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Research Note

Resilient cities, a key solution to safeguard the environment

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Abstract. In the 21st century, the world population is growing at a spiraling pace. Much of this growth is occurring in developing countries, where access to food, sanitary water, education, and health is severely limited. The ever-increasing urbanization highlighted the need for sustainable development based on human-environment interaction. The excessive and unplanned expansion of cities has resulted in numerous environmental predicaments due to clearly emphasized economic issues at the expense of social and environmental concerns. The most significant features of megacities are indicated in this paper and the environmental, social, physical, and economic criteria are addressed in order to attain sustainability and resilience. To examine the practical use of these criteria, extensive studies and field activities were carried out at District 14 of Tehran Municipality. The results of this study highlight the desire of authorities to move toward sustainable development as their activities indicated environmental improvements during the 2009-2014 period. At the end, several recommendations are made based on the obtained results to speed up the move toward sustainability and resiliency.

1. Introduction

Currently, more than half of the human population resides in cities and by 2030, about 60% of the world's inhabitants would live in cities with more than five million residents. Meanwhile, 95% of the future urbanization would take place in developing countries. Cities across the globe occupy only 2% of the main land; however, they consume 60% to 80% of the energy and cause 2% of the total carbon emissions. They deplete freshwater resources, endanger ecosystems, and strain public health. On the other hand, cities could play an essential role in the global green economy through improvements in transportation, building construction, energy conservation, water

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sanitation, sewage treatment, and addressing socio-economic issues [1].

A very large city, typically one with a population of over ten million people, is defined as a megacity [2]. Megacities all over the world have destructive environmental effects that require governmental interventions to manage them. This calls for the redefinition of the urban management principles by the governments and metropolitan authorities. Otherwise, urban areas in developed and developing countries would be susceptible to adverse impacts of climate change, depletion of resources, lack of food security, and economic instability in the near future. These factors would significantly alter the status of urban and suburban areas in the coming decades. Thus, the term "resilient city" is being used to address the above-mentioned challenges in order to attain sustainability. A resilient city is one that has developed capacities to help absorb future shocks and stresses to its social, economic, and technical systems and infrastructures so as to still be able to maintain essentially the same functions, structures, systems, and identity [3]. Sustainability in a city can be defined as a safe environment, productive economy, and active community.

Since more than half of the global population resides in urban areas, there is no doubt that the issue of urban management is a priority for any given government in the world [4].

Urbanization as the transition phase from rural to urban population will grow rapidly in the coming years, and will continue especially in the developing countries [5]. Presently, more than half the population of Asian and African countries are living in rural areas. However, the trend is rapidly changing towards urbanization.

From 29 megacities of the world in 2014, Tokyo-Yokohama in Japan tops the list with 37,555,000 population, while London with 10,149,000 residents is at the bottom and Tehran, the capital of Iran, with a population of 13,429,000 people is ranked 22nd [6].

The rapid urbanization and increase in the number of megacities have resulted in serious environmental and socio-economic predicaments and have created various challenges in urban strategic planning and policy making [6]. Some of these challenges are cities increasingly having to face rising population, worldwide and regional investments to generate employment, revenue and funds for development, high costs of living, economic disparity, increase in crime rate and dealing with the rising levels of pollution. There are also cities that cannot compete because of low productivity, economic instability, poverty, inequality, and social conflicts [7].

The international concerns about the issue of urban overpopulation are due to its impacts at the global scale, such as excessive exploitation of resources, air pollution, lack of food security, poverty, social discrimination, and vulnerability. These are serious challenges confronting urban policy makers and strategists. Studies conducted by various national and international networks highlight the urgent need for the development of well-defined strategies for expansion of cities, urban land use, and socio-economic management [8].

This paper discusses various elements of megacities and examines steps taken at District 14 of Tehran Municipality toward sustainability and resiliency in Iran.

2. Features and challenges of megacities

There are numerous large and wide cities all around the world. At the present time, urban population has been estimated to be around 3.5 billion of inhabitants and will probably be more than 5 billion by 2030. The term "megacities" was defined for metropolitan agglomerations which hold more than 10 million of inhabitants [9].

As shown in Table 1, the following features are the major characteristics of megacities to be addressed for identification of their potential threats and opportunities at national, regional, and international levels [6].

The increase in number of megacities is considered as the driving force of the global economy that effectively influences the flow of goods, people, culture, and knowledge. Megacities are potentially unique concentration areas of skills and technical resources to improve the quality of life for large numbers of people.

According to the United Nations reports, megacities are struggling to reach a balance between the quality of life, economic competition, and preservation of the environment.

Megacities are the 21st century phenomena whose sheer size, complexity, and essential role as the global economic gateways have created many obstacles to sustainable urban development [1]. It is important to point out that only the environmental challenges are addressed in this article.

Regardless of the megacities' positive aspects, they have a long list of environmental problems. Built-up of water and air pollution, lack of proper waste management, and soil erosion are familiar issues for such cities worldwide. Thus, the main barriers to the sustainable expansion of megacities include [1]:

- Lack of public awareness;
- Lack of proper social behavior;
- Inadequate/insufficient technical knowledge;
- Lack of adequate infrastructures;
- Lack of compatibility between the college curriculum and the actual socio-economic needs;

Table 1. Major characteristics of megacities.

Megacities features	Factors
Population density	Concentration of the human population in reference to space.
Dynamism of growth	Society: Population growth rate; Economy: Real growth rate of the Gross Domestic Product (GDP); Land: Suburbanization rate, land sealing rate.
Settlement, infrastructures, and land ownership	Number and the size of unofficial urban settlements; land-use alteration; quality and the quantity of the urban infrastructures.
Socio-economic inequalities	Poverty rate; unemployment rate; and mortality rate.
Hazards and vulnerability	Mortality risk; economic risk; level of vulnerability determined for each risk.
Urban governance	Participation, rule of law, transparency, responsiveness, consensus; orientation, equity, effectiveness, efficiency, and accountability Indicators; i.e. corruption index.

- Lack of guidelines for effective public participation.

3. Sustainable and resilient city

Sustainable development is a broad term emphasizing the proper long-term use of resources. Sustainability refers to the procedure that could be repeated over and over without affecting other aspects of environment, while being cost-effective. Therefore, "sustainability" simply means to satisfy the needs of the present generation without endangering the well-being of the future generations [7].

A resilient city is built through engagement of its government, citizens, and other stakeholders in the process of disaster risk reduction, where specific actions are taken to identify, manage, and lessen the impacts of natural and human-induced hazards [10]. A city should have certain characteristics to be resilient against potential risks and natural disasters without incurring irreparable damages [11]. Such resilient city, by its capacity can withstand or absorb the impact of a hazard through resistance or adaptation, which enable it to maintain certain basic functions and structures to bounce back or recover from a crisis. Table 2 presents four categories of resilient and sustainable cities based on 12 criteria.

This paper reviews environmental features of a resilient and sustainable city, of which the elements are mentioned in Table 3. However, there are defined indices that determine the quality of each of these factors for sustainability and resiliency. For a case like air, presently several indices can be used such as AQI, AQHI, AQRI [12], or for the case of noise, there are several standards such as US Environmental Protection Agency (US.EPA) noise pollution standards; of course there are national and international regulations for different regions.

3.1. Environmental category

- **Environment conservation.** Protection of the urban environment plays a significant role in its sustainability. For example, the reduction of air pollution or greenhouse gases mitigates the climate change and its adverse consequences [13-18].
- **Protection and expansion of green space.** Green spaces not only reduce the greenhouse gases and improve climate, but also reduce runoffs and risk of flooding, because most cities with asphalt paved streets are vulnerable to flooding. Therefore, protection and expansion of green landscape have effective impact on prevention and mitigation of risks with ensuing financial damages [3,13,14,18].
- **Optimized use of resources.** It includes the reduction in consumption of resources and increase in use of clean or renewable resources and energy. Such steps can mitigate the damages during a crisis and help the sustainability and resiliency of the city [3,15,18].

4. Environmental activities toward sustainability and resiliency, District 14 of Tehran municipality

District 14 with an area of 22.04 km^2 located at the eastern part of Iran capital, Tehran, covers about 3.2% of this city. It is comparatively a small district with high population density. District 14 has 6 regions and 26 neighborhoods with 483,833 residents. Figure 1 shows the location of District 14 alongside other districts in Tehran [19].

Table 2. Considered environmental, social, physical, and economic criteria.

Categories	Criteria
Environmental	Conservation of the environment; Protection and expansion of green space; Optimized use of resources.
Social	Providing continuous education and training at schools and local communities to increase public awareness; Interaction with the social media; Communication with various communities and institutions.
Physical	Establishment and improvement of infrastructures, monitoring the construction process; Risk assessment and determining the potential dangers and planning for their mitigation and implementing action plans; Defining and determining the organizational structure and the responsibilities for the management of crisis.
Economic	Determining and allocating the required budget for the establishment and development of infrastructures and other effective steps to increase city resilience; Providing loans for the modernization of old buildings and reinforcement of weak structures or those located in high-risk areas; Ability to allocate the required budget in a crisis.

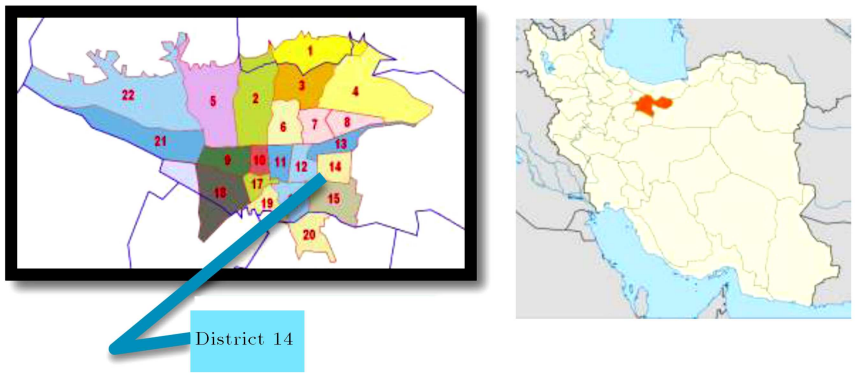

Figure 1. Location of District 14 in Tehran City's municipal divisions.

The following is a brief description of activities in District 14 during the 2009-2014 period.

4.1. Environmental protection

District 14 of Tehran Municipality has conducted measurements on air, ground water, and noise pollutions with subsequent implementation of ongoing mitigation measures since 2011. These actions have been in line with the conservation of the environment. The status of the district in terms of the above-mentioned issues is explained below:

- **Air pollution in District 14.** Air pollution is a serious problem in Tehran. Due to lack of proper and modernized model of urbanization, high concentration of population, and heavy traffic, District 14 is one of the most polluted areas of Tehran. Thus, with the objective of air pollution reduction, District 14 developed a crisis map of air pollution in 2011. To this end, a lengthy study at 25 selected monitoring stations was conducted. Particulate matter of pollutants less than 2.5 micrometers ($PM_{2.5}$) was measured at the aforesaid stations. The results indicated that District 14 had $PM_{2.5}$ concentrations above the permissible standards in accordance with the Iranian Department Of Environment (DOE) regulations during every monitored season [19]. Since the air pollution was above the permissible limits, actions have been taken to mitigate pollution and improve air quality of the district in recent years as a priority in its urban planning. Amongst these actions were the use of less polluting vehicles and enforcement of

Table 3. Environmental elements of a resilient and sustainable city [22].

Topic	Factors determining sustainability & resiliency of megacities	Issues influencing the factors
Air	Urban environmental quality	Air quality in urban areas
	Environmental management	Density of stationary control sites
		Number of supervised pollutants
		Number of polluted days
Energy	Energy usage	Energy consumption per person
		Energy consumption in each sector (household, industrial, agricultural, commercial, services, etc.)
		Amount of natural gas consumption per person
	Urban action plan	Implementation of Environment and Energy plan
Green Space	Urban environmental quality	Density of public green spaces
		Density of various green centers (urban parks, historical green areas, local parks, green belts, children playgrounds, gardens, etc.)
	Environmental management	Annual construction of new green spaces
		Annual statistics of green spaces
		Implementation of urban green plans
Noise	Environmental management	Number of noise measurement stationary sites
		Installation of noise barriers
		Number of noise supervision camps
		Number of public protests due to noise pollution from industrial, traffic, and repair sources
		Number of activities conducted by the municipality causing noise pollution (festivals, sports events, vehicles, etc.)
		Number of driving tickets for noise pollution
	Urban action plan	Implementation of noise zoning plan
		Implementation of noise reduction plans
Transportation	Infrastructural equipment	Length of railroad infrastructures
		Density of railroads
		Density of railroad lines per type (conventional railroad, monorail, subway, etc.)
	Density of vehicles	Density of personal cars
		Density of transportation vehicles
		Density of taxis
		Number of urban vehicles per type (personal cars, buses, motorcycles, trucks, etc.) and fuel type (regular gasoline, unleaded gasoline, diesel, etc.) and their average age
	Environmental management	Number of sidewalks
		Length of bicycle paths
		Number of traffic limitation zones
		Number of free public parking
		Number of pay public parking
	Passengers of transportation fleet	Number of passengers riding on buses, monorails, subway, etc.
	Urban operational plan	Implementation of urban traffic plan
		Innovative traffic control plans

Table 3. Environmental elements of a resilient and sustainable city [22] (continued).

Topic	Factors determining sustainability and resiliency of megacities	Issues influencing the factors
Wastes	Production and management of wastes	Collection of urban wastes
	Environmental management	Separated collection of wastes based on their type (paper, glass, plastic, aluminum, metal, wood, organic, etc.)
		Number of sanitary land fills
		Number of garbage bins
		Number of camps promoting separation of wastes from the origin
		The amount of fine for illegal disposal of wastes
Water	Water resources	Water consumption per capita
		Household consumption per capita
		Consumption per capita (household, industrial, agricultural, commercial, etc.)
	Environmental management	Number of sewage treatment facilities
		Percentage of sewage network subscribers
Demographic land information	Public indicators	Lands across the urban area
		Population density
		Number of housing units

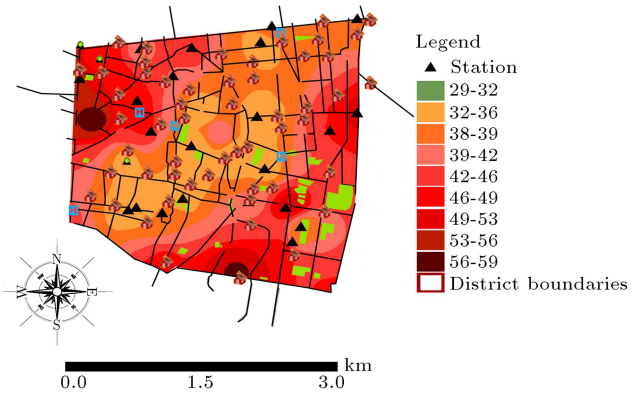

Figure 2. A sample of $PM_{2.5}$ (micrometers) distribution at District 14 [19].

regular technical inspection, promoting bicycle rides to reduce fossil fuel consumption, and development of green spaces to reduce air pollution. Figure 2 illustrates the distribution of $PM_{2.5}$ at District 14.

- **Noise pollution in District 14:** The measurement of noise pollutants was conducted in 2011 and specific steps were envisioned to reduce noise pollution till 2014. Thus, 91 stations were selected and noise equivalent levels were measured three times on Saturdays to Wednesdays in the morning (7-9), noon (12-3), and afternoon (5-8). Based on the results of this research, noise equivalent levels in all stations were above the standards [20].

Due to high level of noise pollution, some recommended measures for control and mitigation were put on the district agenda. Figure 3 illustrates the recommended steps. Some of these actions include increase in highways green spaces through plantation of dense vegetation with a combination of broad-leaf and needle-leaf trees, construction of noise absorbing levees covered with vegetation, and use of acoustic walls based on technical specifications as shown with dark lines in Figure 3. Also, some of the streets were widened as indicated with red lines in Figure 3.

With respect to the potential impacts of high noise levels on certain residential areas, engineering measures are being implemented during the building construction, including the use of double layered windows, thick glasses, insulated external walls, ceilings and floors, and the use of noise-absorbing building materials. All of these measures are being implemented in this district to mitigate noise pollution.

- **Ground water contamination in District 14:** The assessment of ground water pollution and prevention of its contamination are essential. Sampling of 16 wells (their locations are shown in Figure 4) used for green space irrigation was conducted in order to identify the qualitative status of ground waters and the factors threatening their quality. The

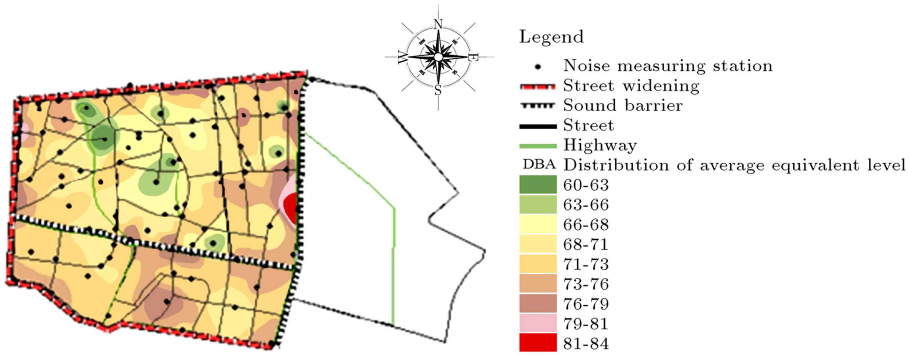

Figure 3. Recommended actions to mitigate noise pollution in District 14 [20].

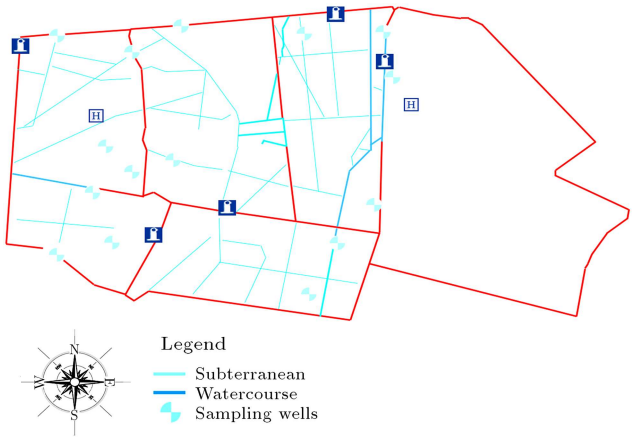

Figure 4. Location of sampling wells in District 14 [21].

measured factors were physical parameters (temperature, color, and odor), chemical parameters (pH, EC, TSS, and TDS), anions (NO_2, NO_3, Cl, SO_4, CO_3, and HCO_3), cations (Mg, K, and Na), heavy metals (Pb, Ag, and Cd,), and MTBE. Comparison of the 17 measured parameters with the standard levels (the chemical parameters and the anion concentrations were compared with FAO standards, the heavy metal concentrations were compared with Australian Water Quality Guidelines) revealed that these wells were within the accepted standard limits, which are presented in Table 4, and suitable for agricultural purposes based on the Wilcox classification [21]. Reduction in use of pesticides and chemical fertilizers as well as practicing environmental protection measures throughout painting and washing of urban structures are on the agenda of the municipality. Measurements of ground water and comparison of them with international standards show that concentrations are within standard limits, as indicated in Table 4.

4.2. Protection and expansion of green space

The green space area at District 14 has increased from 2,430,000 m^2 in 2009 to 2,857,600 m^2 in 2014. Also, the nearby forest called Ghasr-e-Firouzeh has been expanded from 355 hectares to 369 hectares during the same period. Although the expansion plan is considerable, there are still potentials to extend and reclaim more lands. With the aid of proper planning, such as implementation of drip irrigation, use of recycled waste water, etc., the green space per capita in the district can reach more than 6.08 square meters in the future; the present value is around 5 square meters.

4.3. Optimized use of resources

Despite the steps taken for utilization of renewable energies, reduction of waste, and recycling, there are many shortcomings.

Lack of optimized use of rain water and local water resources, and inability to suitably exploit solar and wind energies are the main deficiencies in District 14. However, there are certain measures outlined to attain the optimized use of resources and energy.

Table 4. Minimum, maximum, and average amounts of parameters of the ground water in the region [21].

Parameter	Analysis								
	Nitrate NO_3^- (mg/L)	NO_2^- (mg/L)	SO_4^{2-} (meq/L)	CO_3^{2-} (meq/L)	HCO_3^- (meq/L)	Cl^- (meq/L)	Na (meq/L)	K (meq/L)	Mg (meq/L)
Average	106.96	0.26	2.69	0	4.85	4.23	5.87	0.055	2.25
Maximum	297	3.1	5.95	0	6.96	9.94	12.21	0.117	2.95
Minimum	33	0.06	1.66	0	2.95	2.99	3.08	0.033	1.63
Median	102.15	0.06	2.35	0	4.91	3.97	4.95	0.049	2.21
Acceptable max [23]	10	5	20	1	10	30	40	0.051	5
Acceptable min [24]	0	0	0	0	0	0	0	0	0

Table 5. Environmental criteria as the city resilience indices and actions taken by Tehran Municipality, District 14.

Classification	Criteria	Actions taken by Tehran Municipality, District 14
Environmental	Environmental conservation	Attainment of ISO 14001 certificate in 2009 and its extension for 5 consecutive years
		Studying the pollution sources (air, ground water, and noise pollutions) and existing pollutions in the region, eventually providing an action plan to remove or control them
	Conservation and expansion of green landscape	Expanding the green landscape from 2430000 m^2 in 2009 to 2857600 m^2 in 2014, expansion of Ghaser-e- Firouzeh Forest from 355 hectares in 2009 to 369 hectares in 2014
	Optimal use of resources	Use of renewable energies, like solar, through installation of 7 solar water heaters and 64 solar light stands in parks
		Use of local water resources and wells for the irrigation of green spaces
		Increasing the separation and recycling of urban wastes from 19.15% to 22.1% with potential for future activities.

The pertinent environmental criteria and the actions taken by District 14 are listed in Table 5.

According to the results of this study, the status of several environmental criteria, such as environmental conservation, expansion of green space, and optimal use of resources, has improved from 2009 to 2014.

5. Conclusion for the attainment of resilient city and safe environment

The expansion of cities has increased the population density, created various types of environmental pollutions, raised energy consumption, and produced greater amounts of waste. Therefore, there has been great environmental impact at local and global levels that require profound urban management and planning.

This paper evaluated the sustainability and resiliency of District 14 of Tehran Municipality from the environmental perspective. Outcomes of this research indicate that certain criteria have improved significantly during the 2009-2014 period.

This was achieved by senior management's commitment to environmental conservation, green space development, obtaining ISO 14001 as well as HSE management system certificates, and performing detailed studies on air, noise, and water pollution. Subsequently, effective measures have been taken to mitigate the adverse effects of environmental pollution and a monitoring plan has been implemented through an annual environmental auditing program.

The local authorities intend to move towards resiliency and sustainability not only to safeguard the environment, but also to tackle socio-economic issues and to initiate preventive measures combating natural disasters. However, the study results indicate that there is still a long way to go in other important issues such as optimized utilization of water and energy resources. Albeit, the overall resilience status of District 14 has increased during the past 5 years. It could be concluded that the ultimate benefits of resilient and sustainable cities outweigh the initial investment by the national and local governments. The long-term national goal is to establish a network of resilient cities.

Although economic activities result in better individual and collective well-being of citizens, they usually instigate individual, social, and environmental tensions. On the other hand, economic recessions in large populated areas instigate unemployment, weaken social cohesion, disturb social security, and neglect environmental issues.

Therefore, sustainability of cities requires all the environmental and socio-economic ingredients coupled with public awareness and strong commitment to conduct the envisioned tasks including:

- Development of new plans and/or revision of the present plans;
- Establishment of new priorities;
- Utilization of resources for sustainable causes;
- Cooperation with other legal entities in the regions to attain sustainability [11].

Other proper activities for future achievements can be listed as follows:

- Promotion of the use of alternative energy resources;
- Construction of energy-efficient buildings;
- Using higher energy-efficient vehicles;
- Taking actions to combat the emission of Greenhouse Gases (GHG), especially CO_2;

- Recycling water and waste;
- Utilizing vegetation coverage to filter pollution and absorb atmospheric carbon dioxide;
- Cooperation with governmental institutions and municipalities;
- Cooperation with higher education institutions and executive; organizations;
- Conducting urban repair and maintenance plans;
- Reducing air pollution caused by urban transportation vehicles;
- Promotion of green construction and sale;
- Taking actions to mitigate the emission of GHG gases;
- Decrease in the use of pesticides in urban areas;
- Promotion of environmental preservation;
- Encouraging use of public transportation;
- Improving and optimization of the transportation infrastructures;
- Improving and expansion of the infrastructures of the green city;
- Participation in the local, national, and international meetings and sharing the attained experiences with them and eventually joining the global network of sustainable cities;
- Using endemic knowledge alongside the scientific studies in order to find ways to combat the potential risks by recognizing the intrinsic value of local know-how.

Since the nature of each megacity can be different in terms of geographical, social, economic, and other aspects, further studies are required in order to be able to clarify required specifications for the factors of resiliency.

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Biographies

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