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Effects of Caspian Sea water level fluctuations on existing drains

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ABSTRACT
This study is an attempt to develop an integrated methodology to predict the impact of the Caspian Sea on flooding using Geographic Information Systems (GIS) and hydrodynamic modeling. A rise in the sea level might lead to major flooding events, and have a severe impact on the spatial development of cities and regions. The feasibility of simulating a flood event along a drain channel is evaluated near residential development areas along the Chapakroud drain. The results of the study show that about 2 km of the drain embankments would be influenced by changes in sea water levels. For elevations of -23 m and -24 m, the maximum depths of water in the drain are 3.95 m and 2.94 m. The tail of the backwater reaches 3465 m and 2390 m, respectively, leading to flooded areas of 35.97 ha and 12.88 ha. The study shows that at these elevations environmental and social problems arise with regards to the drain. The results also indicate that GIS is an effective tool for floodplain visualization and analysis. It should be noted that the mixture of salt and soft water, as a result of rising sea water level, is a problem that was not investigated in this study and should be examined in the future.

Keywords: *Flood Delineation; Flood hazard Area; HEC-RAS; River Hydraulics.*

INTRODUCTION
Floods are one of the most life threatening natural hazards on earth. A significant rise in water level of a river would cause flooding of the surrounding areas. It is therefore very important to estimate floods and to map areas under inundation. GIS is useful for integrating various geographic data, and for carrying out analyses of such data (Church et. al., 2001).A set of tools that can be applied within a Geographic Information System (GIS) has been developed to assist coastal municipalities to identify areas that are at risk of coastal flooding. Drains with their outfalls that flow into the sea are influenced by sea level variations. An increase or decrease in the Caspian Sea water level can take place for numerous reasons, such as temporary responses to a natural phenomenon (wind and water storage), changes in human activities (agricultural and industrial or construction of dams) and climate change (increasing rainfall in sea basin).
The fluctuations of the Caspian Seawater level have a very significant impact on the Chapakroud drain, since it directly affects its hydraulic conditions and drain depth. Records of the Caspian Sea level measured at Anzali station (1926-2006) indicate that from 1931 to 1976, the water level decreased from -25.5 m to -28.5 m; however, from1976 to 1994, it went up by 2.3 meters. From 1994 to 1999, it again decreased by around 0.5 meters. In conclusion, the water level fluctuated between -25.3 to -28.4 meters during the recent 80-year-recorded period (Fig.1).
Figure 2 shows more details about the sea water fluctuation from2004-2005, and 2006-2007. The sea had reached its maximum water level in the summer of 2004-2005 and its minimum water level in the winter of 2006-2007.

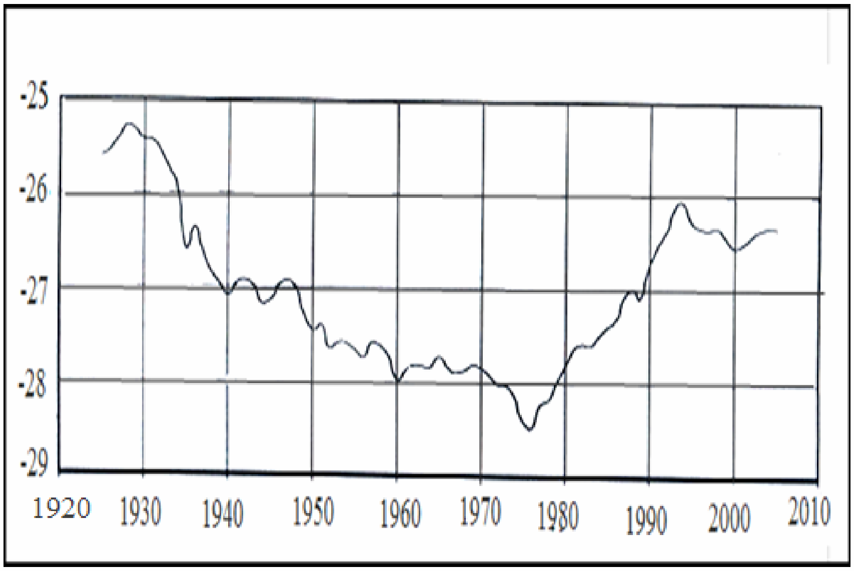

Fig 1. Caspian Sea water surface fluctuations in Anzali station from1926-2006

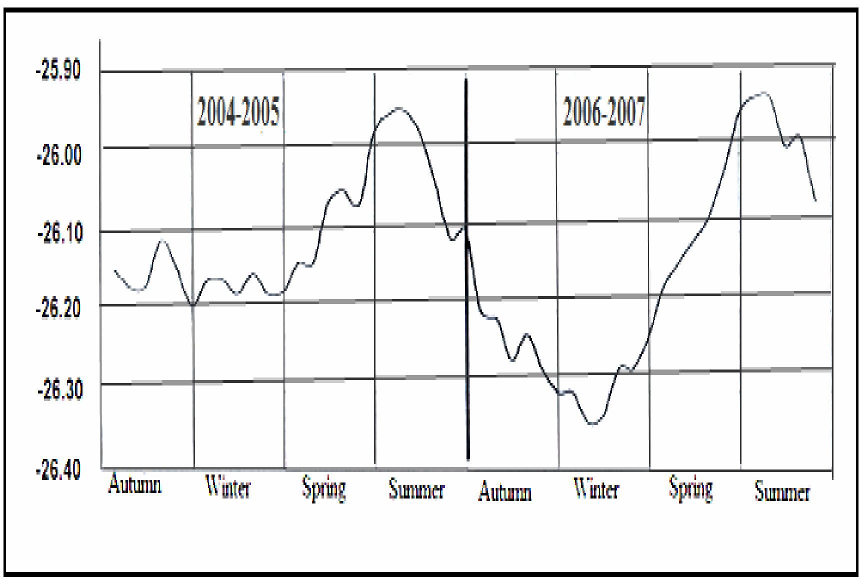

Fig 2. Caspian Sea water fluctuation in Anzali station in 2004-05 and 2006-07

Photogrammetric maps of the study area (scaled 1:5000) from aerial photos taken in1991, confirm the above mentioned fluctuations (Mazandaran Regional Water Company, 2007). The fluctuations of the Caspian Sea water level affect the rivers and drains of the coast basin, among which is the Chapakroud drain. The Alborz dam and its irrigation and drainage network discharge a large amount of water in the Chapakroud drain, largely exceeding the drainage water flowing in present conditions.

The existing drainage problems for paddy fields forced the farmers to excavate large storage for water (Ab-bandan)in order to collect and save the runoffs from seasonal rainfalls and surplus water diverted from the drains. The integrated hydraulic system that resulted is complicated since it is affected by the variations of the sea level.

Moreover, this region is subject to flash flooding and urban areas in the region are at risk of frequent flooding, as it was the case in the previous years when several devastating floods occurred.

Recent progress in making use of digital elevation models (DEM) in the form of triangular irregular networks (TIN) has allowed engineers to create geometric representations readily usable in hydraulic modeling, in a far more cost-effective manner (Noman et. al. ,2003). Through combination of the GIS extension, HEC-GeoRAS and HEC-RAS, engineers can now make use of an available DEM to build the geometric file needed for an HEC-RAS model. Additionally, the GeoRAS extension has simple import and export capabilities for a smooth transition of the processes, including creation of a geometric file, operation of the model and display of the results. The final result of the process is not only quicker with a more accurate floodplain delineation than traditional methods, but it also generates a grid of flood depth indicating to the user the level of inundation of any area simulated in the model.

Malkin (2009) studied climate changes and sea level rising in New Castle County, Delaware. In his study, the spatial representation as well as the analytic capabilities of a computer based geographical information systems (GIS) are used to develop a comprehensive visual illustration of the impacts of flooding on the railway, and assess the risk of being either flooded, or perhaps destroyed. This study intends to establish some design criteria for setting the elevations of rail beds or relocations to less flood prone locations. The objective was to prevent potential damage to the national infrastructure along the east coast, more specifically, the Port of Wilmington, which is the most likely to be affected by flooding.

Washington University and King County (2007) have examined the Olympia region with GIS Environment, HEC-RAS, HEGeoRAS and ArcView software to predict the extent of flooding. They concluded that a GIS map was more appropriate to predict floods rather than traditional methods. Their significant findings include inundation levels and changes in high tides.

Yang, (2006), studied flood plain zones of the South Nation river system, located east of Ottawa, in Ontario, Canada. In this regard, 2Dand 3Dmaps were prepared for the region by integrating hydraulic model and Geographic Information Systems (GIS). The study followed two objectives. The first was to construct and validate the use of the Hydrologic Engineering Center's River Analysis System (HEC-RAS). To do so, the system made use of existing HEC-2 model-generated data for river network model. Secondly, HEC-RAS simulations were used to generate water surface profiles throughout the system for six differently designed storm events. The in-channel spatial data of HEC-RAS were then geo-referenced and mapped in the GIS domain, and integrated with digital elevation model (DEM) of over-bank data to build a triangular irregular network (TIN) terrain model. In the final step, floodplain zones for the six designed storms were reproduced in three dimensions by overlaying the integrated terrain model for the region with the corresponding water surface TIN.

Chuan and Jing (2006) explored the methodology for assessing the torrent hazard and risk zone mapping by means of GIS technique for the Red river basin in the Yunnan province of China. The Red River basin is prone to frequent flooding. Based on a 1:250,000 scaled digital map, they analyzed six factors including the slope angle, rainstorm days, buffer zone of river channels, maximum runoff discharge of the river, debris flow distribution density and flood disaster history. The results of risk evaluation in the upper Red river basin showed that the extremely high risk area covered 17.9% of the total inundated area; the high risk area covered 45.9%, the moderate risk covered 25. 3%; whereas the low risk area covered only 11.0% of the total inundated area.

Walker and Maidment (2006),demonstrated that in addition to natural disasters, flooding is also a hazard with serious socioeconomic consequences for all activities and infrastructures within an affected floodplain. They concluded that an accurate delineation of flood extents and depths of flooding water within the floodplain is essential for flood managers in order to make sound decisions regarding construction, insurance, and other regulated practices on land and property that could potentially be affected by flooding.

Suareza, et. al. (2005),set the basis for linkage of GIS with hydrologic modeling;

they studied inundation levels with climate change scenarios by using HEC-RAS and HEC-GeoRAS software. This approach may prove to be useful for assessing water resources, especially in developing countries.

Earles et. al. (2004), demonstrated the value of the HEC-GeoRAS model for floodplain delineation and determination of key hydraulic parameters.

Marfai, (2003), simulated part of Semarang Central Java, Indonesia. They integrated Hydrological software in GIS Environment using digital elevation model (DEM), hydrological and geometrical data. In their study, they established river flood and tidal flood models, and they also conducted a model evaluation and risk assessment. In this study the risk of inundation was acknowledged.

Kresch, et.al. (2002) in Olanchito, Honduras made use of hydrological method, HEC-RAS and HEC-GeoRAS software for their study. The basic data used for their study was: DEM, stream discharge, geometric data and Manning's roughness coefficient. Fifty-year flood inundation maps were generated through this study.

Mastin, et.al. (2002), Santa Rose de Aguane, Honduras used analytical method with HEC-RAS and HEC-GeoRAS software. They could generate fifty–year storm and tide flood–inundation maps. For this, the researchers made use of DEM, stream discharge, geometric data, Manning's roughness coefficient and storm surge data. The inundation maps that were obtained show that the study region is at risk of flooding caused by storm-surge events.

Mastin, (2002), studied the Turialba, Costa Rica region. To make a simulation, they identified elements at risk of damage by geomorphologic mapping, and they made a risk assessment using hypothetic cost value in the model. In this study,an80 cm increase of the sea-level in the next 100 years was assumed; Mastin (2002), then recalculated the return periods of given water levels using a water modeler with annual peak discharge, precipitation, and topographic data. The results were translated into a flood hazard map and the hydraulic model showed that the study area was sensitive to flooding.

The objective of the current study is to simulate the last 6 km of the Chapakroud drain for different scenarios. By means of simulation using HEC-RAS and GIS tools for different return periods, the fluctuations of the sea water level and their effect on the existing Chapakroud drain flow conditions are studied.

MATERIALS AND METHODS

Study Area

In this study, the last 6 km of an existing drain, which is located in the north of the Caspian Sea region, was studied. This drain is located inthe Mazandaran province near Babol city in the north of Iran. Figure 3 shows the coastal regions and its surrounding area.

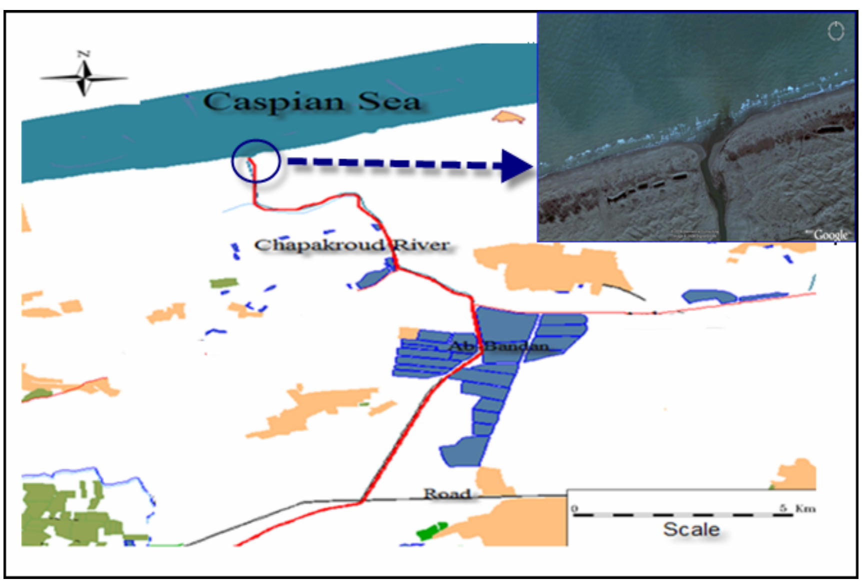

Fig 3. Location of the Chapakroud outlet to Caspian Sea and its surrounding conditions

Hydraulic simulation

In this study, steady flow analysis is carried out, and water surface profiles for steady and gradually-varied flow are generated. Additionally, the steady flow conditions allow the modeling of subsurface profiles in subcritical, supercritical and mixed flow regimes. The basic computational procedure in HEC-RAS model is based on solving a one-dimensional energy equation (Figure 4). Energy losses due to friction are evaluated by Manning's equation, and contraction/expansion is computed by means of a coefficient that multiplies the change in velocity head. The momentum equation is then utilized in situations that the water surface profile changes abruptly. These situations include mixed flow regime calculations (hydraulic jumps), hydraulics of bridges and evaluation of profiles at river confluences (stream junctions). The steady flow system is generally assumed for simulation in flood plain management.

The water surface profiles are computed from one cross section to the next by solving the energy equation with an interactive process called the standard step method. The energy equation is written as follows:

$$y_2 + z_2 + \frac{a_2 v^2{}_2}{2g} = y_1 + z_1 + \frac{a_1 v^2{}_1}{2g} + h_e$$

Where:

y_1, y_2 = Depth of water at cross sections

z_1, z_2 = Elevation of the main channel inverts

v_1, v2 =Average velocities (total discharge/total flow)

a_1,a_2 = Velocity-weighting coefficients

g = Gravitational acceleration

h_e = Energy head loss

Based on these parameters, the water surface elevation is the sum of y and z.

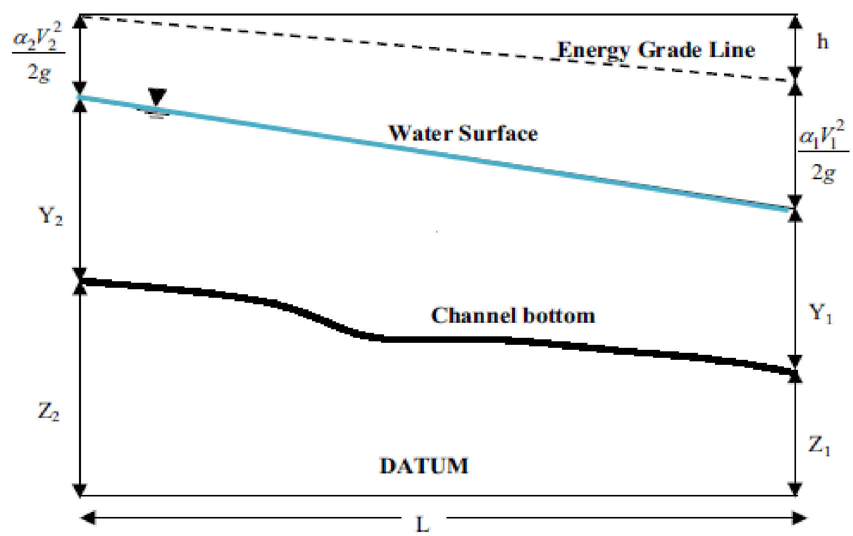

Fig 4. Energy equation parameters for gradually varied flow

For the hydraulic analysis with HEC-RAS, topographic conditions of the drain network were represented by a number of cross sections. By integrating GIS with HEC-RAS, these cross sections were extracted from a digital terrain model (DTM). Moreover, the area of inundation could be mapped with HEC-GeoRAS from HEC-RAS computation results. The type of terrain model used for cross section extraction was triangulated irregular network (TIN). The digital contour map of the study area was the source of elevation data from which the DEM was determined (U.S. Army Corps of Engineers, 2000). For simulation, we used ArcView GIS and its extension, HEC-GeoRAS, and the drain system schematic was designed. Cross sections were then prepared. The cross sections and the required hydraulic data were input using HEC-RAS software. Then, the GIS Integrated flood inundation modeling of the study site was conducted.

The conceptual and detailed technical approach for generating the drain flood model is described as a flow chart in Figure5:

Fig 5. Conceptual flowchart for generating drain flood model.

A number of GIS tools were applied to make an accurate risk assessment of the Chapakroud drain inundation. Advanced flood modeling was based on 3D terrain models as it can cover all existing terrain elements including human objects on the ground, like various types of buildings and other infrastructures. As mentioned, after pre-processing the GIS environment's spatial data, the next step is to model the land in HEC-RAS.
For each cross section, the following geometric parameters were required to describe the shape, elevation, and relative location along the stream:
*Drain station (cross section) number;
*Lateral and elevation coordinates for each (dry and unfolded) terrain point;
*Left and right banks station locations for the main conveyance channel to specify the bank elevations in floodplain areas;
* Reach lengths between the left floodway, main channel, and right floodway of adjacent drain stations;
*Manning's roughness coefficient; these lection of a representative roughness coefficient is very significant for an accurate computation of water surface profiles. There are several references that guide us in the selection of the Manning's roughness coefficient for a typical channel. In this study, a Manning's roughness coefficient of 0.035 was selected for the design of the Chapakroud drain by Mahab Ghodss Consulting Engineers. (Mahab Ghodss Consulting Engineer (MGCE), 2007)
*Contraction and expansion coefficients
*Geometric description of hydraulic structures (bridges, culverts, weirs, etc.)
At each cross-section, HEC-RAS assumes that the energy is constant and that the velocity vector is perpendicular to the cross section. Care should therefore be taken to ensure that the flow through each selected cross section meets these criteria. An average distance of 80 m between sections has been considered, and 101cross sections have been extracted. The stream centerline and left and right channel banks, flow path and cross section cut line themes are prepared using the preRAS that is shown in Figure 6.

Fig6. Flow path, bank and cross section cut line themes prepared using the preRAS option

After defining the stream geometry, flow values for each reach within the drain system are entered. Geometric description of the channel as well as flow rate values are the primary model inputs for hydraulic computations. According to MGCE design, the maximum flow of the Chapakroud drain is 19.6 m^3/s. Boundary conditions in this study are considered to be within normal range with a slope of 0.0003 m/m. A hydraulic model has been carried out for 2, 5, 10, 25, 50-year flood discharges (return periods) with an overall fluctuation change in sea level from -23 to -28 (MGCE, 2007). For steady and gradually varied flow, the primary procedure for computing water surface profiles between cross sections is the standard step method. The basic computational procedure is based on the iterative solution of the energy equation (Hatipoglu et. al., 2007). Then the GIS integrated flood inundation modeling of the study site is performed in post RAS menu; the model output includes: water surface TIN, flood zone with a different return period, velocity grid, flow specifications in each section and water profiles along the drain, as well as significant specifications such as water surface variations and water maximum depth. Froude number and shear stress were considered as the main hydraulic factors for analyzing drain and reach length for this analysis.

Results and Discussion

When the model was applied with a design flow of 19m^3/s for the Chapakroud drain and for the given sea boundary conditions (with elevations of -23m, -24m, -25m, -26m, -27m, -28m), the extent of flood plain and network depth were then obtained. According to Table 1, the maximum depth, maximum velocity, and the area along the drain that would be influenced by sea water level changes were derived from the model outputs.

Table 1. Max depth, Max Velocity and the rate of being influence for various elevations

Sea Water Surface Elevations (m)	Flood area (ha)	Sea water effect distance in drain (m)	Max water Depth (m)	Max Velocity (m/s)
-23	44.21	3465	3.95	1.1
-24	25.98	2390	2.94	1.1
-25	19.43	1794	2.56	1.1
-26	4.93	446	2.56	2.1
-27	0.98	105	2.56	2.1
-28	0.1	97	2.56	2.1

As the table shows, when the sea level is -23m, the maximum depth of water would be 3.95m and influenced by its outlet. The flooded area for this elevation is 44.21 ha; it appears that at this sea water level there would definitely be flooding for the lands along the Chapakroud drain. Figure 7 shows the flooded areas at different sea water elevations. Obviously, most of the area would be flooded when the sea water level is -23m. In this condition, salt intrusion to the ground water is dangerous because most of the area used is agricultural land, and mixture of salt and soft water have a severe impact on these lands.

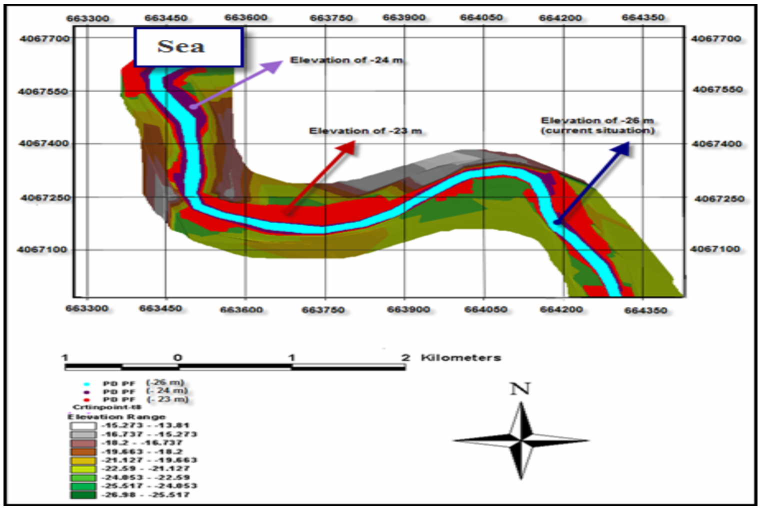

Fig 7. TIN of the area and Floodplain for -23, -24 & -26 meters elevations

For visual appreciation, the floodplain can also be mapped. Inundation occurs wherever the elevation of the water exceeds the land surface.

Some of the most important hydraulic parameters such as Froude number, flow shear stress, flow velocity and stream power are studied through flow hydraulic data. The Froude number variations along the drain are variable and subcritical. The flow velocity has been studied for various return periods; it's been observed that because of the variations of the bed slope curve, the velocity and variation ranges were higher in the upper reach of the drain. These variations are high at 5.3 km and 5.9 km reaches as the maximum velocity was 0.84 m/s at that point; therefore, some solutions are recommended such as widening the drain to slow down the flow velocity. On the last parts of the drain (where the drain joins the Caspian Sea), the lowest velocity is observed. This area would be influenced by water elevation and fluctuations of sea water level. This can lead to adverse effects such as salinity of the ground water and surrounding lands. Some works such as dikes are recommended to control water logging and prevent salty water intrusion to ground water sources. Throughthe computations and simulation conducted in the elevations model, the stream power (the total flow capacity in the main stream) along the drain can alsobe obtained, and as shown in Figures8 and 9, the range of variations of this parameter were 0.01-6.11 N/s. The variation of the parameter is high in the upper reach; in some parts it increasesup to 7.14 N/s because of significant changes in the topography of the bed.

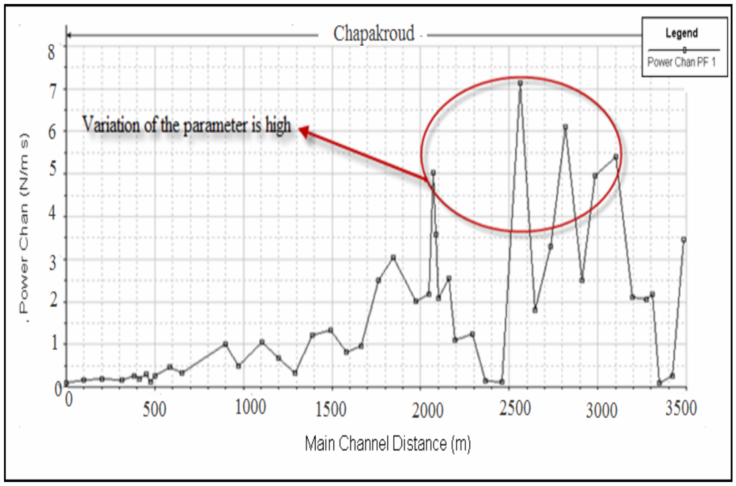

Fig 8. Stream power changes from 0 – 35000 meters distance

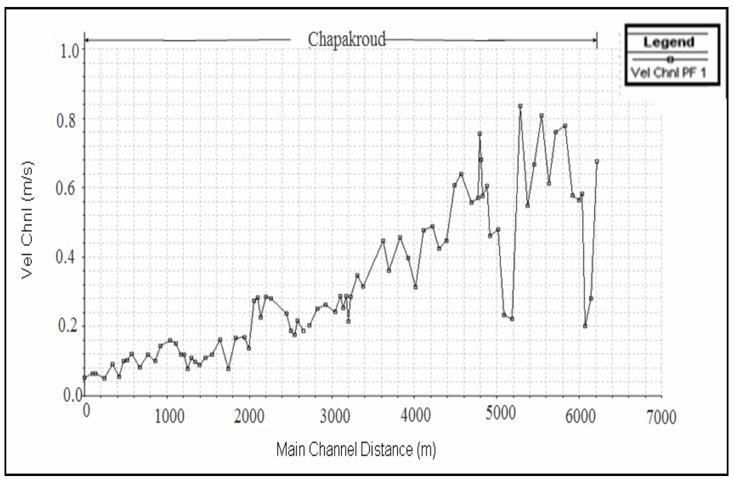

Fig 9. Velocity changes in upper and lower reach

One of the most important results of the HEC-RAS simulation is the production of different water surface profiles for different T-year floods. After carrying out hydraulic computations by HEC-RAS, water surface profile diagrams are obtained. This is shown in Figures 10 and 11. Figure 11 shows that reach water depth (1.9 m) in tributary is more than any other reach.

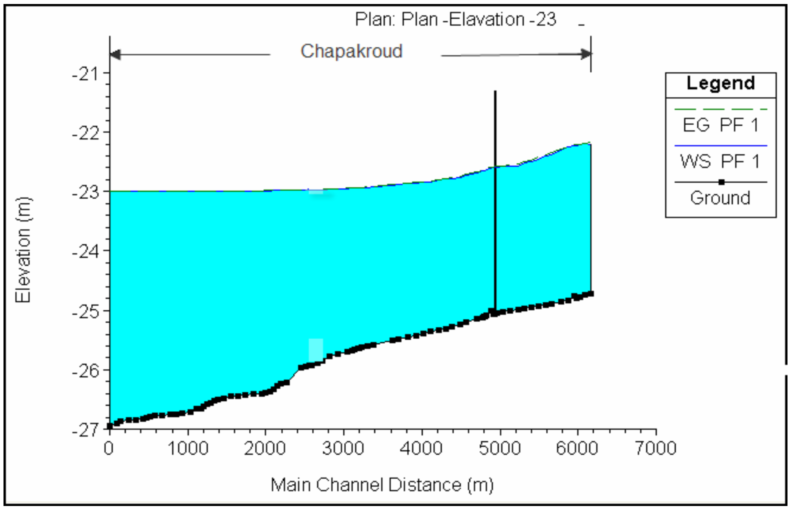

Fig 10. Water surface profile diagram in the lower reach

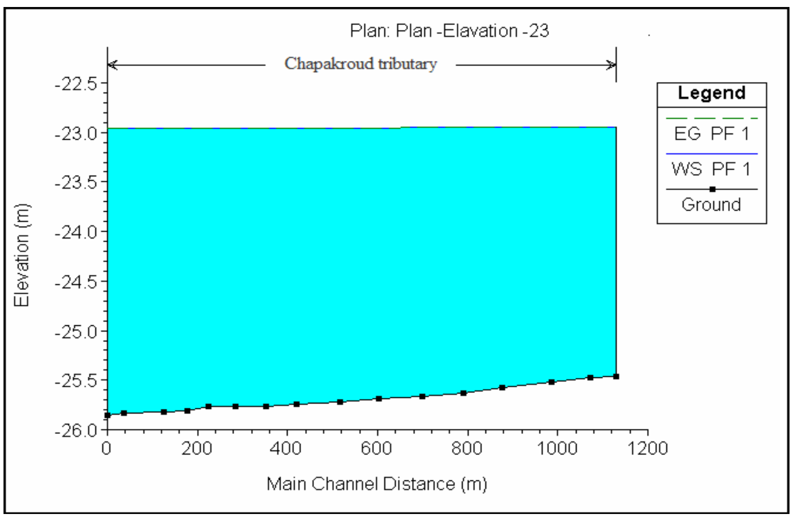

Fig 11. Water surface profile diagram in the tributary reach

The results of this study show that the area is sensitive to sea water surface fluctuations. These changes in the sea level will cause problems to the flow in the Chapakroud drain. Considering the fact that the lands adjacent to this drain are being used by locals, it appears from the simulations that a large area of these lands will be impacted by floods with a two-year (or more) return period or high seawater level. It is suggested that some protective structures to prevent water from flooding the lands be provided. The presence of three Ab-bandans and an aviculture house in the vicinity of the drain is a matter of particular concern. If the salty water floods the areas it will have an ecological impact. This poses a threat to the ecosystem and ground water quality. Suitable solutions (e.g. building proper structures) should be examined to stop salty water intrusion to the region.

Conclusions

In this study, a 3D GIS system with high resolution TIN allows coastal communities to simulate the impact of any possible flood events and to estimate the flooded area in the vicinity of the Chapakroud drain. The storm flood tool allows generation of inundation maps at detailed intervals ensuring connection between the low-lying areas and the sea. The risk of inundation can then be assessed by using the HEC-RAS if a time series of water level records is available. Ideally, the water level time series must be for the same location as the area under study. The minute and precise flooding map of the study area could be used as an efficient tool to foresee potential hazards for coastal areas, and to determine best types of infrastructure that can sustain the impact of seawater level rises. A relative sea level change is expected in this region, and based on our results; risks of flooding are high for these local coastal communities.

Finally it should also be noted that the mixture of salt with soft water has not been investigated in this study. This issue is one of the other important potential impacts of the rise of sea water surface level. It is recommended to study this issue in the future.

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بررسی اثر نوسانات سطح آب دریای خزر بر زهکش‌های موجود

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چکیده

هدف از این مطالعه، پیش‌بینی اثر بالاآمدن آب دریای خزر با استفاده از سیستم اطلاعات جغرافیایی (GIS) و مدل هیدرولیکی، بمنظور توسعه یک متدودولوژی جامع است. بالا آمدن آب دریا یکی از اصلی ترین وقایع سیلاب می‌باشد و محافظت‌های جدی در محدوده‌های توسعه یافته شهرها را می‌طلبد. در این بررسی، قابلیت شبیه‌سازی واقعه سیلاب در کانال- زهکش چپکرود که در نزدیکی مناطق توسعه یافته مسکونی قرار دارد، مورد بررسی قرار گرفته است. نتایج نشان داد که در حدود ۲ کیلومتر از سواحل زهکش تحت تاثیر تغییرات سطح آب دریا خواهد بود. برای رقوم ۲۳- و ۲۴- متر، حداکثر عمق آب در زهکش بترتیب ۳/۹۵ و ۲/۹۴ متر است و طول مسیر برگشت آب از دریا ۳۴۶۵ و ۲۳۹۰ متر و به‌دنبال آن سطح زیر سیلاب به ترتیب ۳۵/۹۷ و ۱۲/۸۸ هکتار خواهد بود. مطالعات نشان داد که این رقوم‌ها برای زهکش، مشکلات زیست محیطی و اجتماعی به بوجود خواهند آورد. همچنین نتایج این تحقیق نشان داد که GIS یک ابزار موثر و کارا برای آنالیز و تجسم پهنه سیلاب است. لازم به ذکر است که تداخل آب شور و شیرین، یکی دیگر از مشکلات بالا آمدن آب دریا است و در این بررسی به آن پرداخته نشده است و پیشنهاد می‌شود در آینده مورد بررسی قرار گیرد.