THE NEW BALANCE(S) OF PORTO'S CLIMATIC SUBSYSTEM: AN EVIDENCE OF WELL-BEING AND QUALITY OF LIFE OF POPULATIONS

Ana Monteiro
Curso de Geografia da FLUP
Via Panorâmica, s/nº, Apartado
4150 Porto, Portugal
Telef. (3512-6077100)
Fax (3512-6077153)
E-mail - anamt@letras.up.pt.

Abstract:

The results achieved, to the present date, in relation to the obtainment of a clear evaluation of the effects due to the development strategy choosed for all the NW of Portugal, still seem far from the desirable. The impact assessment of such a strategy, first on the Ecosystem and, later, on the sustainable development strategy itself, is, in my opinion, a priority to endow the decision-makers with the most adequate planning alternatives.

However, the impacts caused by the growing urbanisation process in Porto's Urban Ecosystem (namely at the level of the energetic balance) made us aware of the difficulties faced in the process of identifying causes and consequences deriving from such a complex area, in wich the variables, the web of inter-relationships and feed back mechanisms are so diversified.

Although the results obtained during the last two decades from the analysis of behaviour of some climatic elements clearly showed several examples of what we called the **new balances** of **Porto's Climatic Subsystem,** they also revealed the difficulties concerning the dissociation between the intrinsic climatological variability and the induced by anthropic processes.

The evidences of urban heat islands and of a cause-effect relationship with the urban metabolism, represent a definite encouragement to use the local and regional climate as a potential indicator of urban environment quality.

Keywords: Urban Environment, Sustainable Development, Urban Heat Island, Urban Air Quality Degradation.

1. Introduction

Porto is a north-west coast portuguese city, stage of an enormous economic growth during the two last decades. Especially after becoming membership of the European Union, in 1986.

During this period of growth Porto's industrial and commercial location patterns and accessibility changed and were closely followed by the already expected reflexes in behavior and mentalities. There was an enormous increase in the family incomes for the majority of the people, induced by this continuous afflux of money from E.U., imediately translated in a wild competition in an enlarged and more appellative market, wich obviously carried at the same time some more negligent attitudes towards all the environmental components (eg. air, water, soil, etc.).

The economic growth of Porto metropolitan area, as well as all the coastal cities from Braga till Setúbal (Fig 1), was one of the main responsible for the extraordinary national increase in energy requirements and emissions recorded during the 80's.

Aware of the potential impacts on the ecosystem, and particularly on the climatic system, due to this land use and atmospheric modification, as we witness during the last 20 years at Porto, and sensible to the widespread debate around the *Global Warming*, we started to compile the available climatological data in order to investigate the possibility of finding some consistent evidences that regional climatic change has begun.

Porto's geographical context is however, very complex (Fig.2). Confined by the Atlantic Ocean on the west and to the south by the Douro's River and with some important orographic barriers on the east, it has a mosaic of local climates whose boundaries are not always easy to delineate.

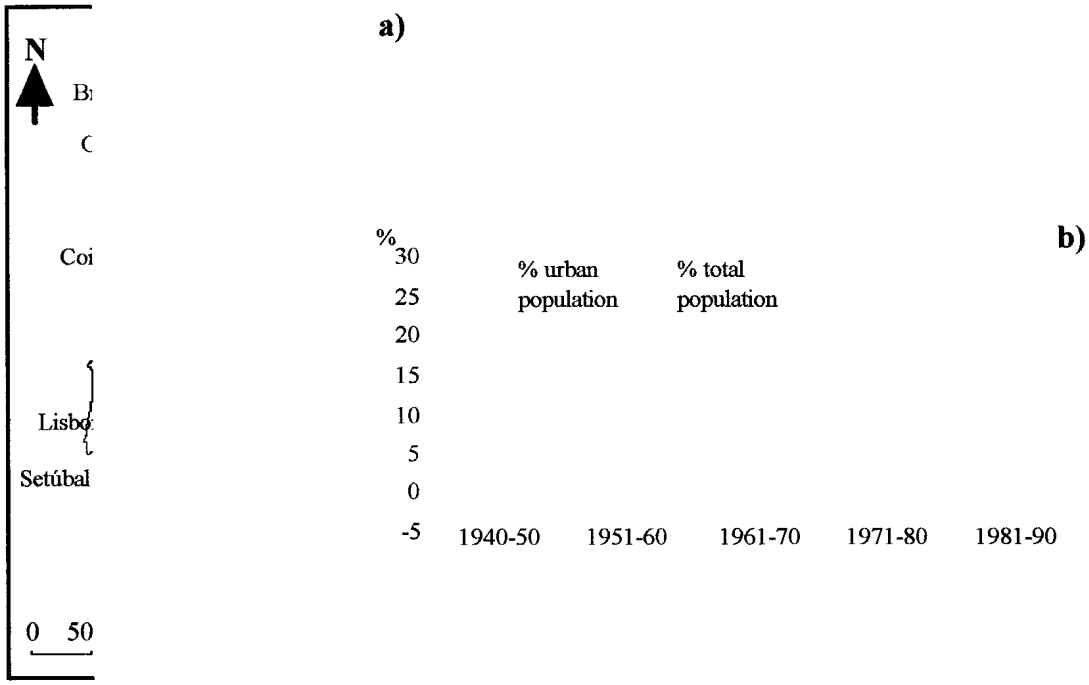

Fig. 1- Most important cities in Portugal (a) and relationship between total and urban population increase in the country during the last 50 years (b).

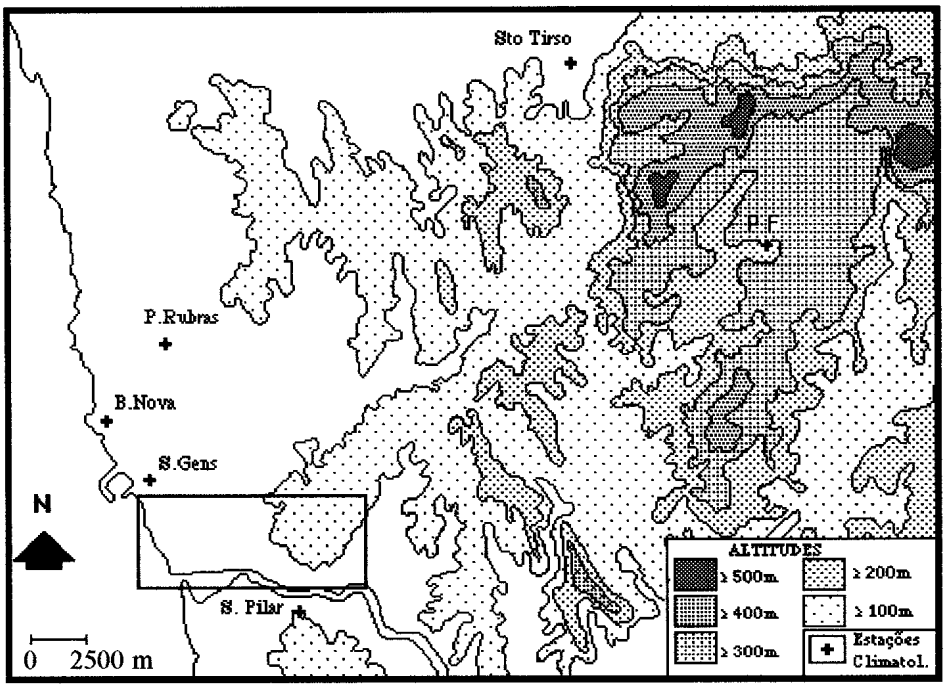

Fig.2 - Porto and its geographical environment.

With all this geographical diversity it is not easy to understand and differentiate, as we would like, the intrinsic climatic variability from that induced by anthropogenic influences.

However, almost all Porto citizens have noticed, during the last 30 years, the air quality and soil degradation, the dilapidation of the natural patrimony, the constant reduction of the green areas and the local and regional climate change

To support this though, first, we have to demonstrate that there are some evidences of climatic modification, and second that these changes are due to the intensification of the urbanization process.

2. Climatological Statistics

We begun our research by looking through the mean, maximum and minimum temperature records at Porto-Serra do Pilar[1] (Fig.2) for the period 1900-1996, and it emerges that especially the 1980's second half and 1990's correspond to extraordinary hot years. This is particularly evident when we plot the values recorded during this more recent years in the Minimum and Maximum Temperature Century Probability Calendar (Monteiro, 1993).

This conclusion is drawn also if we compare the minimum and maximum temperatures for the periods 1931-60 and 1960-89 at Porto-Serra do Pilar (Table I) as well as it can emerge if we observe the upward trend of the 4 years running mean for the maximum and minimum temperature at the same climatological station, during the last 20 years.

This upward trend is especially evident in the minimum temperatures and during the colder season. For example, the minimum temperature increase of 0.4°C in January, 0.8°C in February, 0.6°C in October and 0.3°C in December during the last 30 years period (Table I).

		Tmax.(°C)	**Tmin.(°C)**
JANUARY	NORMAL 31-60	13,2	4,7
	NORMAL 60-89	**13,4**	**5,1**
FEBRUARY	NORMAL 31-60	14,2	5
	NORMAL 60-89	**14,2**	**5,8**
MARCH	NORMAL 31-60	**16,3**	**7,5**
	NORMAL 60-89	16	6,8
APRIL	NORMAL 31-60	**18,4**	**8,8**
	NORMAL 60-89	17,5	8,3
MAY	NORMAL 31-60	19,6	**10,8**
	NORMAL 60-89	19,5	10,6
JUNE	NORMAL 31-60	**22,6**	13,4
	NORMAL 60-89	22,5	**13,5**
JULY	NORMAL 31-60	24,7	14,6
	NORMAL 60-89	24,6	**14,9**
AUGUST	NORMAL 31-60	**25**	14,6
	NORMAL 60-89	24,9	14,6
SEPTEMBRE	NORMAL 31-60	23,7	13,6
	NORMAL 60-89	**23,9**	**13,8**
OCTOBRE	NORMAL 31-60	20,8	10,8
	NORMAL 60-89	20,9	**11,4**
NOVEMBRE	NORMAL 31-60	**16,7**	**7,8**
	NORMAL 60-89	16,6	8

[1] Porto-Serra do Pilar is the only climatological station within the area with sufficient data to do this exercise. The other 5 climatological stations shown in Figure 2 - Boa Nova, S.Gens, Pedras Rubras, Paços de Ferreira and Santo Tirso- do not have the sufficiently long time series.

DECEMBRE	NORMAL 31-60	13,7	5,4
	NORMAL 60-89	**13,8**	**5,7**

Table I - Comparison between the 30 years average of maximum and minimum temperature for the period 1931-60 and 1960-89 at Porto-Serra do Pilar (Monteiro, 1993)

A more detailed look at the data of the last two decades (Table II) strengthens that the higher temperatures at Porto are neither accidental nor fortuitous. They agree with the tendency shown by other cities located in the middle latitudes wich belong to the so called group of *Developed Countries* (Flohn & Fantechi, 1984).

	Tmin (°C)	Tmax (°C)
1971-74	9.25	18.6
1975-78	9.75	18.5
1979-82	9.90	18.9
1983-86	10.00	18.9
1987-90	11.00	19.5
1991-94		

Table II- The 4 years average of maximum and minimum temperature during the period 1971-90 at Porto-Serra do Pilar (Monteiro, 1993)

Analysis of the climatological data of the 6 available stations in the region, for the period 1970-89, show that[2]:

- the highest values of minimum temperature always occurred during the 1980's (1988 and 1989 and include 45% of the highest values found in all the series);
- the lowest values of minimum temperature always occurred during the 1970's (90% of the values recorded in all the series of the 6 stations);
- the highest values of maximum temperature always occurred during the 1980's (85% of the highest values in the series).

This, wasn't followed by an increase in the irregularity of the climatological series. For example, 53 of the 60[3] lowest minimum temperature values occurred during the 1970's, and only 7 of the lowest values happened after 1980. At the same time 50 of the total 60 lowest maximum temperature records also occurred during the 1970's.

Further, neither the coefficient of variation, nor the standard deviation showed any increase in the irregularity of the data sample during the 1980's.

We conclude that this steady increase, especially in the winter minimum temperatures, can not be merely interpreted as the result of intrinsic climatic variability. It should be viewed as a short-term temporary answer to the uncountable human interferences in the climatic system.

The precipitation data of the available climatological stations in Porto region, besides exhibiting much more variation, add a helpful contribution to corroborate our previous hypothesis about the persistent peculiar, sudden and unexpected answers of the climatic system during the 1980's.

Either the 5 years running means or the regression analyses seem to denounce an increase of the monthly precipitation totals in April and November, in all the 6 stations, and a general tendency for a major variability in the intra and interannual rythm. It looks like we are facing a transitory phase of a certain disarrangement and disorganization within the climatic system.

---

[2] Remember that now our matrix is 12 months x 6 stations x 20 years.

[3] The 12 monthly minimum temperature records of the 6 climatological station.

As a good example of this, at least apparent, disorder in the usual intra and interannual rythm of precipitation in our region, we can bear in mind the increased frequency of occurrence of successive periods of unusual droughts and heavy showers, as happened in 1988-89, when after the extraordinary wet Summer of 1988 took place an astonishing drought that persist since September 1988 till August 1989 (Table III).

3. Urban Heat Island

The climtological evidences suggest that the warming is, to some extent, due to the intensification of the urbanization process of Porto, we should be able to find within the urban area considerable differences among the absolute values for several climatological variables (temperature, precipitation, humidity, nebulosity and wind velocity, etc.).

Year (Sep/Aug) Clim.Stations	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89
S.Pilar	110%	119%	99%	89%	121%	59%
P.Rubras	88%	112%	91%	88%	115%	50%
S.Gens	103%	128%	104%	104%	135%	63%
Paços de Ferreira	91%	116%	94%	74%	115%	51%

$$\text{Drought intensity} = \frac{\text{Annual precipitation of a considered year}}{\text{Average annual precipitation for the century}} \%$$

Table III - Drought intensity during the last 6 years of the last decade (Monteiro, 1993).

Having seen this we proceed our research presuming that to be sure that all this evidences are, at some extent, due to the intensification of the urbanization process of Porto, we should be able to find within the urban area considerable differences among the absolute values for several climatological variables (temperature, precipitation, humidity, nebulosity and wind velocity, etc.).

If the climatic system isn't immune to the considerable increase on the amount and diversity of the outputs delivered by the Porto urban metabolism to the atmosphere, especially during the last twenty years (Fig.4), then all this modifications in the chemistry of the atmosphere should emerge, for instance, by the presence of one or many intense *Urban Heat Island(s)*.

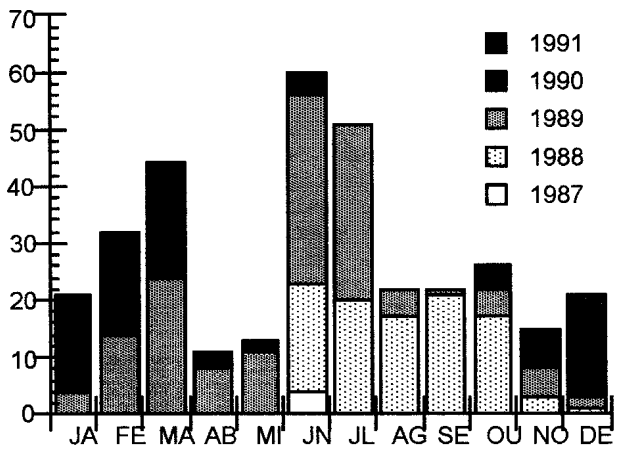

Fig.4 - Number of days with SO_2 concentration $\geq 150\mu g/m^3$ recorded in the air quality monitoring stations at Porto (Monteiro, 1993).

Unfortunately the intense land use, the compact but heterogeneous build area, the variety of construction materials, the great proportion of impermeable surfaces, associated with considerable topographic differences didn't allowed us to find an *urban heat island* as intense, as frequent and as well delimited as we know that appears in other cities.

Having had the chance of collecting the half-hourly temperature records during December 1990 at the city centre we noticed the great impact on the temperature patterns due to an major and more extense activity in the Porto's CBD. In fact, during the period of late-night shopping immediately before Christmas the daily behaviour of the temperature changed completely (Fig.5).

Fig. 5 - Half-hourly records of temperature at the Porto's city centre and at Porto-Serra do Pilar in 22nd, 23rd and 24th December 1990 (Monteiro, 1993).

Using a combination of the records obtained in several traverses temperature and relative humidity measurements (1989-1997) we came out with rural-urban temperature differences of as much as 10°C (Fig 6).

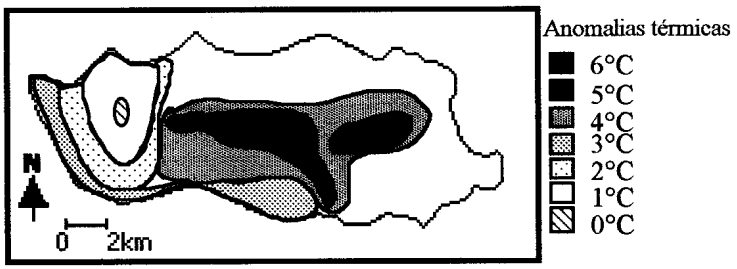

Fig.6 - Average of the urban-rural temperature differences recorded in several traverses temperature measurements (Monteiro, 1993).

Nevertheless the shape and intensity of the Porto ***urban heat island*** changed a lot, from one day to another, according with the the weather type prevalent. The wind velocity and direction, the type and the vertical structure of the atmosphere have an effective control upon the thermic pattern within the city favorable to some factors more than others.

As we said before the the thermic pattern, of Porto, is the instantaneous result of 3 main vectors: the distance to the atlantic ocean and/or to the Douro's river, the altitude and the intensity of the site urbanization phenomena.

The ***urban heat island*** developed better and persisted longer under anticyclonic weather conditions, especially when there was an outstanding temperature inversion in the atmosphere.

The east, north-east and south-east winds often confine the breeze effect to a small narrow zone along the west coast allowing the urbanization effect, on the energy balance, to proceed almost till the sea. In addition, this winds E-W carry with them all the pollutants emitted by the old small and disperse industries located in the oriental half and hilly terrain of the city (Fig. 7).

While looking to the available air quality data we found that the majority of the high polluted days recorded in the urban air quality stations were associated with this type of circulation, what may mean that the city is polluted by its own emissions. The main sources of this emissions seem to be the old, small and high pollutant industries of the east part of the city. In those days it looks like Porto is the victim of it's own industrial outputs delievered to the atmosphere without any kind of control (Fig.9).

The huge plants located in the NW outskirts of the city, under NW or NNW fluxes, may also carry to the city a considerable amount of pollutants (Fig.9 and 10).

Having seen this we understand better now that besides all the originality of the geographical context when we compare the results obtained in our research about the urbanization effects on regional climate, with the predicted by the Oke, T.R. (1973) formula, relating population size and *urban heat island* intensity, we come to the conclusion that there is a minor and insignificant difference (Table IV).

CITY	INHABITANTS	T(u-r)measured	PREDICTED	AUTOR
LONDON	8500000	10°C	9.9°C	CHANDLER, 1965
BERLIM	4200000	10°C	9.3°C	GRUNOW, 1936
VIENA	1870000	8°C	8.5°C	SCHMIDT, 1927
SHEFFIELD	500000	8°C	11.5°C	GARNETT, 1966
MALMO	275000	7.4°C	7.4°C	LINDQVIST, 1972
LISBON	830000	4°C-5°C	7.8°C	ALCOFORADO,1988
COIMBRA	98000	5°C	6.0°C	GANHO, 1992
PORTO	300000	**6.0°C**	**6.9°C**	MONTEIRO, 1993

Table IV - Comparison of Porto urban-rural temperature differences measured and predicted with the Oke, T.R. formula: DTu-r (max.) = 2.01 log. pop.- 4.06, with the results obtained in other European cities, (adapted fom OKE, T.R.,1973, except the values of Lisbon, Coimbra and Porto included afterwards by us).

Apart from the fact that the shape and intensity of the Porto *urban heat island* changed a lot according with the the weather system, and even doesn't exist during some good atmospheric dispersion days, we suppose that it's clear that in spite of all the excellent geographical conditions to dilute the urban impacts on the energy balance, especially due to the frequence of occurrence of good *clean air* conditions, the impacts exists and are relatively easy to witness and testify.

Conclusion

Accepting this systemic view of the environment, it's important, even from the economic point of view, to include the climatological constraints or enhancement at the planning level in order to improve the decision-makers knowledge of the reality and to make more useful and take advantages from the validate

References

DAVEAU, S.- *Répartition et rythme des précipitations au Portugal*, CEG, 1977.

DAVEAU, S., *Geografia de Portugal I. Posição Geográfica e o território*, Edições João Sá da Costa, Lisboa, 1991.

DETWYLER,T.R., MARCUS, M.G., Urbanization and environment, Duxbury Press, Belmont, 1975.

DICKINSON, R.E., "Impact of human activities on climate- a framework", Sustainable development of Biosphere, W.C.CLARK, MUNN,R.E. (ed.), IIASA, Cambridge University Press, Cambridge, 1986, p.252-289.

DJEN, C.S., "The urban climate of Shanghai", Atmospheric Environment, vol.26-B, n°1, 1992, p.9-15.

DOORNKAMP, J.C., Global Warming: Climate Change and rising sea levels : a bibliography, Long Eaton: M1 Press, 1990

DOUGHTY, R., "The human predator: a survey", Perspectives on environment, Association of American Geographers, public.n°13, Washington, 1974.

DOUGLAS, I., The urban environment, Edward Arnold, London, 1983.

DOUGLAS, I., "The rain on the roof: a geography of the urban environment", Horizons in Human Geography, GREGORY, D., WALFORD, R. (ed.), London, 1989, p.217-238.

FEIO, M., HENRIQUES; V.- *As secas de 1980-81 e de 1982-83 e as principais secas anteriores - intensidade e distribuição regional,* CEG, nº10, Lisboa, 1986.

GANHO,N., MONTEIRO, A.- "Nota sobre a anomalia climática de 1 de Junho a 10 de Julho de 1988 em Portugal Continental", *Biblos,* vol.LXV, Coimbra, 1989, p.166-188.

HARE, F.K., Climatic Variability and Change, in *Climate Impact Assessment*, Jonh Wiley & Sons, New York, 1985.

HOUGH, MICHAEL ,*City form and natural process*, Routledge, London, 1989.

JONES, P.D., WIGLEY, T.M.L, Marine and land temperature data sets: a comparison and a look at recent trends, in *Greenhouse-gas-induced climatic change: a critical appraisal of simulations and observations*, SCHLESINGER, M.E.(ed.), Elsevier Science Publishing Company, New York, 1991.

MacDONALD, G., SERTORIO, L. (ed), *Global Climate and Ecosystem Change,* NATO ASI Series, vol. 240, Plenum Press, New York, 1989.

McBURNEY, STUART, Ecology into economics won't go or life is not a concept, Green Books, Cornwall, 1990.

MILLIMAN, J.D., Sea-level response to climate change and tectonics in the Mediterranean sea, in *Climatic Change and the Mediterranean - environmental and societal impacts of climate change and sea-level rise in the Mediterranean region*, JEFTIC, L., MILLIMAN, J.D., SESTINI, G., (ed.), Edward Arnold, London, 1992.

MONTEIRO, A.- *O Clima Urbano do Porto - contribuição para a definição de estratégias de planeamento e ordenamento do território*, Tese de Doutoramento, FLUP, Porto, 1993, polic.

O' RIORDAN, T., *Environmentalism*, 2ª ed., Pion Limited, London, 1983.

OKE, T.R., "City size and urban heat island", Atmospheric Environment, 7, 1973, p.769-779.

OKE, T.R., "Review of urban climatology - 1973-1976", WMO Techn. Note, nº 169, Geneva, 1979.

OKE, T.R., "Canyon geometry and nocturnal urban heat island: comparation of scale model and field observations", Journal of Climatology, 1, 1981, p.237-254.

OKE, T.R., "The energetic basis of the urban heat island", Quarterly Journal of the Royal Meteorological Society, 108, 455, 1982, p.1-24.

OKE, T.R., Boundary Layer Climates, 2ª ed., Routledge, London, 1990.

OKE, T.R., ZEUNER, G., "The surface energy balance in Mexico City", Atmospheric Environment, vol.26-B, nº4, 1992, p.433-444.