Soft Computing Forecasting of Cardiovascular and Respiratory Incidents based on Climate Change Scenarios

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Abstract— Climate change is one of the most serious threats for modern societies. It contributes to the fluctuation of air pollutants' concentrations which affects the number of respiratory and cardiovascular incidents. This research initially determines the contributing meteorological features for the maximization of air pollutants on a seasonal basis. In the second stage it employs Fuzzy Cognitive Maps (FCMs) to model and forecast the level of morbidity and mortality due to the above health problems, which are intensified from the changes in minimum and maximum meteorological values. This research effort takes into consideration the climate change scenarios for the period up to 2100. The assessment of the proposed model is done on historical meteorological, pollution and nursing data from the prefecture of Thessaloniki, for the period 2000-2013.

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Keywords—Fuzzy Cognitive Maps; Morbidity; Mortality; Cardiovascular; Respiratory; Thessaloniki; Climate Models

I. Introduction

During the last decades, climate change (CC) has contributed to the increase of O_3 and particulate matter concentrations and in the frequent transfer of African dessert dust in Greece. This has caused significant increase of the respiratory and cardiovascular incidents that should be hospitalized, reducing the survival expectance (SUREX). Moreover, long term exposition in high values of air pollutants (AIPO) can result in the appearance of various forms of cancer. Under certain circumstances the concentrations of primary (CO, NO, NO_2, SO_2) or secondary (O_3) AIPO, can reach critical alarm levels. Such an environment offers low Quality of Life (QL) to the citizens, where the chances for vascular stroke (VAS) or infarction (INF) are quite significant.

The precise quantification of residents' morbidity (MRB) and mortality (MRT) in an urban center due to the maximization of AIPO levels, is a multiparametric problem. Modeling of the system under consideration, requires an in-depth spatiotemporal analysis of the meteorological conditions that create and maximize the problem. More specifically, the pollution problem in the wider area of Thessaloniki during the winter is directly connected to the production and distribution of energy. Lately, the problem is getting worse due to the frequent use of old heating methods (such as fireplaces and stoves) or to the burning of biofuels, because of the financial situation. In addition, the significant growth of road transportations and industrial activities (especially in "*Sindos*" area) are responsible for the increased values of pollutants in the atmosphere. There is a serious *Smog* problem (comprising of CO, SO_2, and PMx) during the winter. On the other hand, the photochemical cloud (PHC) (containing mainly NOx and O_3) is the main concern during the summer months.

The mild meteorological conditions of Spring and Autumn, sometimes contribute either to the creation of Smog or to the development of the PHC [1].

This research proposes an innovative hybrid Soft Computing (SC) system, that models the correlations between the atmospheric conditions and the respiratory (RES) - cardiovascular (CARD) nursing incidents in Thessaloniki. Correlation Analysis has contributed towards the determination of positive or negative correlations among the recorded daily values of the parameters under consideration. Additionally, a hybrid model for medium or long-term prediction of RES or CARD MRB and MRT has been developed by developing FCMs. More specifically, the correlation values are fuzzified, in order to be imported as fuzzy weights in the FCMs. The final model performs forecasting of the MRB and MRT levels due to the fluctuations of the minimum, average and maximum monthly temperature and average monthly precipitation values.

Climate parameter variations are modeled according to the predictions of distinct *climatic models* and scenarios, as defined in the recent research project entitled "*Coupled Model Inter-comparison Project Phase5*" (CMIP5) for the period till 2100. The FCMs forecast the future relative changes of all correlated parameters for the area under study (Thessaloniki).

Theoretical Background

A. Fuzzy Cognitive Maps

FCMs are fuzzy-graph structures. In the model of a fuzzy cognitive map (FCM), the nodes are linked together by edges

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and each edge connecting two nodes describes the change in the activation value. The direction of the edge implies which node affects the other. The sign of the causality relationship is positive if there is a direct influence, negative if there is an inverse influence relation and zero if the two nodes are uncorrelated. The causal relationships are described by fuzzy linguistics and they are fuzzified by using membership functions in the closed interval [-1,1] [2-4]. Unlike the majority of complex dynamic systems, characterized by nonlinearity and high uncertainty, the FCMs use advanced learning techniques in order to choose appropriate weights for the causal connections between the examined variables. This is done in order to reflect the examined problem with absolute realism.

Combining the theoretical background of fuzzy logic, FCMs cover the comparison and characterization purpose of the reference sets, towards modeling and solving complex problems for which there is no structured mathematical model. The FCMs constitute a very strong tool towards modeling multiparametric environmental risk cases like air pollution, forest fires or even CC [5-7]

B. Climate Change Scenarios Used

CC is the most important environmental risk globally. Our team has already modeled complex systems related to CC and its direct impacts including increased air pollutants concentrations in the atmosphere [5, 8-12]. The Intergovernmental named "Committee International Panel on Climate Change" (IPCC) which deals with the assessment of CC is an international scientific body which until today has published five reports. The aim of the program (CMIP5) that was defined in the Fifth Assessment Report on CC (IPCC-AR5, Assessment Report 5) was the design of climate models, aiming to estimate future climatic changes both in the short and in the long range. This objective is achieved by using Earth System Models (ESM) and global climate ocean-atmosphere coupling models "Atmospheric - Ocean General Circulation Models" (AOGCMs).

The latest report (AR5) finds significant improvement in the models to analyze mechanisms of temperature and precipitation, in the study of anthropogenic impact on the environment and in the study of the biochemical cycles. According to the report, four future scenarios of *GreenHouse* Gases (GHGs) concentration in the atmosphere have been developed. These scenarios are known in the literature under the RCPs acronym (Representative Concentration Pathways).

In the RCP2.6 scenario, a small increase in the emissions of greenhouse gases till the mid of the decade, would result in an increase of the solar radiation (SR) as high as 3 W/m^2 by 2050 and then in a decrease to the level of 2.6 W/m^2 by 2100. In the scenarios RCP4.5 and RCP6.0, a moderate increase in the greenhouse gases emissions, would result in the increase of SR. In RCP4.5 the SR values stabilize at about 4.5 W/m^2 before 2100 and respectively in the RCP6.0 they are stabilized at 6.0 W/m^2 after 2100. Finally, in the most extreme scenario (RCP8.5) with rapid and continuous increase of the GHGs the SR rises as high as 8.5 W/m^2 and continues to rise after 2100.

The climate models bcc csm1_1, bcc csm1 1 m, ccsm4, cesm1 cam5, csiro mk3 6 0, fio esm, gfdl cm3, gfdl esm2m, giss e2 h, giss e2 r, ipsl cm5a mr, miroc esm, miroc_esm_chem, miroc5, mri cgcm3, noresm1 m of the CMIP5 project were employed in this research, as the most modern and reliable for finding changes in temperature and precipitation for the time period 2020-2099 [13].

C. Correlation Analysis

In order to test the level of linear relationship between meteorological parameters and air pollutants, the typical relativity analysis was performed, using the parametric correlation coefficient of Pearson (r). The Pearson linear correlation coefficient between two parameters X and Y is defined based on a sample of n pairs of observations (x_i, y_i) $i=1,2,...,n$, and it is denoted as $r(X,Y)$ or more briefly as r. The variables $\bar{x}$ and $\bar{y}$ are the averages of (xi,yi). The r is the covariance Cov(X,Y) of the two variables divided by the product of their standard deviations (s_x, sy). It is given by the following equation 1:

$$r = \frac{s_{xy}}{s_x s_y} = \frac{\sum_{i=1}^{v} x_i y_i - v\bar{x}\bar{y}}{\sqrt{\sum_{i=1}^{v} x_i^2 - v\bar{x}^2}\sqrt{\sum_{i=1}^{v} y_i^2 - v\bar{y}^2}} \quad (1)$$

The correlation coefficient [14] is a pure number in the interval [-1,1]. More specifically, when $0 < r \leq 1$, then X, Y are linearly positively correlated and when $-1 < r < 0$, then X, Y are negatively correlated. When $r = 0$ or close to zero there is no correlation between them.

II. Literature Review-Motivation

This research effort is an extension of a previous research of our team [1] where we had developed a fuzzy rule-based system combined with a fuzzy chi-square test, in order to produce dependency indices between the meteorological and air pollution conditions with the actual CARD and RES incidents in the hospitals of Thessaloniki. The research presented herein has a significant level of innovation, since it aims in performing estimation and forecasting of the increase/decrease of the CARD or RES diseases caused by the CC in Thessaloniki prefecture with a projection into the future till 2100. To the best of our knowledge this is the first time that such a modeling effort is announced.

FCMs are used to solve complex non-linear problems and they can project into the future helping us to make decisions. Luiz et al., [15] constructed a FCM in order to understand the viability of Clean Development Mechanism (CDM) projects in South Africa and how they would influence greenhouse gas (GHG) emissions. Fons et al., [16] proposed a conceptual model of an eco-industrial park and used a FCM to analyze the impacts of this model in terms of pollution and waste disposal. Anezakis et al., [5] used FCMs to analyze the conditions and to correlate the factors contributing to air pollution. This modeling effort aimed in forecasting the evolution of the air pollutants concentrations in Athens as a consequence of the upcoming CC.

Various research works have applied machine learning/data mining algorithms to predict CARD Disease (CVD), but these methods suffer from a) lack of transparency of the predictive model building, b) lack of capability to introduce human wisdom, and c) lack of sufficient data. Singh et al., [17] provided a novel approach to tackle the above issues and designed a very robust and reasonably accurate model. Their approach was based on Structural Equation Modeling (SEM) and FCMs. They used Canadian Community Health Survey, 2012 data set to test their approach. Wu et al., [18] proposed a sort of forecast model for weather diseases based on the Artificial Neural Network (ANN). The factor resulted in weather diseases could be the temperature of a day, the relative humidity, the air pressure and the wind speed. Authors took RES disease treatment records as an example, the simulation result points out that it was consistent between the change trend of being sick and the actual situation. Borracci and Arribalzaga [19] developed and validated a fuzzy logic model (FLM) to predict cardiac surgery MRT risk. The FLM was developed in the following stages: expert selection of different MRT predictive variables, tables of influence among variables, construction of a FCM and its implementation in an ANN, expert-determined patient risk score, test set risk calculation based on fuzzy predictors, validation set risk using calibrated FCM, and comparison with the other scores according to the level of agreement and precision with ROC curves.

There are no hybrid intelligent models with similar or identical orientation for the area of Thessaloniki in the literature. Computational Intelligence (CI) models have been developed for this area, only to forecast air pollutants' concentrations [20-22]. Voukantsis et al., [20] formulated and employed a novel hybrid scheme in the selection process of input variables for the forecasting models, involving a combination of linear regression and ANN models. The latter ones were used for the forecasting of the daily mean concentrations of PM_{10} and $PM_{2.5}$ for the next day. Karatzas and Kaltsatos [21] used ANN for modeling ozone, and for simulating its behaviour in relation to other atmospheric parameters of interest, for the city of Thessaloniki, Greece. Kyriakidis et al., [22] evaluated the values of the Common Air Quality Index (CAQI) in Thessaloniki, Greece, in 2001-2003, using a wide range of CI models. They have applied ANN and Decision Trees for the forecasting of the CAQI, and they compared the results with those obtained via statistical regression models. Vlachokostas et al., [23] presented a methodological approach in order to estimate health damages from particulate and photochemical urban air pollution and assess the order of magnitude as regards the corresponding social costs in urban scale. Zoumakis et al., [24] analyzed MRT during heat waves in Northern Greece, separately for June, July and August, during the period 1970-2009, and to quantify a preliminary relationship between heat stress and excess MRT, taking into consideration the population adaptation to the local climate. Kassomenos et al., [25] studied the sources and the factors affecting the particulate pollution in Thessaloniki. Hourly PM_X concentrations from two monitoring sites were therefore correlated to gaseous pollutant concentrations and meteorological parameters during the 2-year period between June 2006 and May 2008. Papanastasiou et al., [26] used meteorological and air pollution data which observed in Athens, Thessaloniki and Volos were analyzed to assess the air quality and the thermal comfort conditions and studied their synergy, when extreme hot weather prevailed in Greece during the period 2001-2010.

III. Innovation Elements

According to the literature review, there is lack of a holistic approach for this environmental and quality of life problem. More specifically, there is a gap in the production of periodic classifications of health risks caused by the combination of meteorological conditions and air pollution. Also, to the best of our knowledge there is a limitation of research efforts towards forecasting of future CARD or RESP nursing incidents due to CC and air pollution. On the other hand, it is the first time that FCMs are built to model the above cases using a large volume of respective historic data vectors. The innovation of this research is based on the development of a hybrid Intelligent Soft Computing System, to model the consequences of CC to air pollution and the direct effect of AIPO and meteorological conditions to public health.

This system can be used as a crisis forecasting and management tool for the update of authorities (civil protection) citizens and hospitals. It can contribute significantly towards the design of long term policies aiming to improve the citizens' quality of life.

IV. Data

Aiming to produce a symbolic representation of the complex correlations between atmospheric pollutants with MRB and MRT in Thessaloniki, a statistical analysis of twelve air pollution measuring stations for the period 2000-2013 was carried out. The averages of the pollutants' values from the twelve stations were calculated as the selected stations record the atmospheric pollution from all the prefecture of Thessaloniki. In most of the data records missing values were observed for periods of hours, days even months for the whole period of 2000-2013, probably due to malfunction. The NO, NO_2, SO_2, CO and O_3 pollutants are recorded hourly whereas only average daily values are measured for the PM_{10} and $PM_{2.5}$ particles [1]. The average daily values of CO and O_3 have been estimated after the calculation of the maximum daily average rolling values per 8 hours. Except from the seven air pollutants, ten meteorological features were gathered from Thessaloniki airport station (Micra). As far as extreme prices are concerned, they were considered important as based on them emergency patient imports are intensified, thus it was considered appropriate not to remove them from our data. In terms of disease selection, CARD system diseases (I00-I99) and RES diseases (J00-J99) were categorized based on the tenth review of the ICD-10 International Statistical Classification of Diseases and Related Health Problems [27]. The rejection of patients' cases with injuries, traffic, poisoning, in-hospital illnesses or transported from other regional hospitals was necessary for the reliability of the data. The collection of MRB data was carried out by all public hospitals in the Prefecture of Thessaloniki. At county level, the collection of MRT data for CARD and RES diseases was carried out by the Hellenic Statistical Authority (ELSTAT).

V. Description of The Proposed System

The algorithm of the modeling approach described herein includes seven discrete steps. The values of the involved parameters that maximize air pollution per season, were investigated and four FCMs (one for each season) were constructed. The aim was the fuzzification of the positive or negative correlations and their incorporation as weights in the four FCMs. The features mentioned in step 1 were used in all four FCMs. Characteristic moisture values were chosen for each season. More specifically, the average daily moisture values (AvRH) and the respective highest average ones (MaxRH) were used for the winter. The combination of minimum temperature, maximum moisture, and hours of sunshine, contributes towards the appearance of Smog. The average daily moisture values (AvRH) the respective minimum (MinRH) and maximum ones (MaxRH) were used for the summer. The combination of high temperature and low humidity values contributes to the creation of the photochemical cloud. Also, the combination of high temperature and maximum humidity values contributes to the discomfort. We have only considered the average humidity (AvRH) values for the periods of spring and autumn. These seasons are characterized by milder climatic conditions.

The first algorithmic step, includes the insertion and naming of all associated parameters, which are then interconnected with synapses in order to create the causative negative or positive correlations.

The fuzzification of each correlation, is the assignment of a fuzzy linguistic (FL) term to each interconnection. There were six FL to choose from, namely: Three Positives (low positive (+), middle positive (++), high positive (+++)) Three negatives (low negative (-), middle negative (--), high negative (---)), which correspond to fuzzy weights (Table I).

TABLE I. EFFECT AND VALUE OF SIX LINGUISTICS WHICH CORRESPONDING TO FUZZY WEIGHTS

Effect	Value
high positive (+++)	1
middle positive (++)	0.5
low positive (+)	0.25
low negative (-)	-0.25
middle negative (--)	-0.5
high negative (---)	-1

The description of the algorithmic steps is done in the next paragraph:

Step1 (Modeling): Application for the calculation of the degree of Correlation [28] between the variables under consideration: Maximum Monthly Temperature (MaxMT), Average Monthly Temperature (AvMT), Minimum Monthly Temperature (MinMT), MaxRelative Humidity (MaxRH), Average Relative Humidity (AvRH), MinRelative Humidity (MinRH), Monthly Precipitation (MP), Atmospheric Pressure (AP), Wind Speed (WS), sunshine hours (SUN), Carbon Monoxide (CO), Nitrogen Monoxide (NO), Nitrogen Dioxide (NO_2), Ozone (O_3), Sulfur Dioxide (SO_2), Particulate Matter (PM_{10}) and ($PM_{2.5}$), Cardiovascular Hospitalization (CH), Respiratory Hospitalization (RH), Cardiovascular Deaths (CD), Respiratory Deaths (RD).

Step2: Partitioning the variables with negative or positive correlation, by fuzzifying their crisp numerical values. This was performed with the development of three triangular fuzzy membership functions (TRIMF) used to classify the correlations in the respective fuzzy sets (FS) “Low”, “Medium” and “High”. The results of this step are presented in the following tables II-V.

TABLE II. THE DEGREE OF INFLUENCE BETWEEN SOME VARIABLES FOR THESSALONIKI IN SUMMER

	Max MT	Av MT	Min RH	Max RH	CH	RH	CD	RD
MaxMT	1	+++	---	--	-	+	+	+
AvMT	+++	1	---	--	-	-	+	+
MinRH	---	---	1	++	-	-	-	-
MaxRH	--	--	++	1	-	-	-	-
CH	-	-	-	-	1	++	+	-
RH	+	-	-	-	++	1	-	+
CD	+	+	-	-	+	-	1	-
RD	+	+	-	-	-	+	-	1

TABLE III. THE DEGREE OF INFLUENCE BETWEEN SOME VARIABLES FOR THESSALONIKI IN WINTER

	Min MT	Max RH	PM_{10}	$PM_{2.5}$	CH	RH	CD	RD
MinMT	1	+	--	--	-	-	-	-
MaxRH	+	1	++	++	+	-	-	-
PM_{10}	--	++	1	+++	+	+	+	-
$PM_{2.5}$	--	++	+++	1	+	+	+	-
CH	-	+	+	+	1	++	-	+
RH	-	-	+	+	++	1	-	+
CD	-	-	+	+	-	-	1	+
RD	-	-	-	-	+	+	+	1

TABLE IV. THE DEGREE OF INFLUENCE BETWEEN SOME VARIABLES FOR THESSALONIKI IN SPRING

	Av MT	Max MT	Min MT	AvRH	CH	RH	CD	RD
AvMT	1	+++	+++	--	-	-	-	-
MaxMT	+++	1	+++	--	-	-	-	-
MinMT	+++	+++	1	-	-	-	-	-
AvRH	--	--	-	1	-	+	+	-
CH	-	-	-	-	1	++	+	+
RH	-	-	-	+	++	1	+	+
CD	-	-	-	+	+	+	1	-
RD	-	-	-	-	+	+	-	1

TABLE V. THE DEGREE OF INFLUENCE BETWEEN SOME VARIABLES FOR THESSALONIKI IN AUTUMN

	Av MT	Max MT	Min MT	AvRH	CH	RH	CD	RD
AvMT	1	+++	+++	--	-	-	--	-
MaxMT	+++	1	+++	--	-	-	--	-
MinMT	+++	+++	1	--	-	-	-	-
AvRH	--	--	--	1	-	+	+	+
CH	-	-	-	-	1	++	-	+
RH	-	-	-	+	++	1	-	+

CD	--	--	-	+	-	-	1	+
RD	-	-	-	+	+	+	+	1

Step3 (Grid): It involves the design of the FCMs following the input and the interconnection of all correlated variables, based on the Linguistics that emerged after the fuzzification of the crisp numerical values. The algorithm simulating the interactions between two nodes of the FCM was implemented by performing a repetitive calculation of the new link value corresponding to each node. This value depends on the weight of the node from which an edge begins and also on the weight of the edge joining the two nodes. The transfer function estimates the new value of each node and the weight of each connection. The negative type of influence is depicted with an orange color and the positive with a blue color. The degree of influence depends on the thickness of each line. The higher the influence the thicker the line, as you can see in the Fig. 1 (Table VI). The degree of influence between some variables in winter depicted in the Fig 1.

TABLE VI. THE DEGREE OF INFLUENCE FOR THESSALONIKI IN WINTER

	SO_2	PM_{10}	$PM_{2.5}$	CO	CH	CD
SO_2	1	++	++	++	+	+
PM_{10}	++	1	+++	+++	+	+
$PM_{2.5}$	++	+++	1	++	+	+
CO	++	+++	++	1	-	+
CH	+	+	+	-	1	-
CD	+	+	+	+	-	1

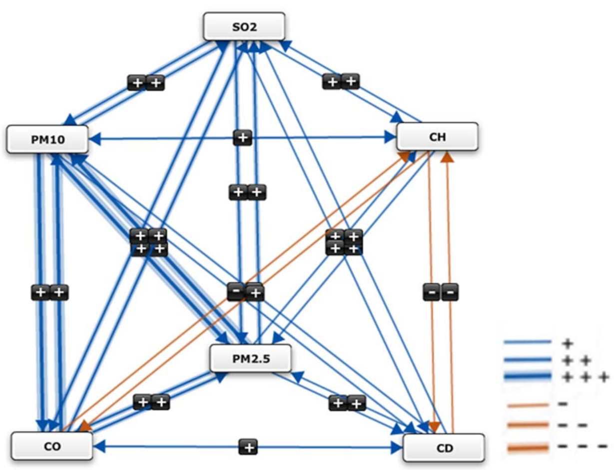

Fig. 1. A FCM between SO_2, PM_{10}, $PM_{2.5}$, CO, CH, CD winter for Thessaloniki

The Changes in the values of Temperature and Precipitation caused by the CC for the period 2020 to 2099 were fuzzified in order to obtain the corresponding Linguistics. The whole process was based on sixteen Climate Models and on extended trials of various scenarios (RCP2.6, RCP4.5, RCP6.0, RCP8.5) for every season of the period 2000-2013.

Step4 (Scenarios): Partitioning of the scenarios variables based on the changes in minimum, average and maximum monthly temperature and monthly precipitation, according to the sixteen climate models. Moreover, the obtained crisp numerical values are fuzzified, with the use of eight triangular fuzzy membership functions (FMF) and sixteen semi-triangular fuzzy membership functions (S-FMF). For example, winter two of FMF and four of S-FMF are related to Average Monthly temperature changes in the closed interval [-3.06, +6.6] ^{O}C. The first S-FMF, the FMF and the last S-FMF cover the reduction in the interval [-3.06, 0]. These FMF correspond to the fuzzy sets: low negative (-), middle negative (--), high negative (---), whereas the linguistic high negative (---) contains values close to the highest temperature reduction. The next S-FMF, the FMF and the last S-FMF were used for the increase of the average monthly temperature. These FMF correspond to the low positive (+), middle positive (++), high positive (+++), with the high positive (+++) being close to the maximum temperature increase. In the same way, two FMF and four S-FMF were developed for the precipitation with crisp values in the closed interval [-4.85,+246.95] mm. The same approach was used for the other three seasons.

TABLE VII. FMF AND S-FMF BOUNDARIES OF AVERAGE MONTHLY TEMPERATURE (AVMT) AND MONTHLY PRECIPITATION (MP) THE WINTER FOR THESSALONIKI AREA

Fuzzy Sets corresponding to AvMT and MP changes	FMF and S-FMF boundaries in the closed interval [-3.06,+6.6] ^{O}C	FMF and S-FMF boundaries in the closed interval [-4.85, +246.95] mm
--- (S-FMF)	[-3.06 -1.836]	[-4.85 -2.91]
-- (FMF)	[-2.754 -1.53 -0.306]	[-4.365 -2.425 -0.485]
- (S-FMF)	[-1.224 0]	[-1.952 0]
+ (S-FMF)	[0 2.64]	[0 98.78]
++ (FMF)	[0.66 3.3 5.94]	[24.69 123.5 222.3]
+++ (S-FMF)	[3.94 6.6]	[147.6 246.95]

TABLE VIII. FMF AND S-FMF BOUNDARIES OF MINIMUM MONTHLY TEMPERATURE (MINMT) AND MAXIMUM MONTHLY TEMPERATURE (MAXMT) THE WINTER FOR THESSALONIKI AREA

Fuzzy Sets corresponding to MinMT and MaxMT changes	FMF and S-FMF boundaries in the closed interval [-10.25,+7.6] ^{O}C	FMF and S-FMF boundaries in the closed interval [-4.32, +7.15] ^{O}C
--- (S-FMF)	[-10.25 -6.15]	[-4.32 -2.592]
-- (FMF)	[-9.225 -5.125 -1.025]	[-3.888 -2.16 -0.432]
- (S-FMF)	[-4.127 0]	[-1.739 0]
+ (S-FMF)	[0 3.04]	[0 2.86]
++ (FMF)	[0.76 3.8 6.84]	[0.715 3.575 6.435]
+++ (S-FMF)	[4.54 7.6]	[4.272 7.15]

TABLE IX. FORECASTING THR CHANGE OF THE MAXMT, AVMT, MINMT, MP VALUES BY APPLYING CLIMATE MODELS SCENARIOS TILL 2100

Climate Data	Summer	Spring	Autumn
MaxMT changes	[-9.42,+11.79]	[-6.39,+9.07]	[-6.09,+8.3]
AvMT changes	[-8.22,+8.82]	[-4.64,+5.96]	[-5.65,+6.98]
MinMT changes	[-6.79,+9.11]	[-9.9,+6.77]	[-9.91,+7.81]
MP changes	[-46.27,+187.19]	[-42.46,+179.54]	[-38.23,+244.44]

Step5: It includes extended testing of various scenarios based on the potential changes in temperature and precipitation and moreover its influence in the MRB and MRT

due to CARD and RES incidents. The fuzzy Linguistics produced by the use of CC scenarios are defuzzified in order to obtain the forecast of the potential future crisp values of MRB and MRT from CARD or RES incidents. In this way we perform a projection in the distant future for the problem of public health, as we estimate the "*most harmful conditions per season*".

Step6 (Forecasting): For the defuzzification the centroid function was used which estimates the center of gravity of the fuzzy set distribution [29].

$$x = \frac{\int x \cdot \mu(x)dx}{\int \mu(x)dx} \qquad (2)$$

Step7: The index of the magnitude of change in MRB and MRT due to CARD and RES cases is calculated based on the amount of relative change of the value of each parameter [30].

$$\frac{FinalValue - InitialValue}{InitialValue} \qquad (3)$$

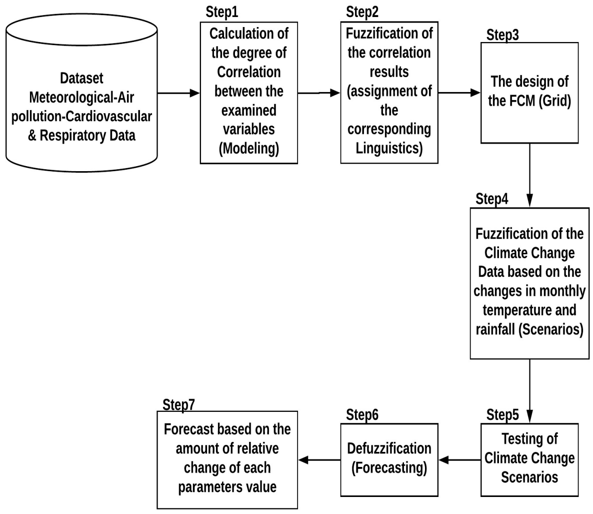

Fig. 2. Flowchart of proposed model

VI. Results And Discussion

After applying various CC scenarios for each season (including various potential changes in minimum-average-maximum monthly temperature and monthly precipitation) under the sixteen climate models for Thessaloniki, the forecasted Relative Changes (RC) in the MRB and MRT were obtained. The RC of the values of the CARD and RESP incidents and of the rest interconnected parameters was calculated based on historical data for the years 2000-2013 which were used as initial values in equation (3).

The application of various climatic models and scenarios has contributed in finding variations in the monthly values of climatic parameters, for the historical period 2000 to 2100. http://sdwebx.worldbank.org/climateportal/index.cfm These changes were used as the final values of the equation (3).

The output of equation 3 which represents the magnitude of the RC is estimated by employing the initial and final values of the monthly climate parameters. All of the RC of the involved parameters were estimated based on the positive or negative interfaces of the modeling FCM process and also on the final result of the equation (3).

This equation denotes the positive or negative deviation of each examined parameter from its initial value. Based on the most significant changes observed in the prefecture of Thessaloniki, the most extreme scenarios per study period till 2100 are presented below. Scenario **ID1** forecasts high increase of all CARD or RESP diseases in the winter due to the high decrease of the average monthly Temperature (T) by -3.06°C and a decrease of the minimum monthly T by -10.25°C combined with a Moderate increase of the maximum monthly T (+3.575°C), and a small increase of the monthly precipitation (P) (+40mm). This scenario is derived from the climate model ipsl_cm5a_mr, RCP2.6 for the time period (2020-2039, 2040-2059, 2080-2099). The highest increase of CARD deaths (+0.22) is directly related to the high decrease if the average monthly T (-3.06°C), which is connected with the small decrease of the minimum monthly T by (-1°C), and a high decrease of the maximum monthly T (-4.32°C), and the small decrease of the monthly P (-1mm) (ID2). This increase is applied by the climate model mri_cgcm3 during the period 2020-2039 in the RCP6 scenario. In both cases (ID1,ID2) we had a small increase (+0.04) in the emissions of SO_2.

In the summer, the biggest increase in the CARD and RES incidents (scenario ID3) was obtained under the following conditions.

C1: Small increase (+1.5°C) of the maximum monthly T C2: Moderate decrease (-4.11°C) of the average monthly T C3: High decrease (-6.79°C) of the minimum monthly T C4: Moderate increase (93.57mm) of the monthly P. This scenario is obtained from the model ipsl_cm5a_mr for all the periods till 2100 in the mild scenario RCP2.6.

According to the most extreme scenario RCP8.5, for the period 208-2099 the following two climate models miroc_esm and miroc_esm_chem, gave a small increase (+0.01) in the PES deaths (ID4). This was caused by the combination of the high increase by (+11.79°C) of the maximum monthly T, an increase of the average monthly T by (+8.82°C) and an increase of the minimum monthly T (+9.11°C) combined with an increase of the monthly P by (+30mm).

During the spring the MRB and MRT increase has been estimated based on ID5 and ID6 scenarios and it is the result of the following climate combinations: C1: High decrease (-4.64°C) of the average monthly T C2: High decrease (-6.39°C) of the maximum monthly T C3: Small decrease (-1.5°C) of the minimum monthly T C4: Moderate (ID5) (+89.77mm) or high increase (ID6) (+179.54mm) of the monthly P. The application of these scenarios is done by the climate model gfdl_esm2m for the period 2040-2059 for all scenarios. In all cases we have a small increase of CO and SO_2.

For the autumn according to scenarios ID7 and ID8 the increase of the RES and CARD MRB and MRT is obtained under the following conditions. C1: High decrease (-5.65°C) of the average monthly T C2: High decrease (-6.09ºC) of the maximum monthly T C3: Moderate decrease (-4.955ºC) of the minimum monthly T C4: Small (ID7) (+30mm) or moderate (ID8) (+122.3mm) increase of the monthly P. Based on the ID7 and ID8 scenarios all air pollutants are increased except for O_3. Both scenario will apply for the period 2040-2059 in all scenarios except for the RCP8.5.

TABLE X. RELATIVE CHANGES FOR THE CARD-RESP INCIDENTS IN THESSALONIKI BASED ON THE CC SCENARIOS

ID	Climate Models	Climate Scenarios	CH	RH	CD	RD
1	ipsl_cm5a_mr	RCP2.6	0.08	0.13	0.17	0.15
2	mri_cgcm3	RCP6	0.03	0.02	0.22	0.03
3	ipsl_cm5a_mr	RCP2.6	0.16	0.1	-0.3	-0.39
4	miroc_esm miroc_esm_chem	RCP8.5	-0.01	-0.01	0	0.01
5	gfdl_esm2m	RCP2.6-RCP8.5	0.05	0.05	0.05	0.14
6	gfdl_esm2m	RCP2.6-RCP8.5	0.06	0.04	0.04	0.1
7	gfdl_esm2m	RCP2.6, RCP4.5, RCP6	0.06	0.06	0.1	0.05
8	gfdl_esm2m	RCP2.6, RCP4.5, RCP6	0.05	0.05	0.09	0.06

VII. CONCLUSIONS-DISCUSSION

This research proposes a SC system that forecasts the CARD and RES hospitalization incidents per season till 2100. Correlation Analysis was performed between the features that influence the problem, with available data from Thessaloniki prefecture for the period 2000-2013. Additionally, a prediction of the evolution of diseases' incidents was made considering the variation of the following parameters: Minimum Monthly T, Average Monthly T, Maximum Monthly T and Monthly P, as they will change on the basis of the forecasts of sixteen climatic models for the period up to 2100. The results of the proposed model have provided important insights into the medium to long term prediction and assessment of public health conditions due to fluctuations of climate parameters, as a consequence of CC. Summarizing we can say that the system provided us with specific fluctuations of the diseases based on the climate model and n the scenario applied. The most significant results are mentioned in this paper. These results can be used as an alarm towards the imposing of actions for the improvement of the quality of life in major urban centers like Thessaloniki in order to reduce the air pollutants. This would reduce the effect of CC in public health and more specifically in the increase of RES and CARD diseases. Also the hospitals could design a new management policy in order to get ready to phase the negative effects of CC in a mid-term horizon. As future research we will work on the improvement of the forecasting accuracy by employing optimization algorithms and approaches, or by designing a potential more effective hybrid approach.

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