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Floodplain Hazard Mitigations, Solutions and Recommendations for Wadi Asla in Jeddah-Saudi Arabia

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Abstract: No simple solution to flood prevention is accessible. This research provides a brief summary of the hydrologic and hydraulic methodology that can be used to develop specific details that integrated the flood information tool. It permits rapid analysis of a wide variety of stream discharge data and topographic mapping to avoid the flood hazard over entire floodplain boundaries. This paper focuses on the water floodplain hazard in Wadi Asla-Jaddah-Saudi Arabia. The most common type of rainfall in the study area is that accompanied by thunderstorms, which usually fall during the winter season as well as in the spring. The primarily evaluation of this problem and the solution is contemplate. The more essential and "doable" elements of a solutions and recommendations are discussed in this research.

Key words: Floodplain, model, flood frequencies, hydrograph, Wadi Asla.

1. Introduction

Wadi Asla site is located in southeast of King Abdel Aziz airport between Harameen and Hedda Sham highways (Fig. 1). The site boundary starts 10 km to 15 km from Harameen highway. The site area is around 120 km^2 while the study area that incorporate Wadi channel to Emergency Dam is around 160 km^2. Wadi Asla is situated about 15 km to the east of the city of Jeddah. The site is owned by Jeddah Development and Urban Regeneration Company (JDURC) and most of it is located within Jeddah governorate boundary. Figs. 2 and 3 show the Wadi Asla lakes and Wadi Asla desert, respectively.

The site hydrological features include hilly areas (340 m, above mean sea level, ASL), east of Jeddah city and several wadis (natural flood channels) that flow from east to west then to Red Sea. Hilly areas forms around 35% of the site, flat plains forms 25% and the remainder part is wadi beds. The difference in elevation between wadis edge and wadi bed varies from location to another within the range from 90 m to 180 m.

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Sewage lake of about 3 km^2 was formed in Wadi Asla to store untreated wastewater due to insufficient wastewater treatment capacity in Jadda city. The natural flow of wadi is stored in the Briman lake (Musk lake). The lake is polluted due to dumping of household sewage from Jeddah city. The lake volume is around 10,000,000 m^3, estimated in 2009. The lake is unlined, therefore pollutants infiltrates to groundwater system in the area. The groundwater level in the lake area is very close to ground surface (1-2 m, Below Ground Level (BGL)), while the regional level is 10 m to 15 m BGL. Groundwater in the vicinity of the lake is contaminated from pollutants in the lake.

Conceptual comprehensive masterplan was developed for Wadi Asla with high level technical strategies. All activities and proposed structures for future development and details for masterplan through constructions and operations are shown in Fig. 4.

The climate conditions in the area are similar to climate in Jeddah and Makkah cities. Rainfall is intermittent and extreme in nature and most frequent in autumn. Heavy rain in short period is expected in winter, autumn and springs. The average annual rainfall in the area is around 100 mm. In 2009 floods,

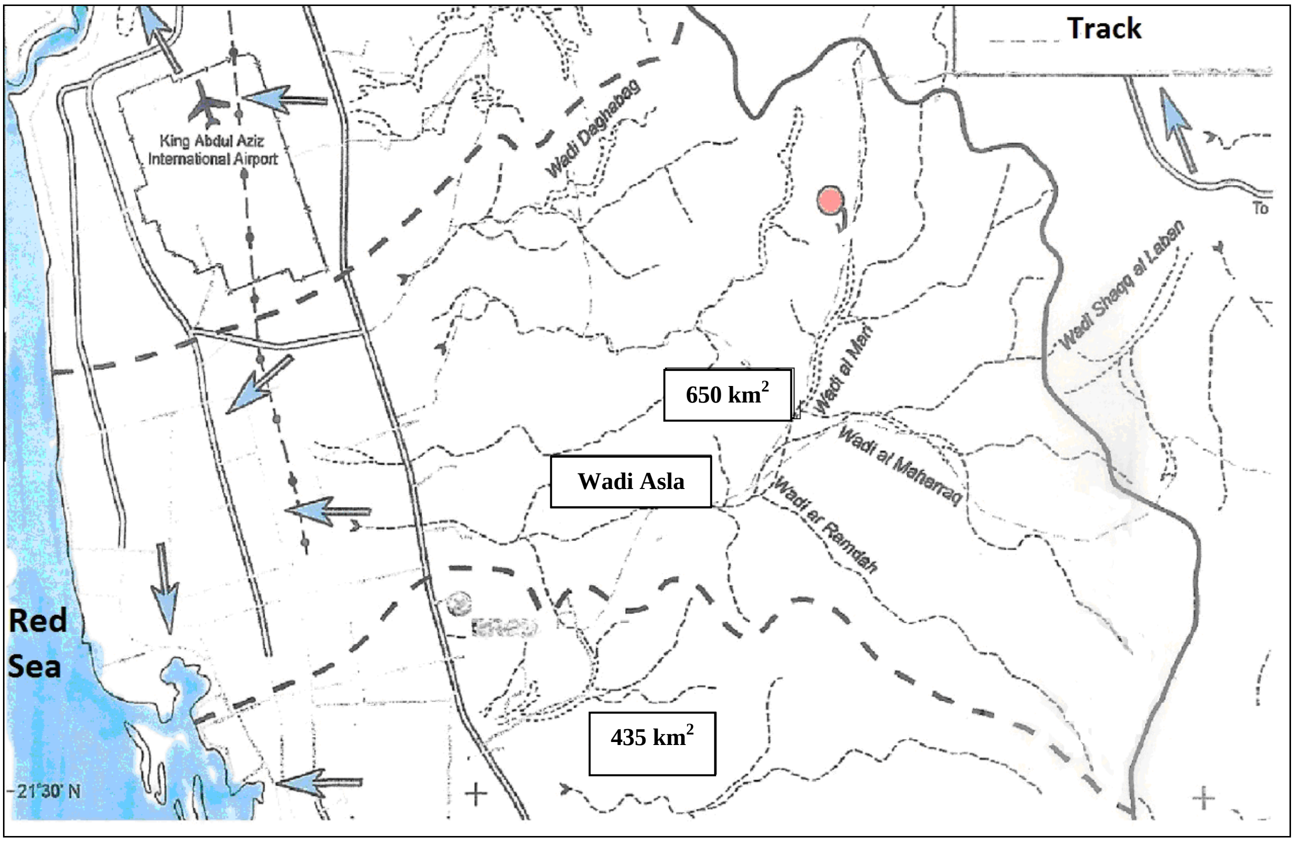

Fig. 1 Location of the studied area.

Fig. 2 Wadi Asla lakes.

Fig. 3 Wadi Asla desert.

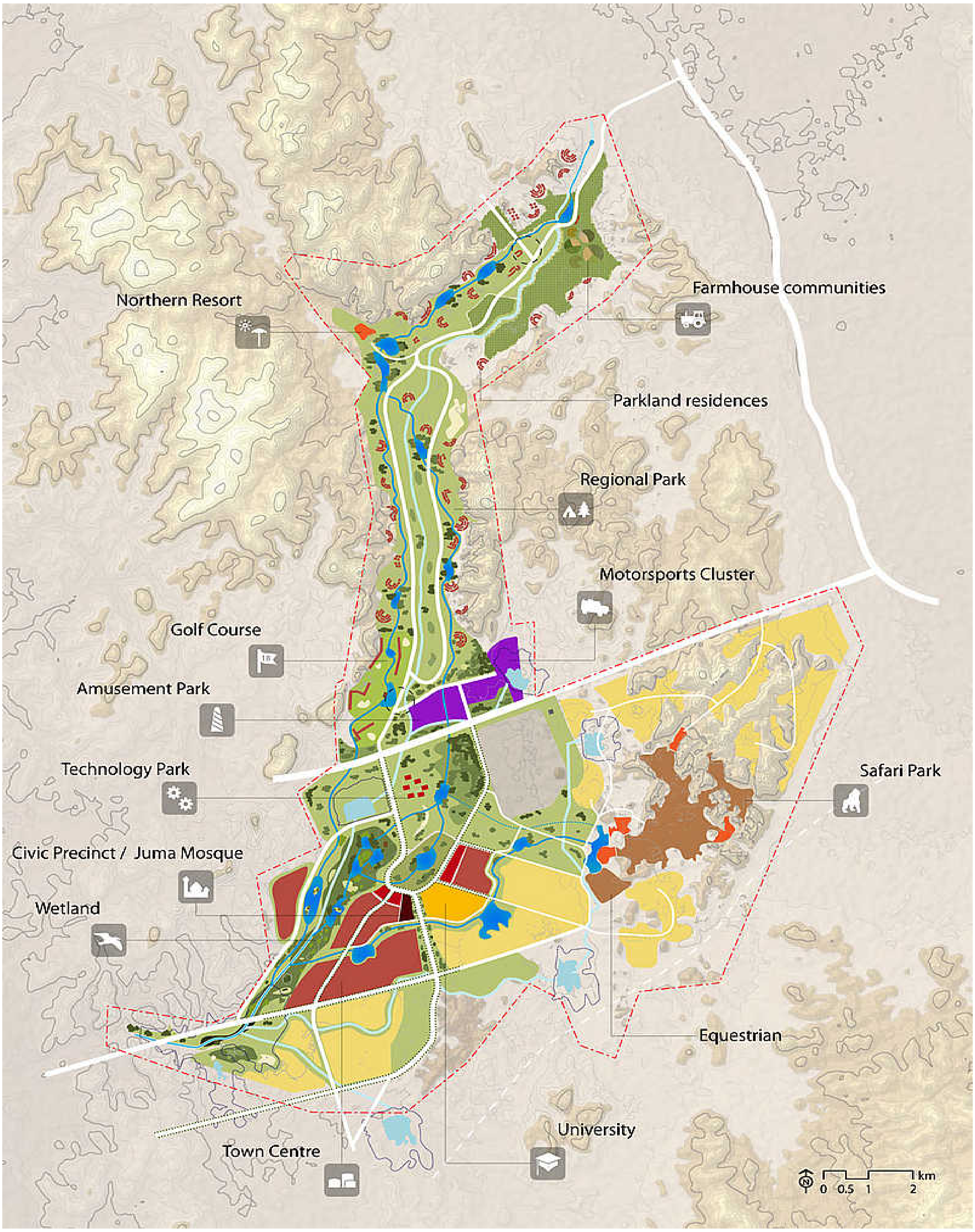

Fig. 4 Wadi Asla masterplan.

Fig. 5 Flooded areas and damage in the city and suburbs areas.

over 100 people were killed in a series of floods in Jeddah city. Damage in the city and suburbs of flooded areas is shown in Fig. 5.

It was found that tree-plant had not prevented or considerably reduced flooding in the case of an extreme weather event [1]. However, more general or overview studies agree on the negative impacts that deforestation has on flood safety, and the positive effects of wise land use and reforestation [2, 3].

2. General Methods of Flood Control

River stabilization structures are designed to protect the river banks and prevent lateral migration of alluvial channel through bank erosion. River stabilization methods can be classified to two different approaches: strengthening the banks and reducing hydrodynamic forces.

(1) Bank riprap revetment

Several engineering method can be used to strengthen river banks against erosion. Method commonly encountered includes the use of riprap or large stone that are not easily removed from the banks. Besides riprap, other methods can be used such as gabions, blocks and rocks, rock-filled trenches, windrow revetment, soil cement, fences, bulkheads and mattresses.

(2) River flow control structure

Flow control structures are designed to reduce dynamic forced against stream banks by controlling of direction, velocity or depth of flowing water.

(3) Slope bank reduction and benching

Slope bank reduction should be maintained to increase the stability of side slope, as a result, it reduces the soil erosion.

(4) Guide banks

Guide banks should be placed at bridge and culvert crossing near the end of approach embankments to guide the stream through the crossing opening.

(5) Retards

Retards are a low permeable structure locates near the toe of the bank slope parallel to the streamflow. The function of retards is to decrease velocity behind the structure and eliminate erosive forces.

(6) Dikes

The design approach for dikes requires a comparison of recent and old topographic maps, a site inspection, confirm the general stream characteristics, survey of cross section bed and bank material, and soil boring to identify exact alignment of dikes.

(7) Jetties

Jetty fields add roughness to a channel or overbank area to train the main stream along selected path. The added roughness along the bank reduces the velocity and protects the bank from erosion.

(8) Drop structures

Grade control structures or drop structures may be used to reduce the slope of a channel. The purpose of grade control structures is to stabilize the bank and the bed of a channel by reducing stream slope and flow velocity.

(9) Floodways

Flood wave attenuation is sometimes possible by diverting some of the flood away from the main channel. Floodways are used to divert water into a topographic depression near the channel or into river or sea.

(10) Levees

Levee is an earth embankment constructed along a stream to protect land on the floodplain from being flooded. A flood wall is a concrete structure serving the same purpose and found in urban area where insufficient space prohibits building a levee.

(11) Channel closure and construct earth dam

It is possible sometimes to enclose the channel by constructing the earth dam to reduce the flow velocity and the threat of the flood.

(12) Channel conveyance

Lowering the flood levels in a channel reach by increasing the discharge capacity of the channel is sometimes possible by reducing the roughness of the river bed.

A flood control project is a work of any nature that is designed, constructed and operated according to sound and accepted engineering practice for flood control. Typically, these projects may include reservoirs, detention or retention ponds, channel improvements, or levees and large or small dams.

3. Selected Measures for Flood Control

3.1 Floods Protection

Wadi Asla performs an important part of the floods protection for Jeddah city, therefore, any study aims to overcome the flood risk should contain:

- Strengthening this natural defence channel to protect Jeddah city;
- Maintain floods natural flow so it remains functional;
- Mitigate any adverse effect created from site development;
- Study the effect of existing infrastructure such as Briman lake earth dam and emergency dam on floods drainage;
- Development of floods masterplan for the site development that includes drainage routes and proposed storage locations. The outcome of the flood master plan should be integrated with the development plans of urban planning, landscaping and roads infrastructure;
- Define zones with flood risks and propose necessary hydraulic structures to protect site;
- Utilize floods water to expand water bodies and green areas within the site.

3.2 Hydraulic Structures

The main purposes of hydraulic structures are to store water for irrigation, landscaping and recharge uses or to drain/divert flood water to suitable drainage locations. The hydraulic structures include [4, 5]:

- Storage Dams to store water and use it in landscaping or irrigation;
- Check Dams to trap the sediment transport;
- Levees and dikes to keep fast-moving and dangerous flood waters away from people's homes and roads. Levees and flood plains are formed when the level of the river is above the level of the land. Levees are banks on the side of the wadi which prevent the flooding into the flood plain. Levees can be man made concrete or artificial-mud.

Multi box culverts, bridges, diverted canal, storm water sewers and other hydraulic structures ensure the runoff to be drained and convey storm water runoff in a safe and orderly fashion [6].

4. Data and Survey

The required data, survey, tests can be grouped as:

- Maps and images include topographic maps, satellite images, and land use maps, digital topographic maps, physiographic and vegetation;
- Hydrometrical records include but not limited to daily raw data records, registered charts, rating curves and daily records for flow gagging stations at Wadi Asla or at any gagging stations close to the site;
- Hydro-meteorological data include but not limited to data such as daily and hourly rainfall data and floods data from the hydro-metrological station close to the area;
- Information about lake and dam structures include but not limited to design capacities, construction year, future plan, area-capacity curves, drawings of the diversion channels within the basin

boundary, records of recharge, utilized and spilled quantities for each dam and the current and future uses of the utilized and spilled water for the domestic and industrial uses, areas of agricultural activities, quality and quantity of treated and untreated water discharging from collection and treatment plants within the basin;

- Information about other infrastructure include roads, buildings, parks, recreation facilities, landscaping areas treatment plants, wastewater plants, etc.;
- Required surveys and tests: geotechnical/hydro-metrical survey and any additional lab tests.

5. Methodology

(1) For large catchment area, it is typically not probable to carry out costly complete hydrologic data collecting, investigation, analysis and details drawings during a planning stage [7, 8]. Remote sensing technology, topographic maps and satellite imagery may provide economically feasible alternative means of supplementing traditional hydrologic data sources.

(2) For ungaged sites in which no flow discharge record is available, it is necassery to estimate the pak flow discharge for different hydraulic structures using synthesis unit hydrograph or estimating maximum flood using envelope curves developed by Crippen, J. R., and Bue, C. D. [9].

(3) Hydrological and hydraulic concerns that the design should be based on collected data at different stage of the work, site visits and investigations. The site project should be positioned on the topographical maps of 1:50,000 or 1:25,000 scales.

(4) The study area locates within the mountainous area. Roads and constructions will affect the natural surface and subsurface drainage pattern of a watershed or individual hillslope since water and debris will flow down. Surface water drainage should be designed for reduction and/or elimination of the affect of successive energy generated by flowing water. The destructive power of flowing water increases as its velocity increases. Therefore, water must not be allowed to develop sufficient volume or velocity so as to cause excessive wears along ditches or along exposed running surfaces, cuts or fills.

(5) Remote sensing technology can be especially useful and desirable when applied during the planning process. With remote sensing methods, the extent of floodplains and flood-prone areas can be approximated at small to intermediate map scales (up to 1:50,000) over entire river basins.

(6) Floodplain mapping techniques are either dynamic or static methods. Many traditional techniques are dynamic: they monitor the continuous change in river or stream flow and require considerable field work and maintenance of long-term records. Some traditional dynamic techniques utilize regression analysis and rainfall estimates derived from models in which long-term records are transferred from similar basins or reaches in a given region. Delineating floodplains and other areas subject to flooding is valuable input for proposing compatible development activities.

(7) Development planners need to know how often, on the average, the flood plain will be covered by water, for how long, and at what time of year. Natural changes as well as changes brought by development activities affect the floodplain and must be understood to identify appropriate development and natural resource management practices. Changes in floodplain utilization such as urbanization and more intensive agricultural production can increase runoff and subsequent flood levels. It is critical for the planner to appreciate these and other effects of land-use change. Early consultation with water resource and management specialists during the planning study is prudent, because it enables the planner to evaluate potential conflicts between present and proposed land use and their relationship to flood events and the hazards they may pose in the future.

(8) Information from floodplain maps can be used

in the preparation of land-use and land-capability maps (at this stage). The areas inside the floodplains are subject to both floods and river channel meandering. Proposed crop production and construction of irrigation infrastructure, culverts, bridges, roads and other permanent structures must be studied to evaluate their flood risk. Similarly, the flood hazard information is critically important in planning urban, industrial, recreational, tourism, and parkland development [10]. Traditionally, gathering and analyzing hydrologic data related to floodplains and flood-prone areas has been a time-consuming effort requiring extensive field observations and calculations. This traditional approach uses historical data of flood events to delineate the extent and recurrence interval of flooding.

6. Technical Approach

The technical approach should be an integrated approach that combines remote sensing/satellite/Arial photos with Digital Elevation Model (DEM), GIS and floods simulation model. Fig. 6 shows the flow chart of integrated approach. The flood model will utilize the 100 year flood event from stochastic model which will be developed for this purpose. In case the predicted rainfall event is less than rainfall occurred in Nov. 2009 and Mar. 2013 in Jeddah, the highest rainfall will be used.

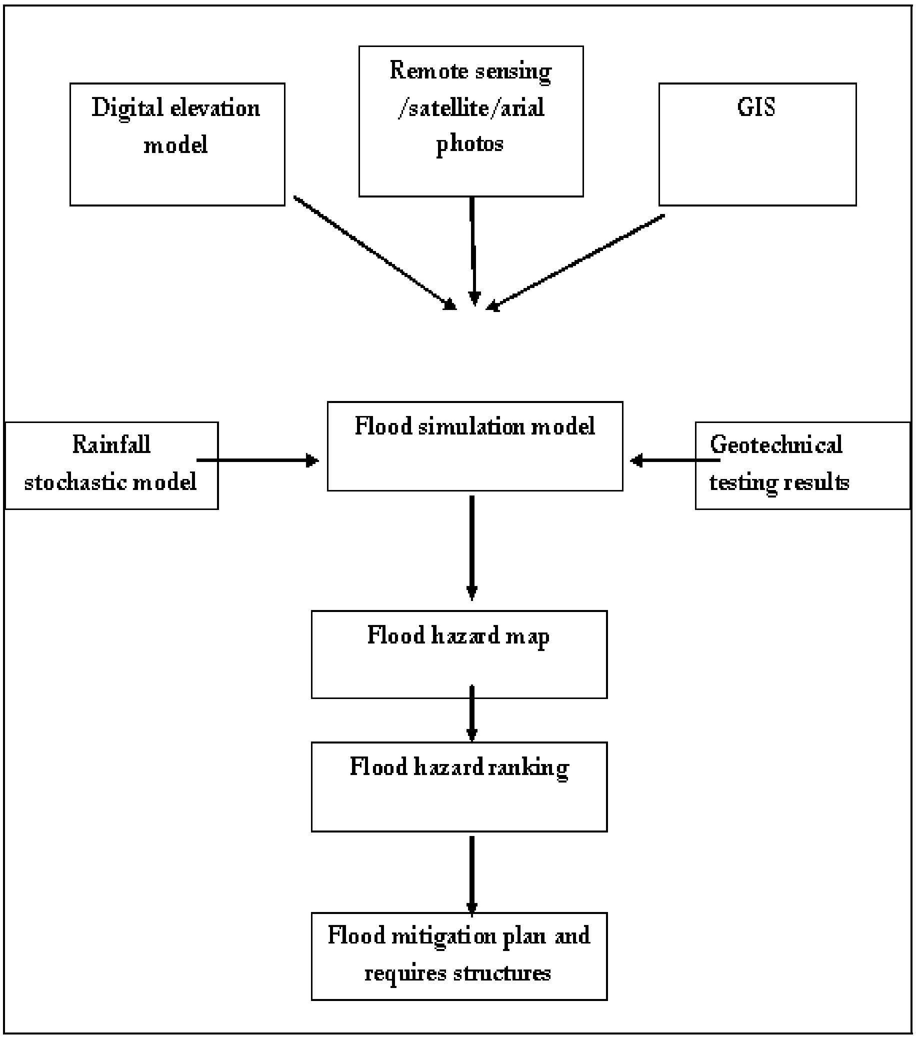

Fig. 6 Flow chart of integrated approach.

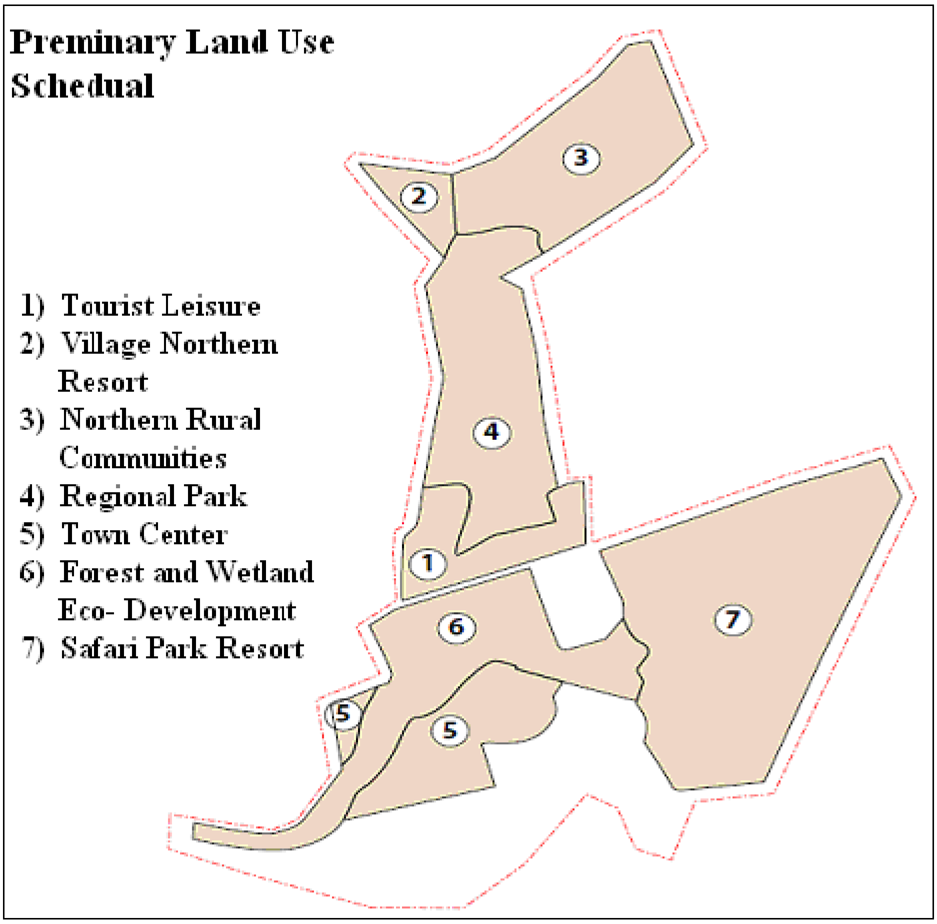

Fig. 7 Integrated development plan (source: Buro Happold, integrated development plan) [11].

The flood model will help in developing a flood hazard maps considering flood depth, land use type and affected area. As a result, a flood hazard ranking system should be designed by combining flood extend, flood depth, land use types and developed by using the matrix multiplication method. Ranking will be done for 7 categories of land use area within study area shown in Fig. 7. The Integrated Development Plan for the study area is shown in Fig. 7.

It will also identify main spilling reach and recommended for structural countermeasures. Identification of such critical river sections would ensure a better use of limited resources. The hazard map can be linked with flood level at an upstream river station by rating curve so that it could be used as an early warning tool for generating flood level versus potential loss maps.

6.1 Models

Two models will be developed for floods simulation:

- Rainfall stochastic model is used to predict the 100 rainfall event. This will base on rainfall historical records from the close rainfall station. It will include development of intensity duration curves for the area;
- Floods simulation model is used to predict flood amounts, routes and identify hazard areas.

The modeling steps of a 2-dimentional model will be as:

- Delineating drainage areas;
- Identify and collect hydro-geological for the catchment area. The availability of streamflow data is very much needed in order to compute the required design floods and their frequencies that be used for the construction of these networks or hydraulic structures.

In this case, the method usually used is the frequency analysis of the time series of the annual observed floods, if such data are available;

- Identify and collect climatic data such as rainfall data;
- Define catchment areas and subcatchment areas for wadi tributaries;
- Develop conceptual model for each catchment area;
- Development of numerical model (model computational theory will be decided based on catchments characteristics and data availability, several theories are proposed below). Internationally well-known software such as Stormwater Management and Design Aid (SMADA), Flow Master, Watershed Modeling System (WMS) and Hydraulic Engineering Center for River Analysis System (HEC-RAS) etc. and/or personally constructed models will be used. HEC-RAS is recommended;
- Model calibration steady-state (floodplain analysis);
- Using model to predict future river flow based on the 100 year rainfall event or Jeddah Nov. 2009 or Mar. 2013 events;
- Investigate surface/groundwater interaction and impact.

6.2 Rainfall Model Computation Theory

As mentioned earlier, the project needs normally the continuous rainfall recording in order to know the short duration rainfall required to draw the Intensity-Duration-Frequency (IDF) curves representative to the area. Different statistical methods could be applicable in the computation for the preparation of these curves. One of the most famous methods to establish IDF curves is Gumbell's distribution whish depends on the data of rainfall for the annual maximum series.

6.3 Floods Model Computation Theory

A flood control project is a work of any nature that is designed, constructed and operated according to sound and accepted engineering practice for flood control. Typically, these projects may include reservoirs, detention or retention ponds, channel improvements or levees and large or small dams.

There are many techniques to estimate the total flow and floods from hydrographs such as Talbot method, modified Talbot method, sub-integral method, Barbara method, SCS method, Clark method, US National Resources Conservative Services (NRCS), Routing method, Snyder method and some computer models, WMS model, TR20, Stanford Watershed Model (SWM), SMADA, etc. [12]. For large catchments such as Wadi Asla area, Unit Hydrograph (UH) approach is recommended. The Unit Hydrograph (UH) for a catchment defines the pattern of runoff for the catchment for a unit volume of rainfall in a specified duration (e.g. 1 hour). Where recorded rainfall and river flows are available, it is possible to derive the unit hydrograph directly from the data. In this study, empirical methods must be used because the scarcity of data or unavailable. The SCS dimensionless UH can be used, with the hydrograph peak and time to peak estimated by using Snyder's method [13]. The key parameters of the hydrograph are the unit storm duration, time lag, time to peak and the time base (total duration). Various formulae have been proposed for determining these parameters from catchment characteristics. These data can obtain from topographic map.

For large catchments (i.e., between 5 km^2 and 5,000 km^2), Snyder's method is generally recommended for larger catchments and a 100-year flood recurrence interval. Rational method is easier to apply and may relevant for catchments of less than 15 km^2, channel mobility, configuration and migration are important in hydrologic design for sandy and desert area [5], such as in Wadi Asla.

Hydrological analysis for floodplain hazard of Jeddah's drainage basin was studied using regression relationships as a simple power function between drainage area, number of the channels in the catchment and other hydraulic variables. The relations among these variables may be utilized to estimate peak runoff for ungauged drainage basins [14].

7. Storm Water Management Plan

As a result of the flood model, the stormwater management plan should include:

- Development of floods hazard map;
- Rank the 7 categories of study area according to floods risk (Fig. 7). Each area will be given flood risk weight;
- Development flood mitigation plan that includes effect on flood plains, existing lake earth dam and emergency dam;
- Propose required hydraulic structures for water storage or diversion for water uses or allow for urban development and roads. It includes micro dams along the waterway for storage, diversion structures and culverts;
- Development masterplan for proposed infrastructure. The plan will include potential locations for water bodies as part of the integrated urban development plan. Flood plains will be classified according to flood risk ranking results and proposed urban planning development infrastructure;
- Development of floods monitoring plan. The plan will cover key location for floods measurements and identifying key locations for floods alarming.

8. Conclusions

Stream-gauging records are insufficient or absent in Wadi Asla. As a result, measuring peak flow discharge based on direct measurements may not be possible, because there is no basis to determine the specific flood levels and frequency and duration for given events. Risk evaluation based on remote sensing data, photo-optical techniques and field observations may answer many questions to delineate flood-prone areas in Wadi Asla. The material in this paper may enable the planner to have working expressions of terms, concepts and knowledge of the important considerations related to reduce floodplain hazard.

It is recommended to construct for example micro dames along the waterways in order to store water during winter seasons, which is in order to use again in the summer seasons as complimentary irrigation water instead of the flowing aimlessly through abandoned uncultivated areas. Natural drainage characteristics of a hill slope, as a rule, should not be changed. For example, surface runoff will be stored in a small depression or ponds in order to collect and transport runoff. This action depends on the amount of collected water, evaporation and infiltrations.

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