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Assessment of dams' efficiency under the effect of climate change and urban expansion: Um Hablian Dam, Jeddah, Saudi Arabia (Case Study)

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Abstract. this paper analyzes the effect of climate change and urbanization on the efficiency of dams that have been built to protect Jeddah city in Saudi Arabia from severe floods. Um Hablian dam is considered a case study. Several data have been collected to address the objectives. Among these data are the historical rainfall, digital elevation models, a base map of Jeddah city, and its future expansion up to 2050. Hydrological analyses have been performed using common software: HEC-HMS, GIS, and WMS software to estimate the floods under the normal (design) conditions, the effect of climate change, and urbanization. It has been shown that under the normal condition (NC) scenario, the Um Hablian dam capacity can accommodate the floods for up to 200 years return period. The effect of the climate change scenario (CC) is more significant than the effect of the urbanization scenario (U). The effect of urbanization scenario (U) leads to shortening the time to peak of the flood. In the combined scenarios (CC+U), the runoff volume exceeded the dam capacity by about 102% and the dam is expected to get overtopped by 40% from the current dam height. The dam lake is expected to inundate 53% more area than the current condition.

Keywords: Urbanization, arid regions, climate change, flash floods, dam capacity, Jeddah, Saudi Arabia.

Intoduction

In recent years, many researchers give special attention concerned to environmental changes either as natural effects or as human interventions which led to a disorder in the amount of rainfall worldwide. This is frequently referred to as "hydrological changes" (Ceola et al., 2014). Evaluating the relationship between environmental changes and anthropogenic pressures (related to all human activities) is a very challenging issue in the hydrological processes (Pumo, 2017).

Internationally and locally, the characteristics of rainfall are being influenced by both global factors such as climate change (Trenberth, 2011), and local factors such as changes in the Land Use Land Cover (LULC) (Luong, 2020) and urbanization (Bahrawi et al., 2020). Furthermore, evidence suggests that climate change and urban sprawl are the most two important factors on the global scale which affect the water cycle (Pumo, 2017).

The average earth's temperature has been rising for the past 150 years unexpectedly and is expected to increase further by the end of the twenty-first century. In addition, the increase of the current atmospheric (CO_2) reaches the twice amount of past conditions, due to the industrial revolution and fossil fuels. For illustration, this leads to an increasing emission increase of (CO_2) and other greenhouse gases which trap heat causing an increase in temperature in the lower atmosphere. For that, the global communities created special groups to concentrate on climate change influences and set up some protocols to collect and organize an international response to deal with the consequences of climate change (Ainsworth, 2020).

Climate change (CC) is a complicated phenomenon, and it might change the variations of rainfall and temperature these values are considered to be the essential component and measure of climate change in any region of the world. The increasing temperatures will lead to a disturbance in the water cycle, thus leading to increased water evaporation, thus leading to more storm events and intensity (NASA). The rainfall characteristics rely on the distribution of temperature in Saudi Arabia (SA) which is impacted strongly by the topography (Subyani, 2011).

Some researchers studied the effect of climate change on SA at the end of this century. It showed that there will be more precipitation and evaporation, thus more runoff across most regions because of the temperature of about 4.2 °C of the daily mean (Al Zawad and Aksakal, 2010). Qassem et al., (2018) showed that the increase in temperatures and changing distribution pattern of precipitation would raise uncertainty regarding improving the management of sustainable water. The predicted temperature has increased in all areas from 2025 to 2084, the highest increase was in the central and northern areas of Saudi Arabia while rainfall showed different patterns with a remarkable increase, especially in the western and southwestern areas where Jeddah city belongs.

The world's population exceeded 7.9 billion (UN, 2021). In 2008, for the first time in the history of human civilization, more than 50 % of the population world was living in cities. By 2030, the city's population will reach about 5 billion which means more than half of the population world (UN, 2006). The increase in population in urban areas occurs more in developing countries than in developed countries. Additionally, many cities in the developing countries are increasing quickly due to real population expansion, but to a much larger extent because of movement from rural areas to the cities and the transformation of the rural countryside into cities. To illustrate, the highest population in the three main cities in

Saudi Arabia are, respectively (Riyadh at 7 million, Jeddah at 4 million, and Makkah at 1.7 million) (General Authority for statistics, 2021).

Governmental efforts aim to ensure a decent and safe life for their residents from any kind of risks. Different agencies among them universities have been working hard on these threats, to prevent, mitigate and address these hazards by comprehending these hazards and giving an active solution.

SA is prone to different kinds of natural hazards. For example, the northwestern part is prone to earthquakes and volcanic threats, whilst the central and western region is prone to floods mostly during heavy rainfall events (Al-Bassam et al. 2014). Landslides are a common phenomenon in the inhabited mountainous areas of southwest SA. Jeddah city has suffered from flash flood hazards and their serious consequences in 2009 and 2011, which led to some disasters and losses of property and lives (Figure 1).

(A) 88.9 of rain in 4 hours on November 25, 2009 (B) 102 mm of rain in 4 hours on January 26, 2011

Figure 1. Disastrous flash flooding problems devastate Jeddah city and cause major damage and loss of lives (https://2u.pw/AGRp7).

During the last 40 years, a statistical report of natural hazards in SA reported that from 1982 to 2005 inducted the flood is the most frequented hazard type with an average of 7 times per year. Besides, the average economic losses reaching to be about 71.25 million Riyal yearly (Al-Saud, 2010). It is worth mentioning that climate change has affected the global rainfall patterns, especially in an arid region such as SA which received more rainfall than before in recent years, (IPCC Report, 2007). This increase in rainfall paired with the unappropriated urban planning increases the severity of these threats.

Despite the high-safety standard of dams due to developed engineering and perfect construction and Infrastructure in recent times, we can't guarantee a non-risk, is not confirmed to be possible, and risks can happen at any time, could be happened by natural normal hazards, human actions, or just because the dam is old, or as result of not taking into account the effect of climate change, which might not have been taken into consideration in the dam design.

The role of climate change and urbanization has received increased attention across several disciplines in recent years as reviewed above. Therefore, the main purpose of this study is to assess the dams' efficiency which has been built to protect Jeddah city. Um Hablian dam is considered a case study. The assessment of the dam is based on three scenarios: (1) the effect of climate change (CC), (2) the effect of urbanization (U) due to city expansion, and (3) the combined effect of CC and U. The three scenarios are compared with the normal condition (dam design criteria).

1. Study Area

Jeddah city is located near the middle of the Red Sea coast of western Saudi Arabia. The city occupies a stretch of land along the shore, 60 km long and 40 km wide, located between latitudes (21.671357°) and longitudes 39.246470° (Figure 2). The city is bounded from the west by the Red Sea and the east by several mountain chains with a maximum elevation of about 500 m above sea level. In this study, The Um Hablian watershed and its dam are studied hydrologically. Um Hablian watershed is located in the north of the Jeddah watersheds, between Wadi Ghia and Wadi Quraa. It has a small drainage area reaching 38 km^2 approximately. The land cover topography includes a large area of steep rocky hills and there is a little urbanized area near to the outlet, in the wadi downstream of the lower sub-basin of the watershed as shown in Figure 2. In addition, the Um Hablian dam was re-constricted in 2012 with a capacity of fore million cubic meters (MCM), a length of 800 m and a height above the land surface is 11.5 m. The dam is constructed from rockfill with reinforced concrete faces. The main purpose of constructing the dam was to control stormwater to discharges the stored water into the eastern channel during flood events that may attack the city. Figure 3 shows some photographs of the Um Hablian dam.

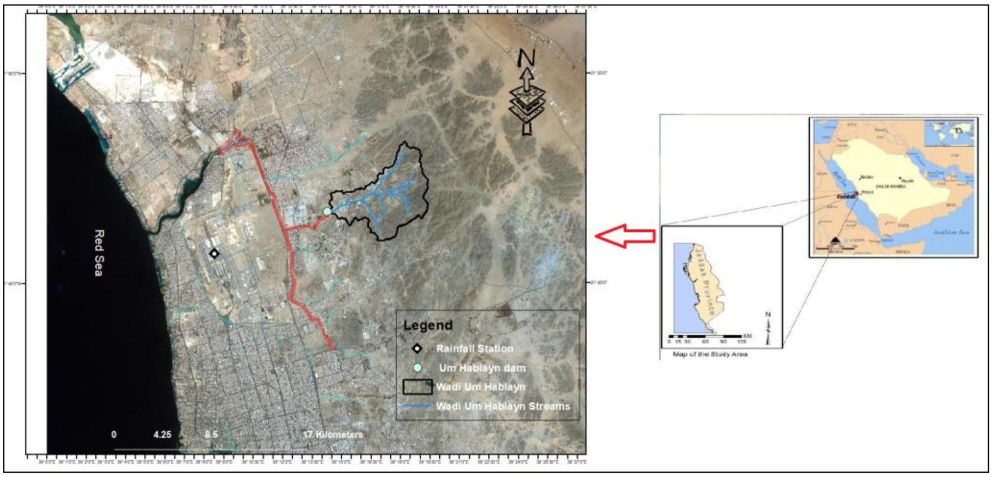

Figure 2. Location of Um Hablian watershed, channel network, Um Hablian dam, and the eastern channel (the red line).

Most of the dam bursts worldwide are caused by flooding because of the insufficiency of the capacity of the reservoir and spillway and the consequent exceed of water over the dam crest. In SA, dam construction activities started in the sixties. In recent years many dam areas were affected by extreme rainfall events. These rainfall events are increasing the threat to communities and putting significant stress on governments. Many dam failures have happened in some areas in SA causing inundation problems. Fortunately, these dams were small ones e.g., the Um Al-Khair dam in Jeddah which failed in 2011 (Azeez, et al. 2020), and the Al-Lith dam failed after severe rainfall in November 2018.

1. Methodology and Data Collection

The current study used geographic information systems (GIS) and hydrologic models (WMS, HEC-HMS, Arc Hydro, and SMADA software) to examine the relationship between rainfall depth and dam reservoir capacity under various rainfall return periods (50, 100, and 200 years). Furthermore, the goal is to assess the influence of climate change and urbanization on the dam to investigate the dam instability by simulating the various effects of rainfall events and runoff using hydrologic models.

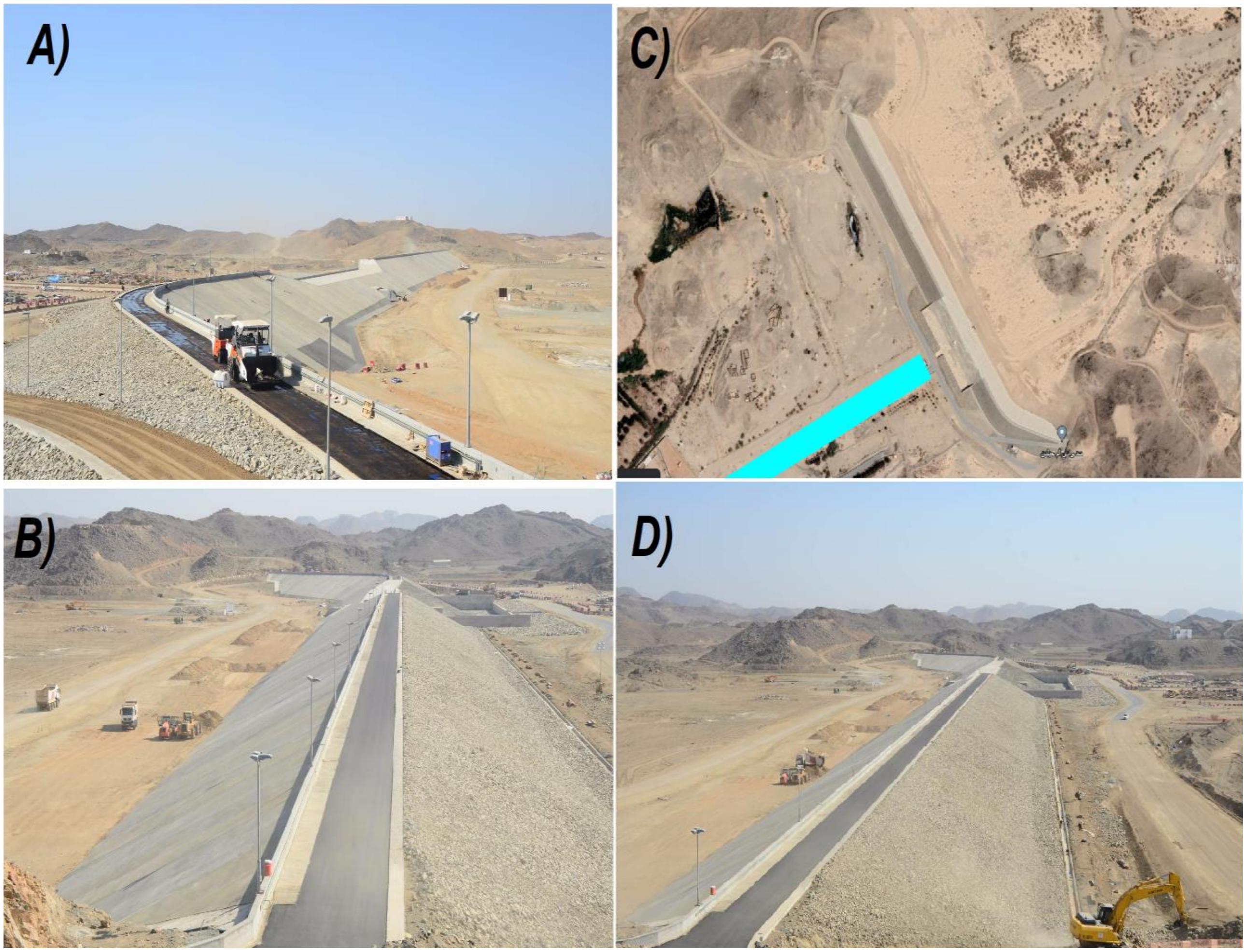

Figure 3. (A) Overview of Um Hablian dam, (B) Um Hablian dam from the left side, (C) Aerial photograph of Um Hablian dam, (D) Um Hablian dam from the right side

The data were used can be summarized as (1) a Digital elevation model (DEM) of resolution 30-m (NASA website), (2) the Dam location and its characteristics, (3) historical data of rainfall from 1970 to 2019 as shown in Figure 4, (4) an expected climate change in rainfall on Jeddah from other studies (meteorological perspective). Table 1 shows the summary of the percentage increase due to climate change, (5) locations of rainfall stations, and (6) current and future urban extensions to extract land use and land cover as shown in Figure 5.

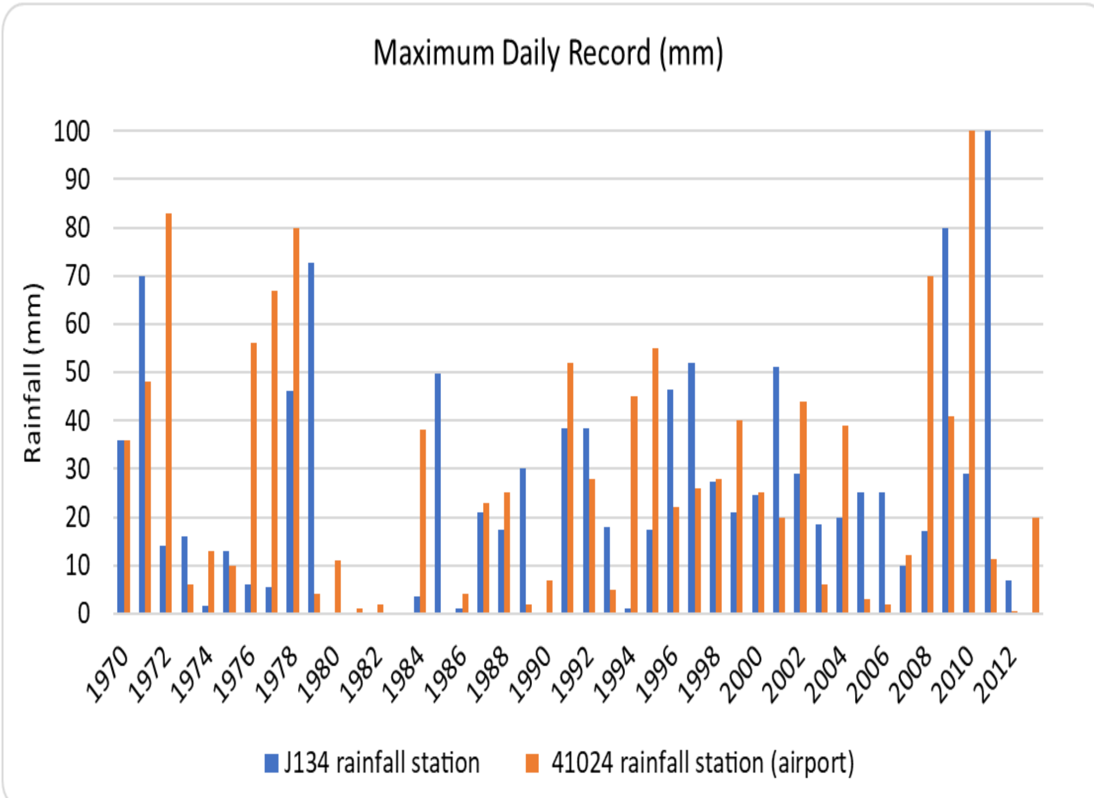

Figure 4. Maximum daily rainfall record from two stations in Jeddah city.

Table 1. Expected change in rainfall based on previous studies for Jeddah city

Researchers	Percentage of rainfall increasing due to climate change
Al Zawad (2009)	40%
Almazroui, (2017)	30.5% to 40.6%
Youssef et al (2008)	15% to 27.8%

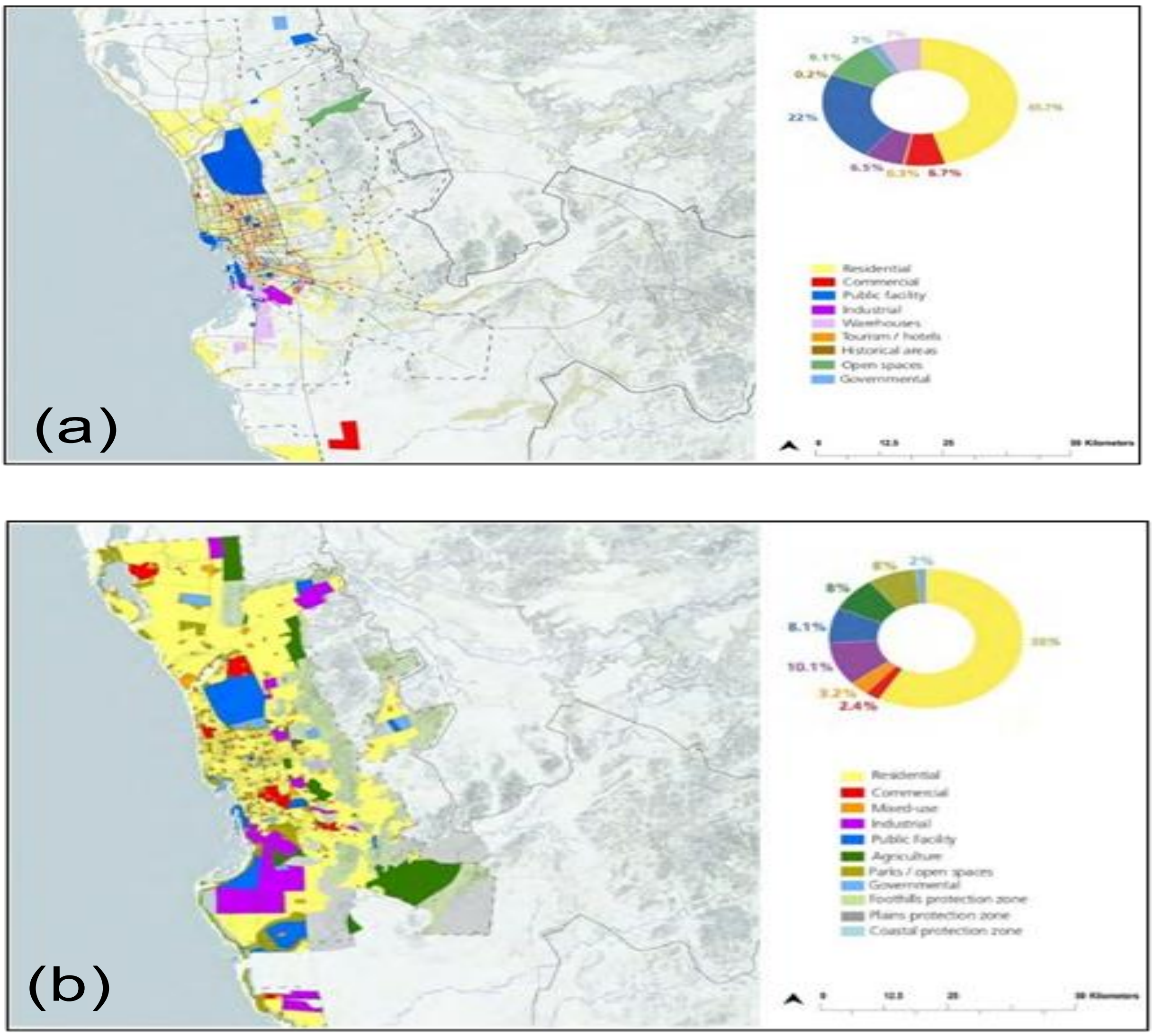

Figure 5. Existing (a) and future (b) land use of Jeddah Metropolitan Region by Al-Amanah of Jeddah city https://unhabitat.org/sites/default/files/2020/04/jeddah.pdf

The proposed methodology, for obtaining the runoff volume considering the influence of climate change and urbanization, consists of eight steps that can be summarized as follows:

Watershed Delineation

The first step is delineating a watershed and extracting streams networks by using the watershed computer simulation and modeling software application from Aquaveo (WMS 11.0).

Rainfall Frequency Analysis

Estimating the depth of rainfall for various return periods (50, 100, and 200) as shown in Table.2 using SMADA software based on the statistical distribution for the two closest rainfall stations which are J143 and 41024. Thus, Gumbel distribution has been applied which is the best frequency distribution method especially when you take into account the natural hazards of extreme rainfall (Koutsoyiannis, 2004).

Table 2: Rainfall predictions based on Gumbel distribution for the different return periods and meteorological stations.

Meteorological Station	**Return Period (years)**	**Probability**	**Rainfall Prediction (mm)**
42024	200	0.995	153
	100	0.99	130
	50	0.98	109
J134	200	0.995	154
	100	0.99	127
	50	0.98	104

Table 4. CN values for each land use and hydrologic soil group.

Land use land cover (LULC)	Hydrologic soil group	
	B	D
	Runoff curve number	
Undeveloped land	77	88
Foothills	81	92
Residential	77	88
Plains	91	94
governmental	98	98

Table 3. Spatial rainfall over the watershed for different return periods in NC and CC conditions

Return period (years)	50	100	200
Um Hablian watershed (NC)	108	130	154
Um Hablian watershed (CC)	152	182.5	216

Spatial and Temporal Distribution of Rainfall over the Watershed

Estimating the rainfall spatial distributions by using inverse distance weighting (IDW), which is a GIS tool that helps to distribute the rainfall over an area that has a lack of meteorological stations which does not represent the real distributions of rainfall. Also, IDW is the most common spatially interpolation technique and is widely used in meteorology (Fung, 2022). As a result, the isohyets maps has been created over the area, and the highest rainfall values over a watershed in normal conditions (NC) as shown in Table 3. IDW can be calculated using Eq. 1.

$$Z^* = \frac{\sum_{i=1}^{N}(\frac{1}{d^c}Zi)}{\sum_{i=1}^{N}(\frac{1}{d^c})} \quad \ldots(1)$$

Where; Z* = estimated value, Zi = a neighboring data point value, N = the number of the neighboring point, d = the distance between the data points and the point being interpolated, and c = a positive power parameter which is normally taking as 2.

Estimating the rainfall temporal distribution for different return periods by using a dimensionless mass curve formula which has been developed by Elfeki et al. (2014) as shown in Eq 2.

$$\frac{R(t)}{R_T} = \frac{1-a^{\left(\frac{t}{D}\right)\cdot b}}{1-a} \quad \ldots (2)$$

Where, $R(t)$ = the cumulative rainfall depth at each elapsed time, t, R_T = the total rainfall depth of the storm, t = the elapsed time since the storm begins, D = storm duration, and (a and b) are the fitting parameters that are equal to 0.037, and 1 respectively for the Makkah region.

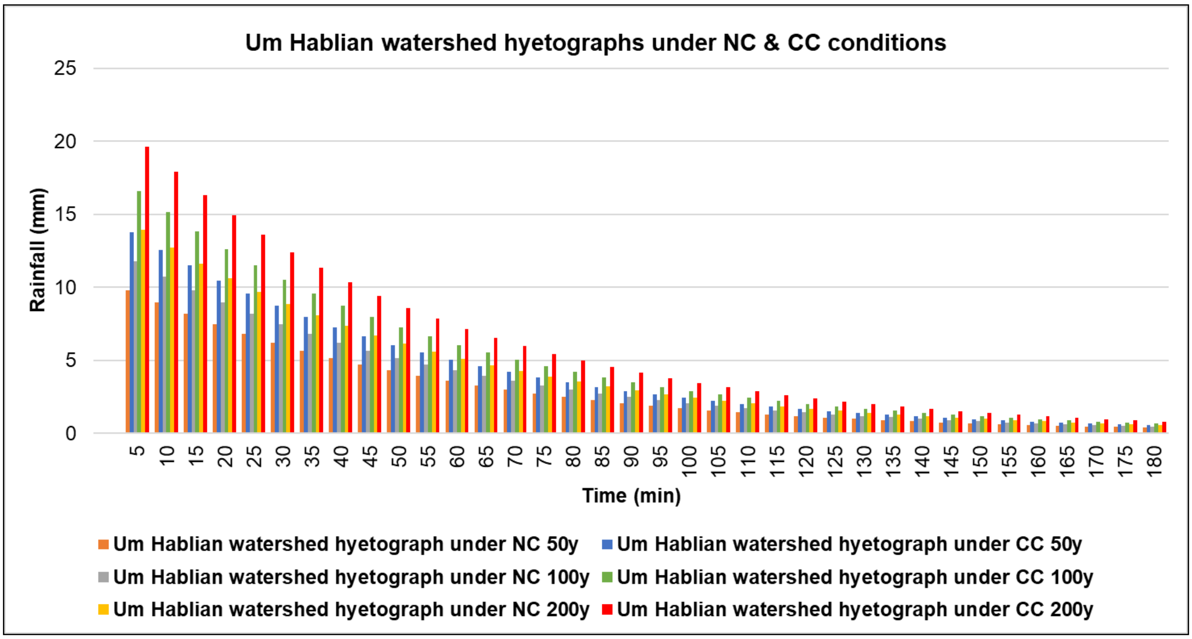

Figure 6. Rainfall temporal distributions hyetographs of Um Hablian watershed based on the dimensionless cumulative mass curve for different return periods

Influence of climate change on rainfall

To assess the influence of changing climate on rainfall over the Um Hablian watershed, Data from Table 1 can be compared with the data in Table 3 which estimate the rainfall temporal distributions under the effect of climate change and have been used as input factors to HEC-HMS. Consequently, applying the given percentage due to climate change in Table 1, the rainfall increased by 40.6 %, because it's the safer percentage and newest research papers compared with other research, Table 3 second row shows the rainfall after the effect of climate change. In addition, Eq 2 is applied to extract new hyetographs under the impact of climate change over the watershed.

Land use land cover (LULC) analysis and CN estimation

Determine the curve number (CN) value for the studied area by using soil type and land cover. The land use map is digitized by using the map in Figure 5 and defined land use classifications visually, the soil type will be prepared by classifying the watershed based on the slope degree of the watershed (bare soil classified as land with less than 4°. while rock is classified as land with a slope of more than 4° in ArcMap. Thus, we will be able to estimate the CN values per grid for the watershed. The CN value for a watershed is determined by SCS TR55 (1986). Figure 7 shows the distribution of CN values over the watershed based on the hydrological soil group in Table 4.

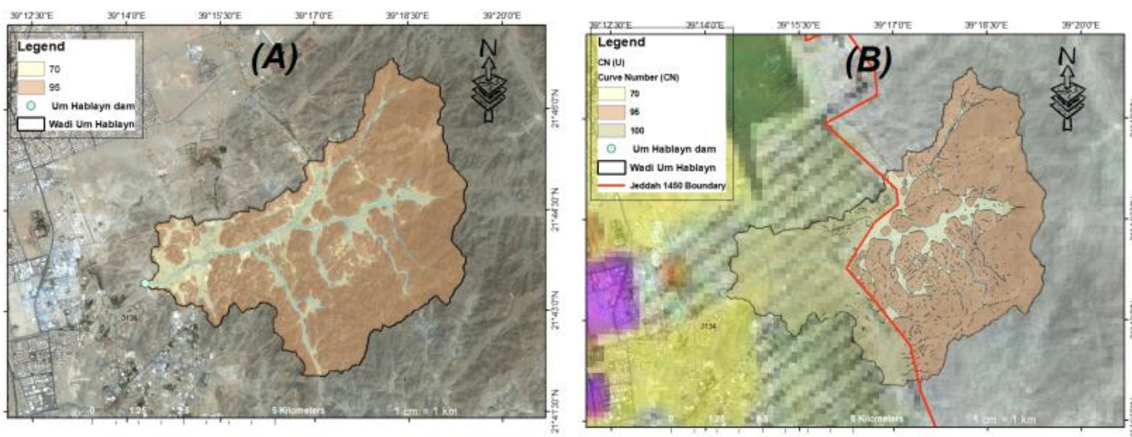

Figure 7. Distribution of CN values over Um Hablian watershed, (A) current situation, (B) future situation.

Hydrologists normally use a weighted average CN (called the composite CN, and is abbreviated as CN_c) over the basin through the application of the following equation,

$$CN_c = \frac{\sum Ai\ CNi}{\sum Ai} \qquad (3)$$

Where, CN_c= the composite CN of area-weighted curve number for each watershed; i = an index of watershed subdivisions of uniform land use and soil type; CN_i = the curve number for each land use-soil group polygon (*CN* for subdivision *i*); and A_i = the area for each land use-soil group polygon (drainage area of subdivision *i*).

The value of CN_c for the watershed in NC condition is 83, as well as CC condition, but in UC and CC+UC conditions the CN_c is about 93 due to the increase of an expected impervious area from 16.8% to 53% of the watershed.

Influence of urban sprawl on runoff

Imperviousness and CN of the watershed under the impact of urbanization will be increased based on the urban expansion. For example, the residential areas will be increased from 45.7 % to 58% in 1450 UGB as shown in Figure 5. Consequently, many hydrological parameters as a percentage of impervious area, initial abstraction, lag time, evapotranspiration, and infiltration will be influenced. So, the CN values are changeable based on expected urban expansion. ArcMap

10.8 software is used to calculate the expected percentage of impervious area and re-estimate CN values based on the expected change in LULC in the future from the map in Figure 5. Thus, the Lag time (T_{lag}), initial abstraction (I_a), and time of concentration (T_c) have been evaluated based on CN_c= 93 for simulation of direct runoff under urbanization impact.

Hydrological Modeling

Simulating direct runoff based on the watershed characteristics, rainfall distribution, duration of rainfall, percentage of impervious area, Lag time, initial abstraction, and composite curve number (CN_c) by applying the SCS curve number method. Furthermore, using the software model HEC-HMS 4.8 needs essential parameters to simulate the complete *rainfall-runoff* processes of dendritic watershed systems. By applying the essential parameters in the HEC-HMS model with the designed rainfall hyetographs, will simulate the direct runoff for different scenarios and then estimate direct runoff hydrographs, discharge volumes, and peak discharges. The following formulas will be used in computing these four essential parameters through HEC-HMS for the watershed:

$$S = 25400/(CNc\ ) - 254 \quad (4)$$

$$l_a = 0.2\,S \quad (5)$$

$$Q = \frac{(P-0.2S)^2}{(P+0.8S} \quad (6)$$

Where S is the highest retention potential (mm), I_a is the initial abstraction (mm) (losses) Q is accumulated rainfall excess at time t, (mm), and P is accumulated rainfall depth at time t, (mm).

Based on the curve number method, the lag is expressed by the following formula (Ponce,1989):

$$T_{lag} = L^{0.8}\frac{(2540-22.68CN)^{0.7}}{14104\,CN^{0.7}S^{0.5}} \quad (7)$$

Where; T_{lag} basin lag in hours, L hydraulic length; length measured along principal watercourse; in meters, CN which is CN_c, and, S average watershed slope in meter per meter.

Simulating direct runoff through the HEC-HMS needs these four essential parameters.

We should note that these parameters are changeable based on the CN_c values which relied on the changing of LULC of the watershed for the scenarios. To succeed in the direct runoff simulation in the HEC-HMS model four components should be set up which are (1) basin models, (2) meteorological models, (3) control specifications, and (4) time-series data. The SCS model generated hydrographs for the watershed by using lag time (T_{lag}) values to determine peak flow (Q_p) and peak time (T_p) using the next equations by the following formula (Jajarmizadeh et al, 2012):

$$Q_P = C \frac{A}{T_P} \quad (8)$$

$$T_P = \frac{\Delta t}{2} + T_{lag} \quad (9)$$

Where; Q_P = UH of peak discharges for 1 cm of effective rainfall in cubic meters per second, C = the peaking factor which is 2.08 in SI unit, A = watershed area (km^2), Tp = the time to peak of the UH (hour), Δt= the excess precipitation duration (hours), T_{lag}= the basin lag (the time difference between the center of mass of rainfall excess and the peak of the UH, in hours). For ungauged watersheds, the SCS suggests that the UH lag time may be related to the time of concentration, T_c, as:

Finally, the model was running at a time duration of five minutes. rainfall duration of 3 hours and the volumes and peaks are estimated for the watershed under all scenarios (normal condition (NC), climate change condition (CC), urbanization condition (UC), and combined climate change and urbanization (CC+UC) for return periods of (50, 100, and 200 years).

Reservoir Characteristic Curves

The most important function of a dam is to store direct runoff to control the discharge of water flow. Thus, the most critical element of the physical characteristic of a dam is storage capacity. in this study, the determination of storage capacity was through the WMS software and digital elevation model (DEM-30) of the study area by using the dam information height, width, and dam location to estimate the stored water based on the topographic characteristics of the drainage watershed and the dam dimension to create the reservoir characteristic curves as shown in Figure 8. This graph shows two curves the surface area-elevation curve and storage volume-elevation curve. These curves are going to be used to estimate the water elevation that corresponds to the runoff volumes at different return periods and the corresponding inundated area in the dam lake at the different scenarios.

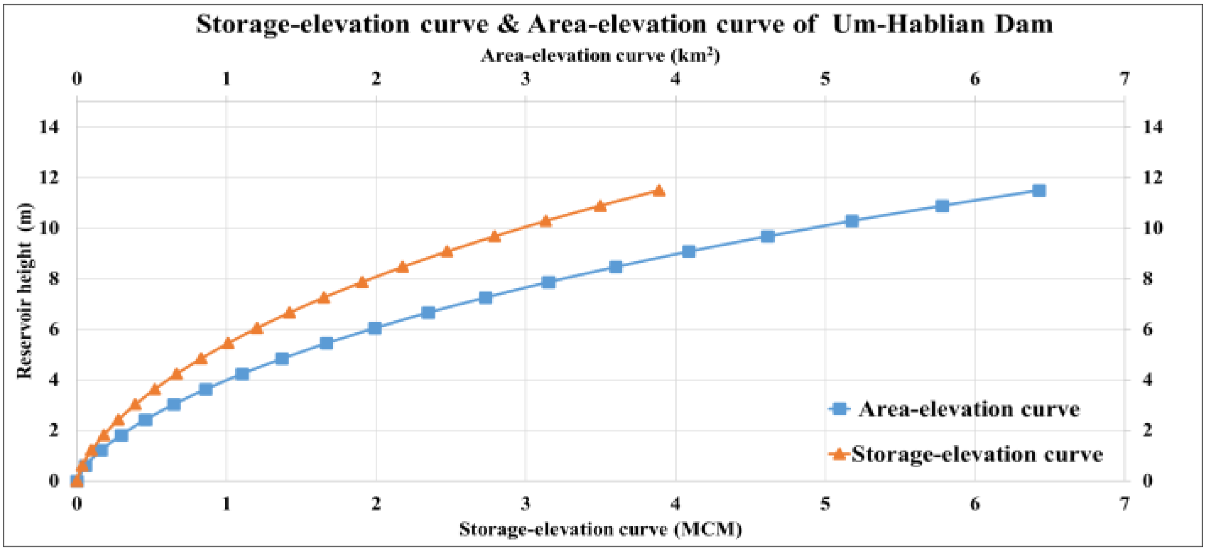

Figure 8. The area-elevation and storage-elevation curves of the Um Hablian dam

Evaluation of dam efficiency

The primary goal of this study is to measure the effectiveness of the Um Hablian dam. Calculating the change in the parameters of hydrological and hydraulic models will clearly show the dam efficiency under the scenarios. Comparing the scenarios to the normal condition (NC) was using the following equation:

$$\% \, change = \frac{Y_i^T - Y_{NC}^T}{Y_{NC}^T} \times 10 \qquad \ldots(11)$$

Where, i = scenarios (CC, U, or CC+U), T = return periods (50, 100, or 200), Y_i^T = the variable under study (Qp, V, tp, flood height, lake area, or flood volume), Y_{NC}^T= the variable under study at normal condition (NC), dam height or flood volume under NC scenario.

2. Results and Discussions

Hydrographs Predictions

The results of Rainfall-runoff modeling are present in Figure 9 and Table 5. The results show the hydrographs under the different scenarios (NC, CC, U, and CC+U).

In the NC, the hydrographs reach their peaks after almost 2.75 hours at 50, 100, and 200 years return periods. The peak discharges were 243 m^3/s, 312.2 m3/s, and 389.6 m^3/s respectively.

In the CC, the hydrographs reach their peaks after about 2.77 hours. The peak discharge increased by 57.9% to reach 383.6 m^3/s, by 55.4% to reach 485.1 m^3/s, and by 53.3% to reach 597.1 m^3/s at 50, 100, and 200 years return period, respectively.

In the U, the hydrographs reach their peaks after almost 2 hours, the reason for reducing the time to peak is because of the increase in the urban area (i.e., increase of the impervious zones). The peak discharges increased by 81.9% to reach 441.9 m^3/s, by 72.6% to reach 538.8 m^3/s, and by 65.4% to reach 644.5 m^3/s at 50, 100, and 200 years return period, respectively.

In the combined of CC+U, the hydrographs reach their peaks after almost 2 hours. The peak discharges increased by 161.9% to reach 636.5 m^3/s, by 147.7% to reach 773.2 m^3/s, and by 136.7% to reach 922.1 m^3/s at 50, 100, and 200 years return period, respectively.

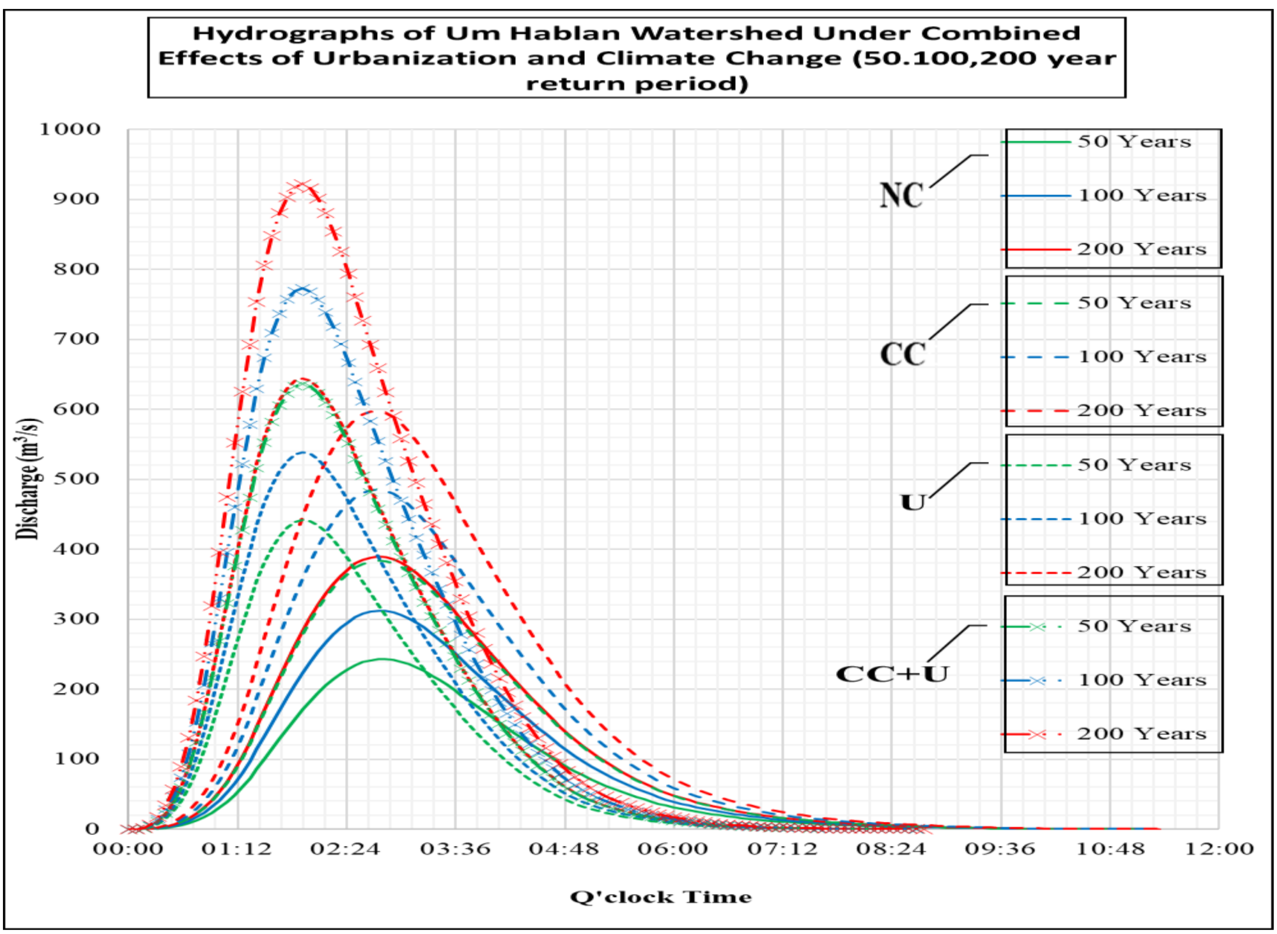

Figure 9. Hydrographs of Um Hablian watershed under different conditions (Normal condition (NC), Climate change condition (CC), Urbanization condition (U), and Combined condition (CC+U) at return periods (50, 100, and 200 years).

Table 5. Summary of hydrological modeling results of Um Hablian watershed for different scenarios (CN_c= composite curve number, Q_p = peak flow discharge, t_p = time to peak, and MCM = million cubic meter).

Conditions		Hydrological results								
Senarios	**Return Periods (Years)**	**Rainfall (mm)**	**CNc**	**T lag (hr)**	**Qp (m3/s)**	**Runoff volume (MCM)**	**Time to peak tp (min)**	**% Increase for Qp (m3/s)**	**% Increase in runoff volume (MCM)**	**% Decrease in tp**
Normal Condition (NC)	**50**	**108.0**	**83**	**1.75**	**243**	**2.7**	**170**	**Non**	**Non**	**Non**
	100	**129.8**			**312.2**	**3.4**	**165**			
	200	**153.6**			**389.6**	**4.3**	**165**			
Climate Change (CC)	**50**	**151.8**	**83**	**1.75**	**383.6**	**4.2**	**165**	**57.9%**	**57.2%**	**-2.9%**
	100	**182.5**			**485.1**	**5.3**	**165**	**55.4%**	**54.8%**	**0.0%**
	200	**216.0**			**597.1**	**6.5**	**165**	**53.3%**	**52.9%**	**0.0%**
Urbanization (U)	**50**	**108.0**	**93**	**1.17**	**441.9**	**3.8**	**115**	**81.9%**	**41.7%**	**-32.4%**
	100	**129.8**			**538.8**	**4.6**	**115**	**72.6%**	**34.5%**	**-30.3%**
	200	**153.6**			**644.5**	**5.5**	**115**	**65.4%**	**29.1%**	**-30.3%**
Climate Change & Urbanization (CC+U)	**50**	**151.8**	**93**	**1.17**	**636.5**	**5.4**	**115**	**161.9%**	**103.5%**	**-32.4%**
	100	**182.5**			**773.2**	**6.6**	**115**	**147.7%**	**92.6%**	**-30.3%**
	200	**216.0**			**922.1**	**7.9**	**115**	**136.7%**	**84.4%**	**-30.3%**

Peak discharge and runoff volumes (Q_p, V)

Table 5 shows the results of the hydrograph parameters in terms of peak discharges, time lag, time to peak, runoff volumes and the percentage of increase or decrease of the parameters. Also, Figure 10 shows a graphical representation of the effect of the scenarios. The peak discharges and runoff volumes were derived from HEC-HMS software. There was an increasing trend of Q_p values from 243 m^3/s (50 years return period) under NC scenario to 922.1 m^3/s under CC+U scenario (200 years return period) due to the increase in the amount of rainfall, CN_c values, impervious area, and decrease in initial abstraction in all scenarios. The runoff volumes (V) showed an increase in each condition. In general, the percentage of increasing V values ranged between 29.1% under U scenario and 103.5% under CC+U scenario compared with NC scenario. Therefore, there was an increasing trend from 2.7 MCM under NC scenario (at 50 years return period) to become 7.9 MCM under CC+U scenario (at 200 years return period) due to the same reasons for increasing the peak discharge. In conclusion, the influence of CC on the Um Hablian watershed is more than the influence of U, and the influence of CC+U is the most affected as shown in Figure 10.

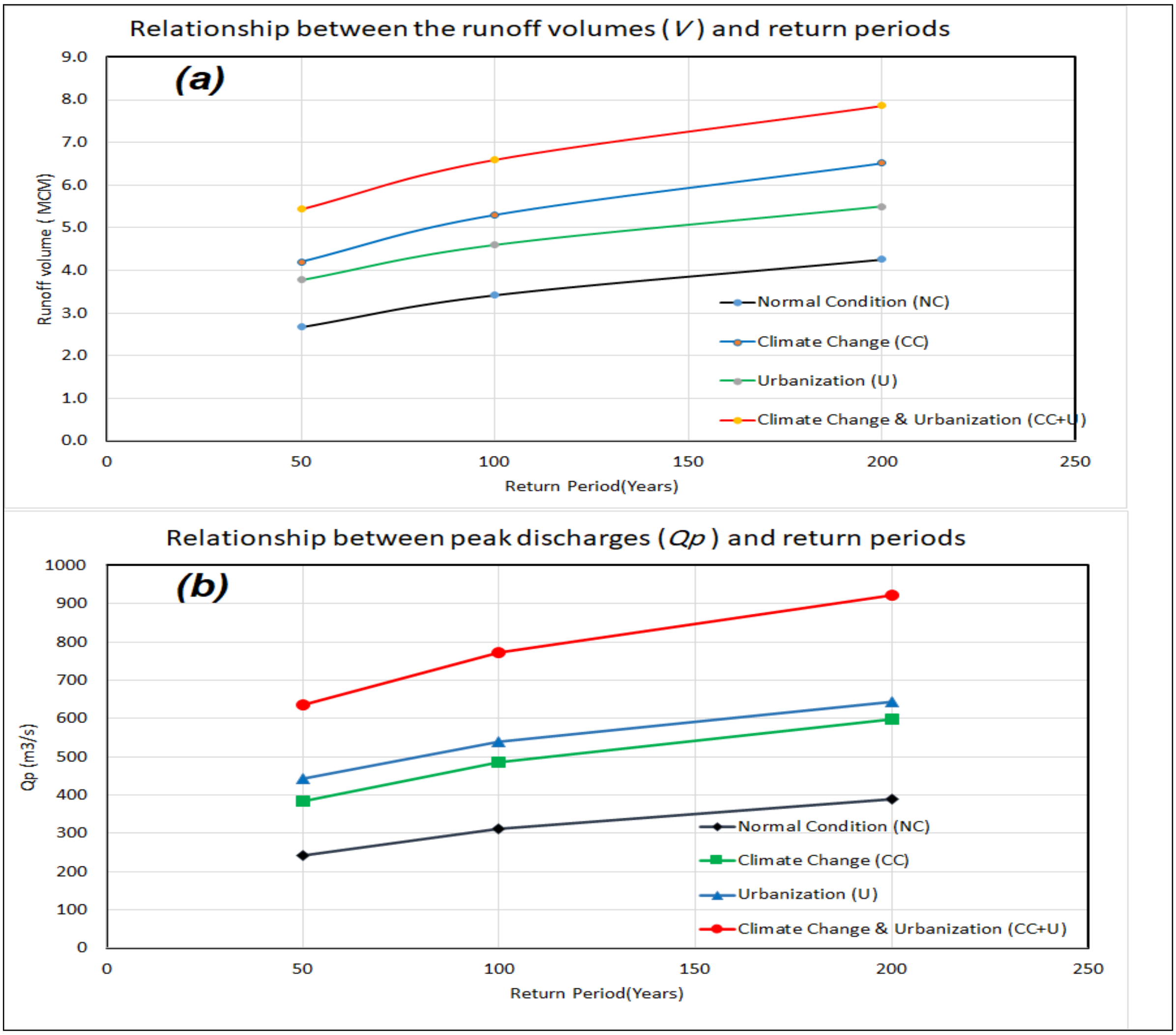

Figure 10. Runoff volumes (a), and peak discharges (b) in the Um Hablian watershed at different scenarios and return periods.

Time to Peak (t_p)

The time to peak is the time interval from the start of the hydrograph to the peak discharge. Table 5 shows a slight decrease generally under NC and CC scenarios and the runoff needs 2.75 hours to reach the peak discharge. The reason for an almost constant time to peak under NC and CC scenarios is that the CN is consistent in both cases and therefore there is no change in the time to peak accordingly. In contrast, under U and U+CC scenarios the runoff needs almost 2 hours to reach the peak discharge. So, t_p decreased by 32.4%. The decrease in t_p is due to the increase of expected urbanization areas that took place over the Um Hablian watershed that influence the CN and its value increased by urbanization.

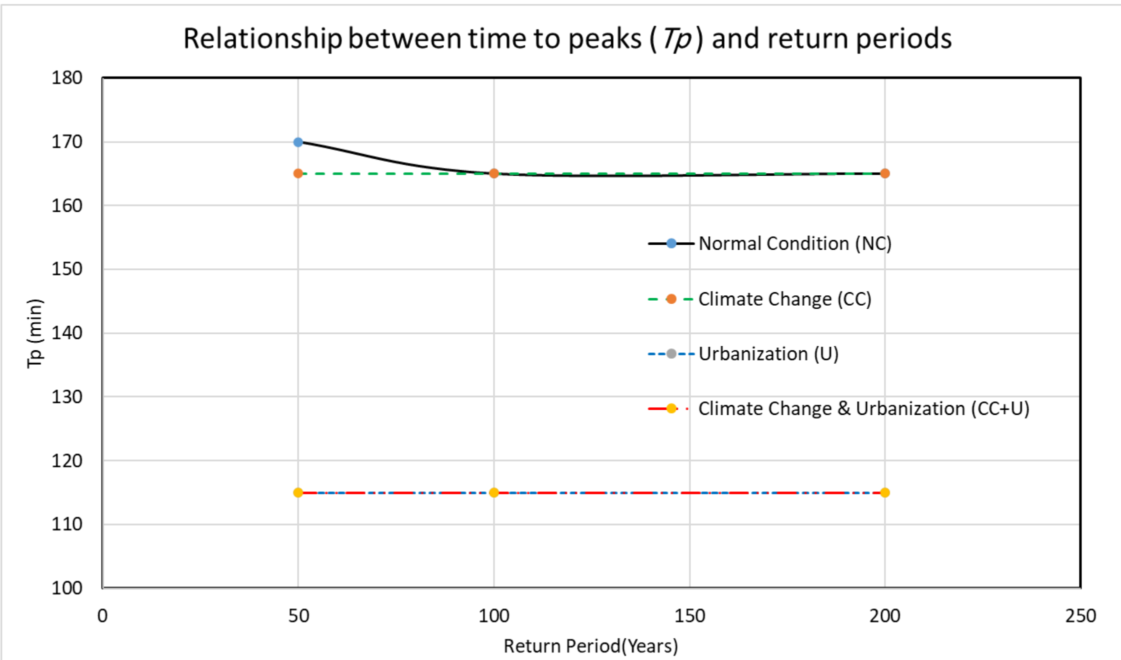

Figure 11. Relationship between time to peak and return periods at different scenarios and return periods of Um Hablian watershed.

Dam Capacity Analysis

Reservoir capacity refers to the maximum volume of water that can be stored behind the Um Hablian dam efficiently and safely. The structural relationship between the water level and dam storage is expressed by a graph as shown in Figure 8. Table 6 shows the runoff volumes under the different scenarios and return periods. It is clear from the NC scenario, the runoff volume is lower than the dam capacity by -31.4%, and -12%, at 50-, and 100-year return periods respectively, so that the dam is capable to store the amount of runoff efficiently and safely, except the 200-years the runoff volume exceeded the dam capacity by 9.6%. Moving to the CC scenario, it was noticeable that the runoff volume higher than the dam capacity by 8%, 36.3%, and 67.7% at 50-, 100-, and 200-year return periods respectively, so that the dam is not capable to store the amount of runoff volumes under CC scenario. In the U scenario, the results are substantially better than in the CC scenario since at the 50-year return period the runoff volume is lower than the dam capacity by almost -2.8%. However, for the 100-years and 200-year return periods, there was an increase exceeded the dam capacity by 18.4% and 41.1% respectively. In the last scenario (CC+U), it was clear that the dam is not capable to store the amount of runoff efficiently and safely because the runoff volumes exceeded the dam capacity by 40%, 69.5%, and 102% at 50-, 100-, and 200- year return period, respectively. In conclusion, the results indicate that the effect of the CC scenario on the Um-Hablian dam is more significant than the effect of expected urbanization. The combined effect (CC+U) shows the extreme scenario on dam safety.

Table 6. Summary of hydraulic results of Um Hablian dam for different return periods and scenarios

Conditions		Dam Efficiency						
Senarios	Return Periods (Years)	% Increase or decrease of volume	% Increase or decrease of water depth	Reservoir hight (m)	Dam Lake Area (Km2)	% Increase of dam lake area (Km2)	Dam data	
							Height (m)	Volume (MCM)
Normal Condition (NC)	50	-31.4%	-17.8%	9.5	5.3	Non	11.5	3.89
	100	-12.0%	-6.3%	10.8	6.2			
	200	9.6%	4.7%	12.0	7.1			
Climate Change (CC)	50	7.9%	3.9%	11.9	7.0	33.1%		
	100	36.3%	16.5%	13.4	8.2	33.5%		
	200	67.6%	28.4%	14.8	9.5	33.9%		
Urbanization (U)	50	-2.8%	-1.4%	11.3	6.6	24.3%		
	100	18.4%	8.8%	12.5	7.5	21.3%		
	200	41.4%	18.6%	13.6	8.5	18.9%		
Climate Change & Urbanization (CC+U)	50	39.7%	17.9%	13.6	8.4	58.4%		
	100	69.5%	29.1%	14.8	9.6	55.6%		
	200	102.0%	39.8%	16.1	10.9	53.3%		

Reservoir Height Analysis

Table 6 displays a significant increase in water reservoir level exceeding the dam height under the CC, U, and CC+U scenarios In the NC scenario under 50- and 100-, return periods the water height is lower than the dam height by -17.8% and -6.3% respectively, and under 200- return periods the water height exceeds the dam height by 4.7%. In the CC scenario, under 50-, 100-, and 200-return periods the height exceeded the dam height by 3.9%, 16.5%, and 28.4% respectively. In the U scenario, at 50- return periods the height is lower than the dam height by -1.4%, and under 100 and 200 return periods the height exceeded the dam height by 8.8% and 18.6% respectively. In the CC+U scenario at 50, 100, and 200 return periods the height exceeded the dam height by 17.9%, 29.1%, and 39.8% respectively. This means that the Um-Hablian dam under these scenarios is expected to undergo significant overload leading to passing a massive amount of water over the crest of the dam during storms under these scenarios. However, the NC scenario was almost safe because the maximum water level that can be reached is 10.8 m which is lower than the dam height (11.5 m).

Dam Lake Area Analysis

It is vital to define exactly what is meant by dam lake area, which is typically defined as some portions of the region upstream of the dam that gets entirely covered with direct runoff while other areas of the land stay safe and dry. Figure 8 displays the structural relationship between the water level and the Um Hablian dam lake area. A closer inspection of Table 6 shows that the Um Hablian dam lake area under the different scenarios and retune periods are increasing gradually under each scenario. In the NC scenario, the dam lake increased the wet area to 5.3 Km^2, 6.2 $km^{2,}$ and 7.1 km^2 under 50-, 100-, and 200- years retune periods, respectively. In the CC scenario, the lake area increased by 33.1%, 33.5%, and 33.9% compared with the NC scenario, under 50-, 100-, and 200- years retune periods, respectively. While, in the U scenario, the lake area decreased by 24.3%, 21.3, and 18.9%, compared with the NC scenario, under the condition of 50-, 100-, and 200- years retune periods, respectively. In the CC+U scenario, the lake area decreased by 58.4%, 55.6%, and 53.3% compared with the NC scenario, under 50-, 100-, and 200- years retune periods, respectively. Thus, the effect under the CC scenario on the dam lake area has more influence than the U scenario. As shown Figure 60, reveals that there has been a gradual increase in the Um-Hablian dam lake area under each scenario and different return periods. Figure 12 reveals that there has been a gradual increase in the Um Hablian dam lake area for each scenario under different return periods.

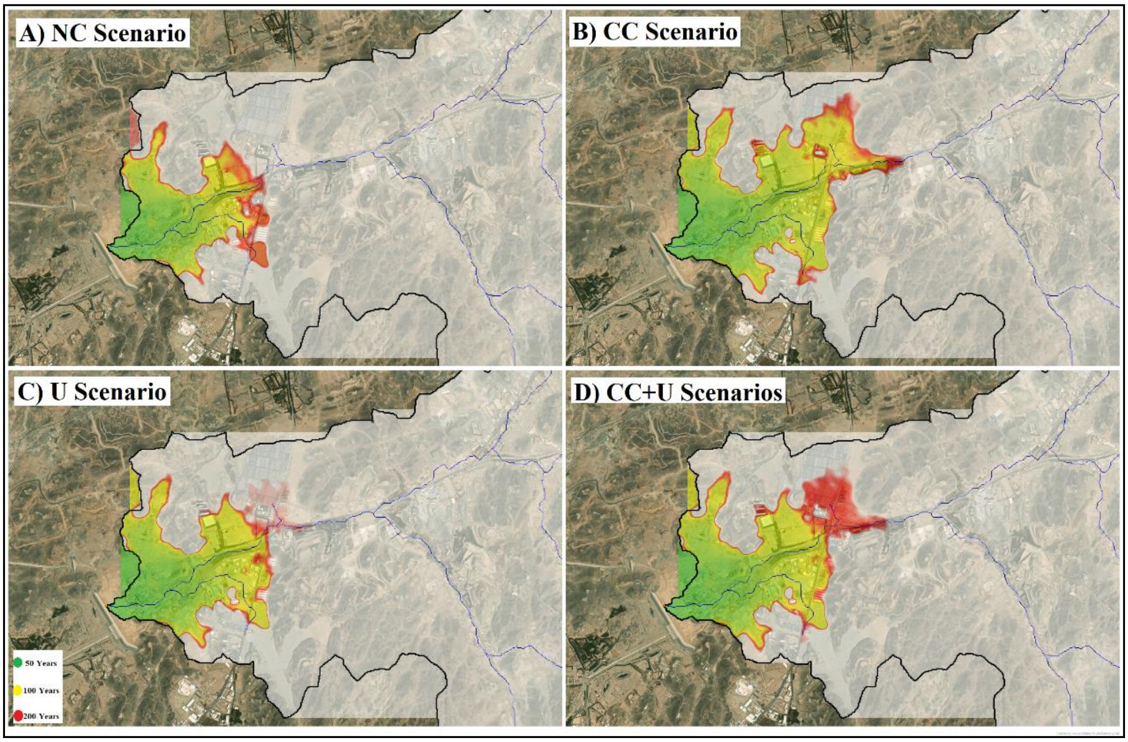

Figure 12: Um Hablian dam lake area for each scenario under different return periods

3. Summary and Conclusions

This paper analyzes the effect of climate change and urbanization on a dam efficiency in Jeddah city. Um Hablian dam is considered a case study. Several data have been collected to address the objectives. Among these data are the historical rainfall, DEM, a base map of Jeddah city, and its future expansion. Hydrological analyses have been performed using HEC-HMS, GIS, and WMS software to estimate the floods under the current condition (NC) where the dam is designed. Three scenarios are considered in the analysis: the climate change (CC), the urbanization (U), and the combined effect of both (CC+U).

The following conclusions are drawn from the study:

1- The overall change in Qp is from 243 m^3/s (50 years return period) under NC scenario to 922.1 m^3/s under CC+U scenario (200 years return period).

2- The overall change in runoff volume is from 2.7 MCM at 50 years return period under NC scenario to 7.9 MCM under CC+U scenario at 200 years return period.

3- The time to peak is not markedly affected by the CC scenario, however, it is reduced by 32.4 % under the U and CC+U scenarios.

4- Under the current (normal) condition (NC) scenario, the dam capacity can accommodate floods up to 100-year return period.

5- In the (CC+U), the runoff volumes exceeded the dam capacity by 40%, 70%, and 102% at 50, 100, and 200 years return period, respectively.

6- The effect of the CC scenario on Um-Hablian dam is more significant in terms of (runoff volume, peak discharge, time to peak, reservoir lake area, and water level in the reservoir) than the effect of the expected urbanization. The combined effect (CC+U) shows the extreme scenario on the dam safety. Therefore, it should be considered in the design of future dams in KSA.

7- From the analysis of the dam height under CC, U, and CC+U scenarios especially at 50, 100 and 200 years return periods, it is expected that the dam undergoes a significant overtopping leading to passing a massive amount of water over the crest.

8- The effect of urbanization leads to shortening the time to peak of the flood. This is very impotent for the design of the flood warning systems.

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تقييم كفاءة السدود تحت تأثير تغير المناخ والتوسع العمراني: سد أم حبلين جده المملكة العربية السعودية (دراسة حالة)

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مستخلص. تحلل هذه الورقة تأثير التغير المناخي والتوسع العمراني على كفاءة السدود التي تم بناؤها لحماية مدينة جدة في المملكة العربية السعودية من السيول المفاجئة. وقد اعتبر سد أم حبلين الواقع في شرق مدينة جده كدراسة حالة. تم جمع العديد من البيانات لتحقيق أهداف البحث. من بين هذه البيانات هطول الأمطار التاريخي ونماذج الارتفاع الرقمية وخريطة أساس لمدينة جدة في الوضع الحالي والتوسع المستقبلي حتى عام ٢٠٥٠. تم إجراء التحليلات الهيدرولوجية باستخدام برامج مشتركة: HEC–HMS و GIS و WMS لتقدير الفيضانات تحت ظروف التصميم العادية، وتأثير تغير المناخ، والتوسع العمراني. لقد ثبت أنه في ظل سيناريو الحالة العادية (NC) ، يمكن لسد أم حبلين أن يستوعب السيول لفترات تكرار تصل إلى ٢٠٠ عام. و تبين من النتائج ان تأثير سيناريو تغير المناخ (CC) أكثر أهمية من تأثير سيناريو التوسع العمراني (U). و أوضح تأثير سيناريو التحضر (U) وجود قصر في مدة الوصول الي زمن ذروة السيل. وفي حالة السيناريوهات المجمعة (CC + U) ، تجاوز حجم الجريان السطحي سعة السد بحوالي ١٠٢٪ ومن المتوقع أن يتم تجاوز ارتفاع السد بنسبة ٤٠٪ من ارتفاع السد الحالي، ومن المتوقع أن تغمر بحيرة السد مساحة أكبر بنسبة ٥٣٪ من الوضع الحالي. لذا يجب عمل التدابير اللازمة لتفادي الاثار المترتبة على ذلك.