Irrigation systems of urban landscapes of the south of the European part of Russia: problems and perspective

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Abstract. The paper discusses the necessity to apply the innovative irrigation technology when creating artificial landscapes in the South of the European part of Russia. The artificial green areas of the Rostov agglomeration significantly differ from the traditional steppe plant associations. They are presented, as a rule, by tree plantings or grassy introduced species which are used to create the city microclimate and also for protection from the eastern winds. Unfortunately climatic conditions and increasing anthropogenic load don’t provide the stable rooting and development of plants without additional moistening, despite the Chernozem high agronomic value. The process of the soil cover replanting of its central part and the phenologically old trees replacing is actively under way. This process should be accompanied by compliance with the requirements for enhanced, both in frequency and volume, irrigation of young trees. But the use of automatic and semi-automatic irrigation systems is associated with the absence of a regulatory framework for the design, installation, and further operation of irrigation systems under the conditions of the Russian Federation. This issue requires the solving with the direct participation of specialists from various fields, both theorists and construction practitioners, land reclamation specialists, soil scientists, landscape designers.

1. Introduction

Artificial green areas are traditionally used in modern agglomerations, as one of the main factors for improving the quality of the urban environment. The microclimate within the city borders is improved [1-3]. In turn, it has a beneficial effect on the psycho-physiological state of the townspeople. The constructive influences of green spaces can be more manifested in an arid urban environment [4]. In arid urban climates, vegetation cover can mitigate the urban heat island effect [5], enhance thermal comfort [6] and reduce air pollution [7]. Vegetation cover absorbs some of the gases from the atmosphere, muffles noise and retards the forward movement of dust carried by the wind from different places, thereby adsorbing pollutants [8]. And it is especially important for industrial megalopolises in southern Russia [9]. At the same time, each plant, both in the conditions of the city and beyond its limits, requires stable nutrients and moisture for stable growth and development. Under the urban landscape conditions, this becomes especially current due to the artificial habitat, increased anthropogenic load on plants and non-specific climatic and soil conditions for introduced plant species [10]. At the same time, not all types of irrigation can be used in the city. It is also obligatory a compliance principle of the economic feasibility in scarcity of water conditions to suitable for irrigation. From this point of view, it is important to consider all existing economical methods of watering, including intrasoi discrete plants watering [11, 12].
The purpose of this work is to review existing irrigation methods suitable for use in urban conditions and specifically in the Rostov agglomeration which is located in the insufficient moisture zone.

2. Material and methods
The study sites were located in the urban area of Rostov agglomeration, southwest of the Rostov district. This is the largest agglomeration in southern Russia, which is characterized by clearly manifested monocentric indices and includes the most urbanized part of population. It concentrates more than 50% of region’s population, including about 60% of urban people. The nucleus of the agglomeration, so-called Great Rostov, which includes the cities of Rostov-on-Don, Bataisk, and Aksai with adjacent communities and villages, is located on the Don River banks and includes the basins of the Don itself and its tributaries. The total area of the studied region is 493.1 km²; the areas of Bataisk, Aksai, and Rostov-on-Don are 77.6, 67.5, and 348 km², respectively. Our studies were concentrated in «Great Rostov», the most urbanized part of the Rostov agglomeration (figure 1).

![Figure 1. Location of Rostov agglomeration.](image)

The primary indicator is the total mineralization of irrigation water, which is characterized by the total content of soluble salts in it. Although there is no finally formed opinion on this issue, and there are various recommendations on the quality of irrigation water, however, Kostyakov’s water assessment is the most widely used [13] (table 1).

Stabler's irrigation coefficient [14] helps to take into account the alkaline characteristic of the soil according to the ratio of sodium ions and chlorine in irrigation water. If sodium ions in water are less than chlorine ions, the coefficient is calculated by the formula: \( K = \frac{288}{5Cl} \). If sodium prevails over chlorine, the formula is different: \( K = \frac{288}{(Na + 4Cl)} \). In accordance with the value of the Stabler
coefficient, the water quality is assessed as good at \( K > 18 \), satisfactory at \( K = 18-6 \); unsatisfactory - at \( K = 5.9-1.2 \). Water is unsuitable for irrigation at \( K < 1.2 \).

**Table 1.** Assessment of water suitability for irrigation according to Kostyakov [13].

| Water class | Mineralization, g/l | The quality assessment |
|-------------|---------------------|------------------------|
| I           | less 0.4             | Good                   |
| II          | 0.4—1.0 (fresh)      | Limited use due to the local natural and irrigation conditions |
| III         | 1.0—3.0 (slightly mineralized) | Increased danger to plants |
| IV          | Over 3.0             | Secondary salinization |

3. Results and discussion

For the South of Russia, the main limiting factor ensuring the stability of the existence and performing of ecological functions by plants is the regular transfer of the optimum amount of moisture into the soil [15]. Table 2 shows the main climatic characteristics of the region, clearly demonstrating the vital necessity of plants in additional amounts of irrigation water.

**Table 2.** Climate characteristics of the territories of South Russia.

| Location                        | Prevailing soils | Standardized Precipitation Index | Precipitation, mm/year | Precipitation during the period with \( t > 10^\circ \mathrm{C} \), mm | Sum of the temperatures \( > 10^\circ \mathrm{C} \) |
|---------------------------------|------------------|----------------------------------|------------------------|---------------------------------|----------------------------------|
| Krasnodar region                | Haplic Chernozems| 0.9–1.1                          | 580                    | 3450                            | 190–195                          |
| South of the Rostov region      | Haplic Chernozems| 0.7                              | 450                    | 3300                            | 160–180                          |
| North and the center of the Rostov region | Haplic Chernozems | 0.7–0.8                          | 430                    | 3000                            | 160–170                          |
| Stavropol region                | Haplic Kastanozems | 0.7–0.8                        | 325                    | 3400                            | 175–190                          |
| Kastanozems Sodic               | 0.5              | 165                              | 3550                   | 175–180                         |
| Southeast of the Rostov region  | Haplic Kastanozems | 0.5–0.6                      | 390                    | 3200                            | 165–180                          |
| East of the Rostov region       | Kastanozems Sodic | 0.4                            | 330                    | 3300                            | 160–180                          |

The low values of the hydrothermal coefficient determine the specifics of the development of the plant cover of the territory, especially of the grass, depending on the season. There is reflected in the phenological stage pauses of the growth and development of plants in the summer, namely the partial extinction of their above-ground part. Of course, this doesn’t correlate in any way with the requirements
for artificial landscapes created in cities. As a result, for normal growth, each plant requires an appropriate additional method of introduction and (necessary) optimal rate of irrigation, which depends on its type, size and age, and may vary during the year [16, 17].

In world practice, more and more cities to improve of their territory are going to the use of automatic and semi-automatic irrigation systems for plants. The installation of such systems allows to take into account the presence of different types of plants in one flowerbed and to ensure both uniform irrigation of the lawn and the supply of a strictly regulated amount of water for each tree or even shrub, excluding under-and over-irrigation.

However, as pointed out by the founder of the soil science, V.V. Dokuchaev [18], the composition of irrigation waters is of great importance, soluble and turbulent parts of irrigation waters significantly affect the fertility of irrigated areas, including, with unfavorable composition, this influence can be harmful. And, therefore, their composition should be thoroughly studied, especially during irrigation periods.

In this regard, when it is necessary and possible to use irrigation systems, special attention should be paid to assessing the suitability of water for irrigation, which takes into account such indicators as the qualitative composition of salts, the risk of salinization, the possibility of alkalinization of soil after irrigation, the probability of carbonate alkalization of irrigated areas.

In this regard, irrigation water should be assessed from four main points:
- by the total salt content in irrigation water;
- by irrigation coefficient (Stabler coefficient);
- according to the degree of danger of soil salinization;
- according to the degree of danger of soil alkalinization.

There are various types of irrigation water, taking into account the particle size distribution of the soil [19]. For the Rostov region, the values of 1.0 g / l are accepted as non-toxic for plants.

However, in practice, in addition to taking into account the total salinity of water, it is necessary to take into account the cationic composition of water-soluble salts, and such an indicator as alkalinity, determined by the presence of anions of carbonate salts in water. In accordance with the methodological recommendations developed for arable soils [20] the suitability of water for irrigation usually doesn’t exceed 60 g / l, and the sodium content in the mass doesn’t exceed 60%. The salt content is from 0.5 to 1 g / l with the participation of sodium in the composition of cations not more than 60%. The higher content of sodium in the water makes water unsuitable for irrigation purposes without chemical reclamation.

Thus, the question of the quality of irrigation water depends primarily on the source of water supply, as well as on the priority task in the development and implementation of irrigation systems, not only in agricultural production, but also in urban greening. In arid and semiarid climates, surface and subsurface water have been traditionally used to irrigate urban green areas [21, 22].

The water sources for irrigation are very diverse in the Rostov agglomeration. Water resources provide surface water resources, lakes and reservoir. The largest cities of agglomeration - Rostov-on-Don, Bataysk, Shakhty, Novocherkassk, Azov, and Taganrog - use water for drinking water supply and irrigation. Don. Water salinity of the river Don near the city of Rostov-on-Don in the winter mean water period is 0.43 g / l, in the summer-autumn - 0.71 g / l. According to the chemical composition of the river water, it has hydrocarbonate-chloride-sulphate calcium-sodium-magnesium composition [23]. In addition, river waters are contaminated with chlorides, sodium sulfate, phenols, petroleum products, synthetic surfactants, heavy metals and pesticides. Consequently, the suitability for irrigation of the Don water, although it is fresh, is estimated as a limited use of water, taking into account local natural and irrigation conditions.

Another source of water is groundwater. The depth of the groundwater level in the territory of Rostov-on-Don varies widely. At the tops of the watersheds, they are at a depth of 4.0–16.5 meters or more. The dry residue of groundwater varies from 0.4 to 15 g / l, the most general value is 2–5 g / l. From the summer season to the autumn-spring groundwater desalination occurs. The lowest salt content for most of the sampling points corresponds to the time of the spring maximum, which is explained by
groundwater recharge due to the infiltrated fresh melt water. In terms of anionic composition, water is sulphate-bicarbonate, rarely sulphate-bicarbonate. The cationic composition is different, with a predominance of calcium and magnesium. The pH value is in the range of 5.8–8.5, more typical values are 6.5–7.5.

The third water sources for irrigation systems are reclaimed water. Reclaimed water is widely used for landscape irrigation with the benefits of saving fresh water and ameliorating soil quality [24-27]. On the territory of the Rostov agglomeration, this water source has not yet been applied to irrigation needs.

Thus, the decision about the source of irrigation water should be accepted each time, taking into account both the water quality and the soil properties. From this point of view, any urban landscape is a more complex object for irrigation than an arable landscapes. This is due to the extreme variegation of the soil cover of urban areas, the presence of buried horizons in the body of urban soils, and often full profiles of native soils. This causes the heterogeneity of soil profile with regards its physical properties, including water filtration (figure 2). Figure 2 shows how heterogeneous the soils can be on the territory of the Rostov agglomeration. Great variety of bulk layers and its different texture must be taken into account when irrigation planning.

![Profiles of anthropogenically transformed soils in the city of Rostov-on-Don](image)

Figure 2. Profiles of anthropogenically transformed soils in the city of Rostov-on-Don: (a) - Urobostratozem on buried Chernozem; (b) - Urobostratozem on loess loams; (c) - Urobostratized Chernozem; (d) - Replantozem on buried Chernozem. In native soils, the following horizons were identified: AU—dark-humus horizons with the humus content of more than 5%; AJ—light-humus horizons with the humus content of less than 5%; BCA—carbonate-accumulative (calcic) horizons; and C—parent material. The urbic horizon UR—a synlithogenic diagnostic horizon; it is gradually formed owing to the accumulation of different substrates brought to the surface in urban and rural settlements. A reclamation compost–humus horizon (RAT) is a filled compost, peat compost, or humusrich material (used for reclamation) and slightly modified by pedogenesis.

The old center of Rostov-on-Don is distinguished by pronounced heterogeneity and heterochronism of composition and properties. The assessment of the soil conditions for updating the tree plantation is particularly relevant [28, 29]. The variety of plants used in gardening, the abundance of their forms and, at times, the intricate solutions of landscape architects have identified several methods of irrigation, allowing to maintain the landscapes created in a stable green and flourishing state.
Currently, in the south of Russia, automatic irrigation systems have already functioned. They are mainly used in areas with private households and commercial facilities. As sources of water used wells, natural or artificial reservoirs, and urban water are applied. At the same time, the most effective solution for lawn irrigation under urban greening is a rotor sprinkler and a spray with a completely underground installation (up to 30 cm deep). It provides anti-vandalism and a longer service life of irrigation systems. In the case of planting woody plants, the drip or subsurface irrigation is the most effective method. The long-term practice of using such irrigation methods has proved their effectiveness and efficiency not only by the necessity for rational use of water resources, but also from the point of view of the material costs of the owners. In addition, one of the essential factors of the application of these systems is the uniformity of irrigation of the territory, which in turn allows one to save such an important resource in a semi-arid climate as fresh water.

In the development and implementation of automatic irrigation systems in the territory of the Russian Federation, at present, they rely on the existing regulatory documents [30-32]. However, each of the regulatory documents was created pursuing its own goals, and the issues of irrigation are of secondary importance, which cause discrepancies and often contradictions in the norms of irrigation in individual cases.

It should also be noted that in any modern city, the process of replanting the soil cover of its central part and replacing phenological old trees is relevant. This process should be accompanied by compliance with the requirements for enhanced, both in frequency and volume, irrigation of young trees. To solve this problem, as a rule, the drop-and-root irrigation systems are introduced. They allow one to provide the optimal amount of water directly to the root zone of the soil. The cost of creating an irrigation system for irrigating trees and shrubs, as a rule, doesn’t exceed 10% of the cost of planting material, which is often incomparably low compared to the cost of all landscaping the territory as a whole. At the same time, the drip irrigation system allows one to increase the survival rate of plants from 60 to 97%. The use of drip irrigation is also of interest because it is sufficient for it to use local runoff, which in some Rostov region, according to some estimates, can provide irrigation on an area about 120 thousand hectares [33]. Unfortunately, the use of automatic and semi-automatic irrigation systems, as well as an understanding of the necessity for timely, reasonable irrigation of the created artificial landscapes, finds its supporters, first of all among the residents of residential areas of private one-story buildings. As for municipal gardening, as well as public areas of high-rise residential areas, the methods of additional irrigation are extremely rare.

4. Summary

In conclusion, it is necessary to consider the issue of the absence of large-scale implementation of irrigation systems when artificial landscapes are created. This is partly due to the low popularization of the capabilities of modern irrigation systems, their unjustified overpriced, often illiterate design and installation of systems. Another reason is the impossibility of the implementation of irrigation systems in new projects due to the absence of a regulatory framework for the design, installation, further operation of irrigation systems of municipal organizations in the Russian Federation. One of the factors that “impede” the widespread introduction of advanced irrigation technologies is the difficulty of connecting to urban networks, namely to water and electricity. Existing networks often cannot satisfy the necessity of the area in normal rainfalls in the recultivated area, but as an alternative, it is possible to consider the creation of semi-automatic irrigation systems with their adjunction from watering machines that flood water from open reservoirs.

Thus, the main task at the present stage of the development of urban gardening and its irrigation support is the introduction of changes in the existing regulatory documentation related to both the design and the irrigation norms. The standards used are clearly outdated and require substantial improvement with the direct participation of specialists from different fields, both theorists and practitioners - builders, land reclamation, soil scientists, landscape designers.
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References
[1] Bezrukova A S, Kozlovsky B L, Kuropyatnikov M V 2018 Study of the influence of Park plantations of the Botanical garden of the southern Federal University on the microclimate parameters. Living and Bio-inert System 26 Available at: http://www.jbks.ru/archive/issue-26/article-1 [in Russian]
[2] Agnihotri A K, Ohri A and Mishra S 2018 Impact of green spaces on the urban microclimate through Landsat 8 and TIRS Data, in Varanasi, India. International Journal of Environment and Sustainability 7(2) 72 doi: 10.24102/ijes.v7i2.913
[3] Rui L, Buccolieri R, Gao Z, Ding W and Shen J 2018 The impact of green space layouts on microclimate and air quality in residential districts of Nanjing, China Forests 9(4) 224 doi.org/10.3390/19040224
[4] Pearlmutter D, Berliner P and Shaviv E 2007 Urban climatology in arid regions: current research in the Negev desert. Int. J. Climatol. 27 1875 doi: 10.1002/joc.1523
[5] Takebayashi, H., Moriyama, M., 2007 Surface heat budget on green roof and high reflection roof for mitigation of urban heat island. Build Environ. 42 2971 doi: 10.1016/j.buildenv.2006.06.017
[6] Petrali M, Brandani G, Napoli M, Messeri A and Massetti L, 2015 Thermal comfort and green areas in Florence. Ital. J. Agrometeorol. 20 39
[7] Wang J, Gao, H., Lv, C. 2018 Analysing the influence of different street vegetation on particulate matter dispersion using microscale simulations. Desalin Water Treat 110 319 doi: 10.5004/dwt.2018.22333
[8] Gudzenko E. O., Bezuglova O. S. 2016 Biomonitoring of pollution by chemical elements of recreational areas of Rostov-on-don Scientific journal of KubSAU 123(09) Available at: http://ej.kubagro.ru/2016/09/pdf/32.pdf [in Russian]
[9] Kamysheva A. S., Mileshko L. P., 2017 The role of green spaces in ensuring environmental safety of cities Technology of technosphere 2 285
[10] Alekseenko E V 2006 Cultural landscapes of Omsk: problems and perspective Omsk Scientific Herald 6(41) 280 [in Russian]
[11] Rykhlik A E and Bezuglova O S, 2017 Method of Intra-Soil Pulse Continuous-Discrete Moistening (Model Experiment) Bioegeosystem Technique 4(1) 39 DOI: 10.13187/bgt.2017.1.39
[12] Kalinitchenko V P, Minkina T M, Skovpen A N, Chernenko V V and Boldyrev A A 2011 The method of intrasoil discrete plants watering (introducing new technologies) Proc. Global Forum on Salinization and Climate Change (Valencia: FAO) p 73
[13] Kostyakov A N 1960 Fundamentals of Reclamation (Moscow: Selhozizdat) [in Russian]
[14] Zaidelman F R 1987 Soil Reclamation (Moscow: Moscow state university publishing) [in Russian]
[15] Chevergin Yu I, Akhtyamov A G and Sautkina M Y 2018 The impact of the regime of groundwater level on the productivity of tree species in forest belts of Kamennaya steppe. Living and Bio-inert System 24 Available at: http://www.jbks.ru/archive/issue-24/article-3. [in Russian]
[16] Iozus A P and Morozova E V 2016 The features of irrigation of seedlings of tree species in nurseries of steppe zone Scientific Journal Advances in current Natural Science 11 (2) https://natural-sciences.ru/en/article/view?id=36228 [in Russian]
[17] Ursula K S, Martin E C, Mahato T and Subramani J 2013 Performance of landscape trees in the Semi-Arid Southwest under three irrigation regimes. HortScience 48(9) 213

[18] Dokuchaev V V 1936 Our Steppes Before and Now: (Soil science essay) (Moscow-Leningrad: Sel’hozgis) [in Russian]

[19] Kashtanov A N et al. 1996 Methods of development of agriculture systems on a landscape basis (Kursk: Publishing House KSAA) (in Russian)

[20] Bezdnina S Y 1990 Regulation and improvement of the quality of irrigation water. Scientific works of VASHNIL "Improvement of irrigation water quality" (Moscow: Agropromizdat) [in Russian]

[21] Reyes-Paecke S, Gironás J, Melo O, Vicuña S and Herrera J 2019 Irrigation of green spaces and residential gardens in a Mediterranean metropolis: gaps and opportunities for climate change adaptation. Landsc. Urban Plan. 182 34 doi.org/10.1016/J.LANDURBPLAN.2018.10.006

[22] Brandt M J, Johnson K M, Elphinston A J, Ratnayaka D D, Brandt M J, Johnson K M, Elphinston A J and Ratnayaka D D 2017 The demand for potable water Twort's Water Supply ed Brandt M J, et al. (Butterworth-Heinemann: Elsevier.) doi.org/10.1016/B978-0-08-100025-0.00001-6

[23] Privalenko V V and Bezuglova O S 2003 Ecological Problems of Anthropogenic Landscapes of Rostov Region. Ecology of the City of Rostov-on-don Vol 1 (Rostov-on-Don: SKNTS VSH) [in Russian]

[24] Lyu S and Chen W 2016 Soil quality assessment of urban green space under long-term reclaimed water irrigation. Environ. Sci. Pollut. R 23 (5) 4639 doi.org/10.1007/s11356-015-5693-y

[25] Zalacáin, D., Bienes, R., Sastre-Merlín, A., Martínez-Pérez, S., García-Díaz, A. 2019 Influence of reclaimed water irrigation in soil physical properties of urban parks: A case study in Madrid (Spain). Catena 180 333 doi: 10.1016/j.catena.2019.05.012.

[26] Weiping C., Sidan L., Neng P., Wentao J. 2013 Impacts of long-term reclaimed water irrigation on soil salinity accumulation in urban green land in Beijing. Water Resour. Res. 49(11) 7401 doi.org/10.1029/wr20550.

[27] Canales-Ide F, Zubelzu S and Rodriguez-Sinobas L 2019 Irrigation systems in smart cities coping with water scarcity: the case of Valdebebas, Madrid (Spain). J. Environ. Manage. 247 187 doi.org/10.1016/j.jenvman.2019.06.062

[28] Bezuglova O S, Tagiverdiev S S and Gorbov S N 2018 Physical properties of urban soils in Rostov agglomeration Eurasian Soil Sci. 51 (9) 1105 doi: 10.1134/S1064229318090028/

[29] Gorbov S N, Bezuglova O S, Tischenko S A and Gorovtsov A V 2017 Organic matter and elemental composition of humic acids in soils of urban areas: the case of Rostov agglomeration. Proc. VI Int. Conf. on Landscape Architecture to Support City Sustainable Development Megacities 2050: Environmental Consequences of Urbanization (Springer International Publishing AG) ISBN 978-3-319-70556-9 https://doi.org/10.1007/978-3-319-70556-9

[30] RF Specification standard 31.13330.2012. 2019 Water Supply. Pipelines and Portable Water Treatment Plants (Moscow: Standardinform) http://docs.cntd.ru/document/1200093820 [in Russian]

[31] RF Specification standard 40-102-2000.2019 Design and installation of polymeric pipelines for water supply and sewage systems. General requirements (Moscow: Standardinform) http://docs.cntd.ru/document/1200093820 [in Russian]

[32] RF Specification standard 42.13330.2011. 2019 Urban development. Urban and rural planning and development (Moscow: Standardinform) http://docs.cntd.ru/document/1200093820 [in Russian]

[33] Voevodina L A 2010 Features of drip irrigation on chernozems of Rostov region. Melioration and hydraulic engineering 4 107 Available at: http://www.rosniipm-sm.ru/dl_files/udb_files/udb13-rec10-field6.pdf [in Russian]