Flood Protection System to Aswan Under Current and Future Climate Conditions

Hazem Ramadan, Habiba El Gindy, Amira Gomaa, Ahmed Ayman,
Menna Fouda, Ahmed Abdallah.

Cairo University, Egypt, hazem.r.mohammed@gmail.com., habibaelgindy84@gmail.com, amiragomaa004@gmail.com, Ahmedayman20011@yahoo.com, menna.fouda00@gmail.com, ahmed.mohamed.abdallah1998@gmail.com

Supervisor: Hesham Bekhit, Professor of Water Resources, Irrigation and Hydraulic Department
Faculty of Engineering, Cairo University, heshambm@hotmail.com
Supervisor: Hany Radwan, Associate Professor, Irrigation and Hydraulic Department
Faculty of Engineering, Cairo University, hradwan77@gmail.com
Supervisor: Mohamed Morsy, Assistant Professor, Irrigation and Hydraulic Department
Faculty of Engineering, Cairo University, mohamed2020@hotmail.com

Abstract– It is predicted that climate change will increase flooding risk, cause severe damage, and endanger lives. It is necessary to develop sustainable solutions to improve the flooding resilience of existing cities. Aswan, Egypt, is one of the driest cities in the world. Aswan was recently hit by severe rain and thunderstorms that caused severe damage to lives, property, and infrastructure. This study aims to provide solutions to mitigate flooding impact and increase flood resilience and sustainability in Aswan. State-of-Art models and tools were used to offer several alternatives. First, the contributing watersheds' delineation and characteristics were determined using WMS and ArcGIS software. Then, meteorological analysis was conducted for the surrounding rain gauges considering the current and future climate conditions. The Thiessen method was applied to determine the affecting rain gauges for each watershed. HEC-HMS software was used to determine the peak flows of the streams attacking the study area. Then a 2D hydrodynamic model, HEC-RAS, was used to simulate, visualize the flood plain, and identify flood risk hotspots caused by events. External and internal flood protection works were proposed to increase the resiliency of the City under current and future climate conditions. For the external protection work, multiple alternatives were provided for each stream attacking the study area. Comparison between the alternatives was applied, considering social impact, total cost, and feasibility, to select the most optimum alternative. For the internal protection work, storm drainage networks were proposed to protect the highly urbanized areas from successive rainfall events using SewerGEMS software.

Keywords--: Flood Protection, Aswan, Sustainability, Climate Change, Watershed delineation, rainfall analysis, 1D and 2D modelling

I. INTRODUCTION

Egypt is in a poor geographical area and climatically fragile, as the rain does not exceed 100 mm except in the coastal regions in the north. Still, as a result of climate change, a distortion occurred in the climate system, as in the case of the current study, Aswan. The Study area is located in Aswan Governorate. It lies in Zone 36N from 32° 52' 09.62" E to 32° 56' 31.03" E and from 24° 01' 58.75" N to 24° 07' 53.18" N.

November 2021, people of the village "Gharb Soheel El Noubia" in Aswan faced heavy rainfall and thunderstorms. Due Area to the unexpected event, the streets filled up with water (see Fig. 1, 2), the shops flooded, and the mud-brick houses with tin roofs were in danger.

Fig. 1 Sample 1 of Damaged Area

Fig. 2 Sample 2 of damaged area

People lost their workplaces, and even some were left with the rubble of their homes. People of "Izbat El Hodood" were victims of the stings of the scorpions that drifted from their burrows. Around 500 people were stung, and three people died. People of "Izbat El Souq" overlooking the tombs of El Shalal in Aswan saw the dead bodies floating on the surface.

The main objective of this study is to propose a suitable flood protection\storm drainage system to protect the study area from any future hazards taking the climate change into consideration.

II. METHODOLOGY

A. Data Collection

1) DEMs

The used DEMs "Digital Elevation Model" are from the SRTM and ALOS websites with an accuracy of 30X30m [1, 2]. Fig. 3 shows the topography of the project's area, confirming that this area is a region of flood accumulation due to its low elevation.

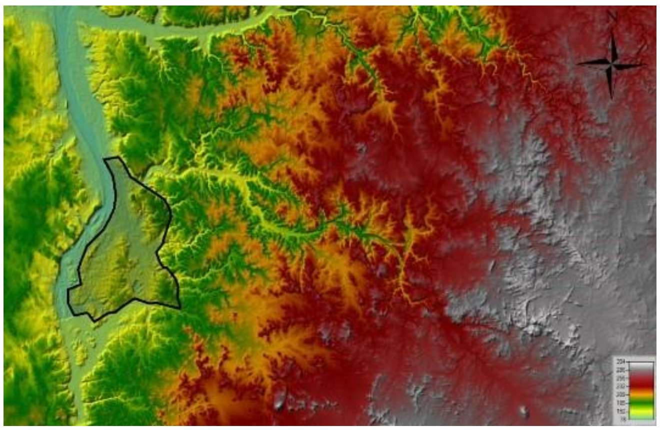

Fig. 3 SRTM DEM showing the location of the study area.

2) Rainfall data

The rainfall data were obtained from "The Egyptian Code for the Design of urban and rural Highways." However, these data weren't sufficient for this project, and therefore other up-to-date data were obtained (see Fig. 4) to increase the accuracy of this project, making it more reliable [3].

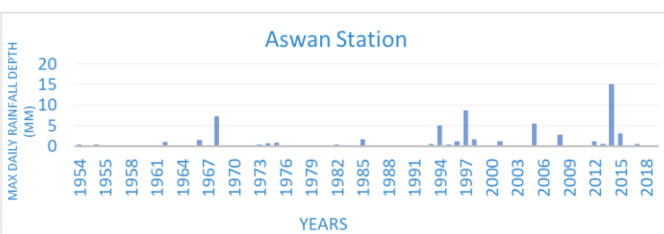

Fig. 4 Aswan station rainfall records

3) Land cover & soil properties

The land Classification layer is used to identify specific parameter values for Manning's n values, soil data, and infiltration parameters. This data is used to determine SCS Curve Number based on runoff modelling. According to Fig. 5, and 6, the study area mostly has soil type B with moderately low runoff potential (50-90% sand and 10-20% clay). The study area is also dominated by bare ground, Rangeland, built area, trees, and water.

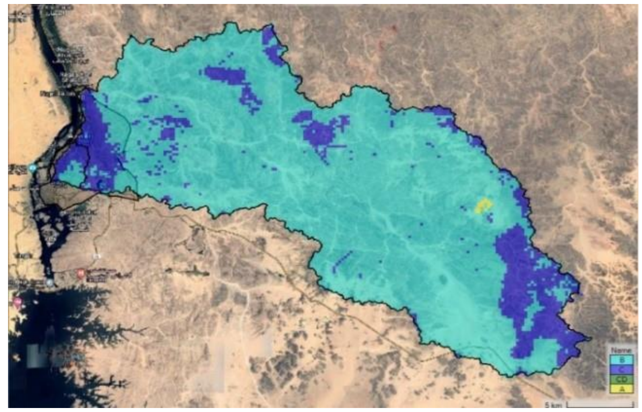

Fig. 5 Soil Properties of catchment.

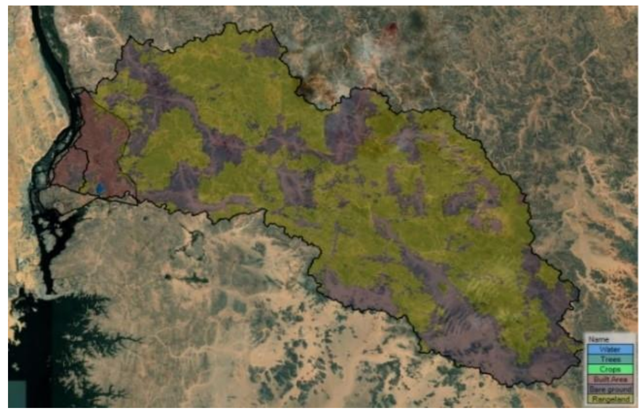

Fig. 6 Land cover of catchment.

III. HYDROLOGICAL STUDIES

1) Watershed Delineation

The main goal of this process is to create boundaries representing the contributing area for a specific outlet. For catchment delineation, the source of information is topographic maps and digital elevation models. Two models were used to delineate the study area (Aquaveo WMS and ARCGIS "ArcMap").

2) Catchment verification

Verification is essential after the delineation to verify that the output from the two models is aligned with reality and correct the wrong ones. Two methods were used to verify the delineation output topo-maps and google earth as shown in Fig. 7, and 8. From both methods, it was concluded that the WMS software was more accurate. Figs 7, and 8 show the verification using topo-maps and google earth.

3) Catchment Properties

By choosing the WMS software output and verifying the output, the catchment properties shown in Fig. 9 were extracted and shown in Table (1).

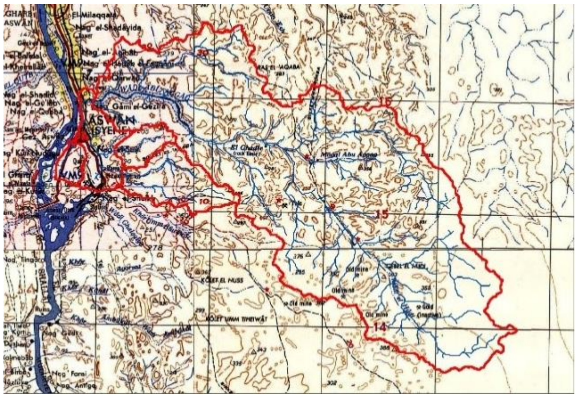

Fig. 7 Topo-maps Verification

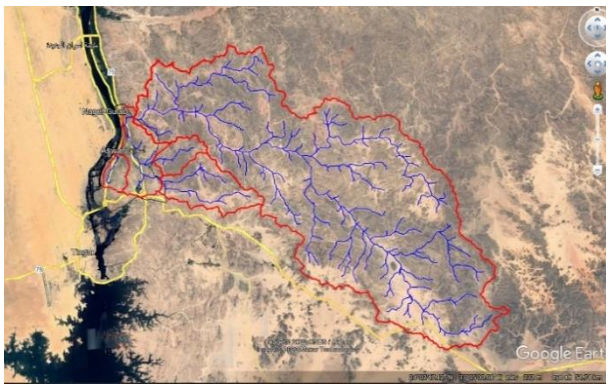

Fig. 8 Google Earth Verification

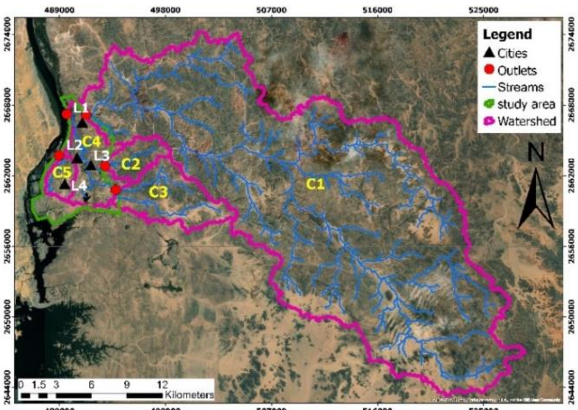

Fig. 9 Delineated catchments

Table 1: Catchment Properties

Sub-Basin	Area(km2)	Max Stream Length(m)	Max Stream Slope(m/m)
C1	25.27	8524.54	0.0063
C2	7.25	4053.95	0.0082
C3	489	54452.39	0.0045
C4	12.37	5198.82	0.0122
C5	34.37	11398.9	0.0072

4) Frequency Analysis

Frequency analysis is a statistical analysis conducted based on data collected from the actual incidents occurring in the field. Fig. 10 shows that the catchment is affected by two rain gauges (Aswan Gauge, and Al-Naqra Gauge) using thiessen polygon method. Analysis was made using HYFRAN for five stations (EL-Naqra, Aswan, Wadi-Elsaayda, wadi-Abadi, Ras-Benas). HYFRAN PLUS software is used to fit statistical distributions, see Table (2) for the results.

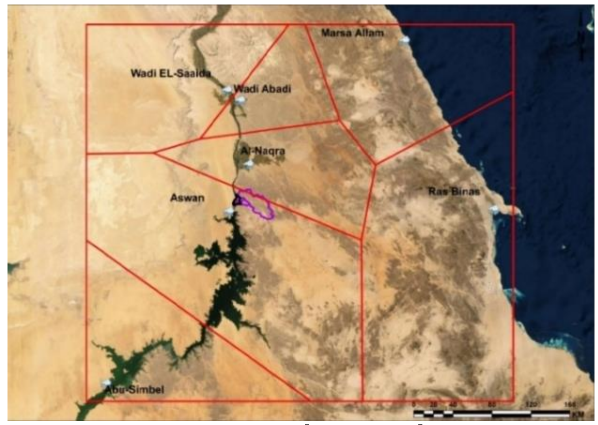

Fig. 10 Thiessen Polygon

The choice of the best-fitting distribution was done by using the Chi-square test and two information criteria: Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC).

Table 2: Max Daily Rainfall Depth (mm)

Rainfall station	Return Period (yrs)			
	100	50	25	10
Aswan	24.5	16.7	10.9	5.67
El-Naqra	23.8	16.2	10.6	5.46

5) HEC-HMS

The Hydrologic Modelling System (HEC-HMS) is designed to simulate the complete hydrologic processes of dendritic watershed systems. The software includes many traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing. The input data for HEC-HMS were area, curve number, and lag time for each catchment. Five catchments' outlets are attacking the study area, see Fig. 11. Table (3) shows the results of the flow values at these outlets.

Table 3: Peak Discharge for Catchments without climate changes

Outlets	Peak Discharge (m^3/sec)
9C	92.6
10C	8
11C	71.5
12C	9.2
13C	13.3

Fig. 11 Outlets Location

IV. Evaluation of the Current Situation

1) HEC-RAS (2D)

HEC-RAS is integrated system software. It was developed for interactive usage in multitasking settings. A graphical user interface, independent analysis components, data management and storage capabilities, visuals, mapping, and reporting tools are all included in the system.

The input data for the HEC-RAS (2D) were terrain, soil properties, and land cover, as well as defining the domain (geometry), break-lines (streams), Rain gauge data, and the hydrographs resulting from the hydrological analysis applied with the HEC-HMS [4].

2) Flooded Area

From the following Figs extracted from the HEC-RAS model (Fig. 12, and 13), some places have not only high depths of water but also high-velocity values. Therefore, Flood Protection schemes should be provided to protect the flooded areas. The model results have been calibrated at the affected areas in Aswan (using water depths), and the calibration results were good.

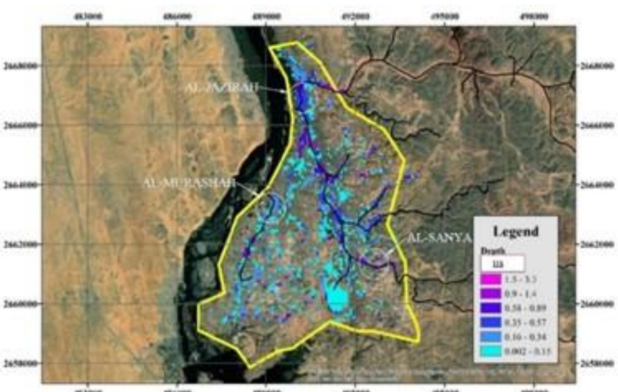

Fig. 12: Evaluation of the Current Situation (Depth)

V. Climate Change

Historical and future data were downloaded from the CMIP6 website, and SSPs3 was used as the experiment ID, and then extracted these data using python code [5]. Frequency analysis was made using the extracted data to calculate the correction factor (delta) for each return period

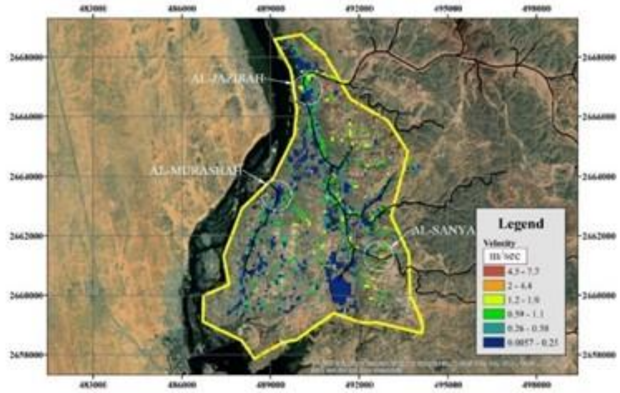

Fig. 13 Evaluation of the Current Situation (Velocity)

Frequency analysis was made using the extracted data to calculate the correction factor (delta) for each return period which was used to estimate the future rainfall depth. Therefore, the previous HEC- HMS and HEC-RAS outputs were re-calculated considering the climate change effect.

The following equation (Equation 1) represents the formula used to determine the delta (Δ) using different climate change models (see Table 4), where '$Y_{sim.future}$' is for the extracted future depth at different return periods, and '$Y_{sim.historical}$' is for the extracted historical depth at different return period. Table (5) shows the results of the flow taking climate change into consideration.

$$\Delta = \frac{Y_{sim.\ future}}{Y_{sim.\ historical}} \qquad (1)$$

Fig. 14, 15 show that the depths and velocity values increased after applying the climate change effect, which assure the need for flood protection schemes.

Table 4: Delta Values for Different Return Periods

Return Period (yr.)	Delta Value (Δ)
100	1.23
50	1.17
10	1.08
5	1.06
2	1.11

Table 5: Peak Discharge for Catchments with Climate Change

Outlets	Peak Discharge (m^3/sec)
9C	132.1
10C	113
11C	102
12C	13.1
13C	19

VI. External Flood Protection

The main objective of this study is to create a full protection system. The delineation of the catchments showed that three streams (A, B, and C) are attacking the study area. Multiple alternatives were proposed for each stream to protect the study area externally, and a storm drainage network was proposed internally to protect the highly urbanized areas from the extreme events overland flow (see Fig. 16). The proposed alternatives depend mainly on assessing the current situation and then making some modifications to reach an optimal solution that minimizes the social impact and optimizes the implementation cost.

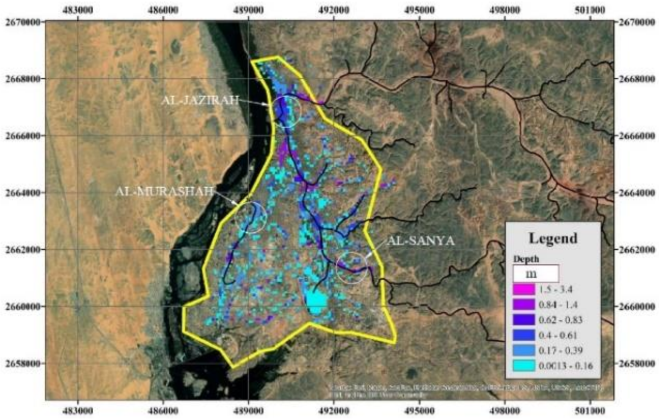

Fig.14 Evaluation of the future Situation (Depth)

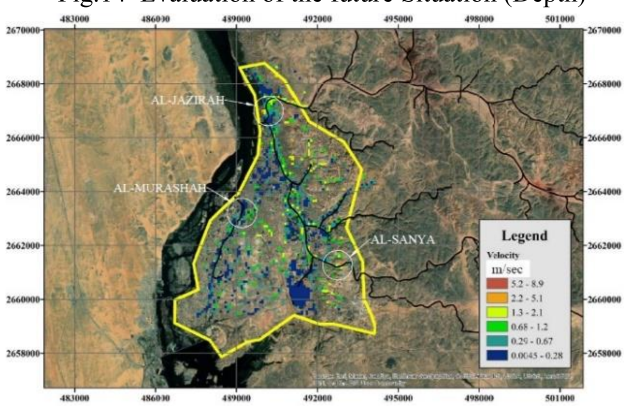

Fig. 15 Evaluation of the future Situation (Velocity)

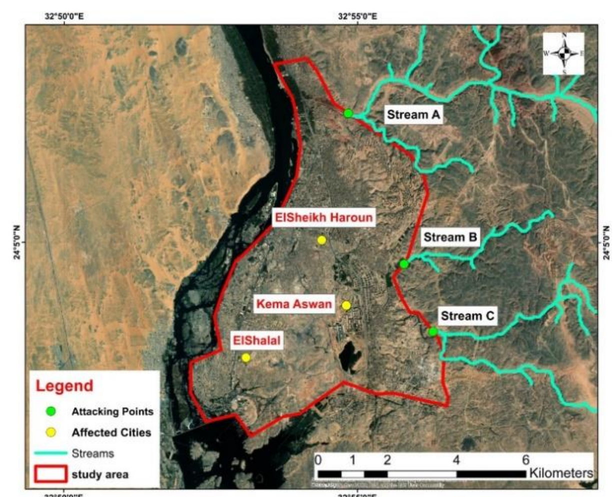

Fig. 16 The attacking streams and hotspot

1) Alternative 1

The description of alternative 1 for the three streams can be shown in Fig. 17.

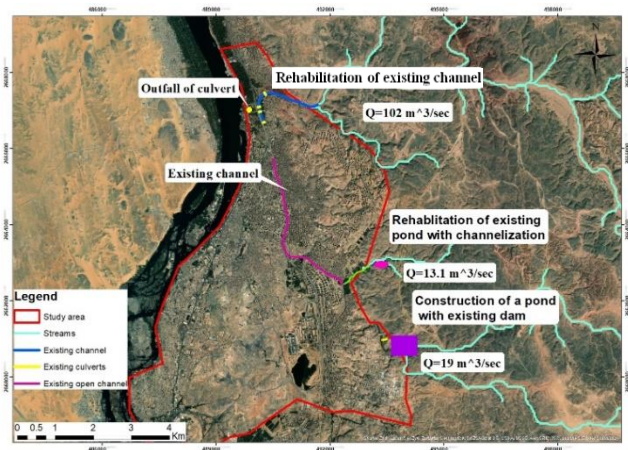

Fig. 17 Conceptual Design for Alternative 01

a) Stream A (Channelization)

After assessing the current situation of stream, A, it was found that there is an existing trapezoidal open channel with variable dimensions (bed width varies from 10 to 18 m with total depth of 1.8 m, side slope 2H:1V) with two control structures, culverts. This channel drains its water to the River Nile at its end. The assessment of these culverts using CULVERT MASTER showed that they are unsafe in 100 years event with existing dimensions of two vents 5X2.5m. Therefore, using three additional vents culvert with the same dimensions was proposed. For the existing channel, assessment results showed that the channel can't accommodate the incoming flow, so rehabilitation was proposed with the following dimensions: bed width to be constant with 18m and total depth of 2.0m (1.8 m normal depth plus 0.2 m freeboard) with side slopes 2H:1V, and longitudinal slope 0.2%.

b) Stream B (Channelization)

The proposed protection work was to rehabilitate an existing pond by increasing its depth by about 2 m to partially store the incoming flow volume, accompanied by constructing a new trapezoidal open channel with bed width 5 m, total depth of 1.3m, and side slopes 3H: 1V to convey the upcoming flow from the pond towards the main existing channel at the middle of the study area then to the River Nile.

c) Stream C (Pond)

The world imagery showed the existence of a dam. The proposed protection work was constructing a pond with dimensions (300m*240m*3m depth) with side slopes 3H: 1V upstream of the existing dam to hold the excess flow volume beyond the current dam reservoir capacity in order to prevent water to go downstream the dam.

2) Alternative 2

The description of alternative 2 for the three streams can be shown in Fig. 18. For stream A, there is no better option for this stream than alternative 1

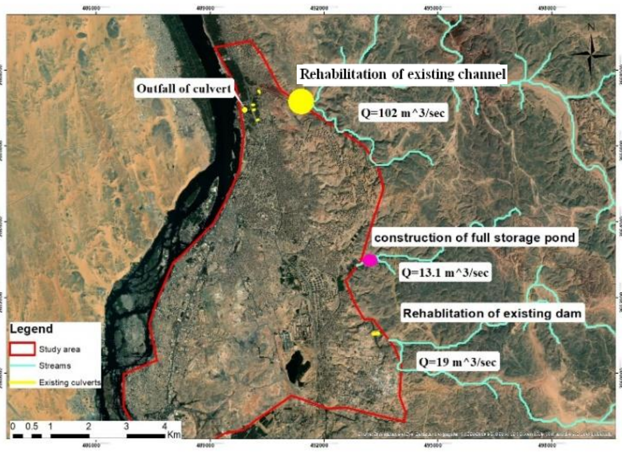

Fig. 18 Conceptual Design of Alternative 02

a) Stream B (Detention Irregular Pond)

Instead of rehabilitating the existing channel, it was proposed to use the existing pond and increase its depth by about 5 m to hold the total incoming flow volume.

b) Stream C (Increasing Dam Height)

When assessing the current situation, an existing dam of 5m in height was found, and after checking the capacity of this dam, it was insufficient to withstand the total flow volume, so after calculations, it was proposed to increase the dam's height with 3.5m and total dam height of 8.5m.

A comparison between the alternatives for the three streams has been conducted as shown in Table 5. The optimum alternative was selected based on the social impact, total cost, feasibility, and possibility of implementation.

Table 5: Alternatives for flood mitigation works

Stream No.	Alternative No.	Alternative description	Estimated Cost (L.E)	Selected Alternative
A	1	Rehabilitation of Existing Channel	5,287,578	√
B	1	Channelization and Rehabilitation of the Retention Pond	6,723,996	√
	2	Rehabilitation of the Existing Irregular Pond	8,543,160	
C	1	Retention Pond	37,777,684	
	2	Increase Dam Height	1,840,791	√

VII. Internal Storm Drainage Network

The development of any community is related to the proper provision of the most basic public services, such as energy, water, and sanitation; thus, it is important to have an appropriate internal storm drainage system to reduce the risk of flooding inside the study area due to local rainfall. Three populated zones (A, B, and C) were selected inside the study area to design the proper storm drainage system for them as shown in Fig. 19.

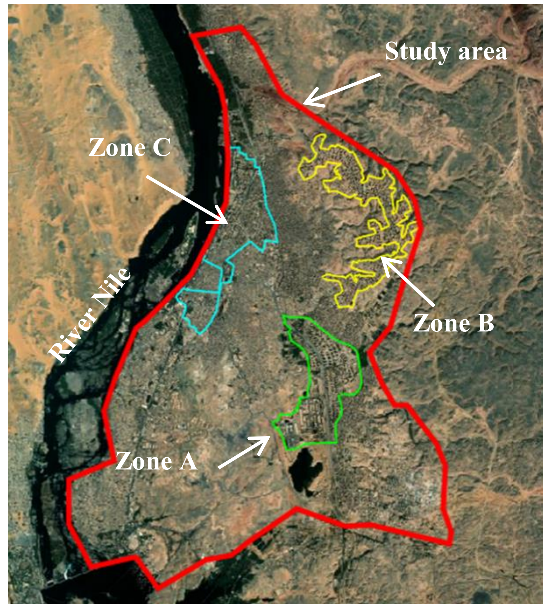

Fig. 19 General Plan for Storm Network Zones

Modelling and analysis of the storm drainage system for the three zones has been developed using SewerGEMS software. DEM was used to represent the ground level for the three zones due to no survey data are available. In the model, the rational method to calculate the flow based on the runoff coefficient 'C', intensity 'I', and area 'A' which is showed in Equation 2. The composite runoff coefficient 'C_e' was calculated, based on the percentage of roads, green area, and other land covers. Equation 3 explains the calculation of composite runoff coefficient 'C_e' where 'C_i' is the runoff coefficient, and 'A_i' the area extent of the sub area i having runoff coefficient C_i, 'N' the number of sub areas in the catchment.

$$Q_P = 0.0028CIA \quad (2)$$

$$C_e = \frac{\sum_1^N C_i A_i}{A} \quad (3)$$

As for the constraints used in this network, velocity's minimum value 0.6 m/s and maximum value 3 m/s. the earth cover over pipe crown (1~6) m. the Pipe slope (0.1%~3%). The material of the pipe was UPVC. Results of the design of the storm networks for the three zones can be summarized as in the below sections.

1) Zone A

The proposed storm network contains variation in the diameters where the diameters range from 300mm to 700mm. The existing pond and the existing open channel (Northeast side) were mainly used as drains (see Fig. 20). The storm network was divided into six networks with six outfalls. The velocity varied from 0.6 m/sec to 2 m/sec. The total cost of the network was 8,940,720 LE.

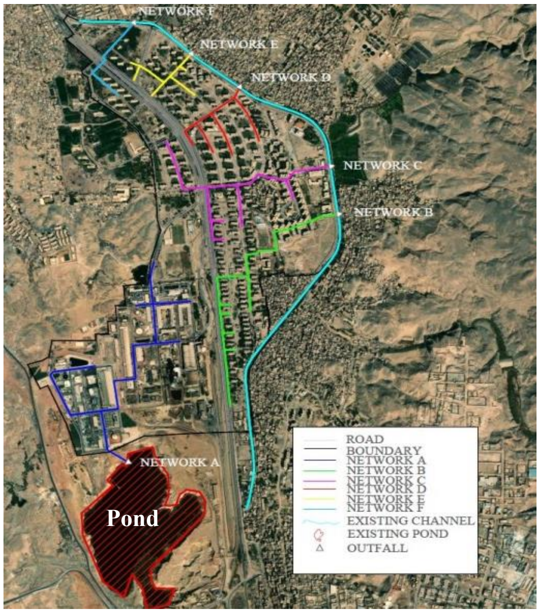

Fig. 20: Storm Network for Zone A

2) Zone B

The proposed storm network contains ten sub-networks with ten outfalls with diameters varies from 300mm to 800mm. The main drain for most of the networks is the natural stream surrounding the zone (see Fig. 21). The velocity varied from 0.6 m/sec to 2.94 m/sec. Slope ranged from 0.1% to 2.5%. The expected total cost of the network was 9,931,484 LE.

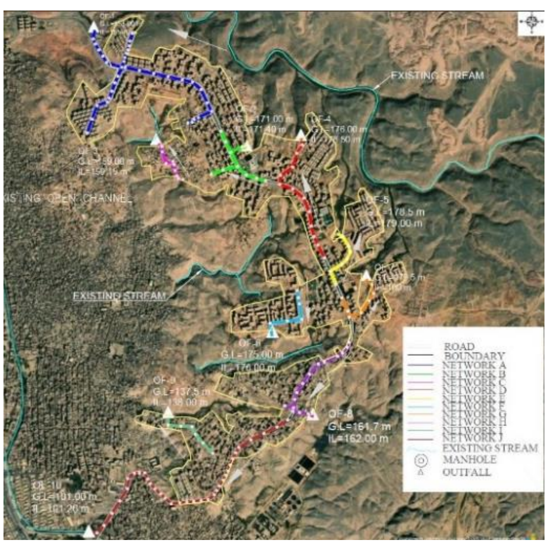

Fig. 21: Storm Network for Zone B

3) Zone C

The main proposed storm network in this zone is divided into ten networks, and most of them drain toward the Nile River (above the water level of the River) and the remaining toward an existing drain (see Fig. 22). The diameters for the networks range from 300mm to 900mm. The velocity varied from 1 m/sec to 3 m/sec. Slope ranged from 0.5% to 3%. The total cost of the network was 12,489,726 LE.

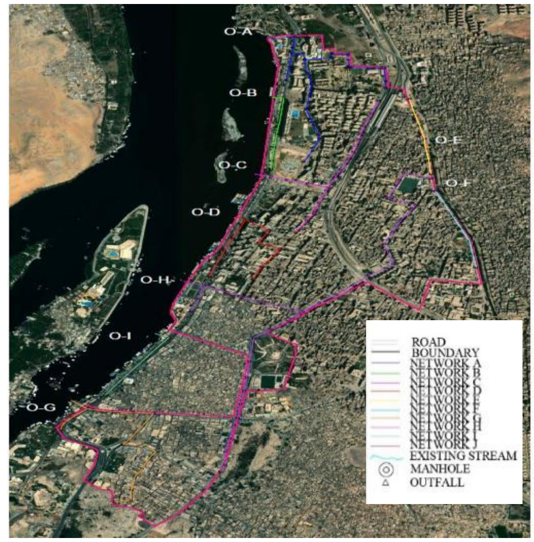

Fig. 22: Storm Network for Zone C

VIII. Conclusions

The main objective of this study is to provide solutions to mitigate flooding impact and increase flood resiliency and sustainability in Aswan under the current and future climate conditions. Climate change is expected to increase the flooding risk that causes severe damage. This study started with the delineation, meteorological analysis for rain gauges, and Thiessen polygon to understand the contributing catchments with respect to the surrounding rainfall stations. Climate changes analysis have been done to estimate the expected increase in the rainfall data in the future. As a result, the attacking streams' location, water discharge was determined using HEC-HMS. Then with the help of HEC-RAS 2D modelling, flood plain was created to visualize and identify the risk hotspots caused by the events. Therefore, external flood protection alternatives and internal storm drainage networks were proposed to increase the resiliency and sustainability of the City under current and future climate conditions. For external protection, multiple alternatives were proposed for each attacking stream, and the optimum alternative was selected based on the social impact, total cost, feasibility, and possibility of implementation. For Internal protection, storm drainage networks were proposed to protect the highly urbanized areas from excess rainfall.

References

[1] SRTM Data. CGIAR. (n.d.). Retrieved July 18, 2022, from https://srtm.csi.cgiar.org/srtmdata/
[2] ALOS Research and Application Project. ALOS@EORC homepage. (n.d.). Retrieved July 18, 2022, from https://www.eorc.jaxa.jp/ALOS/en/index_e.htm
[3] The Egyptian Code for the Design of Urban and Rural Highways: Part 7: Protection of Highways Against Rainfall Flooding and Quick Sand.
[4] Hydrologic Engineering Center. (n.d.). HEC-RAS Documentation. https://www.hec.usace.army.mil/software/hec-ras/documentation.aspx

[5] The SSP4: A World of Deepening Inequality | Earth & Environmental Systems Modeling. (n.d.). Climate Modeling.https://climatemodeling.science.energy.gov/publications/ssp4-world-deepening-inequality