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Evaluation and Prediction of Precipitation in Qassim Region using Adaptive Neuro Fuzzy Inference System

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ABSTRACT. Storm water analysis is a highly daunting but useful task in arid regions which face seasonal flows from wadies. Flash floods causing threat to life and property require extensive management for their mitigation in such a way that it may help in reducing to some extent the problem of scarcity of water in the region. This vital issue demands in-depth analysis of rainfall and storm water. This research has analyzed rainfall in Qassim Region Saudi Arabia using statistical techniques. Future predictions have been made by the application of Adaptive Neuro Fuzzy Inference System (ANFIS). Three ANFIS models were tested with different architectures and comparatively better performing one was used to simulate the future precipitation. Long historic records of rainfall from 1979 to 2015 collected from Municipality of Buraydah have been scrutinized. Seasonality of rainfall was examined by appraising the seasonality index (SI). The prevailing rainfall intensity was premeditated from Intensity Duration Frequency (IDF) curves. Rational formula was used to find peak of storm-water. It was found that drainage of infrastructure needs improvements especially in downtown of Buraydah city, Saudi Arabia.

Keywords: Rational Method, Geomorphological parameters, Digital Elevation Model.

1. Introduction

Water is considered as one of the most valuable commodities in arid region of whole of the Gulf countries. The annual rainfall in most of such regions is small but due to high intensity of rainfall it causes flash floods. The drainage facilities are normally poor in Gulf countries [1-2]. Due to inefficient drainage, the losses from flash floods are further aggravated [3]. Saudi Arabia is one of the most prominent country in the Gulf Region. Flood hazards have been reported in various places in the country which have caused nearly 295 fatalities from 2005 to 2018 [4-7]. The floods in Buraydah-Qassim time to time effected not only property but also caused troublesome situation, traffic blocks and the human health-threats. At the same time the groundwater which is the major source of water supply in Qassim Region is being depleted day by day. There is utmost necessity for its recharging to ensure sustainability of water resources. It can only be made possible by proper storm-water management. A multi-disciplinary research consisting of prediction of future rainfall changes due to environmental changes, stormwater modeling and improving storm water drainage facilities is straightaway required.

This paper emphasis on two research questions related to water resources sustainability and environmental changes: i) what will be the variations in rainfall in Qassim Region predicted by ANFIS ii) what is impact of rainfall variations on overall stormwater in the region?

2. Literature Review

The 20th and 21st century has unique developments regarding knowledge, information, technology, industrialization, urbanization, living standards. This boom of development has many positive points but it has caused several life-threatening effects as well. Environmental changes have threatened human life in several ways. It is expected that there shall be droughts in some regions and floods in other parts of the world [6, 8]. So, the study of future predictions using some latest technique like ANFIS has become need of the day. There are hundreds of publications world-wide in this field of specialization, covering all possible cases of humid, semiarid and arid regions [9-15].

Some researchers have steered environmental changes in Kingdom of Saudi Arabia [2, 6, 7, 16]. Chowdhury and Al-Zahrani [17-18] have examined the climate variation repercussions over water resources of Saudi Arabia. Chowdhury et al. [19] and Tarawneh and Chowdhury [6] have prefigured precipitation trends up to fifty years in Kingdom of Saudi Arabia.

Most of the above studies have shown concerns about the use of global climate models because of being computationally expensive, complex and associated with uncertainties in their results. There is another very emerging technique of data driven modeling for future predictions. It would be very important for decision-makers in the field of water resources engineering to examine the predictions from such models to build an additional scenario for water resources planning and management. ANFIS has been used in several studies for prediction of important meteorological and hydrological parameters in various regions worldwide [20-25]. Kyada and Kumar [26] for example used ANFIS for daily rainfall forecast in Junagadh, Gujarat, India. According to them, ANFIS predicted the daily rainfall with high accuracy. Tiwari et al. [27] has compared ANFIS models and used the best one to predict water quality index in India. According to them the data driven models avoid lengthy computations as those in other models. So, development of a model and its application for faster dissemination of information based on data driven modeling may be highly useful. Arslan and Kayis [28] has compared artificial neural network modeling with ANFIS for forecasting daily precipitation using data from two gauging-stations of Huston, USA. They found that input combinations should be made carefully to obtain accurate predictions from data driven models. El Ibrahimi and Baali [29] have applied several data driven models for predicting meteorological parameters in Northern Morocco. They have observed that ANFIS produced comparatively better accuracy in predictions as compared to the artificial neural network and support vector regression models.

ANFIS are simple to use and require comparatively lesser time and effort when compared to other modeling techniques [30]. ANFIS models can efficiently address the non-linearity of systems due to their inherent architecture. However, ANFIS require careful training based on the database and have previously been used for short term predictions although they have the ability to predict for the long-term bases. Furthermore, performance evaluation of ANFIS for rainfall predictions in arid regions has not been done so far. Hence predictions for long term bases using ANFIS for arid regions will definitely be useful for water resources engineers and managers in the region.

3. Study Area

Nearly whole of the Gulf Region lies in arid to semiarid zone. Kingdome of Saudi Arabia is one among the top importance countries, which is located between the latitudes 16° and 33° N and longitudes 34° and 56° E. The climate of the Kingdome is similar to other Gulf countries. It has mostly the desert area with highly dry and hot days in summer season. The rainfall occurs in winter and autumn. The rainwater flows in various wadis instead proper rivers and streams. Qassim is one of the large provinces of Saudi Arabia (Figure (1.a, b)) [2]. Some agricultural activities produce some fresh vegetables/fruits, dates, fodder and wheat in the alluvial deposits in wadis of Qassim Region. The capital of the region is Buraydah which is located on the north edge of Wadi Al-Rummah and has latitude of 26°21'33.23"N and a longitude of 43°58'54.52"E The main source of water supply in Qassim is its groundwater [31].

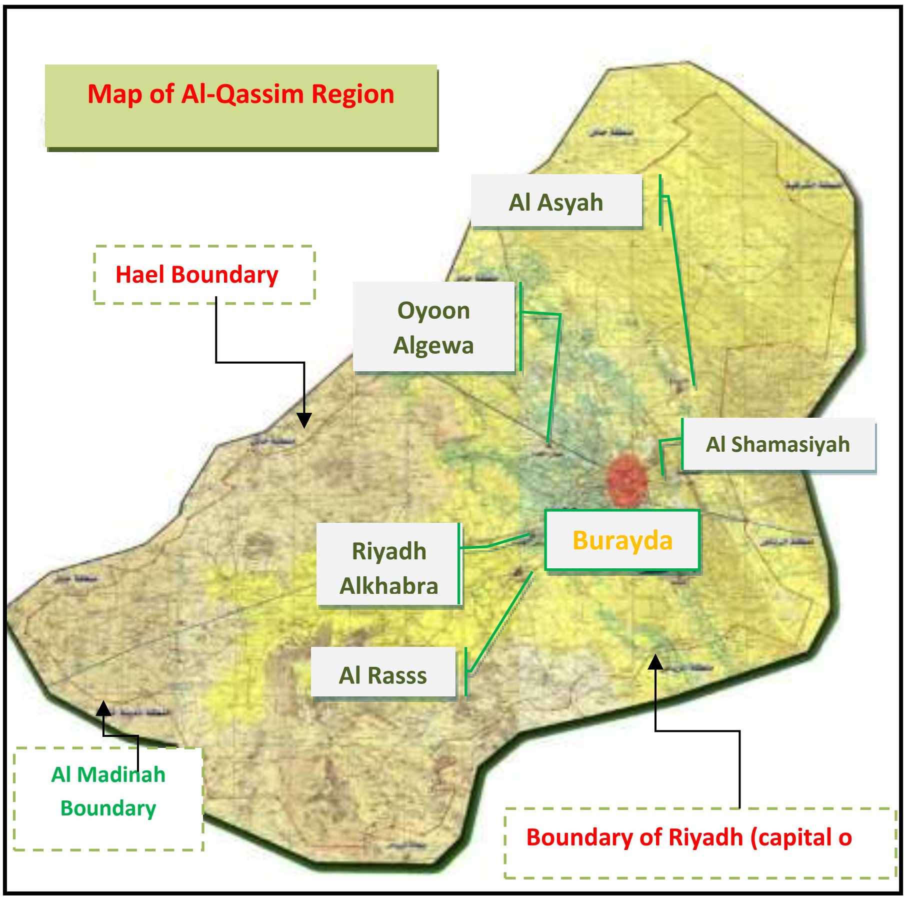

Fig. (1.a). Map and Main cities of study area

4. Methodology

4.1 General

The overall methodology developed in this research for analysis of rainfall is given in Figure (2). The collection of long records of rainfall from 1979 to 2015 have been managed with the courtesy of relevant authority. Various characteristics of rainfall were determined as a first part of analysis of rainfall. Seasonality index and normal annual rain was estimated by using general formulae described in coming sections. The future prediction of rainfall was modelled using ANFIS.

4.2 Basic Data Collection

Daily and monthly rainfall data and IDF curves for Qassim region were collected from the Municipalities of Buraydah-AlQassim.

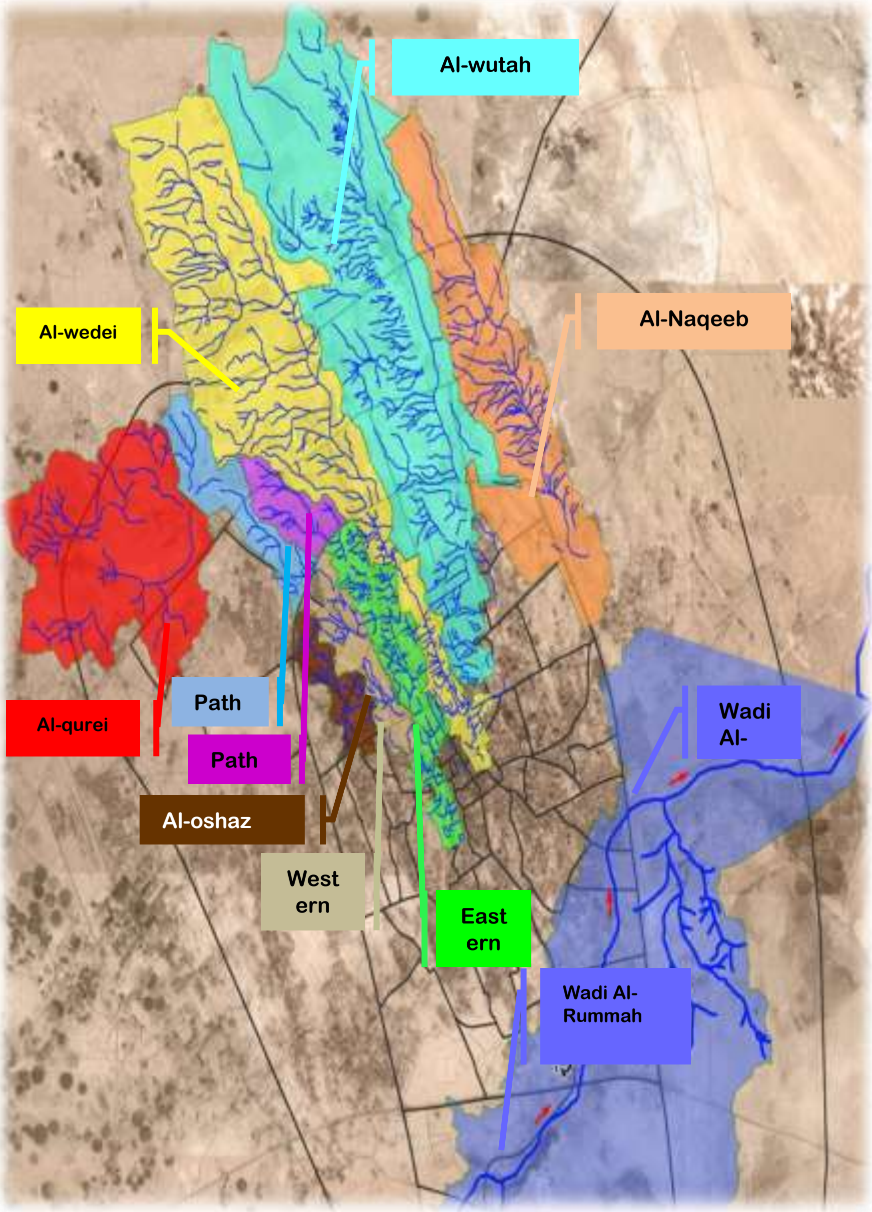

Fig. (1.b). Map showing Wadies in Buraydah city

Fig. (2). Framework for methodology used in the paper

4.3 Seasonality-Index

Seasonal variation of rainfall may be found by using seasonality-index (SI). It is given by the equation as described below.

$$SI = \frac{1}{P_t}\sum_{j=1}^{j=12}\left|P_m - \frac{P_t}{12}\right| \qquad (1)$$

Where P_t= Total annual rainfall, Pm= Total monthly-rainfall in month j. Table (1) provides information for rainfall variation divided into different classes with respect to seasons.

Table (1). Classes of rainfall with respect to SI [32]

Range of SI	Rainfall-seasonality
>1.2	Extremely seasonal rainfall, having nearly all rainfall in 01 to 02 months' time.
1.0 to 1.19	Most of rainfall occurs in less than 3 months' time
0.8 to 0.99	Rainfall markedly-seasonal having a long dry spell
0.6 to 0.79	Rainfall-seasonal
0.4 to 0.59	Rainfall seasonal having a short dry-season
0.2 to 0.39	Rainfall spread all over the year, but having a definite rain season
<0.19	Rainfall spread all over the year.

4.4. Adaptive Neuro Fuzzy Inference System

The relationship of input–output for a real-system is elaborated with the help of fuzzy if–then rules in Adaptive-Neuro-Fuzzy-Inference-System (ANFIS). A combination of input variables along with a constant term defines the output of each rule. The weighted output average of each rule becomes the final output. The fuzzy systems mainly contain three parts: fuzzification, inference, and defuzzification, and are composed of five functional blocks as shown in Figure (3). Three types of ANFISs were tested with 50, 100, and 500 maximum epochs.

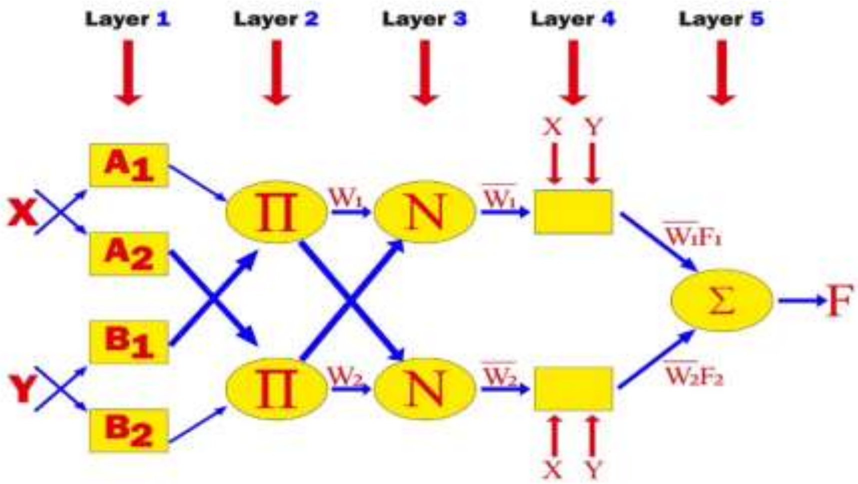

Fig. (3). Adaptive Neuro Fuzzy Inference System- equivalent ANFIS structure

4.5. Rational Method:

It is important to design the storm-water drainage infrastructure for peak runoff generated for design return period. The design of storm-water drainage pipes in urban areas does not require necessarily the complete runoff-hydrograph. Only the peak flow is sufficient for design of pipe networks. Several methods are in practice and used for estimating the peak flow. The rational method is one of the simplest and most commonly used for simulating the peak flow from a small watershed [33]. Hence this method was chosen in this paper for predicting the peak flow with the following equation:

$$Q = C_w * I * A \quad (2)$$

where Q is the peak flow (m3/s); Cw is runoff coefficient (dimensionless) which is related to land use of the watershed. A represents watershed area (m2) and I is the design rainfall intensity (m/s) determined from intensity-duration-frequency (IDF) curves [34]. It needs the time of concentration which was obtained Kirpitch equation as given below [35]:

$$(T_c)_i = 0.06628 L_i^{0.77} / S_i^{0.385} \quad (3)$$

where $(T_c)_i$ is time of concentration in hours for i^{th} sub-basin,
i is an index varying from 1 to N
N is number of sub basins in the whole catchment area
L_i is length of stream of i^{th} sub-basin in km and
S_i is land slope (m/m) of sub basin i.

Digital elevation model data was used to find the values of parameters required by the above equations.

5. Results and Discussion

5.1. Precipitation Analysis

General pattern of monthly rainfall and number of rainy days in Qassim is shown in Figure (4) (a, b). Monthly rainfall is in the range of 10 mm to 140 mm. It is observed that there is hardly any rain during June, July, August and September, so only winter, spring and autumn rain is shown in Figure (4. a). The dry spell is very large. In rainy months the number of monthly rainy days rarely exceed 15.

The seasonality index (SI) for the region is given in Figure (5). The SI values range from 0.75 to 1.59. According to criteria given by Bari et al. [32], the seasonality index from 0.6 to 0.79 represents seasonal rain and from 0.8 to 0.99 indicates markedly seasonal rain with a long dry spell. Hence the rainfall in Qassim can be categorized as seasonal/ markedly seasonal with a long dry spell. All the water resources and flood management strategies should be adopted accordingly on the basis of rainfall patterns presented in this section.

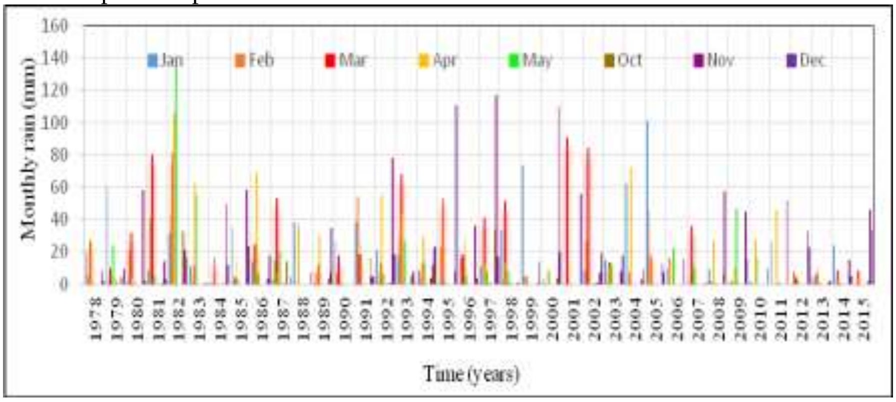

Fig. (4. a). Monthly rain during winter, spring and autumn in Qassim

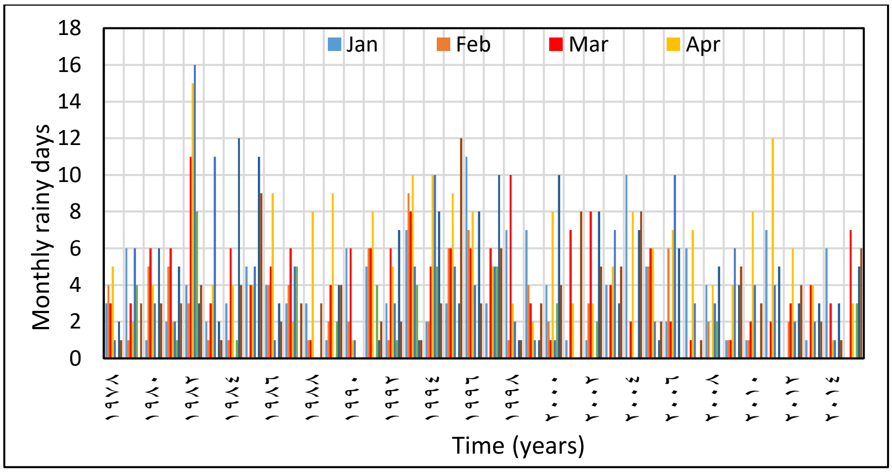

Fig. (4.b). Monthly rainy days during winter, spring and autumn in Qassim

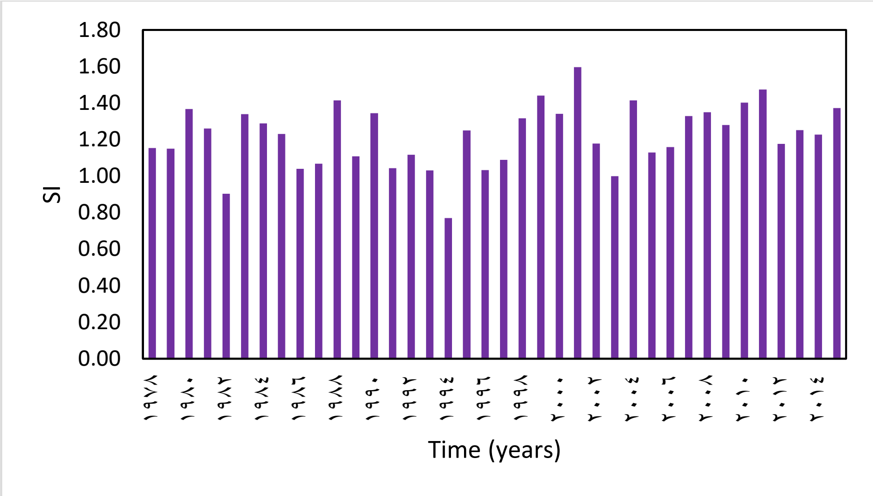

Fig. (5). Seasonality Index Qassim

Three ANFIS models were tested for prediction of rainfall. The comparison of models for their performance is tested using two statistical parameters AIC and R2. Both of these parameters are defined by the following equations:

$$R^2 = \frac{(\sum X_i.Y_i - n\bar{X}\bar{Y})^2}{(\sum X_i^2 - n\bar{X}^2)(\sum Y_i^2 - n\bar{Y}^2)} \tag{4}$$

where Xi and Yi are two variables; $\overline{X}$ and $\overline{Y}$ are the mean values of X and Y; n is the total number of data points; and i varies from 1 to n. X represents the simulated values of precipitation by the ANFIS models, and Y represents the values of precipitation from data.

$$AIC = nlog\left(\frac{SSE}{n}\right) + 2K \tag{5}$$

where AIC is the Akaike Information Criterion; SSE is the sum of squares of errors; n is the number of data points; and K is the number of parameters (for example the number of neurons in hidden layers +1). This statistical index is combination of error and complexity of the model. A model with comparatively lower AIC values is accurate and comparatively lesser complex.

The results of testing the three ANFIS models are given in Figure (6). Model 1 (ANFIS-1) produced comparatively better results (low AIC and higher R2). So ANFIS-1 model was selected for further predictions of rainfall from 2011 to 2045, 2046 to 2079 and 2080 to 2099. The future rainfall results are shown in Figure (7 & 8). Figure (7) shows that the monthly rainfall in January, April, October and

November during 2011-2045 is slightly higher than that of other periods of 2046-2079 and 2080-2099. The annual rainfall shown by Figure (8) from 2011 to 2045 as whole is also comparatively higher than that of other time spans of 2046-2079 and 2080 to 2089. It is observed that there is an increase in rainfall during 2011–2045, 2046-2079 and 2080–2099 as compared to past rainfall values from 1978 to 2015. It is observed that there is no uniform trend in rainfall values over various time spans from 2011 to 2099. There is an increase in rainfall during 2011-45. A slight decrease in rainfall occurs during 2046-2079 as compared to the rainfall predicted for 2011-2045 and again there is some increase in 2079-2099 as compared to the rainfall during 2076-2079.

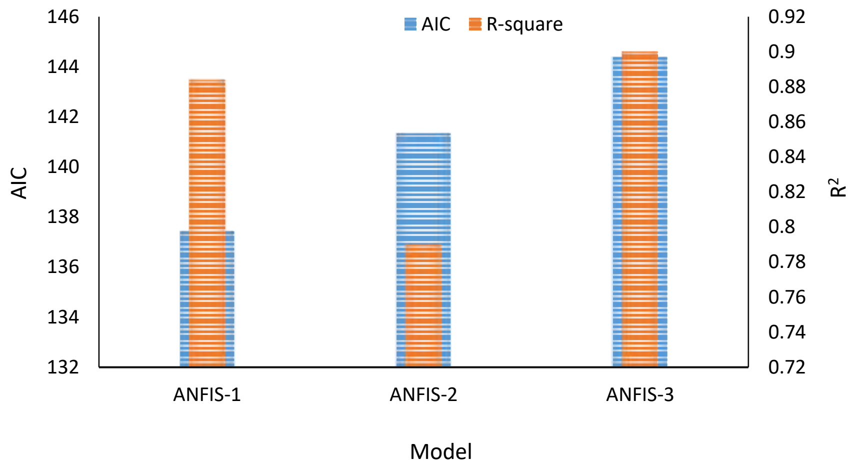

Fig. (6). Comparison of three ANFIS Models

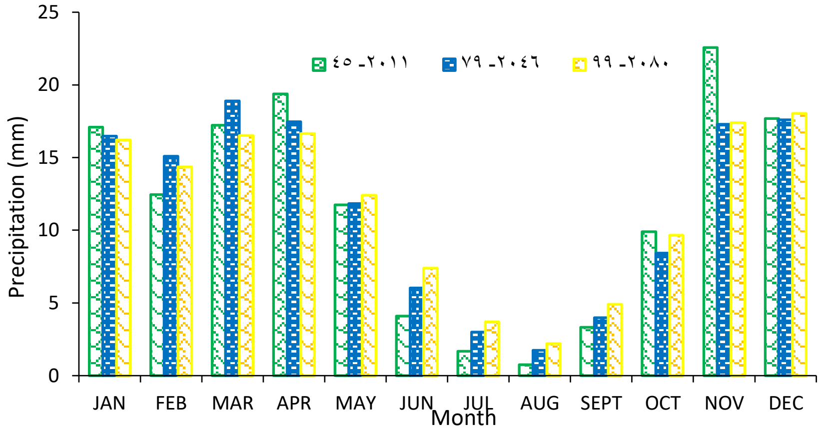

Fig. (7). Monthly precipitation predicted by ANFIS-1

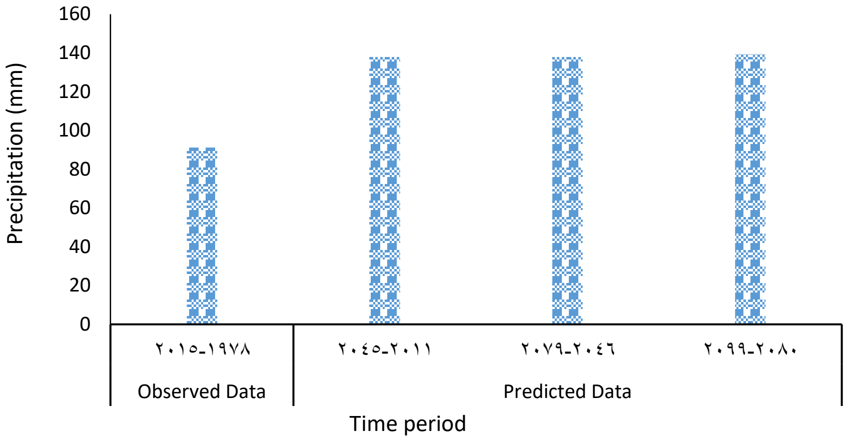

Fig. (8). Annual precipitation predicted by ANFIS-1

Design rainfall values for various return periods estimated by Gumbel Extreme Value Distribution are given in Figure (9). For a return period of 2 to 100 years the Design Rain (DR) values range from 20 to 84.5 mm/day respectively in Qassim region. For design purposes different DR values are selected for various infrastructures according to the regional practices and their importance. The return period may vary from 2 to 50 or even 100 years depending upon the nature of structure and cost. Figure (9) may help in choosing DR values and performing the cost benefit analysis. The cost of the structure obviously will be higher if the return period chosen for its design is higher. Figure (9) shows that the DR will increase by about 93% if for example, the design return period is taken 10 years instead of 2 years. The values of DR are 20.97 mm/day for 2 years return period whereas it will be 40.51 mm/day for 10 years return period.

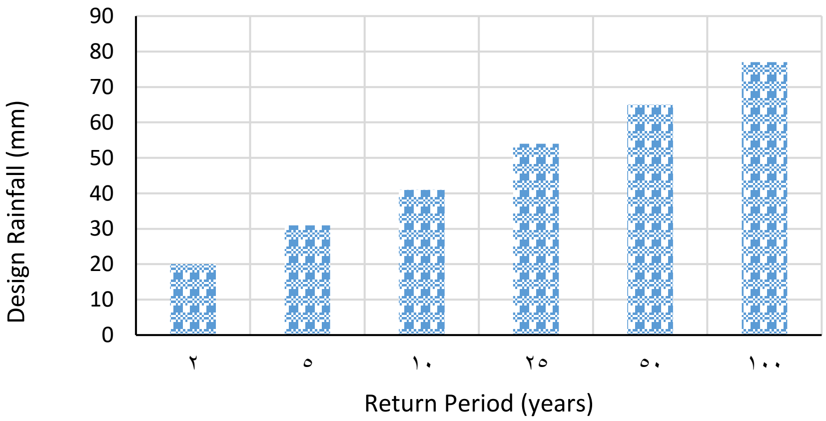

Fig. (9). Probability Maximum Precipitation values for Qassim

Various parameters of hydraulic/hydrologic model obtained from 30 m DEM are shown in Table (2).

Table (2). Geomorphological parameters determined from 30 m DEM[1].

Sr No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Parameter	Catchment area	Number of Streams	Basin perimeter	Length of highest Order	Main channel length	Stream Length Ratio[2] (for highest order steam)	Drainage Density[3]	Stream Frequency[4]
Unit	km^2	-	km	km	km	-	m^{-1}	No.
Symbol	A	*N*	P_b	L_Ω	*L*	R_L	*D*	*F*
Value	54.38	4	72.82	8.49	14.24	2.88	0.32	0.07

[1]Digital Elevation Model ,

[2]$R_l = L_i/L_{(i+1)}$, where R_l is stream area ratio, L_i is the total length of order *i* and all lower order channels

[3]Drainage density is the ratio of the total length of streams to the total watershed area, m^{-1}.

[4]Stream frequency is the number of the streams per unit area = L_N/A.

5.2. Design of Storm Drainage Pipe Network

Design calculations for all the pipes in Khubaib area were made step-wise. There are a total of 21 no of pipes in the storm water drainage network of Khubaib. The minimum diameter of drainage pipe was found to be 0.48 m. However, here-after mainly the results of trunk drainage pipe have been discussed. The maximum area contributing to storm for this pipe, was found to be 4.08 km2. The design discharge for main pipe was found to be 13.98 m3/s. The maximum pipe size was estimated as of about 2.4 m diameter (say 2.5 m). The existing storm drainage pipe diameter was found to be nearly 25 % less than the pipe estimated in the present work. This might be due to the changes in the land use (increased urbanization and paved area).

5.3. Impact of Change in Return Period on Peak Flow and Diameter of Drainage Pipe

Common practice in Qassim is to design the city drainage pipe network for 10 years return period storm. Whereas it is recommended that 25 years' design period may be adopted for higher factor of safety. The impact of changing design return period on peak flow and diameter of trunk drainage pipe is given in Figures (10&11).

It is observed that a reduction of design return period from 25 to 10 years will reduce the diameter of drainage pipe by 11%.

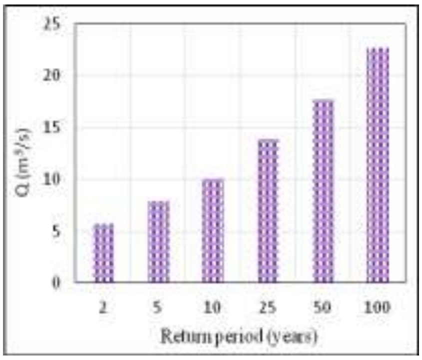

Fig. (10). Peak runoff variation with return period main storm drainage pipe (Khubaib)

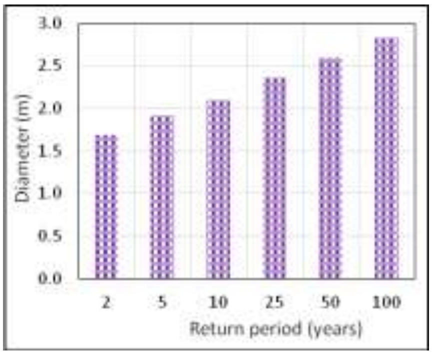

Fig. (11). Variation with return period in design diameter of main storm drainage pipe (Khubaib)

6. Summary and Conclusion

Mean daily, monthly and annual precipitation in Al Qassim, Saudi Arabia was analyzed in this paper. It is concluded that Qassim Region has long dry spells and its rainfall is markedly seasonal. The study revealed that there are only small changes in precipitation patterns during the period from 1978 to 2015 in the Qassim province. ANFIS-1 model has been developed for future predictions of rainfall. A slight increase in annual precipitation was found by future predictions. The design values of rainfall in Qassim for 2, 5, 10, 25, 50 and 100 years return period is about 17, 30, 39, 50, 59 and 67 mm. The existing drainage network in Khubaib-Central Buraydah city needs to be improved for sustainable development in future. The existing capacity of drainage infrastructure is approximately 25% less than the design capacity to accommodate runoff as a result of 25 years return period rainfall.

7. Recommendations

It is recommended that there should be an accurate storm runoff measurement arrangement for further research on optimal design of infrastructure in Buraydah Al Qassim.

Water is an important commodity in Saudi Arabia so it is recommended that marvelous research work may be arranged for water conservation and rainwater harvesting which may have multifold benefits: i) by increasing green area or by using storage tanks for rainwater harvesting in houses can significantly reduce the flood peaks and diameter of drainage pipes accordingly, ii)it will save energy requirements for sewage treatment as well as it will prevent environmental hazards, and iii) it will conserve existing water resources to meet future demands, and iv) large amount of rain water can be utilized by recharge wells through surface ponds in the city of Buraydah.

8. Acknowledgements

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9. References

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تقييم وتنبؤ الأمطار في منطقة القصيم باستخدام نظام الاستدلال التكيفي العصبي

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ملخص البحث. يعد تحليل مياه العواصف مهمة شاقة ولكنها مفيدة في المناطق القاحلة التي تواجه تدفقات موسمية من الوديان. تتطلب الفيضانات المفاجئة التي تتسبب في تهديد الحياة والممتلكات إدارة مكثفة لتخفيف آثارها بطريقة قد تساعد في التقليل إلى حد ما من مشكلة ندرة المياه في المنطقة. تتطلب هذه القضية الحيوية إجراء تحليل متعمق لهطول الأمطار ومياه الأمطار. قام هذا البحث بتحليل هطول الأمطار في منطقة القصيم بالمملكة العربية السعودية باستخدام الأساليب الإحصائية. تم إجراء تنبؤات مستقبلية من خلال تطبيق نظام الاستدلال التكيفي العصبي (ANFIS). تم اختبار ثلاثة نماذج ANFIS مع أبنية مختلفة واستخدم الأفضل منهم نسبيا لمحاكاة هطول الأمطار في المستقبل. تم فحص سجلات تاريخية طويلة لهطول الأمطار من عام ١٩٧٩ إلى عام ٢٠١٥ تم جمعها من بلدية بريدة. تم فحص موسمية هطول الأمطار من خلال تقييم مؤشر الموسمية (SI). تم الحصول على شدة هطول الأمطار السائدة من منحنيات خاصة تسمى (IDF). تم استخدام الصيغة المنطقية لإيجاد ذروة مياه الأمطار. لقد وجد أن تصريف البنية التحتية يحتاج الى تحسينات خاصة فى وسط مدينة بريدة بالمملكة العربية السعودية.