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Brief notes

Resilience actions to counteract the effects of climate change and health emergencies in cities: the role of artificial neural networks

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Abstract
Both the World Health Organization (WHO) with its 2015 "Climate and Health Country Profile Project" and the Istituto Superiore di Sanità (ISS) with its 2018 "Health and Climate Change", agree on the emergency generated by the climate change and concerning health problems. The mitigation strategy suggested by the Intergovernmental Panel On Climate Change (IPCC) against greenhouse gas emissions and their effects on climate change, has not yet yielded the desired results. It is therefore necessary to focus on adaptation strategies, to immediately counter the effects of climate change (CC) on most vulnerable people and environments, by increasing their resilience through local interventions and targeted resilience actions. Coordinated resilience actions are necessary to combat the effects of CC especially in urban areas. Useful tools to manage and optimize resilience actions are artificial neural networks (ANN) in complex and dynamic domains as cities are. The case of ANN applied to a city is presented as an example to increase the climate resilience of health local systems. In the current state of knowledge, ANN prove to be the most advanced and global solution to coordinate and manage a set of resilience actions in urban areas.

Key words
- climate change adaptation
- climate resilience of health
- urban resilience actions
- health
- artificial neural networks

INTRODUCTION

The earth's average temperature has been steadily increasing in recent decades as the scientific observations and meteorological models on a global scale have shown. Consequently, the United Nations (UN) held the Kyoto Conference, Conference of the Parties 3 (COP3) of 1997, in which almost all nations signed the so-called Kyoto Protocol on Climate Change, pointing the finger to climate-changing gases. In fact, the Intergovernmental Panel on Climate Change (IPCC) has shown that greenhouse gases are responsible for climate change (CC) on the planet, especially in polar areas, where glaciers are constantly decreasing with potentially serious consequences, in particular for people's survival and health. For example, in the 2015 WHO "Climate and Health Country" survey, the health impact related to the effects of CC was highlighted, confirmed by the first scientific symposium "Health and Climate Change" organized by Istituto Superiore di Sanità (ISS) in 2018. Two main strategies have been identified and implemented so far. The first is mitigation, to act on the causes of climate change both by reducing greenhouse gas emissions and by reducing the use of fossil energy sources. The second is adaptation, to reduce the impacts of climate change, i.e. to implement all those actions that can limit and counteract climate disruption, hydrogeological and coastal fragility, reduction of biodiversity, etc., in order to preserve the quality of life on Earth and in particular the health and well-being of citizens [1]. Recently, in Italy, a National Integrated Plan for Energy and Climate (PNIEC) has been defined. The PNIEC will be adopted from 2020. This document, the result of a collaboration between three ministries, the Ministry of the Environment, the Ministry of Economic Development, and the Ministry of Infrastructure and Transport, aims to achieve specific objectives such as decarbonisation, energy efficiency, innovation, and competitiveness through an integrated approach. In addition, in Italy, the National Plan for Adaptation to climate change (PNACC) was defined in 2015 to limit the impacts of CC. The PNACC indicates the national strategies needed to protect natural systems and the health and well-being of citizens. Unfortunately, mitigation, which was the first way indicated by the IPCC

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to reduce greenhouse gas emissions due to CC, has not yet produced the expected results, as demonstrated by the latest COP21, 2015, Paris Agreements to keep the variation of Global Warming below the limit of 2 °C, up to COP24 (Katowice, 2018). Therefore, while continuing to pursue mitigation actions, it is necessary to focus and take action on adaptation in an incisive manner [2]. The adaptation that takes place through actions intended to limit, counteract, and reduce the effects of the CC in all its forms on mankind and the environment – living and non-living elements – translates into a single word: resilience [3]. One of the most important skills of human beings is being able to increase their degree of adaptation to mutations, whatever they may be, demonstrating that they are endowed with *natural* resilience, as distinct from *planned* resilience. For example, environmental and climate changes can lead to social and economic changes, some of which are quite significant, even to the extent of inducing mass migration [4, 5] as an adaptation strategy.

THE RESILIENCE

An element of the living and non-living environment is resilient if it increases its capacity to adapt to CC (i.e. to limit, counteract, and reduce – with appropriate technical, structural, and other interventions – the effects of climate change that may damage that environment). In addition a resilient element helps protect humankind and the environment from the effects of CC. This resilience manifests itself in different ways, depending on the type of element or context that is considered. For example, the resilience for a living being is its capacity for "self-repair" after damage; for an ecological system [6], it is the ability to return to its initial state after being subjected to a disturbance; for psychology, it is the ability to cope positively with traumatic events. To facilitate this adaptation to CC, resilience needs to be improved and promoted with procedures and technologies applied at local, national, and supranational levels, bearing in mind that the more resilience technologies are shared, the more effective they are. On the subject of adaptation, the Cancun Agreements created a new framework and a Committee for Adaptation, designed to provide guidelines and know-how to implement adaptation actions in a more coherent and efficient manner by all countries, and in particular by developing countries (WHO, Cancun Agreements, 2010).

LOCAL RESILIENCE AND URBAN AREAS

Today, the resilience of local areas, and in particular urban areas, is one of the principal concern of the UN related to the global environmental situation. For several years now, we have been informed by the reports of IPCC about the worrying global environmental situation: the increase in concentrations of climate-changing gases in the atmosphere, the increase in average temperature, and in the number of extreme or intense weather events. Although almost everyone was convinced of the seriousness of the problem at a global level, many thought that a clear impact at a local level could only be perceived in an unspecified future. Today, however, we know that these great global dynamics are already having an effect at a local level so that not to act immediately and effectively would be a serious mistake. We are therefore witnessing a paradigm shift with regard to climate change, a shift that may be defined from the general to the local level. In fact, after the UN Conference on Environment and Development held in Rio de Janeiro in 1992, 200 governments around the world, including Italy, adopted "Agenda 21", a document of intent to promote sustainable development aimed at combating environmental degradation and improving the quality of life of populations. Agenda 21 deals with very detailed proposals on economic, social, and above all environmental areas, and it addresses specific issues both at a general (or long-term) level and at a local level. In particular, the thematic lines of general importance have been widely disseminated, and many experts have discussed them from a social, economic, environmental, and policy viewpoint. However, few actions have really been taken at local level, thus losing the opportunity to promote sustainable growth in counteracting the effects of CC. In fact, at local level the most significant phases were poorly treated, contrary to the objectives of Agenda 21, which includes:

- programs of concrete local actions;
- audit of the urban environment and specific indicators at a local level;
- monitoring and evaluation of environmental plans at a local level.

Confirmation that acting at this level could be incisive and decisive is given by the observation that the effects of CC are not manifested in the same way throughout the planet, but rather depend on the characteristics and fragility of the environment at a local level [7]. In Italy, for example, in the South and in the extreme north, the effects of the changes taking place are evident, but are very different in their manifestations. The desertification of vast areas in the south and the glaciers that are thinning or disappearing in the Alps are evidence that something important is taking place, but in very different ways. Starting from these different manifestations of the global effects of CC, experts and governments must start to tackle them locally with appropriate methods. In particular, with regard to the health risks associated with CC, which can vary greatly from one place to another, it is necessary to increase the capacity for the adaptation enhancing the climate resilience of health with particular attention to the organization of the facilities and the health services, at the local level. Urbanized areas and, above all, large cities, are not able to respond autonomously to external changes and therefore not even to changes due to CC. In fact, urban settlements do not have "natural" resilience (see PNACC) because they are not able to respond independently to the pressures of any type of external change. In the fight against CC, the European Union also recognizes that cities have a central role to play with the launch of the Covenant of Mayors in 2009 [8, 9], with the adoption of the Adaptation Strategy in 2013, and with the Mayors Campaign for Climate Adaptation, Mayors Adapt [10], in 2014. Urban areas are at the same time among the major emitters of CO2 resulting from human activities (mobility, residence, productive activities, etc.) and the most vulnerable to the impacts of climate change. Much has been written about planned resilience for cities, but not enough, given the complexity [11] involved. Intervening locally in urban areas, and in all those areas where anthropogenic intervention is present in a significant way, is essential in order to increase resilience in a targeted and effective way. In the case of local resilience, some points have not yet emerged well, and others have only partially been dealt with, so in this short paper we will try to add some pieces of the puzzle about local resilience in the urban environment. Due to the delays that have unfortunately occurred, cities that are the most vulnerable to the effects of the CC are confronted with the challenge of developing, implementing, and disseminating:

• local adaptation and resilience measures and interventions;
• technological applications of local adaptation and resilience, more synthetically "resilience actions".

RESILIENCE ACTIONS

The resilience actions are carried out according to an overall area project, in which applications of multiple adaptation technologies are integrated with each other in order to optimize and increase the resilience of the area [12]. The urban effects of exogenous climatic phenomena, such as extreme weather events and abnormalities of heavy rainfall and high temperatures (floods and heat waves that have increased their frequency and duration) in cities add to those already present due to heat islands, air pollution, and hydraulic hazards. All this highlights how air pollution acts as a "multiplier" of the effects of CC [13] in cities. For this reason, resilience actions often have to counteract air pollution in order to be more effective. Local resilience actions, if applied well, can alleviate climate and air pollution discomfort, favouring "adaptation" to CC, with benefits to the environment and the quality of life of citizens, especially their health. As we have seen, resilience means reducing criticality to the effects of CC, of intense or extreme weather events, and of air pollution. At a local level, resilience is all the more effective if it can be implemented in all its forms, that is, each element of the urban area has to be preserved (the resilience of the individual elements contributes to the resilience of a site). Once the resilience of each element has been improved (for those in which it is possible to intervene), it must be monitored, maintained, and related to the resilience of the other elements of the scenario. The resilience of a site and its elements must be:

• maintained and monitored in the technical and functional parts;
• verified in terms of its ability to limit and counteract the effects of CC.

The attention to maintenance and monitoring is aimed at verifying that the resilience of an area remains effective over time and, if not, at allowing timely interventions to restore it. A typical strong point of resilience actions at local level is their *tailor-made* design and organization according to both the site and the elements that compose it, and the environmental and anthropogenic characteristics. The dimension of local government – *an active component of resilience actions* – enables it to steer/support the best design and organisational choices for the characteristics and needs of a site. Local governments can acquire the greatest amount and level of knowledge of the environmental, social, and economic conditions of a given area, in terms of its criticality, risks, and opportunities. Therefore, these actions at the local level are particularly effective because they are tailored to the actual specific characteristics and vulnerabilities of the site, in particular with regard to the effects of CC on the environment and on humankind in terms of health. Another fundamental aspect of resilience actions at local level, which, if well promoted, helps their effectiveness, is the active participation of citizens (individual citizens, businesses and the education sector) in resilience action projects. Their contribution of knowledge and direct use of the territory and their requests are precious elements because they manage to bring out the importance of choosing and activating appropriate solutions to local contexts in terms of social inclusion, ability to activate internal social resources, and ability to self-organize. Participation and sharing in the project allows citizens to be users who are aware of the resilience of the area and also supporters, promoters, and custodians of a resource realized with their contribution. It is difficult to find a better way to raise public awareness of the problems of the effects of CC. The inclusion and the involvement of citizens in evaluation activities are necessary tools in resilience projects as well as technological adaptation devices, because they determine the success of resilience actions in urban areas to be preserved. It is an appreciable achievement to create a sense of belonging, and general appreciation for the conditions of comfort and efficiency in the face of the risks of climate change, in citizens, the users of urban space. Today, the panorama of technological devices to increase resilience at the local level is wide and diversified, with increasingly innovative solutions. To achieve more effective resilience actions to counter/limit the effects of CC in an urban area and achieve the best results, it is essential to prepare a project with the aim of achieving the best resilience actions for that area, in order to safeguard the environment and preserve the quality of life, in particular, the health and well-being of citizens. The initial part of the project needs to involve a careful preliminary environmental study of the area with all the territorial aspects at a local and, if necessary, regional scale. Special attention should be paid to the meteo-climate and hydrogeological-hydraulic scenario, the sources of pollution, the anthropogenic component, and the biodiversity status to define the vulnerability of the natural and human systems of the area and everything that contributes to intensifying the effects of climate change. Particularly in densely populated urban areas, it should be considered that CC affects the health of populations. Prolonged exposure to high air temperatures or heat waves can adversely affect human health with mild disorders such as cramps, fainting, and oedemas. In addition, pre-existing or chronic diseases such as cardiovascular and cerebrovascular diseases, lung diseases, mental disorders, and diabetes are aggravated. Infectious diseases are also influenced by climatic variations, because they favour the migration of pathogenic vectors from different latitudes. Moreover, intense rainy events and the consequent floods can have far-reaching health effects such as immediate deaths by drowning, traumatisms, hypothermia, road accidents, and electric shocks, while in the medium and long term they also include waterborne infectious diseases, mental health and stress problems, respiratory diseases, and allergies. Wind can become dangerous and destructive and in some cases comparable in violence to a hurricane, with gusts that can knock down trees, blow roofs off, knock down structures, and transport blunt objects, carrying with them sand or dust, with obvious repercussions on the physical safety of inhabitants. In addition, drought damages cultivated areas by decreasing agricultural production, and can lead to spontaneous fires in green areas, even within cities, with resultant danger for inhabited areas; in these cases the power of the wind can fuel the flames and carry the smoke away, with consequent intoxication and respiratory problems. Only after having evaluated the components that contribute to the effects of the CC of the area and the connected vulnerabilities is it possible to choose the interventions to be carried out, the devices or the adaptation procedures, and/or the best places to install them. It may happen that a device of proven effectiveness, while responding to the need for adaptation of an area, does not give the expected results because the choice of its location on the territory and/or the method of use is wrong. The location chosen for positioning must have all the characteristics necessary for the device to operate effectively. The choice of the device to be installed and the position in which it is to be placed are the decisive points for the success of a resilience operation. Numerical meteorological models of georeferenced type and of the transport of pollutants in the atmosphere, together with hydrogeological and hydraulic models, are excellent support tools that are able – with adequate simulations – to identify some critical points and vulnerabilities of the area to direct the choice of the device and the best place to install it.

EXAMPLES OF RESILIENCE ACTIONS

Some examples of resilience actions in urban area are outlined below. In the first two cases, the operational tools of adaptation use natural materials and techniques such as vegetation and water that effectively, efficiently, and cost-effectively can act to make the urban environment more resilient. The concept of ornamental greenery is to be considered surpassed by that of functional (or rather multi-functional) greenery:

• The urban park is a large green extension within an urban territory where you can find a natural environment without leaving the city boundaries. It performs a CO_2 reduction action that can be obtained from trees, grassy soils, and all the different forms of greenery; at the same time, it reduces the impact of heat waves, contributing to the thermal well-being of the people who may cool off in an urban park. Cities are becoming larger and more populated; urban parks help to combat pollution and promote the psychological well-being of citizens. There are many examples in various cities around the world, including the park of the Via Appia Antica in Rome, the largest urban park in Italy, or Stanley Park, in Vancouver, Canada.

• The protective vegetal barriers are biological filters studied and used for several years to reduce climate-altering gases and atmospheric pollution. The Institute of Biometeorology (IBIMET) of Consiglio Nazionale delle Ricerche (CNR) has carried out extensive studies on the mitigation of the urban climate through the use of shrub species and trees in cities [14]. According to these studies, the best plants for absorbing CO_2 are wild linden (*Tilia cordata*), hawthorn (*Crataegus monogyna*), and ash (*Fraxinus ornus*), while hackberry (*Celtis australis*) has the best performance in combatting fine atmospheric dust. The elimination of air pollutants occurs by absorption and subsequent metabolization. The subsequent examples instead use natural and non-natural elements, together with innovative technologies and tools.

• The vertical forest aims, through a high concentration of plants, to reduce the amount of CO_2 in the air, to control the microclimate, and to reduce the effects of heat islands and urban pollution [15].

• The distributed urban greenery well conceived and adequately connected with the urban fabric, is able to connect without interruption a city centre with different urban and extra-urban green spaces, parks, gardens, rows of trees, meeting several objectives very well. It reduces greenhouse gases, traps fine dust, produces microclimate mitigation with shade and evapotranspiration, increases the well-being of people in open spaces, reduces the energy consumption required for cooling the surrounding buildings, improves the management of the water cycle by reducing runoff, supports cycling and walking, and gives attractiveness and liveability to streets, squares, and parks, encouraging social aggregation (Atlanta: Proctor Creek Greenway Project).

• The meteoric water, a renewable and local source, requires simple and economical treatments to be used in applications that generally require water of lesser value. Possible uses of rainwater that could mitigate some of the effects of CC are in waterfalls, tanks, water fountains, water mist, water along paths, and water blades. Some examples of rainwater use are washing of paved areas (roads, squares, parking lots), irrigation of green areas, (lawns, gardens), and providing water for fire-fighting tanks.

• The sustainable rainwater management can be oriented to restore permeable spaces, desealing-depaving of portions of land, Rain Gardens, ditches and flood basins, Rain Squares.

Resilience actions using natural and non-natural elements, associated with innovative technologies and tools, can contain local air pollution and greenhouse gas and help control the microclimate [8]. Below are listed examples of these actions, implemented according to environmental sustainability criteria in large cities.

• The Italian pavilion at Expo-Milan shows the use of biodynamic cement in which, on exposure to sunlight, the active ingredient in the material allows certain pollutants in the air to be "captured", transforming them into inert salts. This contributes to freeing the atmosphere from smog and particulate matter also affecting the microclimate [16].

• The Fog-cannon (*Figure 1*) and Fog-lamp are examples of technological tools to contain particulate pollution and maintain the controlled microclimate, reducing the effect of heat island and heat wave by enhancing the resilience of the area.

These technologies have also been used in synergy with catalytic networks for the containment – in open spaces – of dust and fine particles with positive effects also on the microclimate. All these actions, and many others, are likely to counterbalance the traumatic effects of CC, with an obvious advantage not only in the physical health, but also in the psychological balance and mental health of potentially involved people.

ANN FOR RESILIENCE ACTIONS

The artificial neural networks (ANN) are the best solution for the resilience actions management. Resilience actions interact with the complexity of the environmental and anthropogenic systems of the urban area where they are applied, and their effectiveness improves when the feedback generated is interpreted and used effectively. Given the characteristics of dynamism, nonlinearity, and complexity of resilience in the urban environment, the ANN are the best resource available today to optimize the management of resilience actions in the territory [17, 18]. ANN are designed and built for the selection, management, maintenance, and best use of resilience actions, with the aim of limiting the harmful effects of CC, intense or extreme weather events, and air pollution [19].

ANN are the result of extensive interdisciplinary cooperation between computer experts, climatologists, meteorologists, atmospheric physicists, health workers, mathematicians, geologists, environmental engineers, and others. ANN must be able to dynamically relate local climate data and weather forecasts with analytical maps of the urban territory. ANN detect, in the area to be preserved, those elements that are vulnerable to any critical weather event or effects of climate change, which may affect human health or the urban environment, and they suggest a range of appropriate actions to be implemented with specific resilience actions. ANN can identify in advance the most vulnerable elements (thanks also to local weather forecasts) and can therefore support not only interventions in the territory but also health interventions by activating health systems and by providing the local operators in advance with preventive actions.

Figure 1
Application of a Fog-cannon placed at the Italian Embassy in Beijing (Sanlitun).

The positive effects and effectiveness of the resilience actions implemented in urban areas to be preserved will in turn be monitored and evaluated by ANN, in order to select the most effective actions on the territory for both the environment and human health, thus optimizing the future responses of the ANN themselves.

Thanks to the "training function", typical of artificial neural networks, the more ANN work the more they improve their performance [20], and they will be able to suggest the most effective preventive actions to be implemented using the memory of choices and results previously achieved by the resilience actions already applied.

CASE STUDY

A case study of health resilience action is applied to the Phoenix city (Arizona, USA). This new approach using the ANN are able to significantly improve the resilience of a city by managing climate and health emergencies in a preventive and dynamic way. From a scientific research activity between the Arizona State University (ASU), University of Notre Dame (Indiana, USA), and the authors, as part of an ASU-Enea collaboration (2009), it has been developed and tested a particular ANN with the following characteristics consisting of three-layer MLP (MultiLayer Perceptrons) network, of an interconnected system of nodes (neurons) within a hidden layer, of an exponential transfer function, of a training method of conjugate gradients, of an excellent compromise for a non-linear function both globally and locally. These ANN, specialized for Phoenix city, is named EnviNNet (or ENVINNET) [21] to increase the resilience of health facilities. The ENVINNET is based on an overview of the urban territory and its weak points as a function of health resilience to increase it if necessary as happens during the storms of dust from the desert. Therein, an additional advantage of ENVINNET is that doesn't require an expensive emission inventory or its regular upgrading, though input-output relationships are derived using large volumes of historic data. With the ENVINNET computational power and model architecture, it is expected to be reliable and tenable for future resilience actions and human health warnings. For Phoenix area, trough ENVINNET it is possible to make spatio-temporal predictions, which can be automated to issue health advisories for urban communities. Its ability to respond effectively depends on the capacity of self-correcting over time. The aim of ENVINNET is to alleviate, support, and rescue the population during health emergencies due to air pollution peaks generated by the arrival in the city of a dust storm (extreme weather event). The population in such conditions is subjected to great stress, with respiratory crises even of asthmatic type [22], especially in children, and aggravation of pre-existing and chronic diseases. From this arises the need to be able to alert health facilities 24-48-72 hours in advance [23] and prepare them for the onset of the emergency, increasing their resilience, by the assistance of the specialized ENVINNET to the Phoenix city. Due to its characteristics, ENVINNET constitutes a real leap in quality in designing and increasing the resilience of a city, allowing it to manage climatic and health emergencies derived, in an integrated, targeted way, without excessive investments. With the current state of knowledge, this new approach is therefore the most advanced and comprehensive solution available to design and manage resilience actions at city level.

Conflict of interest statement

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