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Original Article

Management of Harvesting the Surface Water of City of Bandar Abbas and using it for Green Space with SWMM Software

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ABSTRACT

Water resources management in the arid regions is of particular importance. This issue is considered of great importance especially in urban areas with respect to urban development in the recent years. On this basis and for management of water resources of the city of Bandar Abbas, district no. 1 of the urban area was selected with an area of approximately 2,760 acres which is fed by four upstream watersheds. Then the area was divided into 57 hydrological units by GISARC software. Forty eight main irrigation channels were identified in these areas and their specifications were recorded. Also the area, the latitude and longitude, Manning's roughness coefficient and the percentage of permeability and impermeability were determined for each hydrological unit and the obtained results were entered into the SWMM model. The two-year return-period precipitations derived from Bandar Abbas synoptic station were also entered to the model to take advantage of the urban runoff. With the implementation of the model, the total urban runoff volume of district no. 1 of Bandar Abbas was determined 297,241 cubic meters which discharges to the Persian Gulf through four outputs. Also thirty five critical water supplying channels were identified by investigating the transport capacity of the water supplying channels. Therefore, considering the average water requirement and the location of the urban green spaces, it is possible to supply the required water for more than 70 acres of urban green space from urban runoff. Thus in case of reforming the urban drainage network, the urban green space in Bandar Abbas can be developed by using the urban runoff.
Keywords: Bandar Abbas, Urban Runoff, Green Space, SWMM Software

INTRODUCTION

Iran is known as a low rainfall country which is grappling with drought for many years. Also the Hormozgan province is confronted with the problem of shortage of water resources available for drinking, agriculture, etc. for nearly 14 years. Lack of production of horticultural and summer crops can be seen in the agricultural sector and in the urban sector the administrators of the drinking water supply are faced with difficulties due to the consecutive droughts, considering that currently the only source of water supply for the city of Bandar Abbas is the transfer of water from 100 km of the city. Although the lack of clear and long-term administrative policies in recent years for the use of the Persian Gulf sustainable water resource and sweetening it for use as drinking water is no secret to anyone, the supply of drinking water from the Minab dam for domestic use is justifiable, but the lack of water resources available for irrigation of trees and maintenance of urban green spaces has caused the current irrigation of amounting to 60 percent of urban green space from the drinking water sources. Natural beds are normally able to absorb and transfer a significant amount of runoff, but in areas with low soil permeability or in semi-saturated conditions the soil cannot absorb water, thereby increasing the runoff in the region which will lead to flooding with the continuation of precipitation. Expansion of artificial constructions and increasing destruction of natural beds has led to decreased soil permeability in the urban and residential areas which plays a significant role in flooding. Accordingly, this study aims to investigate the issue of urban floods by the use of the latest scientific and software findings considering the above-mentioned requirements, and provide appropriate strategies for the management of surface water in Bandar Abbas city. Among the main objectives of this research the following cases can be noted:

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Optimized application of surface waters in the urban green spaces of the studied region, identification of the weaknesses of urban drainage systems in the studied region, identification of the challenges related to the management of surface runoff and rectifying the current problems and acquiring new practical solutions for better management of surface water. In the past decade the number of models has significantly increased with the spread of personal computers. For example, about 75 computer programs developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers (HEC) are available which nearly a third of them are usable in personal computers, and this trend is growing. These programs are provided in hydrology, groundwater, reservoirs, water quality, economic analysis and management of data processing fields. Recently, the U.S. Committee for Civil Engineers has compared competencies of 28 models applicable in the urban areas.

Generally, some of the existing models are directly applicable for designing an urban flood collection network and simultaneously perform meteorological-hydrological studies, hydraulics, dimension determination and economic evaluation (including ILUDRAIN, ILLUDAS and WALLRUS). Some others can be used only in a part of the study, and subsequently the study and designation can be performed based on their results. For example, HEC models can be considered a part of this category (e.g. HEC-1, known as the flood hydrograph model, and HEC-2, which is used for computations of the water surface profile in rivers and plain floods). In this study, management of the surface water was performed by the SWMM model (Storm Water Management Model).

Dietz and Clausen [1] suggested application of low-impact development approach as an alternative to the traditional designs of runoff management. For example, methods such as biological conservation and the use of permeable surfaces and grasslands have been very effective in keeping large amounts of runoff and their pollutions and reducing the concentration of pollutants such as metals. Also green roofs are estimated to hold 36 percent of the runoff volume in them. The use of porous surfaces is also heavily effective in the runoff filtering.

Elliott and Trowsdale [2] have examined 10 models of available floods related to the low Impact development modeling (Low Impact Development or LID). The existing models are all based on the common methods of production of runoff and routing them, but in half of these models the component of base flow and in a number of them the penetration component in low impact development techniques are also considered. Some of the models are also based on the production and control of pollution, particularly in runoffs from areas in which construction operations are in progress. Actually advanced models are the ones that include more types of such models as the model components, and somehow some of the recently introduced models cover a wide range of different methods of LID or its related operations. Ghafouri [3] indicated in his research with the help of combined hydrological-hydraulic models for urban runoff that for every percent of increase in impermeable areas of the range, two to four percent is added to the peak flood discharge before the development.

Sanei and Ahmadi Jazi [4] investigated the volume or discharge of the flood on three major floodways of city of Mashhad by using two methods of reasoning or logical and advanced SWMM method. The obtained results indicated that in general the flood discharge values obtained from the logical approach is much more than the SWMM method, and this difference is due to the structure of the two methods.

Sufi [5] also divided the desired strategies into two groups, while investigating the problems in city of Shiraz after the effective rains and occurrence of floods and urban runoff. The first group is the non-structural strategies for developing areas such as the under construction settlements which include increasing rangeland vegetation cover and planting trees around the settlements, the use of water seeding and covering the ground by materials without adversely affecting the environment, establishment of dams or flood storage lakes upstream of the city, etc. And the second group includes structural measures in developed and old parts of the city which are costly methods. Accordingly in the present study management of surface water harvesting in city of Bandar Abbas and using it for green space has been studied with SWMM software (case study: district no. 1 of city of Bandar Abbas).

MATERIALS AND METHODS

The studied area

Bandar Abbas city is located in geographical coordinates of 25°24'N to 28°57'N and 53°41'E to 59°15'E. It is influenced by desert and semi-desert climate and has warm summers and short mild winters. Due to being located in the southern dry belt of the country its average annual rainfall (147.5) is even lower than the average annual rainfall of the country. Precipitations mostly occur as rainstorms and floodwaters during winter months. Study of the physical properties and morphological situation of a range as the range physiography has a determining effect on its hydrological characteristics and water regime. So that knowledge of these characteristics alongside the information about climatic conditions of the region provides a fairly accurate picture of the quantitative and qualitative performance of the hydrological system of the region. The physiographical data consists of topography, surface area, shape and gradient of the region, geology, soil type, the pattern of density of natural waterways and artificial flood paths, vegetation cover, land use and physical and hydrodynamic properties of the soil.

Damahi estuary (Khor-Damahi): Damahi estuary is located in the eastern part of city of Bandar Abbas and has suburban origins, in addition to the disposal of surface waters around itself. Unfortunately, due to the manipulation within this estuary and changes in its cross sections with construction of non-technical bridges, there is water logging in some parts of the estuary and causes environmental problems such as forming habitat for insects and accumulation of waste materials. Length of the estuary within the city limits of Bandar Abbas is about 6087 meters.

Shilat estuary (Khor-Shilat): Shilat estuary also has suburban origins and discharges the flood of upstream watershed to the Persian Gulf along with the urban surface waters near itself. The approximate length of this estuary is about 5058 meters within the city limits of Bandar Abbas and is located in the eastern region of the city. A part of this estuary still has remained in its initial state, without any reorganization plan being performed on it.

Tolou estuary (Khor-Tolou): Tolou estuary is located in the eastern part of the city and in the vicinity of Tolou neighborhood. Unfortunately, this estuary has practically lost its existence as a surface water discharger for the surrounding areas and acts like storage reservoirs due to the constructions in its surrounding areas and also its intersection with several streets and finally the intersection with Agriculture Organization which has highly exposed its adjacent areas and communication routes to flood.

Method

Introduction of EPA SWMM model (Environmental Protection Agency Storm Water Management Model)

As mentioned in the first chapter, SWMM model is a dynamic model for rainfall and runoff and can be used in short or long term simulations and for determination of the quantity and quality of runoff. This advanced model is provided by the U.S. Environmental Protection Agency during 1969-1971 for qualitative and quantitative simulation of phenomena associated with mixed and complex floodways and has been rewritten and updated several times so far. SWMM is a dynamic simulation model for rainfall-runoff (single incident or continuous) with the capability of calculating phenomena such as evaporation, snowmelt, plant setting, deep infiltration and subsurface flows. In this model, estimation of the flood is performed by kinematic wave method and combination of the elements of above ground and channelized flows.

It is a Windows software and contains a comprehensive environment for editing inserted data associated with the study area, hydrological implementation and hydraulic and water quality simulation, and viewing results of different data formats in different ways including maps, time series graphs, tables, reports and statistical analysis which eventually makes it possible to resolve the problems in the cities by identifying the bottlenecks.

In this model, each watershed is divided into smaller watersheds and level of each sub-watershed act as a nonlinear reservoir and the input stream comes from watershed rainfalls and runoffs below the upstream watersheds, so that the surface runoff per unit area occurs when the depth of water in the reservoir exceeds the maximum of pothole reserve.

Entering the sub-watershed specifications into the SWMM model:

After determination and drawing of hydrological units, the specifications of the sub-watersheds which include the items in Table 1 are defined in SWMM model for each one of them.

Table 1. Details of specifications of sub-watersheds for entry into the SWMM model

Specifications of sub-watersheds	
Longitude coordinates	Output point of the sub-watershed
Latitude coordinates	Percentage of impermeable surface
Area	Manning's equation on impermeable surfaces N
Width	Manning's equation on permeable surfaces N
Gradient	Pothole reserve on impermeable surfaces
Permeability model	Pothole reserve on permeable surfaces

Entering the joint specifications:

At this stage, considering the drainage network map, specifications of the joints (the flow intersections) were defined in SWMM model. It is worth mentioning that in the model related to the study area, the maximum depth of the intersection was assumed one meter and the initial depth of water and the water logging level were not considered. Entering the specifications of the flow navigation channels. The specifications of the flow navigation channels were entered into the SWMM model according to Table 2.

Table 2. The required specifications of flow navigation channels in SWMM simulator

Joint Specifications	
The maximum depth in the desired joint	Joint height
Water logging level in the desired joint	Flow measurements unit
Waterway length	Trend detection method
Waterway geometry	Waterway roughness

It should be noted that the kinematic wave method was used in this study for flow trend detection within the channels. Also an open rectangular with a depth of one meter and a width of 40 cm was selected for the geometric shape of the channel which represents the hydraulic shape and conditions of urban streams. Channel roughness coefficient was also considered 0.015 in terms of the concrete channel based on the software guide.

Entering the specifications of pluviometric station:

Since the urban watersheds are often small and vary from a few acres to several hundred acres in size, therefore it is assumed that the rainfall on a watershed of this size is expressed through a point precipitation. Therefore, Bandar Abbas synoptic station precipitation data were used. This station is located in 437283 longitude and 3010591 latitude.

RESULTS

After entering the required information of SWMM software and eliminating the computer obstacles in its implementation, we attempted to run the software. Since the SWMM software presents its output in figures, tables, maps etc. thus we present the results of implementation of the model which are shown in Figures 1 and 2.

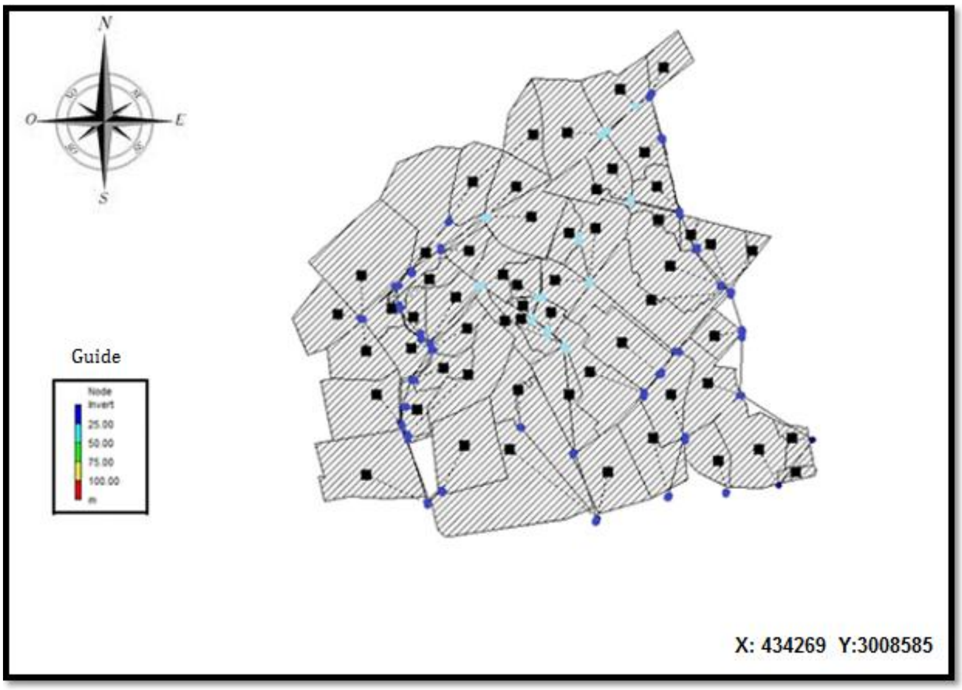

Figure 1. The amount of water overflow in the joints obtained from SWMM software

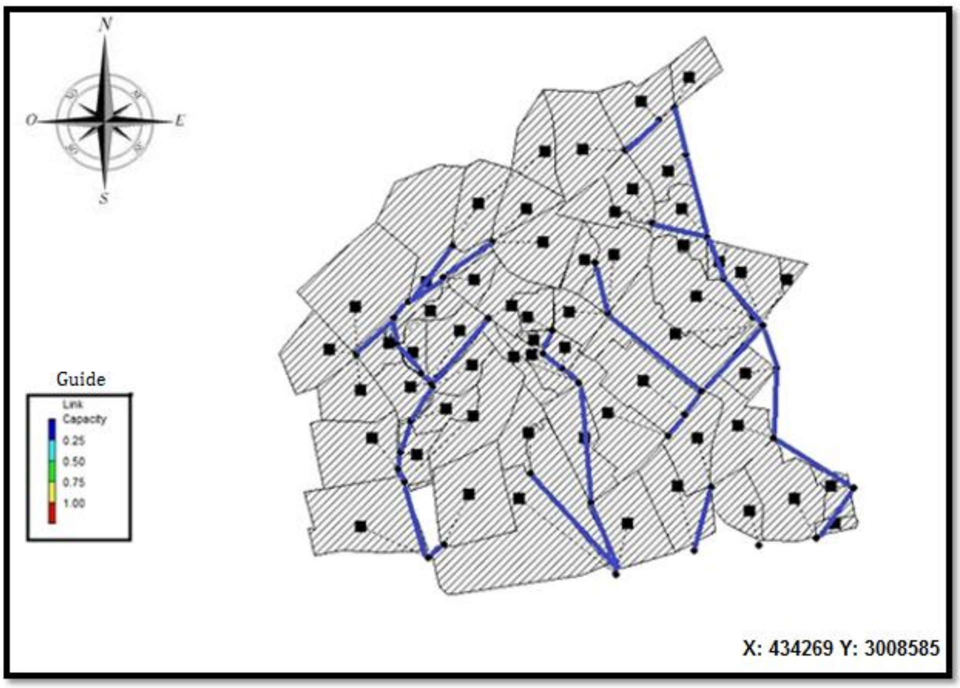

Figure 2. Discharge capacity of the channels obtained from SWMM software

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Output discharge of the hydrological units with a two year return period: Eventually the output discharge of the runoff generated from each hydrological unit in a two year return period was obtained after entering all the information required by SWMM model. The results of the model are presented in Table 3.

Table 3. Output discharge of the hydrological units with a two year return period

Hydrology Unit	Runoff Output	Pick of Runoff	Runoff Coefficient	Influence (Mm)
B1	2532	0/255	0/839	3.324
B10	3437	0.318	0.981	0.826
B11	2371	0.246	0.647	6.972
B12	2809	0.280	0.713	5.990
B13	1631	0.181	0.430	11.247
B14	2677	0.206	0.633	7.505
B15	4408	0.430	0.896	2.324
B16	5156	0.485	0.937	1.660
B17	2777	0.289	0.396	11.734
B18	1738	0.178	0.287	13.782
B19	5926	0.560	0.894	2.525
B2	258	0.034	0.228	15.058
B20	4465	0.430	0.640	7.196
B21	7457	0.576	0.853	3.826
B22	5875	0.542	0.842	3.516
B23	3783	0.214	0.893	2.490
B24	2051	0.211	0.694	6.068
B25	5558	0.522	0.850	3.412
B26	954	0.093	0.921	1.648
B27	6964	0.600	0.945	1.687
B28	2517	0.264	0.701	5.983
B29	7270	0.621	0.899	2.568
B30	7264	0.654	0.898	2.549
B31	7782	0.643	0.945	1.697
B32	3080	0.296	0.930	1.655
B33	1133	0.128	0.616	7.603
B34	740	0.096	0.276	14.086
B35	300	0.040	0.343	12.931
B36	8671	0.691	0.898	2.576
B37	7889	0.743	0.850	3.409
B38	1070	0.133	0.296	14.199
B39	467	0.070	0.245	14.770
B40	9572	0.806	0.945	1.693
B41	9786	0.765	0.945	1.698
B42	9752	0.838	0.942	1.731
B43	2793	0.231	0.806	4.310
B44	8369	0.758	0.851	3.436
B45	3876	0.379	0.882	2.539
B47	2981	0.283	0.265	14.184
B48	7516	0.629	0.597	8.153
B49	13274	1.006	0.944	1.700
B5	980	0.097	0.878	2.535
B50	10976	0.895	0.840	3.620
B51	5982	0.554	0.739	5.408
B52	628	0.110	0.209	15.512
B53	3318	0.340	0.795	4.180
B54	13207	0.959	0.896	2.581
B55	10178	0.774	0.944	1.699
B56	4361	0.399	0.891	2.611
B57	14444	1.136	0.841	3.617
B58	5981	0.637	0.354	12.587
B59	2333	0.236	0.838	3.316
B6	1861	0.191	0.792	4.208
B60	27481	1.405	0.926	1.818
B7	2165	0.215	0.879	2.479
B8	1899	0.182	0.404	11.739
B9	2516	0.240	0.933	1657

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The results obtained from the runoff output discharge of the hydrological units indicate that the hydrological unit B60 with an area of 154 acres produces the largest volume of runoff which is equivalent to 42,624 cubic meters. Also the hydrological unit B35 with an area of 4.55 acres produces the lowest volume of runoff which is equivalent to 468 cubic meters. Figure 4 shows the peak flood discharge diagram in the hydrological unit 40 obtained from the SWMM software.

In order to evaluate the transfer capacity of conduits MAP output of SWMM software was used. The results are shown in Figure 5.

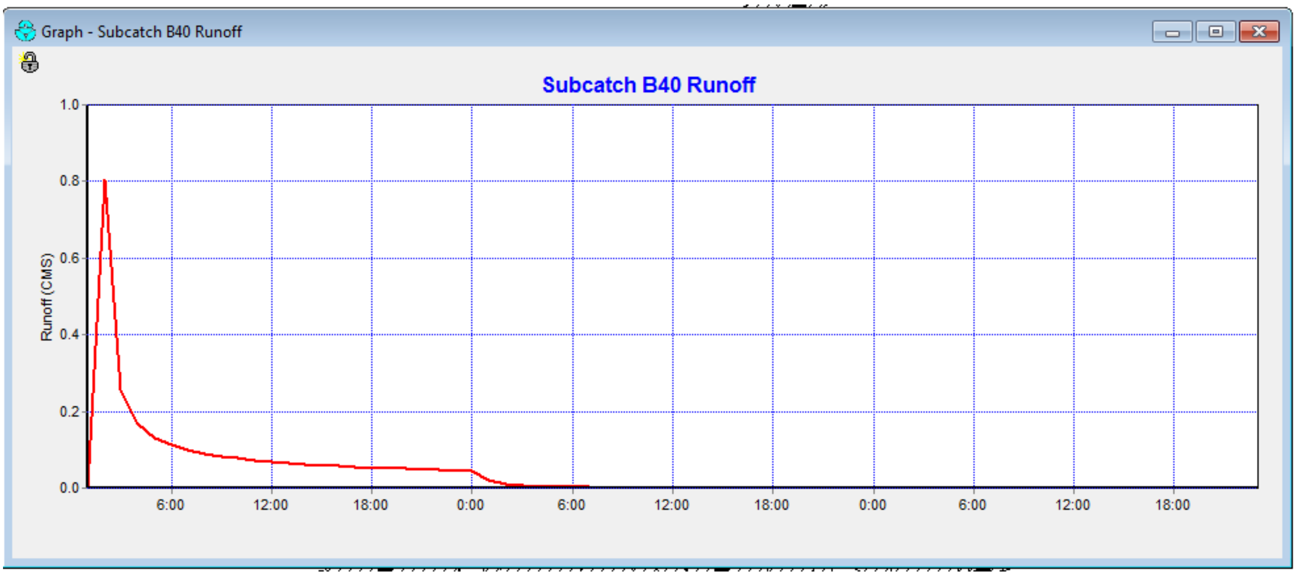

Figure 4. The peak flood discharge diagram in the hydrological unit 40 obtained from the SWMM software 4-1 - Evaluation of the transfer capacity of conduits

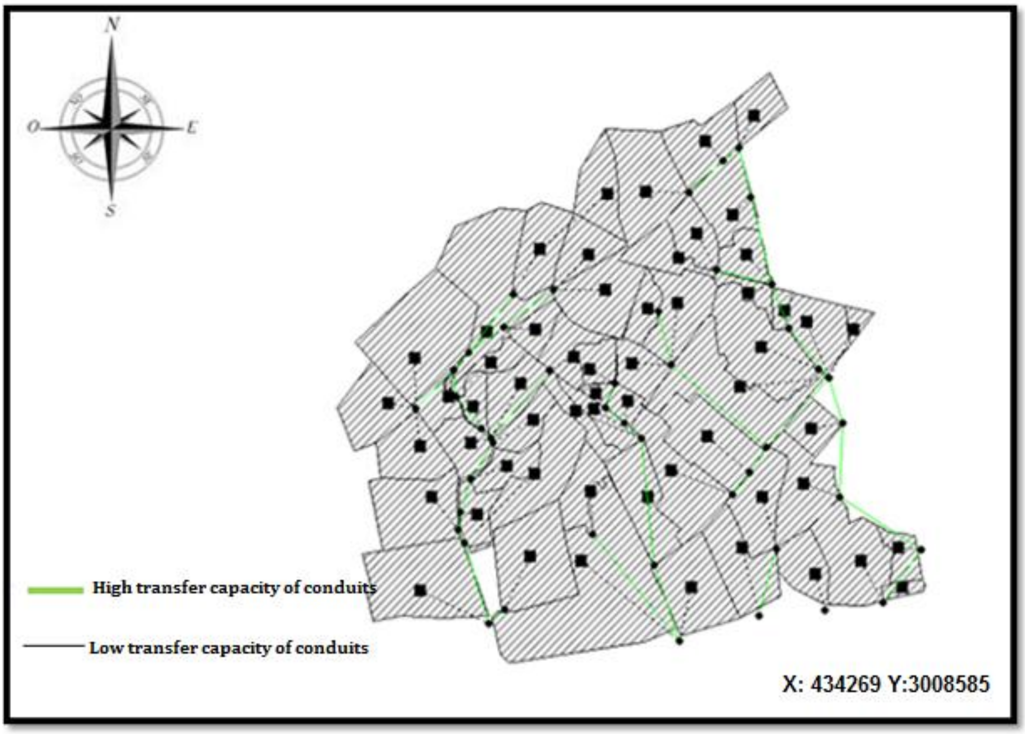

Figure 5. The transfer capacity of conduits

The results obtained from the figure indicate that of the 48 conduits, 35 of them do not have the ability to transfer water. It is noteworthy that during the conducting of the research and estimating the software input parameters and according to the main intention of this study, initial quality tests were performed in two stages on the surface waters obtained from precipitation collected at the output opening of the two main drainage networks of district no. 1 (Khor-Shilat and Khor-Damahi). In the first stage, the EC test results of the water sampled from Khor-Damahi in conditions of heavy and low duration precipitation was obtained 600 micro Siemens and pH was 7.1. In the second experiment with sampling from Khor-Shilat where the rainfall occurred within 4 hours, the EC was measured 1100 micro Siemens and PH was 7.1. It seems that the high EC of the second test is due to the entry of part of the urban sewage from the near neighborhoods into the estuary.

The development trend of the city and placement of the urban contexts and other installations and buildings in the vicinity and range of effectiveness of floodways and the range of damages caused by the flood discharges associated with them is inevitable. At first glance accepting that there is no choice but to live and compromise with floodway and its future consequences in the present and future circumstances seems a simple issue for any citizen or anyone in charge but in the practice many cases are involved in this issue and affect it. Because the impact of the floods and runoffs flowing in the urban fabric can be seen on many of the structures and in overall, it creates a bunch of complicated problems associated with each other for the decision makers which include:

- Damages to the residential areas due to the rush of flood and surface runoff
- Accumulation of water in the streets and squares of the city and causing dissatisfaction of the people due to interrupting the commuting of residents
- Increased costs of cleaning and collecting the surface water from the water accumulates in rainfall occasions
- Accumulation of sediments and transported materials within the city limits and accumulation areas and adverse effects to the environment and urban health

Locating the existing parks within the study area:

Considering that one of the purposes of this study is the possibility of using surface waters in the green spaces of city of Bandar Abbas, the existing parks within the study area were located (Figure 6).

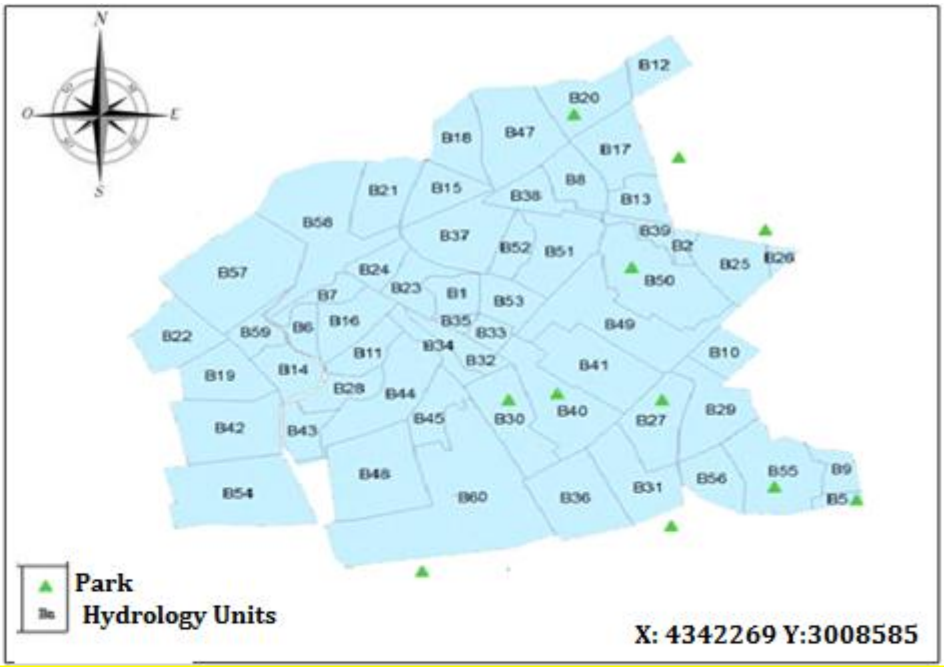

Figure 6. The image of the map of location of the existing parks within district no. 1 of city of Bandar Abbas

DISCUSSION

District no. 1 of the metropolitan area of Bandar Abbas with an area of approximately 2,760 acres is fed by four upstream watersheds. The form factor of the upstream watersheds is smaller than one which indicates that all of them are stretched and there is sufficient time for their surface water management. Since the output discharge of the watershed is directly proportional to its area, it can be said that watershed no. 1 has a low share in the production of runoff and its entrance into the urban area and watershed no. 4 has the most important role in production of runoff. Also watershed no. 4 has more concentration time than the other ones and watershed no. 1 has the lowest concentration time. So it can be said that despite the fact that watershed no. 4 has a greater proportion of runoff production, increasing concentration time of the watershed no. 1 should be the priority in management strategies in order to prevent the quick entry of the upstream flood into the town.

Also the obtained results clearly show that of the total of 57 hydrological units, B_{60} with an area of 154 acres produces the highest runoff volume of 42,624 cubic meters per second in precipitation with a two year return period and hydrological unit B_{35} with an area of 4.55 acres creates minimum flow of runoff of 468 cubic meters per second. In addition, of the 48 intended conduits, 35 of them do not have the ability to carry water which among them these can be noted: 1, 2, 3, 4, 5, 6, 11, 12, 25, etc. It seems that the main reasons for their inability to carry water are the inappropriate form (in some sections formless) or the use of inappropriate materials. And also in some parts, the preliminary estimates for the transfer power of conduits is not properly performed, in other words the basic design has not been correct. Also the wall and floor of a number of conduits need improvement and reformation.

According to the studies carried out in this research, part of the annual water requirements of some eastern parts and the coastline of the studied region which have more green space (over 70 acres) which is 784,620 cubic meters can be supplied with collection and management of surface water. Satellite images of hydrological units with high runoff volumes are shown in Figures 7.

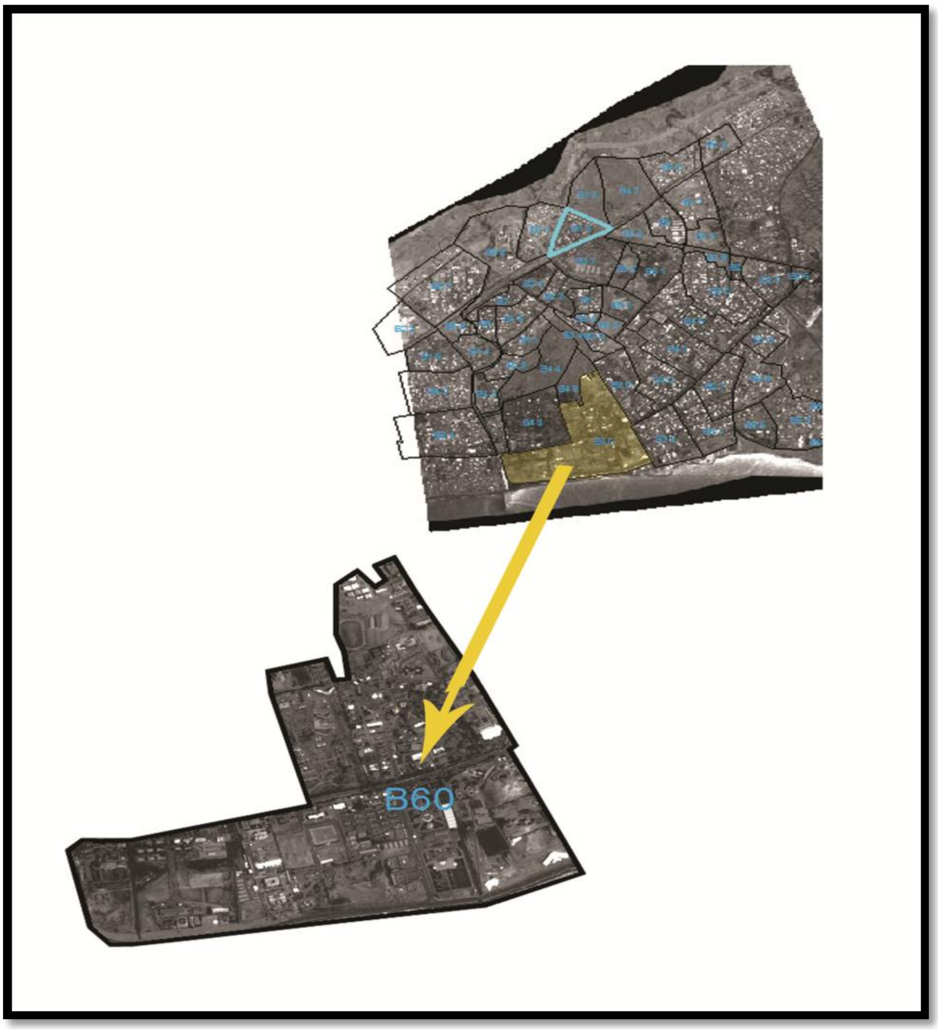

Figure 7. Satellite image of hydrological unit 60

Eastern range of Samado Street to the end of Tolou Avenue in the south side of Qadir Boulevard and coastal parks, western range of Khor-Shilat. Feasibility of irrigation of green spaces of coastal parks and Pardis Boulevard in the end of Tolou Avenue

Suggestions

1. With regard to the fact that the water requirement of the current green space of the studied region with an area of 108 acres is 76 liters per second and with respect to the fact that the output volume of the runoff with a two year return period in district no. 1 is 297,241 cubic meters according to the software's report, it can be concluded that if urban drainage is properly operated in this area and preferably roofed prefabricated underground reservoirs are provided by municipal authorities to collect runoff, the green space of this area can be irrigated for 45 days. Also if it is intended to develop the green space, 10 acres of the created green space can be irrigated for 496 days with the collected runoff.

2. Since there are no accurate information sources about the position and characteristics of the conduit in the city, it is recommended that Bandar Abbas municipality takes the required measures.

3. It is recommended that due to the closeness of Khor-Damahi (estuaries located in the study area) to hydrological units with high output discharge, the collection of runoff at the end of this estuary be managed so that it can be utilized before pouring into the sea.

4. Since hydrological units with higher output discharges are located in residential areas with low permeability, it is recommended that required measures be taken to increase the concentration time and these areas be managed appropriately.

5. It is recommended that the drainage network and surface water collection be investigated in districts no. 2 and 3 of Bandar Abbas using SWMM software.

6. Considering the runoff generated in hydrological units, it seems logical to develop green space in the proximity of each hydrological unit or maintain parks and boulevards located near each unit after improving urban drainage system and repairing the existing channels.

7. It is recommended that model parameters be calibrated in urban watershed where there is long term runoff statistics and be compared with the model's proposed values.

8. Since there are no hydrometric stations in most urban areas, the results of this model should be compared with other models which their accuracy has been evaluated.

9. The effect of land use change on runoff should be investigated in other locations with different topography and climate.

10. It is recommended that necessary measures be taken to provide accurate information which are not currently available, such as required parameters and accurate urban maps for using SWMM software in order to estimate urban runoff in the entire city of Bandar Abbas.

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