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# Assessment of extreme heat stress probabilities in Iran's urban settlements, using first order Markov chain model

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ABSTRACT

Extreme weather phenomena affect human societies, and especially thermal stress is a considerable threat. Therefore, the goal of this study is twofold:

On one hand, to assess the frequencies of classes of the Universal Thermal Climate Index (UTCI) in Iran. The findings showed that a total of 83.7% of the stations have experienced UTCI classes of very strong (VSHS) or even extreme (EHS) heat stress indicating that Iran faces more VSHS and EHS events against cold stress events.

On the other hand, in the process, first order Markov chain model was applied to estimate the probability of extreme heat stress conditions. One of the most important findings of this section was that 63.8% of the stations experienced VSHS conditions in the long term that maximum frequency of the probability of this condition appeared in the zone along the coastal strip of the Persian Gulf and Sea of Oman against to the rest of Iran, it is suggested that early warning system for heat stress should be designed, providing alerts on time to eliminate casualties and strengthen the resilience of the local population.

## 1. Introduction

The weather variability is an important risk factor for mortality and many projects have been carried out in order to reveal the relationship between human health and mortality with environmental parameters, especially air temperature extremes (Hajat, Kovats, Atkinson, & Haines, 2002; Schwartz, Samet, & Patz, 2004; Nastos & Matzarakis, 2006; Shao et al., 2008; Gómeza, Pérez Cuevab, Valcuendec, & Matzarakis, 2013; Nastos, Giaouzaki, Kampanis, & Matzarakis, 2013). For example in Spain, city of Barcelona experienced more than 500 deaths during the extraordinary conditions of summer 2003 (Tobías et al., 2010) while in Vienna around 180 deaths were attributable to heat stress (Hutter, Moshammer, Wallner, Leitner, & Kundi, 2007). In Paris, where the center of the August 2003 heat wave was located (Robine, Cheung, Le Roy, van Oyen, & Herrmann, 2007), more than 300 people died in 2–12 August 2003 (Pascal et al., 2006). In total, during the summer 2003, about 80,000 additional deaths were recorded in twelve European countries (Robine et al., 2007). On the other hand, Analitis et al. (2008) analyzing the effects of cold weather on mortality in 15 European cities found that 1 °C decrease in air temperature was associated with 1.35% increase in the daily number of total natural deaths and the increase was higher for the older age groups. In one study, McGregor (2005) evaluated the possible relationship between ischaemic heart disease mortality for three English counties and the winter North Atlantic Oscillation (NAO). His results showed that, winters with elevated mortality levels, have been shown to be clearly associated with a negative NAO phase and anomalously low temperatures. However, the impacts of heat and cold stress conditions on humans could be better assessed by utilizing human thermal indices based on the energy balance of the human body, instead of a single meteorological parameter (Matzarakis & Nastos, 2011).

Muthers, Matzarakis, and Koch (2010) investigated the potential development of heat-related mortality in Vienna (Austria), using the human-biometeorological index PET (Physiologically Equivalent Temperature). Their results indicated a significant increase of relative mortality on days with extreme heat stress (PET ≥ 41 °C). Nastos and Matzarakis (2012) found that in many cases, the occurrence of biometeorological phenomena such as heat and cold waves cannot be definitively determined and they are considered as random processes from statistically point of view. However, it is not possible to anticipate these atmospheric phenomena simply and decisively (Orosa, Costa, Rodríguez-Fernández, & Roshan, 2014). It should be noted that having access to accurate data and past periods of atmospheric component is an influential factor for correct prediction of these atmospheric events.

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Towards this purpose, one can refer to the prediction of thermal stress (cold stress) based on awareness of past station's air temperature data, as an example for comprehending the issue. In general, prediction of climatic phenomena is possible by utilizing dynamic and statistical models. On one hand, dynamic models are based on physical laws related to solid, liquid and vapor phases and energy exchange between these three phases. On the other hand, statistical models do not correctly consider the physics of the phenomena under investigation and only focus on determining the relationship between inputs and outputs. These models are more convenient to users against dynamic approaches. However, the overall impression is that the results extracted from dynamic models are superior against to those from statistical models, but this assumption is not always true and its correctness depends on understanding of the governing physical laws, model structure and its resolution. For this reason, the use of dynamic models is inevitable in some cases. High complexity, being time consuming, need for spending more and sometimes access to supercomputer to implement dynamic models have forced researchers to use statistical methods for their convenience, minimum time to get results and need for minimizing cost (Wilby & Dawson, 2007; Kallache, Vrac, Naveau, & Michelangeli, 2011; Yang, Li, Wang, Xu, & Yu, 2012; Roshan, Ghanghermeh, Nasrabadi, & Bahari Meimandi, 2013, Roshan, Ghanghermeh, & Orosa, 2013; Sillmann, Kharin, Zwiers, Zhang, & Bronaugh, 2013; Farajzadeh, Oji, Cannon, Ghavidel, & Massah Bavani, 2014). Based on the probability rules, some random phenomena are more likely to occur while the chance of some other ones is less. Besides, sometimes among *n* possibilities, only one of the modes can occur, the possibility of the occurrence of any of the modes is superior to other modes (Mandal et al., 2015; Sonnadara & Jayewardene, 2015; Cindrić, Pasarić, & Gajić-Čapka, 2010). To calculate the odds of occurrence of events it is necessary to select an appropriate model. The science of probability checks these uncertain conditions. Time-series methods, especially Markov chain are some methods of probabilistic forecasting. Markov chain has simplified solving contingencies related to dependent processes using simple mathematical methods (such as multiplication of arrays). Markov chain model has two advantages: First, the predictions are immediately accessible after the observations. Secondly, they require minimum calculations after meteorological data processing. (Cindrić et al., 2010; Mandal et al., 2015; Sonnadara & Jayewardene, 2015). Markov chain model is one of the most relevant and most useful statistical predictive models in atmospheric sciences, which in recent years has been seriously considered by researchers. Anagnostopoulou, Maheras, Karacostas, and Vafiadis (2003) studied changes of spatial and temporal of dry spells in Greece for an extended period of 40 years (1958–1997) with use of Markov Chains. Kottegoda, Natale, and Raiteri (2004) reported that the first order of the Markov chain model was found to fit the observed data in Italy successfully. This model was based on the assumption that there was a dependency of the daily rainfall occurrence to that of the previous day. In most cases, the daily rainfall occurrence can be described by the Markov chain of the first-order model, however, there are cases where the researchers have to identify the best order of the Markov chain models to describe the distribution of wet and dry spells, as in the case of Basu (1971) for Calcutta; Berger and Goosens (1983) for Belgium; Singh, Kripalani, Priya, Ismail, and Dahale (1981) for India; Moon, Ryoo, and Kwon (1994) for South Korea; Dahale, Panchawagh, Singh, Ranatunge, and Brikshavana (1994) for the tropical South-East Asia and Equatorial Pacific; Chapman (1997) for the western Pacific; Martin-Vide and Gomez (1999) for Spain; Harrison and Waylen (2000) for Costa Rica; Hui, Xuebin, and Elaine (2005) for Canada; and Mohd Deni, Jemain, and Ibrahim (2009) for Malaysia. Most studies on using Markov chain models are concentrated on the identification and probability of occurrence of spells, dry and wet periods. Limited studies, such as Yazdanpanah and Alizadeh, (2011), have used Markov chains to estimate the probability of occurrence of heat waves with periods of different duration. In this study, using long-term data from five stations of Kerman province, heat waves were divided into short and long term groups. The results of analysis showed that the most consecutive heat wave was in April and the least one was in September. But what has not been considered in this study is the lack of a valid indicator to determine the heat waves, because only the air temperature deviation from a long-term average has been considered. In another study Asakereh (2010) applying first order Markov chain model investigated the frequency and persistence of early and late frosts in the city of Zanjan. Results of that study showed that the probability of early and late frosts in autumn and spring is higher than its probability in other seasons of the year. In this point, it is important to mention that to the best knowledge of the authors, there is not any study in the literature evaluating the probability of extreme bioclimatic phenomena by means of human thermal indices (such as PET, UTCI) with Markov chain models. Different cities of Iran due to its unique geographical position have considerable climate variability. Therefore, the impact of local factors along with the atmospheric circulation has provided special climatic conditions, so that Iran is not immune from biometeorological, risks such as very cold and very hot stresses.

The goal of the paper is twofold. On one hand, to assess the frequencies of classes of the Universal Thermal Climate Index (UTCI) in Iran and on the other hand to estimate the probability of occurrence of extreme bioclimatic classes of UTCI index over Iran, which could be exploited for establishing an initial early warning system of the bioclimatic extreme phenomena.

## 2. Data and methodology

### 2.1. Datasets and thermal index UTCI

To evaluate the probability of bioclimatic extreme events for Iran, the length of the statistical period and the number of meteorological stations used are of high concern. Towards this objective, mean daily datasets of air temperature, relative humidity, wind speed and total solar radiation were acquired from 155 meteorological stations of Iran, during the period 1995–2014 (Fig. 1). It should be noted that the selected stations are Iran‘s most complete stations with missing values reaching 3% maximum. The times series with missing values were reconstructed using values from neighboring stations by applying linear regression models and thus the results were approved after validation of reconstructed data.

UTCI was used to interpret the thermal conditions over Iran. Lately, the UTCI has been developed following the concept of an equivalent temperature, and is widely applied in human-biometeorological studies. (Bakowska, 2010; Idzikowska, 2010; Bröde, Krüger et al., 2012; Bleta, Nastos, & Matzarakis, 2014; Nastos, Bleta, & Matsangouras, 2016) The UTCI equivalent temperature for a given combination of wind, total solar radiation, humidity and air temperature is then defined as the air temperature of the reference environment which produces the same strain index value (Jendritzky, Maarouf, Fiala, & Staiger, 2002; Jendritzky, Havenith, Weihs, Batchvarova, & DeDear, 2008). The UTCI analysis was performed by the use of the RayMan model, which is well suited to calculate radiation fluxes and human-biometeorological indices (Matzarakis, Mayer, & Iziomon, 1999; Matzarakis, Rutz, & Mayer, 2010). The UTCI scale is presented in Table 1 (Bröde, Fiala et al., 2012). It should be noted that the aim of the present work is not to define and use new thermal zones for Iranian sites. We used the conventional UTCI classes in this paper generalized for all climatic zones of Iran, therefore its application should be considered only as an indicator at this stage of the research. The present study can be the base of a subsequent work where we use calibrated UTCI classes.

### 2.2. Markov chain model

Markov chain model is one of the stochastic processes which are widely used in discrete time series modeling and simulation. For this