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A STUDY OF THE EFFECT OF CLIMATE CHANGE ON RESILIENCE AND HUMAN HEALTH USING BIOCLIMATIC INDICATORS

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Abstract Nowadays, climate change has been accepted as a rapidly changing phenomenon. With the help of documents, these changes would implicitly or explicitly influence human health. The purpose of this study is to examine the effect of important climatic factors on bioclimatic indicators for the human livability in Chabahar port, Iran. In this regard, four climatic models and three scenarios are taken into account. In addition, the average uncertainty of minimum and maximum temperature and precipitation variations are calculated based on the weighted method. According to the hybrid model, taken from the model and scenario, Chabahar temperature is on the rise between 0.52 and 2.38. Accordingly, bioclimatic factors would experience alteration. Eventually, it would lead to reduced resilience. The results of comfort-thermal indicators (bioclimatic) showed that the conditions are optimal and natural from October to March for individuals residing in Chabahar, Iran. However, the conditions are changing due to the future temperature increase. Such changes would significantly reduce the number of inhabitants in Chabahar and villages nearby.

Keywords: Climate change, Resilience, Emission scenarios, Chabahar

Introduction

Human health is explicitly and implicitly influenced by the change in weather patterns due to the formation of abnormal temperatures, severe winds, events associated with precipitation and moisture (Boumans et al. 2014, Anderson and Bell, 2011, Reid et al. 2009). The role of climate on human disease and human health has long been the center of debate so that Hippocrates stated that " Everyone who wants to learn medicine is required to know the following topics: He must learn the effects of seasons and their differences and know cold and hot winds and joint winds among countries, and especial winds for a certain location, and finally he should not forget the effect of water on human health." Weather variability and consequently climate can lead to the emergence of epidemics. This simple fact indicates that, prior to the appearance of medical science, when Hippocrates was teaching; numerous specific human diseases were associated with changes in seasons and temperatures (Committee on Climate; Ecosystems; Infectious Diseases; and Human Health, 2001). The fourth IPCC assessment report shows evidence of climate change contributing to Diseases and early mortality (IPCC, 2007). Climate, in fact, can play a key role in spatial and time distribution of certain infectious diseases such as malaria, bone marrow fever, tick-borne diseases, etc. In addition, climate change can be effective in seasonal distribution of pollen intensity of allergic species. Climate change is believed to increase the diseases caused by heat and extreme weather events. Note that the greatest impact of climate change would be felt in low-income countries, the urban poor, elderly, and children (Giannakopoulos et al. 2016). Studies about Iran in this regard show an increase in thermal wave frequency (Esmaeilnegad et al, 2014) so that the increase is consistent with the studies by Darand (2014) in plain areas. It also experiences a positive trend (Darand, 2014). The continuity of heat waves leads to greater number of causalities. These conditions can be reported in Iran's wet and southern regions due to feeling greater temperature (Dargahian, 2014). Extreme weather conditions have led some problems for human health and may also worsen the health problems. Under the influence of these extreme events, people may even die so that almost 16,166 individuals visited the emergency wards in California in 2006 as a result of thermal waves and 1,182 were hospitalized (Knowlton et al. 2009). In June 2015, 2,500 and 2,000 individuals died in Pakistan and India, respectively. In Central America, over 20 thousand workers have died in cane fields as a result of unknown kidney disease.

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The number of the victims is on the rise annually. It was first thought that the chemicals used in the fields caused the death. However, studies show that workers in coastal regions die and those working in higher and cooler areas do not develop such disease. In fact, dehydration rises with a sharp increase in temperature and their kidneys are exposed to extreme hyperactivity and ultimately they face the disease (Glaser et al. 2016). The review study by Lundgreen et al. on the effect of climate change on the working-class population shows that climate change and increased temperature lead to decrease in labor efficiency. It also results in decrease in the world's economic returns. Another result of the study is that climate change adversely affects the developed countries especially in tropical regions (Lundgren et al. 2013). Due to the effects of climate change on human health, a proper understanding of bioclimatic conditions of wet areas such as Chabahar in future periods seems necessary. Using general circulation models is a field of study in future periods. Therefore, these models can provide us with a future climate perspective. These models enable us to predict the future close to reality and anticipate the issue. World and Iranian studies have been conducted in terms of climate change in future periods and its effect on human health, outbreaks, and even death. Green et al. (2011) used climatic models. They concluded that the number of hot and cold nights and day will increase and the resulting deaths will increase, too. Namachulal et al. (2014) on the effect of climate change on the thermal comfort of the outer environment in the humid and hot areas of Douala, Cameroon showed that the results proved the definite effect in thermal comfort conditions. They stated that the effects are intolerable in very hot regions. Chabahar, coastal city, is located in almost tropical regions of Iran with moisture rarely less than 60%. In fact, the humidity in this coastal city is always high. Humidity, along with high temperatures and lack of wind, results in feeling a higher temperature than what a thermometer records. According to what was mentioned in introduction, the comments of scientists, the IPCC results (IPCC, 2013), and scattered studies in the world (Nian-Zhi et al. 2015) and Iran (Babaian, 2006, Massah-Bavani and Morid, 2006, Roshan et al. 2012), the temperature is on the rise especially in urban areas. This will deteriorate the conditions and have frequent consequences on human health (Smith et al. 2014) so that Jeremy et al. (2015), using regional climate change models, concluded that the evacuation of human habitations in the future is affected by climate change in South-West Asia. The purpose of this innovative study is take advantage of GCM outputs in order to calculate the climatic parameters such as maximum and minimum temperature and precipitation reception in Chabahar. Then bioclimatic indicators of Chabahar are calculated.

Data and Methodology

The purpose of this study is to calculate the bioclimatic conditions of Chabahar port, Iran in the future based on the global warming using GCMs outputs. Two categories of data are used in order to obtain the future climate profiles. The first category is the observed data of synoptic stations in over the period 1964-2010 and the second category is GCMs outputs. In this study, four GCM models (IPSLM4, CCSM3, HADCH3, and INM-CM3) were used together with three scenarios (A1B, A2, and B1). Due to the resolution of these data (more than 2.5 degrees), it is necessary to make the data small-scale in station using downscale techniques. To this end, Lars-WG5 is employed (Semenov and Barraw, 2002). Uncertainty reduction is an important topic in climate change studies (Wilby, 2010). Indeed uncertainty is the difference between simulated and measured values or observation data (Turley and Ford, 2009). So reducing the uncertainty leads in more reliable models. There are various methods for analyzing and calculating uncertainty. In this study, weighted mean was used. Weighted mean is used to calculate the weight of each of models in order to provide a hybrid model (Massah-Bavani and Morid, 2005), as follows.

$$W_{i,j} = \frac{\overline{\dfrac{1}{\Delta F_{i,j}}}}{\sum_{i=1}^{n}(1/\Delta F_{i,j})} \qquad (1)$$

Here, F is the meteorological variable, ΔF is the difference between the simulated variable under various scenarios and observation value at base period, W is the simulated weight of each general atmospheric circulation model under three scenarios in the month. The indices i and j are the month and the general atmospheric circulation model, respectively. Then the average climatic value of each parameter is calculated. After that, the future parameter value is calculated using the general atmospheric circulation model output and bioclimatic indicators including Equivalent Temperature Index, Approximate Thermal Pressure Index, W-Salt Sultry Degree Index, Humidix Humidity Index, and W-Strain Fatigue Degree Index (Blazejczyk, 2001).

Table 1 Tek - Equivalent temperature

below 18 °C	cold
from 18 to 24	cool
from 24 to 32	slightly cool
from 32 to 44	comfortable
from 44 to 56	slightly sultry
above 56	sultry

Table 2 W_Strain - Physiological strain weather subtype index

PhS or pPhS	W_Strain	Strain type
from 0.75 to 1.50	0 (T)	thermoneutral
above 1.5	1 (C)	cold strain
below 0.75	2 (H)	hot strain

Table 3 Humidex Index

Humidex (°C)	Danger category	Heat syndrome:
below 30	Caution	Little discomfort, Fatigue possible with prolonged exposure and activity
from 30 to 40	Extreme caution	Some discomfort, heat stroke, heat exhaustion and heat cramps possible with prolonged exposure and activity
from 40 to 55	Danger	Great discomfort, avoid exercise. Heat cramps or heat exhaustion likely. Heat stroke possible with prolonged exposure and activity.
above 55	Extreme danger	Heat stroke imminent with continued exposure

Table 4 W_Sult - Intensity of sultriness weather subtype index

HSI or pHSI	W_Sult	Intensity of thermal-and-hygric load
below 30	0	non-sultry
from 30 to 70	1	moderate sultry
above 70	2	strong sultry

Table 5 pHSI - Approximated heat stress index

below 0	Slight cool stress
from 0 to +10	Thermoneutral conditions
from more then 10 to 30	Slight and moderate heat stress
from more then 30 to 70	Intensive heat stress; health hazard for unacclimated persons
from more then 70 to 90	Very Intensive heat stress; water and minerals supply necessary
from more then 90 to 100	Maximal heat stress tolerated by young, acclimated persons
above 100	Hazard of an organism overheating; exposure time must be controlled.

Findings

Due to the geographical conditions of Chabahar (60.51° E and 25.30° N and 8 meters above the sea level) and Ambergeh and Demarton methods, it has a wet, hot climate. The mean temperature and relative humidity are almost 26 ˚C and 72% in long-term, respectively. Being near the coast is the main factor of high humidity. The relatively humidity rarely reaches less than 63%. Therefore, the city generally experiences a humid weather. Sultry intensity rises as relative humidity increases, and it is reduced as temperature decreases. On the other hand, the presence of humidity leads to increasing the felt temperature (Table 6).

Table 6 Monthly and Annual Climatic Parameter Changes of Chabahar in Long-term (I), average maximum temperature (˚C) (II), Average temperature (˚C), Average minimum temperature (˚C), Total Precipitation (mm) and Average Relative Humidity (%) (V).

Variable	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
I	24.4	25	27.7	30.7	33.6	34.6	33.3	32	31.8	32.1	29.4	26.3	30.1
II	19.9	20.8	23.5	26.7	29.6	31.4	30.8	29.5	28.7	27.5	24.3	21.5	26.2
III	15.4	16.5	19.3	22.6	25.7	28.2	28.2	27	25.6	23	19.2	16.6	22.3
IV	30	26	16	4	0	0	6	2	1	4	6	19	114
V	63	68	71	73	75	78	79	79	78	75	68	63	72.5

Figure 1 and 2 show the long-term temperature and precipitation changes in Chabahar station. The changes are increasing and significant according to the Mann Kendall qualitative and quantitative method and Sen's slope at 95% level (Table 7). As it can be seen, average long-term temperature is almost 26.2 ˚C in this station. However, this figure has been on the rise in the two recent decades. According to Fig. 1, the temperature has experienced a rising pattern since the 1980s; the average temperature was 26.7˚ C at the turn of century, meaning that the temperature has raised almost 0.5 ˚C. The precipitation is a little complex so that a very slight increase is seen in terms of long-term precipitation. However, dramatic changes and fluctuations are seen due to the unruly behavior rainfall so that precipitation declined dramatically in the early 20th century. In other words, the stations recorded the precipitation of almost 0.7 mm in 2001[1]. This has been the major factor of average precipitation in the last decade. As stated earlier, the general trend of the station is rising associated with the coastal location and the influence of marine conditions and regional convective rainfall.

[1] Note that the authors believed that there was a technical problem in recoding precipitation. However, the review of other stations showed that 6.3, 2.5, 7.5, and 18.3 mm precipitation were recorded in Iranshahr, Konarak, Saravan, and Zahedan, respectively. In fact, a severe drought occurred in Iran and especially in the region in 2004 and the subsequent year.

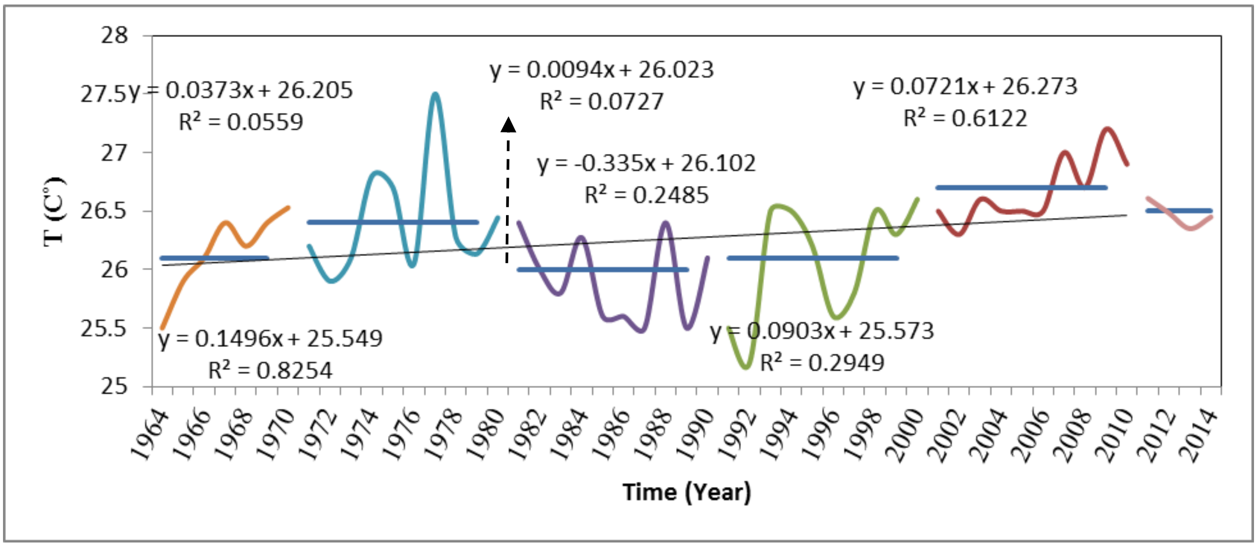

Figure 2 Long-term temperature in Chabahar Station (1964-2010).

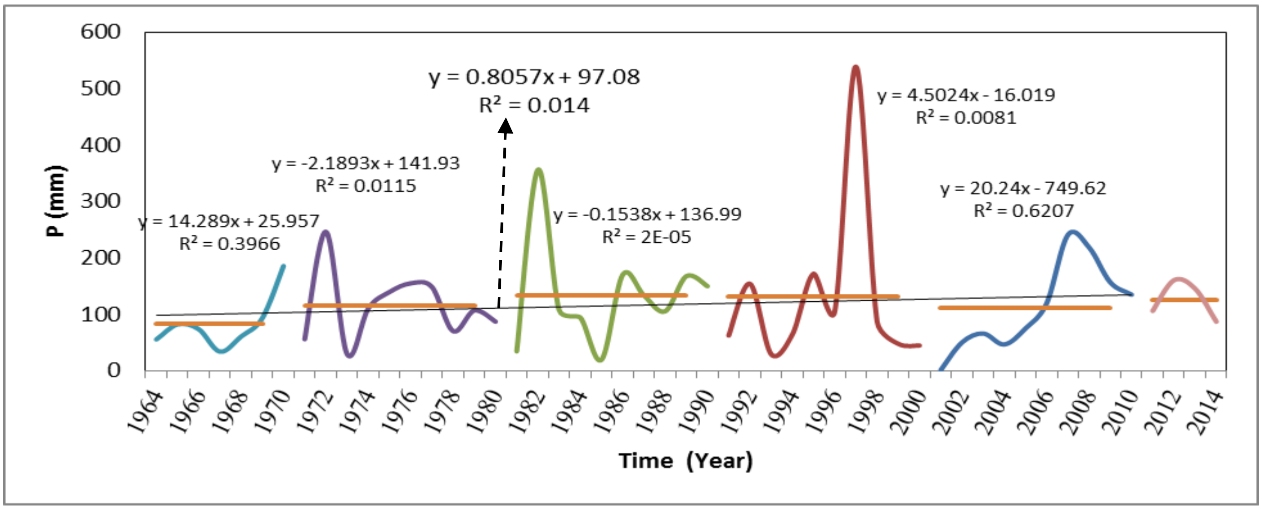

Figure 3 Long-term precipitations in Chabahar Station (1964-2010).

Table 7 Mann Kendall Coefficient and Sen's Slope Changes for Temperature and Precipitation in Chabahar (1964-2010).

		Mann-Kendall trend			Sen's slope estimate									
Time series	n	Test S	Test Z	Sig.	Q	Qmin99	Qmax99	Qmin95	Qmax95	B	Bmin99	Bmax99	Bmin95	Bmax95
P	47		0.73		0.476	-1.466	2.679	-0.908	2.044	89.98	128.56	43.72	117.66	55.00
T	47		2.45	*	0.011	0.000	0.022	0.001	0.019	26.07	26.30	25.78	26.25	25.85

Chabahar bioclimatic indicators are calculated according to its synoptic station after examining temperature and precipitation in the base period and initially recognizing the parameter changes (Table 8). According to W-Strain Index, Chabahar is normal in five months (November, December, January, February, and March). The conditions are tiring in other seven months. According to Equivalent temperature Index (Tek), if they are greater than 56, the conditions are known as sultry (table 1). Accordingly, from April to November follows such pattern. According to Humidex Index, the figures above 30 display Extreme caution, Danger and Extreme danger conditions (table 1). The calculated Humidex index values in Chabahar Station are greater 41 from May to September, which indicates the hazardous conditions. W-Sultry index indicates that all months experience sultry condition; however, it is greater in warmer months. The last indicator, pHSI, shows the approximated heat stress index. If they range between 30 and 70, they show an alarming condition. For values higher than 70, a person is subject to severe thermal stress conditions. The months June and July follow such conditions (table 8).

Table 8 Biological indicators in Chabahar station (1964-2010).

		W_Strain	Tek	Humidex	W_Sult	pHSI
Indicator value in the past (Chabahar station)	Jan.	T	42.81	22.83	0	20.08
	Feb.	T	46.87	24.90	0	22.82
	Mar.	T	54.99	29.61	1	32.06
	Apr.	H	65.21	35.41	1	45.87
	May.	H	76.83	41.54	2	62.95
	Jun.	H	85.24	45.78	2	77.57
	Jul.	H	83.24	44.67	2	72.20
	Aug.	H	78.29	42.02	1	62.25
	Sep.	H	74.76	40.21	1	56.99
	Oct.	H	69.44	37.48	1	50.02
	Nov.	T	56.29	30.59	1	35.17
	Dec.	T	46.83	25.33	0	25.05

Discussion

As it is seen, Chabahar suffers from unpleasant climatic conditions. Biological resilience is affected by climatic conditions. However, climate is changing and the temperature is rising in the region. Accordingly, the regional climate is calculated based on ensemble conditions and calculation of uncertainty using four general atmospheric circulation models under three different scenarios. Table 9 shows the results of the previous indicators. As it can be seen, the mean temperature in Chabahar is on the rise according to the Chabahar Station and general atmospheric circulation models compared to the base period. Average temperature change is almost 0.52, 1.42, and 2.38 ˚C in 2011-2030, 2046-2065, and 2080-2099, respectfully. Obviously, such change would affect the bioclimatic indicators. Since bioclimatic comfort is affect by environmental factors such as temperature, it would cause to change bioclimatic conditions.

Table 9 Total precipitation and average monthly temperature in the base and future periods based on Ensemble

	Precipitation				Temperature			
	Base line	2011-30	2046-65	2080-99	Base line	2011-30	2046-65	2080-99
Jan	28.686	38.6	33.5	40.0	20.16	20.86	21.84	22.90
Feb	23.857	19.2	11.7	9.7	21.30	21.90	22.86	23.80
Mar	16.689	29.6	31.4	41.0	23.42	24.16	25.06	26.00
Apr	3.648	1.5	1.3	1.2	26.72	27.06	27.73	28.35
May	0.024	0.0	0.0	0.0	29.65	30.06	31.05	32.10
Jun	3.821	12.2	10.0	9.9	31.14	31.57	32.44	33.42
Jul	5.245	3.5	3.9	4.2	30.36	30.66	31.48	32.41
Aug	1.633	0.6	0.5	1.2	29.12	29.66	30.49	31.34
Sep	0.822	2.5	4.6	1.9	28.62	28.95	29.81	30.59
Oct	3.990	14.5	25.5	27.1	27.50	27.79	28.61	29.52
Nov	5.156	8.5	8.3	12.8	24.73	25.32	26.32	27.47
Dec	19.737	40.6	31.7	24.8	21.93	22.64	23.78	25.08
Annual	113.309	171.2	162.3	173.91	26.22	26.72	27.62	28.58

Table 10 shows the bioclimatic indicators according to the temperature and precipitation taken from four general atmospheric circulation models under three different scenarios considering uncertainty in future periods. As it can be seen, the indicators show a more critical and dangerous situation compared to the base period for Chabahar.

Table 10 Biological Indicators in Chabahar Station (2011-2030, 2040-60, and 2080-99)

Year	2011 -30					2040-60					2080-99				
Month	Tek	Humidex	pHSI	W_Strain	W_Sult	Tek	Humidex	pHSI	W_Strain	W_Sult	Tek	Humidex	pHSI	W_Strain	W_Sult
Jan	51.98	26.76	22.66	T	0	54.43	28.29	25.81	H	0	57.15	29.91	29.14	H	0
Feb	54.68	28.50	26.46	H	0	57.24	29.96	29.24	H	0	60.01	31.58	32.74	H	1
Mar	60.93	32.61	37.09	H	1	63.95	33.87	38.06	H	1	66.98	35.60	42.36	H	1
Apr	69.26	38.24	57.69	H	1	73.25	39.13	52.18	H	1	76.58	40.99	58.06	H	1
May	79.01	45.04	109.27	H	2	84.47	45.29	74.46	H	2	88.51	47.46	85.00	H	2
Jun	83.55	48.27	221.68	H	2	89.43	47.95	87.71	H	2	93.18	49.94	100.19	H	2
Jul	80.93	46.40	132.62	H	2	86.24	46.24	78.81	H	2	90.01	48.26	89.49	H	2
Aug	77.62	44.05	97.48	H	2	82.45	44.20	69.88	H	1	85.99	46.11	78.24	H	2
Sep	75.52	42.58	83.85	H	2	80.33	43.04	65.32	H	1	83.87	44.96	73.06	H	2
Oct	71.72	39.94	66.29	H	1	76.22	40.78	57.37	H	1	79.68	42.69	64.01	H	1
Nov	64.37	34.91	44.43	H	1	68.04	36.21	43.92	H	1	71.78	38.31	49.75	H	1
Dec	56.82	29.90	29.79	H	0	60.06	31.61	32.82	H	1	63.39	33.54	37.26	H	1

Table 11 summarizes the comfort-thermal indicator changes based on the scope of changes. In fact, this table states that, for example, based on the Equivalent temperature index (Tek) in the base period, 2 months have a few sultry conditions and 8 months of sultry conditions, while based on the ensemble output of the general circulation models (GCMs), the number of months in sultry is 9, 10 and 12 months in periods of 2011-2011, 2040-60, and 2080-99, respectively. In general, Chabahar port suffers from unpleasant resilience condition in terms of certain indicators and climate change during most of year.

Table 11 Predicted changes for the number of months in base period in future period according to the comfort-thermal indicators in Chabahar Station.

		Changes in the number of months			
Index	Stress Category	Baseline	2011-2030	2040-2060	2080-2100
Humidex	Extreme caution	2	4	4	4
	Danger	5	5	6	7
	Extreme danger	0	0	0	0
Tek	slightly sultry	2	3	2	0
	sultry	8	9	10	12
pHSI	Hazard of an organism	2	2	3	5
W_Strain	hot strain	5	12	12	12
W_Sult	strong sultry	3	2	3	5

Health studies have shown that numerous health problems appear due to changes in relative humidity and temperature, especially if people are busy with physical activity (Smith et al., 2014). At 27 ˚C and relative humidity of 40%, even healthy individuals might experience increased fatigue, sore muscles, irritability, and bad temper. A healthy individual busy with heavy physical activity such as construction workers or farmers might experience a 26 ˚C thermal stress. As the results show, assuming the constant humidity in Chabahar and the figure in the past (60%), Chabahar would be in alarming list for locals and tourists based on the temperature increase in Chabahar and other southern Iranian cities. The condition, therefore, requires public training and specific measures such as the localization of construction- that is, climate-based design- and establishment of warning thermal health systems, etc. Past studies have shown that Iranian southern regions are prone to some diseases such as Malaria (Tavousi et al. 2013). Increased temperature will increase the malaria incidence. Increased temperature in the region will contribute to dehydration and this, as previous studies in other regions have shown, results in increased Kidney stone. In fact, hot weather and exposure to situations that predispose an individual to Dehydration (sweating) can increase the Kidney stone risk. Climate change can worsen the situation in this regard in Chabahar.

Conclusion

According to the combined data of GSM outputs, temperature and precipitation are on the rise in Chabahar Station. The temperature is reported 26.2˚ C in the base observational period. According to the models, the temperatures are 26.72, 27.62, and 28.58˚ C in 2011-2030, 2040-2060, and 2080-2099. On the average, 0.52-2.38 increase is seen. In terms of precipitation, it experiences a rising pattern. Precipitation is reported 57 mm in the base period. Chabahar suffers from unpleasant conditions in all months using the bioclimatic indicators. In other words, it is constantly in warning list for human health and urban and rural ecosystem. This is a warning alarm for politicians and planners.

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