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Urban Land: Study of Surface Run-off Composition and Its Dynamics

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Abstract. The qualitative composition of urban land surface run-off is liable to significant variations. To study surface run-off dynamics, to examine its behaviour and to discover reasons of these variations, it is relevant to use the mathematical apparatus technique of time series analysis. A seasonal decomposition procedure was applied to a temporary series of monthly dynamics with the annual frequency of seasonal variations in connection with a multiplicative model. The results of the quantitative chemical analysis of surface wastewater of the 22nd Partsjezd outlet in Samara for the period of 2004-2016 were used as basic data. As a result of the analysis, a seasonal pattern of variations in the composition of surface run-off in Samara was identified. Seasonal indices upon 15 waste-water quality indicators were defined. BOD (full), suspended materials, mineralization, chlorides, sulphates, ammonium-ion, nitrite-anion, nitrate-anion, phosphates (phosphorus), iron general, copper, zinc, aluminium, petroleum products, synthetic surfactants (anion-active). Based on the seasonal decomposition of the time series data, the contribution of trends, seasonal and accidental components of the variability of the surface run-off indicators was estimated.

1. Introduction
Surface waste water or surface run-off (SR) is a significant source of pollution into water bodies [1-11] and a factor reducing water quality of water supply sources [12,13].

2. Relevance
The city of Samara is urban land with a complete separate sewage system. Depending on the topography of the terrain, Samara is divided into 15 sewerage basins to collect and divert surface run-off from the territory of the city. To resolve the problem of polluted surface wastewater discharge from the territory of Samara in 2012, the Municipal program “Development of the rainwater drainage system of Samara for 2013-2022” [14] has been developed and approved. The implementation of a program is still underway. Currently, waste-disposal plants in the territory of Samara are local sewage treatment plants [15] owned by enterprises.

The change in the quality of surface wastewater is not stationary [16]. There are certain seasonal patterns [9,10] and internal interconnections in the drainage composition [16-20].

Let us consider the dynamics of changes in the quality of surface run-off in the last 12 years (from 2004 to 2016), taking "22nd Partsjezd" wastewater outlet in Samara as an example. The main trunk sewer of this wastewater outlet begins at the intersection of Antonov-Ovseenko and Karbyshev streets.
and goes along Antonov-Ovseenko and 22nd Partsjezd streets. There are side connections coming from the streets of Zaporozhskaya, Stavropolskaya, Svoboda, Pobeda, Krasnykh Kommunarov, Yuxhniy Proezd, Rylskaya, Zavodskoe Shosse along the main trunk sewer.

The total length of the main trunk sewer is 5285 m. The depth of the pipe bottom line is between 1.62 and 8.3 m. The diameter of the starting section of the trunk is 500 mm. The maximum diameter of the trunk at the release is 1600 mm. The estimated catchment area is 1707.43 hectares. The wastewater outlet length is 824.0 m. It is located 15.5 km from the mouth of the Samara river. The outlet is of a shore type, it is concentrated. The main pollutants of surface run-off are BOD (full), suspended substances and petroleum products [16]. The content of organic substances in the surface run-off (according to BOD full) at the beginning (the first third) of the period under review (see Figure 1) was sustainable enough. Then it increased almost twofold. There was also an increase in variations of concentration values.

The range of changes in the concentration of suspended substances in the period under review (see Figure 2) was mostly of constant average. In the last third part of the period the variability of the results became significantly lower. The average monthly values of the physico-chemical composition of wastewater in the outlet, calculated according to the quantitative chemical analysis (QCA) in 2004-2016 are shown in Table 1. For a whole range of indicators, waste water does not meet the standards of allowable discharge throughout the year or throughout its greater part. In addition, significant variations of indicators can also be observed.

3. Research Theory

Let us analyze these changes and discover their reasons. For the study of the dynamics of waste-water quality, it is relevant to use time series analysis techniques. A seasonal decomposition procedure was applied to a temporary series of monthly dynamics with the annual frequency of seasonal variations in connection with a multiplicative model.

To point out a deterministic component, an additive model was accepted.

\[ x_t = d_t + c_t + s_t + \varepsilon_t \]  

where \( x_t \) is a time series element; \( d_t \) is a deterministic component; \( c_t \) is an irregular component; \( t, r, +, c_t \) is a trend-cyclical component; \( s_t \) is a seasonal component; \( t = 1, ..., n \) are sequence numbers of the time series elements. The analysis revealed seasonal indices of 15 waste-water quality indicators (see Table 2). The "+" and "-" characters describe the direction of the change of concentration (increase or decrease). It is possible to conclude which groups of indicators have similar seasonal changes and in what time-periods these changes take place.

4. Research

Based on data from the seasonal decomposition of the time series, the contribution of each component to the overall variability of the indicators has been assessed (see Table 3). A simple moving average was used as a trend (trend-cyclical function).

An analysis of the obtained data shows that an accidental factor is the most important factor for all 15 indicators. It is about 72%. The trend of the process under consideration is approximately one fifth (21.1%) and the seasonal average is about 6.9% of the total variability of the indicators.

![Figure 1. Results of waste water QCA (BOD full).](image)
Figure 2. Results of waste water QCA (Suspended substances).

Table 1. Average monthly values of physico-chemical composition of wastewater at the outlet.

| №  | Name of the indicator | Average long-term values, mg/l |
|----|-----------------------|-------------------------------|
| 1  | BOD total             | 8.24 5.67 7.43 6.58 5.50 5.58 9.72 5.88 5.62 6.80 9.14 6.42 |
| 2  | Suspended substances  | 19.76 17.97 27.40 34.85 21.37 19.57 17.49 16.43 14.96 20.06 19.76 16.98 |
| 3  | Mineralization        | 523.9 495.0 531.7 539.9 502.9 531.4 552.7 542.3 515.2 513.0 513.0 488.2 528.0 |
| 4  | Chlorides             | 66.1 64.9 70.2 81.1 67.2 71.9 71.3 77.1 65.9 70.7 67.3 65.1 |
| 5  | Sulphates             | 129.9 116.2 124.5 129.4 118.2 125.6 141.5 122.7 123.5 125.7 114.1 135.9 |
| 6  | Ammonium ion          | 1.7680 1.6791 1.4909 1.4182 1.3879 1.7145 1.3558 1.1604 1.8800 1.5371 1.8127 1.6083 |
| 7  | Nitrite-anion         | 0.1895 0.1386 0.1502 0.1458 0.2247 0.1490 0.2713 0.1632 0.1482 0.1807 |
| 8  | Nitrate-anion         | 2.5640 2.2718 2.3736 2.5555 2.9908 3.2182 2.1725 3.5450 3.5564 2.2233 1.9855 2.4175 |
| 9  | Phosphate (R)         | 0.1830 0.2042 0.2500 0.1946 0.1508 0.1713 0.1551 0.1684 0.1786 0.2058 0.1638 |
| 10 | Iron Total            | 0.5720 0.5891 0.6409 1.1509 0.6483 0.5067 0.5396 0.4545 0.5408 0.5809 0.4325 |
| 11 | Copper                | 0.0067 0.0060 0.0061 0.0124 0.0081 0.0057 0.0063 0.0052 0.0054 0.0066 0.0064 |
| 12 | Zinc                  | 0.0134 0.0116 0.0185 0.0295 0.0129 0.0106 0.0103 0.0123 0.0113 0.0124 0.0115 |
| 13 | Aluminium             | 0.0233 0.0204 0.0284 0.0205 0.0309 0.0195 0.0301 0.0250 0.0150 0.0215 0.0183 0.0225 |
| 14 | Petroleum products    | 0.1215 0.0795 0.1085 1.2529 0.0769 0.0705 0.0693 0.0958 0.1219 0.1201 0.1011 0.3015 |
| 15 | Synthetic Surfactants | 0.0772 0.0582 0.0742 0.0849 0.0694 0.0655 0.0717 0.0790 0.0660 0.0714 0.0654 0.0663 |

Table 2. Seasonal indices for waste-water quality indicators.

| №  | Name of the indicator | Average long-term values, mg/l |
|----|-----------------------|-------------------------------|
| 1  | BOD total             | 2.7090 -1.1217 1.3176 -0.4916 -1.6058 -1.6294 -1.1319 -1.6294 -0.6711 2.5141 -1.4123 |
| 2  | Suspended substances  | 2.1504 -2.6303 4.9220 13.2705 2.4925 0.2981 2.7098 -3.4058 -4.5932 0.3837 -0.9193 -4.9602 |
| 3  | Mineralization        | 3.7315 29.3737 2.5497 15.2097 -16.6509 5.1642 37.5809 22.9786 -3.3812 -4.1615 35.9062 14.8195 |
| 4  | Chlorides             | 1.3200 -5.1048 0.2494 11.0149 -2.7517 0.8070 1.4600 7.1392 -2.6801 -0.6949 -2.1839 -5.9351 |
| 5  | Sulphates             | 1.7881 12.8468 5.9661 1.9546 -7.1100 1.8055 18.6392 -2.0191 5.3724 1.5612 11.3642 15.3816 |
| 6  | Ammonium ion          | 0.3637 0.2732 0.0803 0.1947 -0.1635 0.2792 0.2163 -0.3686 0.2446 -0.3528 0.2917 -0.2366 |
| 7  | Nitrite-anion         | 0.0203 -0.0314 0.0150 0.0194 -0.0248 0.0576 0.0298 -0.0032 0.1048 -0.0202 -0.0350 -0.0039 |
| 8  | Nitrate-anion         | 0.5319 -0.3054 0.0189 0.0102 -0.0513 0.5633 0.4918 0.9784 1.3163 -0.4457 -0.6670 -0.1073 |
| 9  | Phosphate (R)         | 0.0058 0.0511 0.0893 0.0148 -0.0246 -0.2048 0.0254 0.0001 -0.0227 0.0183 -0.0331 |
| 10 | Iron Total            | 0.0431 -0.0246 0.0107 0.4968 0.0704 0.3046 0.1983 -0.0630 -0.1602 -0.3506 0.1012 -0.1621 |
| 11 | Copper                | 0.0004 -0.0007 0.0008 0.0046 0.0016 0.0010 0.0004 0.0003 -0.0016 -0.0011 0.0000 -0.0003 |
| 12 | Zinc                  | 0.0008 -0.0022 0.0058 0.0121 -0.0010 0.0016 0.0034 -0.0025 -0.0029 -0.0020 0.0005 -0.0021 |
| 13 | Aluminium             | 0.0007 -0.0017 0.0034 0.0003 0.0086 0.0022 0.0057 0.0001 -0.0008 -0.0028 -0.0024 -0.0016 |
| 14 | Petroleum products    | 0.0850 -0.1124 0.0899 0.8677 -0.1062 0.1230 0.1225 -0.1235 -0.0940 -0.0629 -0.8166 0.1334 |
| 15 | Synthetic Surfactants | 0.0063 -0.0142 0.0059 0.0125 -0.0005 0.0058 0.0005 0.0073 0.0035 -0.0069 0.0008 -0.0095 |
Table 3. Indicators of seasonal decomposition of variability time series.

| №№ | Name of the indicator | Components Contribution (%) to the variability of surface runoff indicators |
|----|------------------------|-------------------------------------------------------------------------|
|    |                        | Trend | Seasonal | Accidental | Deterministic |
| 1  | BOD total              | 19.3  | 7.4      | 73.3       | 26.7          |
| 2  | Suspended materials   | 16.2  | 8.8      | 74.9       | 25.1          |
| 3  | Mineralization        | 14.3  | 5.5      | 80.2       | 19.8          |
| 4  | Chlorides             | 34.1  | 5.5      | 60.4       | 39.6          |
| 5  | Sulphates             | 35.8  | 7.0      | 57.2       | 42.8          |
| 6  | Ammonium ion          | 42.5  | 6.3      | 51.2       | 48.8          |
| 7  | Nitrite-anion         | 15.8  | 12.8     | 71.4       | 28.6          |
| 8  | Nitrate-anion         | 26.9  | 10.8     | 62.3       | 37.7          |
| 9  | Phosphates (phosphorus) | 20.9 | 8.3      | 70.8       | 29.2          |
| 10 | Iron Total            | 11.3  | 8.4      | 80.3       | 19.7          |
| 11 | Copper                | 11.1  | 4.6      | 84.2       | 15.8          |
| 12 | Zinc                  | 11.2  | 5.2      | 83.6       | 16.4          |
| 13 | Aluminium             | 31.5  | 3.7      | 64.8       | 35.2          |
| 14 | Petroleum products    | 7.3   | 5.5      | 87.2       | 12.8          |
| 15 | Synthetic surfactants anion-active | 19.4 | 3.2      | 77.4       | 22.6          |
|    | Average:              | 21.1  | 6.9      | 72.0       | 28.0          |

Paper [16] considered averaged data of 12 wastewater outlets. The values of individual components (trend – seasonal – accidental) according to that research equaled 11%-34%-55% for BOD (full); 10%-42%-48% for suspended materials; 8%-70%-22% for petroleum products. In this study, the ratio of these components changed. The role of trend and accident components increased for BOD (full) and for suspended materials and a seasonal factor decreased significantly (about 4.5–5 times).

The situation changed dramatically for petroleum products. The role of trend remained the same, the role of the seasonal factor dropped down to 5.5%, and the role of the accident factor rose to 87.2%. In general, a deterministic component accounts for less than 50% (about 28%) of variability of surface run-off.

5. Conclusions

For the first time, a time series analysis upon 15 waste-water quality indicators has been used to assess the quality of surface wastewater of urban land. The contribution of each component to the variability of surface run-off has been determined. It is proved that the quality of surface wastewater shows seasonal variations. The contribution of a seasonal factor to the variability of individual indicators is 3.2% to 12.8% (6.9% at an average). The contribution of the trend varies from 7.3% (for petroleum products) to 31.5% (for aluminium) and is 21.1% at an average. The proportion of the accident factor is also assessed. The accident factor contributes to the variability of all the indicators to the greatest extent and comes up to 87.2% (for petroleum products). Concentrations of ammonium nitrogen (51.2%), sulphates (57.2%) and chlorides (60.4%) are least prone to the accident factor influence. The same indicators are also affected by the trend.

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