provide more details on the steps taken.

Watershed area was delineated using the latest Digital Terrain Model that only consider the Qatar natural topographic and ground elevation. ArcGIS 10.7.1 and Global Mapper software were utilized to perform this watershed delineation. The hydrologic analysis tools were utilized for watershed delineation, flow accumulations and flow length. Figure 4 shows the workflow of how the watershed delineated.

The Sub-catchments were delineated using an automated ArcGIS tool (Arc Hydro). Sub-catchment slopes were calculated based on the study area DEM and the longest flow path lines generated using Arc Hydro. Catchment slopes ranged from 0.2% to 29.5% with an average slope of 3.02%, which is considered to be relatively flat. Manning's 'n' values for each sub-catchment were determined using an area weighted approach and ranged from 0.03 to 0.08. Fraction imperviousness for the sub-catchments ranged from 0.01 to 0.95 with 62% of sub-catchments being highly impervious with fraction impervious values in the order of 0.75 to 0.95 (a fraction value of 1.0 indicates 100% imperviousness).

A hydrologic model of the catchments was developed using XP-RAFTS software to estimate runoff hydrographs at the outlet of sub-catchments for a range of design storm events. Rain on grid hydraulic modelling was undertaken using the 2D hydraulic model developed, the rainfall runoff process was simulated through the application of design rainfall events directly across the detailed 2D hydraulic model domain. The 10% and 1% AEP design flood events were again assessed in the 'rain on grid' hydraulic model through the application of design rainfall intensities and temporal patterns as model boundary conditions. Rainfall loss and infiltration rates were initially set to a base case of zero to obtain conservative results. For the 1% AEP design event, a sensitivity analysis was undertaken on the rainfall loss and infiltration rates based on pre-set scenarios.

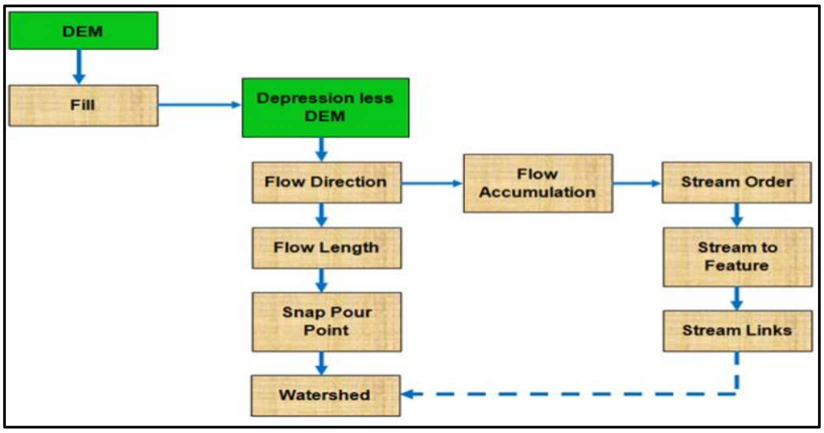

Fig. 4: Watershed Delineation Workflow

The Digital Elevation Model being utilized is a very high resolution elevation models which is possible to extract small wadis. In order to map the watershed area correctly, it is necessary to remove errors and artificial sinks in the Digital Elevation Model where pre-processing is required to allow water movement across the digital landscape. In addition, LIDAR data 2017 Ortho Image from CGIS with the resolution of 0.2m were used for visual assessment of the delineated watershed.

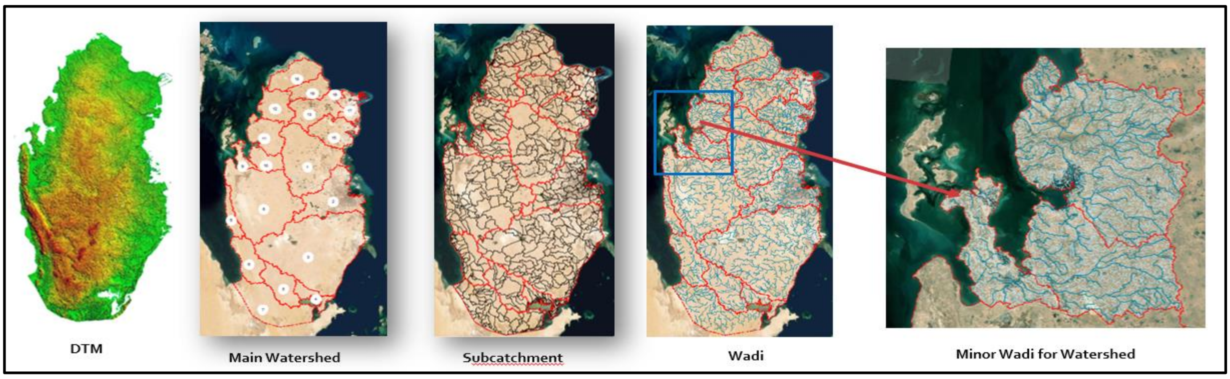

Fig. 5: Output of Watershed Analysis

4.2.3 Depression Area Using LIDAR

Depression area were identified from GIS analysis using an algorithm that extract sink information from the latest 2017 LIDAR data. These depressions may contribute to pinpoint the suitable location for natural wetland design as well as hydrologic connectivity to store the runoff water. Somehow the depth of the depression area requires elevation information or a contour data. Figure 6 shows the mechanism of nested depression that can be design as storm water storage areas.

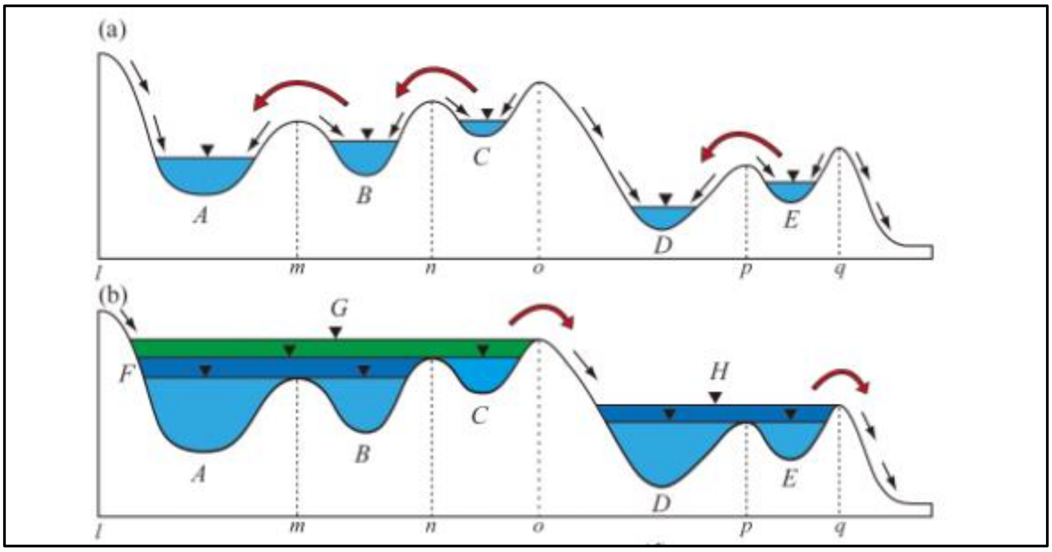

Fig. 6: Mechanism of Nested Depression area

4.2.4 Setting up the Hydrological Model - Rain on Grid Hydraulic Modelling Approach

A hydrologic model was established to estimate runoff hydrographs for a range of design storm events at key locations across the study area. Design event hydrographs were then applied as point source inflow boundary conditions in a two-dimensional (2D) TUFLOW GPU hydraulic model of the pilot catchment at specific inflow locations to simulate the two dimensional behaviour of flooding across the catchment study area. Key features of the model included a detailed DEM, a land use layer, building representation, walls/fences and cross drainage infrastructure.

The catchment model setup included the following features:

(a) The preparation of a detailed DEM using existing topographic and bathymetric data.

(b) The preparation of design rainfall dataset using existing guidelines and hydrologic parametrization/extrapolation techniques.

(c) The development of a detailed hydrologic model including representation of existing catchment area, slope, imperviousness, roughness and rainfall loss rates.

4.2.6 Climate Changes Scenario

In order to determine the potential impact of climate change on flood behaviour in each of the ten model sub-catchments, Year 2050 and 2100 future climate change scenarios were assessed for the 5 year and 100 year ARI design events using the future rainfall intensity and sea level conditions summarised in Table 1 below.

Table 1: Future Climate Change Scenarios

Scenario	Future Climate Era	Change in Rainfall Intensity (5year Ari)	Change in Rainfall Intensity (100 Year Ari)	Tide Conditions Relative to Qatar National Datum (Qnd95)	Sea Level Rise (M)	Storm Surge (M)	Resultant Sea Condition (M Qnd95)
1	2050	+10%	+10%	MHHW	+0.37	+0.5	MHHW +0.87
2	2100	+20%	+20%	MHHW	+0.98	+0.5	MHHW+1.48
3	2100	+30%	+30%	MHHW	+0.98	+0.5	MHHW+1.48
4	2100	+40%	+50%	MHHW	+0.98	+0.5	MHHW+1.48
5	2100	+60%	+60%	MHHW	+0.98	+0.5	MHHW+1.48

In relation to the derivation of the future climate scenarios, it is noted that:

- The rainfall intensity increases adopted for Scenarios 1 to 3 were determined to represent an approximately 'median' year 2050 and 2100 rainfall scenarios.
- The rainfall intensity increases adopted for Scenarios 4 and 5 are consistent with the future climate rainfall scaling factors of 1.4 (for 2 year to 10-year ARI design events) and 1.5 (for 100-year ARI design events) as recommended in the Qatar Rainfall Runoff project Technical Report. It is noted that these scaling factors represent a 'conservative' year 2100 rainfall scenario and will result in higher flood levels than Scenarios 1 to 3.
- Tidal levels vary along the coastline of Qatar. In accordance with Tidal Information (MM 2015), the Mean Higher High Water (MHHW) tidal levels and resultant future climate sea level conditions have been determined using the nearest tidal gauge location. The MHHW tidal levels adopted along the Qatar coast is provided in Table 2.
- The storm surge height of 0.5 m was adopted based on recommendations provided by an internationally recognized storm tide consultant as part of the Qatar Flood Study.

Table 2: Mean Higher High Water Tidal Levels (MHHW) Tide Levels

Flood Model Catchment Name	Nearest Tidal Gauge Location	Mhhw Tidal Level (M Qnd)
Al Khattiya	Dukhan	0.30
Al Nuaman	Ras Ushayriq	0.58
Al Ruwais	Al Ruwais	0.74
Al Thakira	Ras Laffan	0.64
Doha	Doha Port	0.69
Fuwairit	Ras Laffan	0.64
Mesaieed	Mesaieed Port	0.81
Ras Laffan	Ras Laffan	0.64
Rawdat	Doha Port	0.69
Sawda Natheel	Dukhan	0.30

4.2.6 Calibration/verification

Due to the lack of historical flood data in the pilot catchment, the pilot catchment flood model was not calibrated to historical flood events. However, following the heavy rainfall experienced in Qatar on the 25th of November 2015, and other heavy rainfall events in recent years including the latest this year 2022, it was decided that the event would be modelled and where possible model performance checked against available ground flood records.

Based on a review of modelled results against limited on ground flood records, the nature and pattern of flooding estimated by the flood model was found to be generally consistent with that experienced on ground. In the absence of detailed calibration data, this provided confidence in the flood model's ability to simulate the nature of flooding across the study area.

5 Case Study

To better illustrate the implementation of the watershed analysis and the assessment of a proposed development from a climate change perspective, the following case study in Al Ruwais area north of Qatar is presented. The main objective of this assessment is to identify areas prone to risk from possible surface drainage flooding and rise in sea level at the coastal area of al Ruwais.

Site Location and Topography

The area under assessment is located in Al Rwais in Al Shamal Municipality. In general, the average built area elevation is around **2m (QND)** especially for build area within the range of 30-350 m from the sea shoreline. However closer inspection of the elevation in the area suggests a dredge line elevated at around 4 m and form a natural separation line of expected storm water runoff. In addition to this there is some areas identified as naturally depressed areas where elevation drops to less than 10 cm, more details will be covered in depth in the following sections.

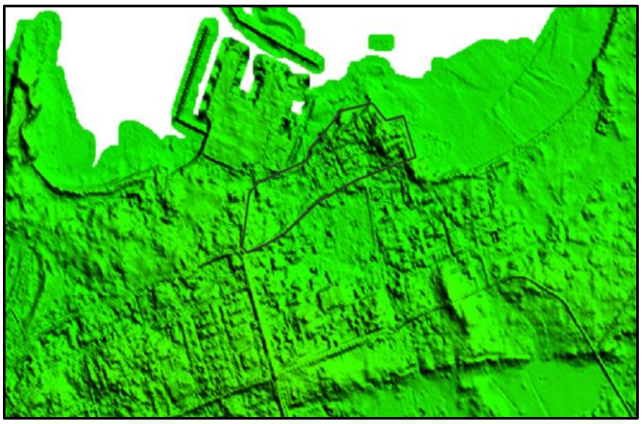

Fig. 7: Al Rwais Area – Digital Elevation Model

Watershed and Catchment Considerations

The line depicted in Green in **Figure 8: Watershed and Catchment Boundaries.** is the natural catchment separation line, with an elevation of around 4 m QND , accordingly the storm water runoff is expected to flow away from this line in both direction as depicted by arrows in black. The current surface drainage/runoff direction is expected to follow the main lines shown in light blue to the line shown in dark blue in **Figure 9: Natural Surface Runoff Direction to main Streams.**

In general the main storm water runoff stream flow direction shown in Dark Blue Figure 3 below indicates that the natural flow line is passing right through the developed area, thus it is expected that the northern part would experience some flooding issue during heavy rainfall events, especially if this natural flow line is blocked by development, accordingly it is highly recommended to take this into consideration during the design and development of the streets in the area, to consider the natural Stream flow line shown in dark blue in Figure 3 below. In addition, it is highly recommended to consider the minor stream flow lines during the development of the local roads and drainage projects in the area.

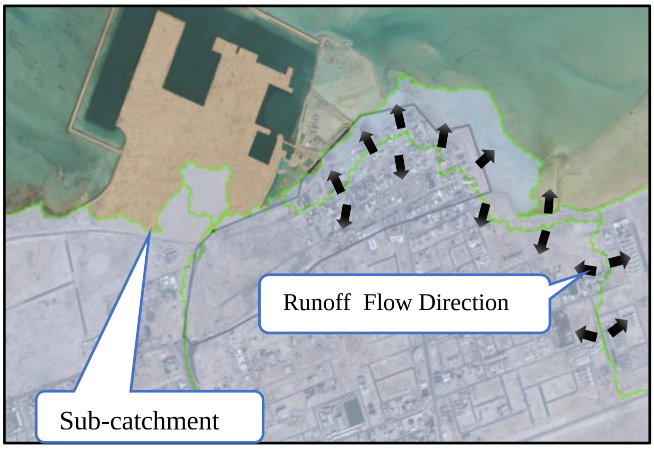

Fig. 8: Watershed and Catchments Boundaries

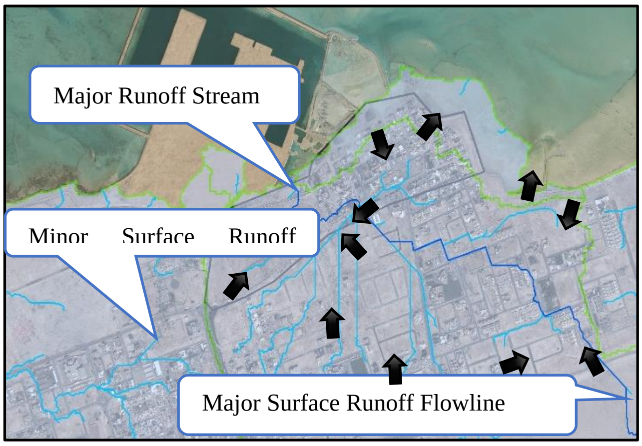

Fig. 9: Major and Minor Natural Surface Runoff Streams

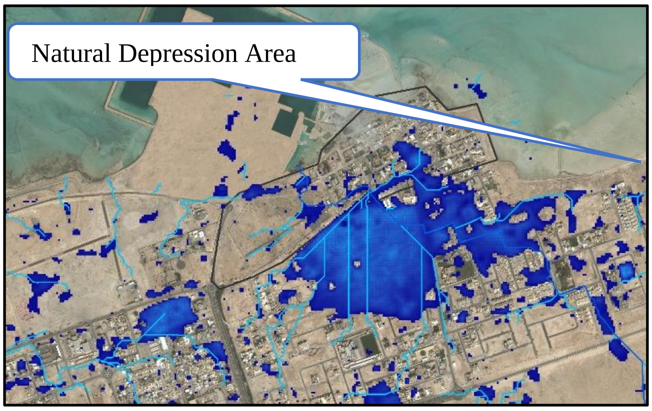

Fig. 10: Natural Depression areas within the Catchment

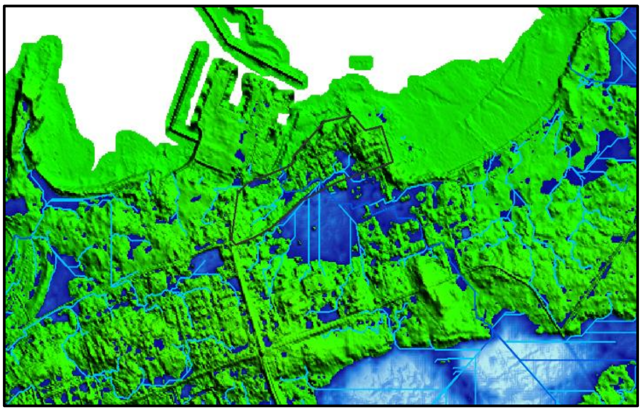

Fig. 11: Depression area and DTM integration

For better assessment IPD has considered a separate model run integrating the DTM together with flood model. **Figure 6** below shown the assessment based on DTM for reference, where the depressed areas shows depth in blue, the darker the blue the deeper the elevation.

Flood Assessment

To confirm the findings in the previous sections, a Flood Assessment is carried out based on the IPD Flood Model developed for the area tacking into consideration the 1 in 100 years event as a return period, to account for expected depth of runoff and associated hazards due to flooding if any. Figures 12 and 13 below confirm the fact that multiple inland areas are prone to flooding, especially in the naturally depressed areas.

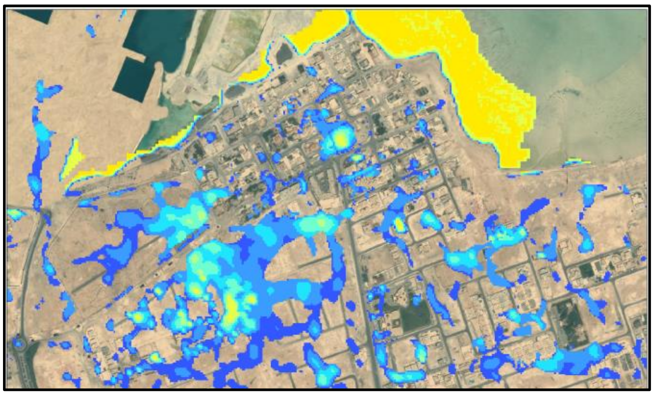

Fig. 12: Flood Depth for 1 in 100 Years – Base Model

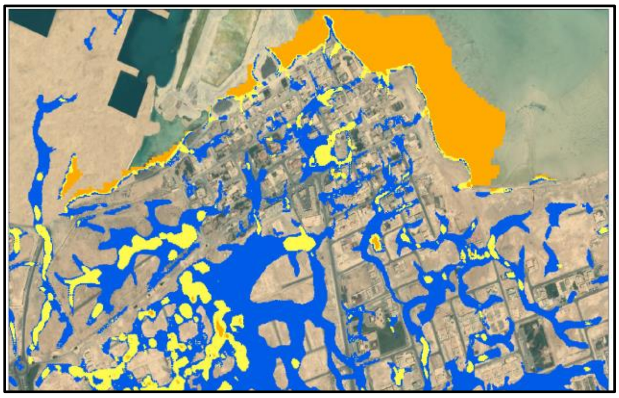

Fig. 13: Flood Risk for 1 in 100 Years – Base Model

Climate Change Scenario

In order to assess the area under extreme rainfall event based on Climate Change scenario, the team considered a Return period 1 in 100 years storm event with expected rise in rainfall intensity 20 % and Storm Surge of 0.5m. Based on the nearest Tide gage in the area (the Al Ruwais Tide gage) a Mean Higher High Water Tidal Levels is 0.74 m (relative to QND) and Considered Sea Level Rise of 0.98 m (QND)

Accordingly based on the above the expected final **Sea level is expected to be around 2.22 meter.**

Bases on this any development in the area that would be above the 2.22m mark would be considered safe from the effect of sea level rise. Based on best practices it is recommended that the final floor level to be 0.3m above the freeboard level from the flood levels expected in this area. Figure 14 and 15 below shows the result of the flood model run including sea level rise considering the above information related to climate change scenario.

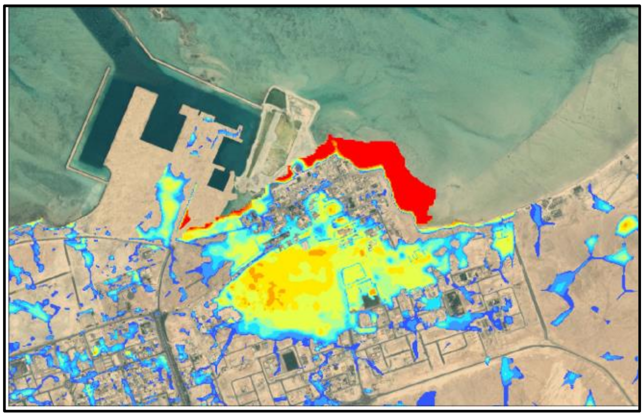

Fig. 14: Flood Depth 1 in 100 Years Climate/Ch Scenario

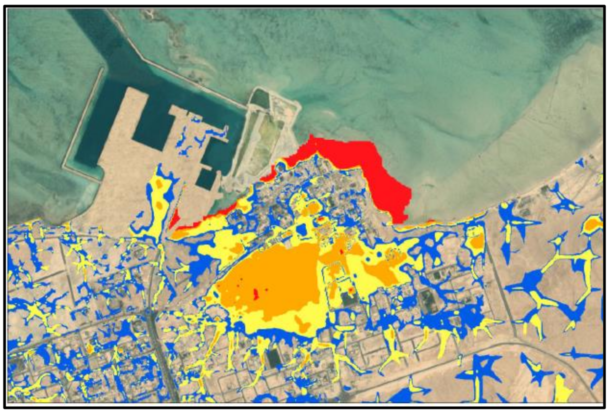

Fig. 15: Flood Risk 1 in 100 Climate Change Scenario

Findings:

- The assessment area is falling into two separate catchments within the Ruwais watershed area, where the elevation cut off point is found to be around 4m as shown Figure 9 in light green. Although might not be a continuous line, it is expected to form a high ground level, thus rainfall runoff would flow away from this line as shown in Figure 8 and 9, also same catchment boundary line would act as a natural protection against sea level rise in the future.
- Under current rainfall intensity and 1 in 100 years return period, specific locations in the area are expected to have flooding in the range of 0.30 to 0.75 cm as shown in Figure 12, and thus low to medium level of hazard risk as shown in Figure 13.
- Under climate change scenario however, with 20% increase in intensity and 0.5 m surge in storm, the same areas identified would experience more flooding in the range of 0.75 to 1.5 m as shown in Figure 14 herein above.
- The expected rise in sea level based on the climate change scenario is expected to be in the range of 0.98m. The adopted Mean Higher High Water Tidal Levels based on Al Ruwais Tidal gage is 0.74 m. Thus The Expected Sea level rise based on Climate Change conditions coupled with storm surge is found to be around 2.22m.
- The flood model run based on the criteria considered in the above mentioned climate change scenario indicate that the risk in specific areas would be medium to high as shown in Figure 15 herein above.

Recommendations:

Based on the findings summarized herein above, it is recommended to:

- Regulations for developing the area could be more flexible and tailored to take into considerations the findings above, to guarantee safety of development.
- The area east of Al Ruwais Port is not considered a high-risk area from a sea level increase point of view, even under climate change scenario for 100 years.
- The area discussed above might be considered under higher risk of flooding with expected change in rainfall intensity and thus flood protection measures need to be considered especially for the areas prone to high-risk hazard risk shown in Figure 15 hereinabove.
- It is recommended to regulate development within the high-risk area in such a way that would enforce implementing a 30 cm first floor level above the expected flood freeboard depth in the area, accordingly placing only development within the high-risk area on-hold to guarantee safer development until final regulations are developed for the area.

  Example: Property is located in high-risk area (orange), the expected flood depth is 1 m, and accordingly final first floor elevation shall be 1.3 at minimum.
- Development north of Street 840 could be considered safe to develop as it is not falling within the high-risk area, but it is recommended to consider a 2.22m +30 cm final first floor level to be safer considering a climate change scenario.

6 Conclusion

Urban Planning communities in close coordination with storm water engineers shall consider storm water and watershed elements at an early stage of the planning process, mainly to prevent development in major storm water streams/Wadis and naturally depressed areas. Land use and zoning regulations shall consider the major watercourses within the catchment areas, and more attention shall be granted to developing naturally depressed areas as parks and storm water collection infrastructure as possible to avoid flooding risks rather than randomly allocated land uses without respecting the natural runoff topography. Finally, assessment of future development from a climate change perspective shall take precedence during the early stages of urban planning new areas, especially areas close to coastal line.

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