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Heat Contamination of Ground Waters in Moscow

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ABSTRACT

Moscow is one of the largest cities of the world, occupying an area of 1081 square kilometer. Density of the population also is very high at about 10000 people per square kilometer. The infrastructure in the city is powerfully developed, however significant part of it is found in unsatisfactory condition. The majority of infrastructure objects promote heat contamination of the city environment. The significant share of the contamination occurs in the geological environment. The sources of the contamination are in the first queue water-caring communications, plants, heated buildings with greater heat losses, ponds and rivers in which heat regime is changed etc.

The result of hot water leakage from underground water-caring communications, in particular, is a change of the thermal field of ground waters. The depth and periods of soil freezing in Moscow are also powerfully violated in contrast with background region. Influence of the heat contamination on hydrodynamic and temperature regimes of ground waters is researched in the article.

1. INTRODUCTION

Moscow is one of the largest cities in the world, occupying an area of 1081 square kilometer. Density of the population also is very high and is about 10000 people per square kilometer. The infrastructure of the city is powerfully developed, however significant part of it is in unsatisfactory condition. The majority of infrastructure objects promote heat contamination of the city environment. The significant share of the contamination is in geological environment. Water-caring communications, plants, buildings with heat losses, ponds and rivers are the main sources of the contamination.

2. CLIMATE FACTOR

The temperature of the upper part of soils and of the shallow ground waters strongly depends on temperature of air and atmospheric precipitation. For the last 100 years the mid-annual air temperature in Moscow has risen on 2,5 °C (fig. 1, 2). On the average in the Northern hemisphere - on 0,8°C, and 0,6°C took last 30 years (fig. 3). The difference between temperature on suburbs and in city centre reaches 3-4 degrees. Therefore vegetation in the city centre comes in 10 days earlier.

During recent years it is possible to observe a so-called phenomenon as "islands of heat" - average air temperature on Fridays is0.7 degrees more than in other days. In days off the city cools down a little, but starting on Monday cars and factories begin to heat the environment, achieving a local maximum of warming on Friday.

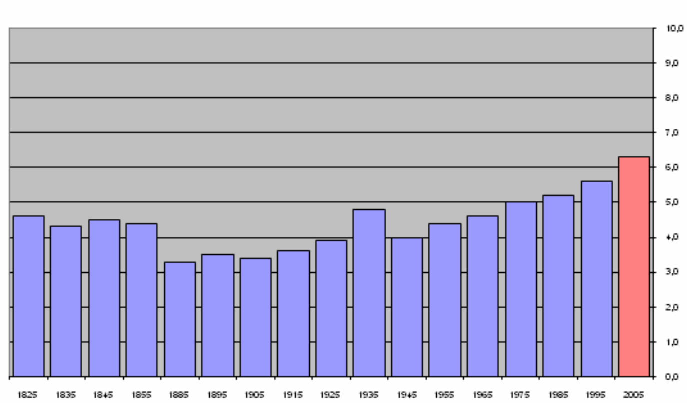

Figure 1: Mid-annual temperature in Moscow from the beginning of its measurements (acc. to Moscow State University, A. Isaev)

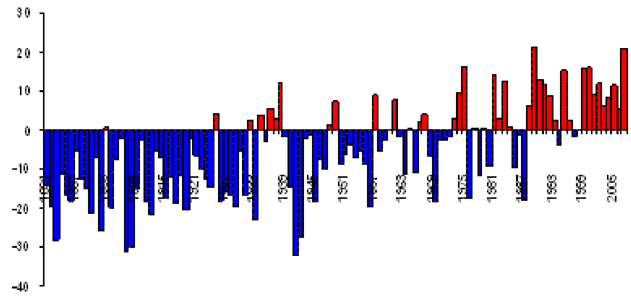

Figure 2: Anomalies of mid-annual temperature of air in Moscow in 1891-2007 (acc. to Moscow State University).

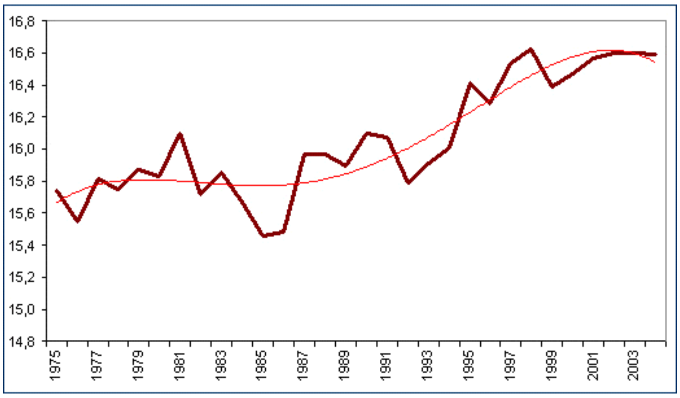

Figure 3: Mid-annual temperature of air in Northern hemisphere

It is visible on the diagrams that the air temperature in Moscow steadily increases. One part of a trend is caused by global processes and another part is caused by local urban activity in the city. All these result in an additional heating of the lithosphere from the surface.

2. SOIL TEMPERATURE

The influence caused by urban change of temperature regime of the top layers of the lithosphere now represents a serious environmental problem. The sources of heating are: the dumps of hot technological waters in the rivers and open reservoirs, leaks of technical water supply and industrial conditioners, warmed underground constructions, water-caring communications, tunnels, collectors etc. As a result in the territory of Moscow at average depths of 10-30 m, a steady geothermal anomaly with excess of temperature 2-6 degrees above background is observed. The anomaly is much bigger than the administrative border of the city and reaches a part of forest-covered zone to the west, south and east directions from the capital.

Warming up of sandy-argillaceous soils in Moscow does not cause its structural changes, but promotes change of clay and organic soils properties that result in some surface subsidence. Heating of rocks causes increase of aggression in relation to concrete and metal of designs.

The depth and periods of soil freezing in Moscow are also powerfully violated in contrast with the background region. Below a frost penetration depth of 1.6 m the soil temperature is characterized by the following values (fig. 4):

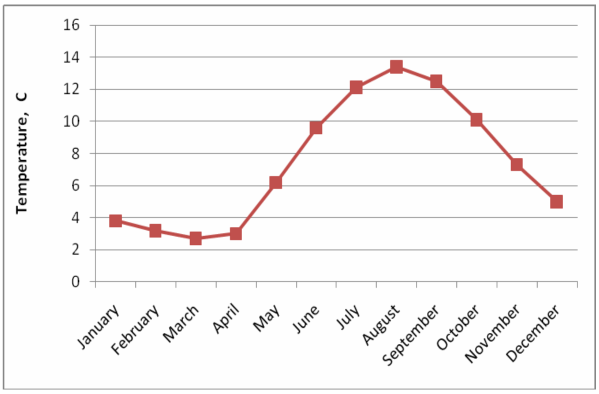

Figure 4: Mid-annual soil temperature in Moscow on depth of 1,6 m

For instance, heat anomalies of plants are concentrated basically in east, south-east, northeasterly and north part of the city. The largest contaminant areas are situated on the ZIL plant and Moscow refinery. The result of hot water leakage from underground water-caring communications, in particular, is a change of the thermal field of ground waters.

3. TEMPERATURE OF GROUND WATERS

In a regional view, the area of Moscow is an artesian ground water basin in which three geothermal zones have been allocated (V.Pokrovsky, 1960, G. Plotnikov 1966). The top zone of cold waters with temperature of 20°C occupy quaternary, Mesozoic and upper Paleozoic aquifers up to depths of about 1000 - 1200 m. The zone of warm waters with temperature 20-40 occupies Devon horizons and Paleozoic bottom up to depths of 2 km. The bottom zone of the high temperature (40-60°C) is situated in Ordovician, Silurian and Cambrian bottom aquifers.

The most interesting from the environmental point of view is the quaternary and Mesozoic ground water horizons. The maximal measured values of ground waters temperature for old industrial districts in Moscow reach 35°C, and the average is 3-10°C. The maximal changes of temperature in residential areas reach 15°C, and a primary range is from 1 to 4°C.

Intensity of thermal pollution was fixed on the aerial photographs made by infra-red thermal radiation in summer and winter periods by companies "Aerogeology" and "Aerogeophysics". The area with positive thermal anomalies (more than 10°C) occupy more than a quarter of Moscow territory (fig. 5).

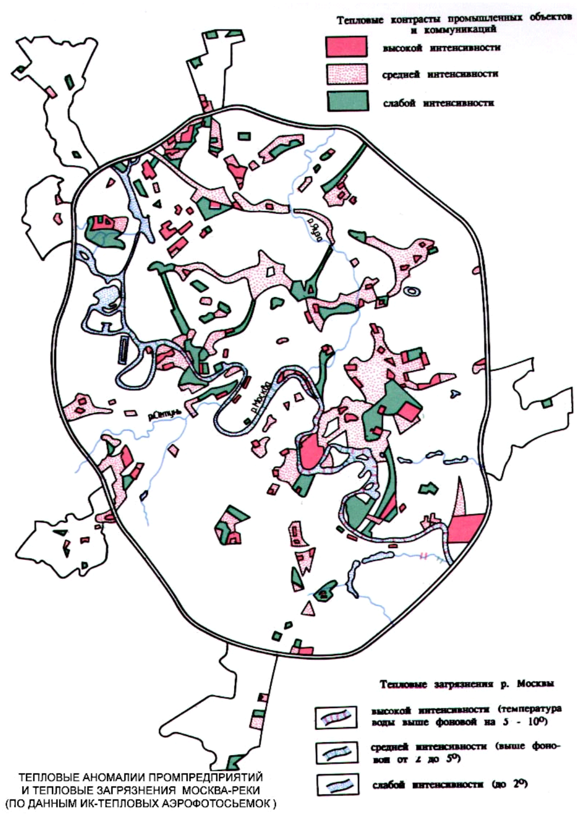

Figure 5: Thermal anomalies of factories by aeromonitoring (according to "Aerogeology" and "Aerogeophysics"). Red color – high intensity, pink color – middle intensity, green color – low intensity.

The biggest thermal anomalies connected to the industrial objects are situated in Southeast, East and Southern administrative districts, representing the extended zone in width up to 6 km. On the other territory thermal anomalies are observed locally.

The distribution of intensity of leakage from underground water-carrying communications is revealed as a result of the analysis of the infra-red thermal aeromonitoring. The most intensive outflow and accordingly the thermal anomalies connected to them are situated in the Central district. It is caused most likely by a bad condition of communications in the historical part of the city. Territories in which the intensity of leakage is more than 4 l/sec at 1 km^2 occupy 4.6 % of the city area (basically in the centre). Less intensive thermal anomalies with leakage from 1 to 4 l/sec at 1 km^2 are situated in the districts of mass building that was constructed over 60-80 years and cover approximately 60 %

of Moscow territory (Moscow. Geology and the city. V. Osipov and others. 1997).

According to groundwater monitoring in Moscow the thermal anomaly is also observed. Hanging of ground waters temperature in a zone of seasonal fluctuations in the central part of the city in comparison with its suburbs was estimated in 2-3°C (F. Kotlov, 1961). The mid-annual temperature of subsoil waters in the centre in 1934 was 9-10°C, and in the suburbs 6-6°C. At local sites rise in temperature of subsoil waters on 5-10°C was fixed.

According to a map of isotherms in the Moscow area, an excess of temperature above background is around 1.0-1.5°C at the depth of 25 m (N.M. Frolov 1968).

In 1960, an increase of mid-annual temperature of subsoil waters in the central part of the city of 10-11 °C was observed, and in some places up to 16°C. Positive temperature anomaly was fixed at depths of 100-150 m, up to Miachkovsko-Podolskiy horizon inclusive (V.I. Prosenkov, 1967, 1970).

The quaternary-mesozoic complex in Moscow area in details is characterized by observations in intervals of depths from 2.5 up to 20-30 m, i.e. from the top part of a zone of seasonal amplitudes up to depths of "a neutral layer”. Within the limits of Moscow area with the broken temperature conditions most precisely come to light on character of distribution of temperature on depth of "a neutral layer”.

At a depth of 2.5 m in area with a temperature regime close to natural mid-annual temperatures change from 5.4 up to 7.0°C, more often making 6.1-6.6°C. The annual amplitude makes from 6.4 up to 12.6°C. The highest temperatures of 10.0-12.9 % are observed in August - September, the lowest 0.2-3.6°C - in March.

At a depth of 10 m the mid-annual temperature changes from 6.6 up to 7.0°C, on the average making 6.7-6.9°C at amplitude from 0.1 up to 1.7°C and its average values 0.3-1.5°C. The highest values of temperatures 6.6-7.9°C are observed in December - March, and minimal 6.2-6.5°C in March - May.

As it was specified above, "the neutral layer" in strict sense of these words is not traced at the appropriate depths, since the annual temperature amplitude is traced much more deeply. However in an interval of 20-40 m the curve demonstrates relative stability of temperature (table 1).

Thus, at the depth of a neutral layer (on the average 25-45 m) fluctuations of temperature in an annual section seldom exceed values of 0.1-0.2°C.

Especially high value of temperatures at the depth of the “neutral layer” is fixed in the Arbat area, the Centre (13.0-15.0 °C) and in car factory ZIL (13.0-21.4°C).

It is necessary to note that for areas with a background temperature regime (when the mid-annual temperature differs from background in limits of 1.0-2.0°C) thermal curves for the various periods of year form a bunch as in natural conditions. Thus, the long-term data of ground water regime of researched area testify that within the last century it has undergone significant changes.

Table 1

N /n	Well number	Location	"the neutral layer" depth, m	Maximum temperature, °C	Minimum temperature, °C	Average temperature, °C
1.	437b	Moscow, Mendeleev str.	35,0	6,8	6,7	6,75
2.	92a	Balashiha town	30,0 – 35,0	7,28	7,15	7,18
3.	94a	Krasnogorsk town	38,0 – 45,0	6,5	6,41	6,46
4.	13	Chepelevo town	25,0	7,0	7,0	7,0

The temperature regime of the quaternary–Mesozoic complex is especially strongly broken here. The temperature anomaly on this complex covers the most part of city territory. In its central part the temperature of ground waters exceeds background by 1.5-3.0 times. Appreciable rise in temperature in the area of Moscow and suburbs is measured up to depth of 250-300 m.

Researches of present ground water temperatures in Moscow are proceeding. In 2006 it was revealed by experts of governmental firm "Geocenter - Moscow", that for the last years as a whole in the city the situation with thermal pollution of ground waters is kept (fig. 6).

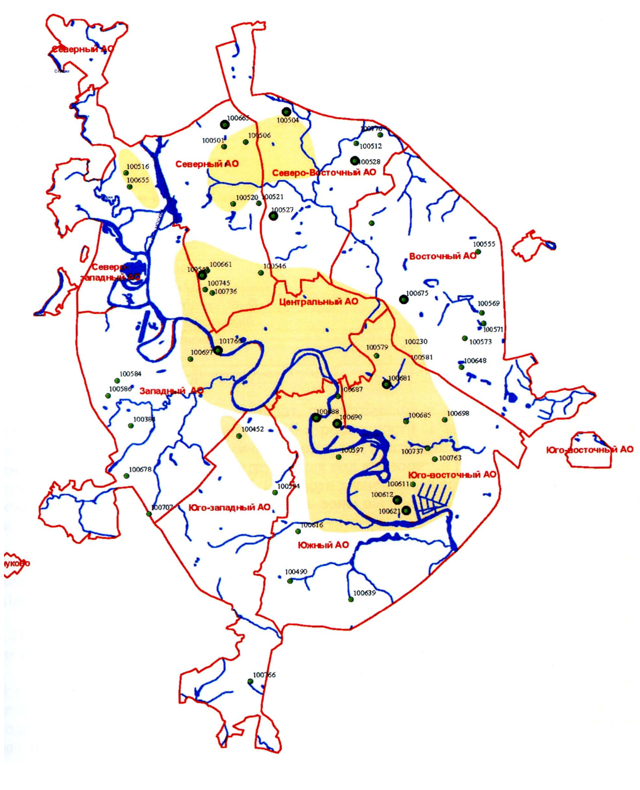

Fig. 6. The map of the thermal anomaly distribution. Yellow color – the area with ground water temperature above 10 °C.

In the quaternary aquifer there is an extensive area of thermal anomaly with temperature 12-16 °C. The anomaly is fixed for the central oldest and most densely built-up part of the city. At inspections of the Bolshoi theatre and the Moscow state university ground waters with temperature 20-40 °C were measured.

Active development of underground space in the city is the powerful factor of temperature pollution of the geological environment. Our institute (IEG RAS) operates automated observation in the area of construction of the Alabiano-Baltiyski automobile tunnel (one of the biggest in Moscow). The temperature of ground waters in this place reached 28 °C in summer 2009 (fig. 7). We use it for indicating of leakages of hot waters.

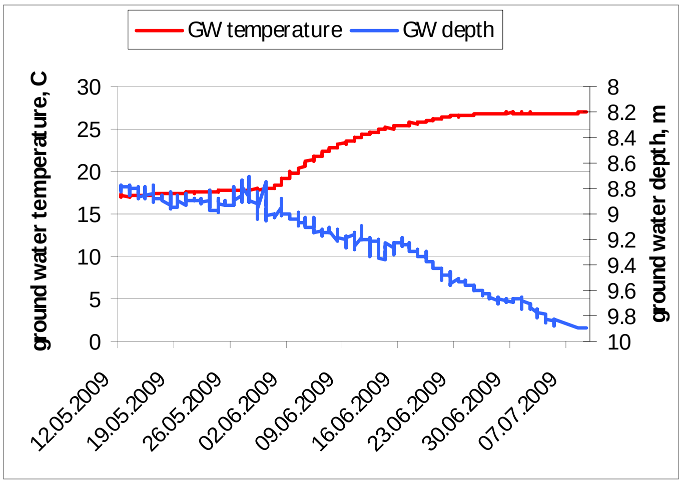

Fig. 7. Thermal anomalys and ground water level in area of construction of the Alabiano-Baltiyski automobile tunnel, Moscow