Urban land surface wastewater: dependence of formation and changes in its composition

E D Palagin, M A Gridneva, P G Bykova
Samara State Technical University, Architecture and Civil Engineering Academy,
194, Molodogvardeyskaya St., Samara 443001, Russia

E-mail: kafvv@mail.ru

Abstract. The paper presents summarized data on the composition of surface wastewater from the territory of Samara. It also outlines the results of studies investigating main factors which affect surface wastewater composition and analyses the obtained tendencies. The research further defines a representative set of parameters, which gives an opportunity to diagnose the state of the system in general and to monitor surface run-off composition. The authors determine regressive dependencies to assess a possible composition of surface run-off. This analysis is based on monitoring data and is supported by a representative set of parameters. In conclusion, the researchers provide results and their interpretation.

1. Introduction
Surface wastewater is a significant source of pollution to water bodies [1-3]. The surface wastewater qualitative composition [4-11], as well as its discharge [12-17] is subject to significant seasonal fluctuations and requires regulation [18, 19] of its disposal into different water-bodies.

It is evident that surface wastewater composition depends on wastewater system operating conditions, sanitary conditions of the watershed, industrial and drainage water discharges and on other local conditions [3,6,7].

It is possible to control surface waste water discharge into water objects only on condition that certain preventative measures are implemented [15-17]. These measures are supposed to monitor the factors affecting surface waste water formation.

2. Relevance
The object of this research is the water disposal system of Samara surface runoff. The territory of Samara city is referred to urban lands [1,5]. The study focuses on surface wastewater quality parameters within the period of 2004 to 2016. The list of parameters, which were examined in the discharge of wastewater into water bodies, includes the following 16 positions: pH (Col_1), BOD total (Col_2), Suspended substances (Col_3), Mineralization (Col_4), Chlorides (Col_5), Sulphates (Col_6), Ammonium ion (Col_7), Nitrite-anion (Col_8), Nitrate-anion (Col_9), Phosphate (R) (Col_10), Iron Total (Col_11), Copper (Col_12), Zinc (Col_13), Aluminium (Col_14), Petroleum products (Col_15), Anion Synthetic Surfactants (Col_16).

The generalized characteristic of surface run-off from the territory of Samara, its quality and main statistical characteristics for the period under consideration are given in Table 1.
Table 1. Summary Statistics.

| № | Statistics | Parameter | Col_1 | Col_2 | Col_3 | Col_4 | Col_5 | Col_6 | Col_7 | Col_8 |
|---|------------|-----------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1 | Average    |           | 7.8891| 7.09657| 20.7371| 550.647| 82.8499| 126.711| 1.57536| 0.177752|
| 2 | Median     |           | 7.9   | 4.2   | 16.0  | 464.0  | 59.0  | 105.0 | 0.69  | 0.1   |
| 3 | Mode       |           | 8.0   | 3.2   | 14.2  | 572.0  | 48.0  | 102.0 | 0.05  | 0.08 |
| 4 | Variance   |           | 0.0436777| 90.7079| 388.095| 286393.0| 51740.7| 8691.43| 11.168| 0.040996|
| 5 | Standard deviation |   | 0.208992 | 9.52407 | 19.7001 | 535.157 | 93.2278 | 3.34198 | 0.202475 |
| 6 | Standard error |         | 0.00473517| 0.21009 | 0.43489 | 11.811 | 5.02266 | 0.0737042 | 0.0044664 |
| 7 | Minimum    |           | 5.7   | 0.75  | 2.67  | 159.0  | 20.8  | 8.6   | 0.0   | 0.0   |
| 8 | Maximum    |           | 10.8  | 164.0 | 378.0 | 11284.0| 4375.0| 1861.4| 88.5  | 3.74 |
| 9 | Range      |           | 5.1   | 163.25| 375.33| 11125.0| 4354.2| 1851.4| 88.5  | 3.74 |
| 10| Lower quartile |     | 7.8   | 3.1   | 11.1  | 384.0  | 47.7  | 1.77  | 0.25  | 0.067 |
| 11| Upper quartile |    | 8.0   | 7.3   | 23.2  | 580.0  | 71.0  | 145.0 | 1.77  | 0.22 |
| 12| Interquartile range | | 0.2   | 4.2   | 12.1  | 196.0  | 23.3  | 61.0  | 1.52  | 0.153 |
| 13| Skewness   |           | 0.340956| 6.63223| 6.07984| 11.098 | 13.5793| 8.64633| 12.2767| 4.87439|
| 14| Kurtosis   |           | 31.111| 68.330| 71.8897| 159.19 | 204.425| 124.292| 255.02| 55.1807 |

Table 1. Summary Statistics (continued).

| № | Col_9 | Col_10 | Col_11 | Col_12 | Col_13 | Col_14 | Col_15 | Col_16 |
|---|-------|--------|--------|--------|--------|--------|--------|--------|
| 1 | 2.70092 | 0.183161| 0.642019| 0.00784739| 0.0149128| 0.0340799| 0.181648| 0.0934916|
| 2 | 2.2   | 0.11   | 0.45   | 0.006  | 0.009  | 0.018  | 0.09   | 0.06   |
| 3 | 2.2   | 0.05   | 0.31   | 0.005  | 0.005  | 0.005  | 0.005  | 0.05   |
| 4 | 5.07581| 0.0580017| 1.43425| 0.000263842| 0.00598849| 0.00590019| 0.01268 | 0.01268 |
| 5 | 2.46492| 0.240835| 1.1976 | 0.0162432| 0.0773853| 0.0768127| 0.749066| 0.156974 |
| 6 | 0.0543746| 0.00331282| 0.026412| 0.000358665| 0.00170832| 0.00169568| 0.016528| 0.00348229 |
| 7 | 0.0   | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    |
| 8 | 41.6  | 3.9    | 31.74  | 0.43   | 2.87   | 1.22   | 19.1   | 4.2    |
| 9 | 41.6  | 3.9    | 31.694 | 0.43   | 2.87   | 1.22   | 19.1   | 4.2    |
| 10| 1.53  | 0.06   | 0.31   | 0.004  | 0.007  | 0.009  | 0.058  | 0.04   |
| 11| 3.08  | 0.21   | 0.64   | 0.008  | 0.013  | 0.035  | 0.15   | 0.09   |
| 12| 1.55  | 0.15   | 0.33   | 0.004  | 0.006  | 0.026  | 0.092  | 0.05   |
| 13| 5.57887| 5.71657| 14.5858| 17.8163| 28.7858| 8.71936| 17.7821| 12.9346 |
| 14| 52.6778| 60.3357| 303.169| 411.554| 964.743| 101.896| 359.942| 270.81 |

The paper aims to identify the main factors affecting the surface run-off formation and to determine its qualitative composition.

3. Research Theory

Papers [3,6] demonstrate that this task can be solved with the help of factor analysis.

The main linear model of factor analysis has the following form:

$$x_i = \sum_{j=1}^{p} a_{ij} F_j + u_i \quad (i = 1, 2, \ldots, N) \quad (1)$$

where $F_j$ are latent common factors; $a_{ij}$ are factor loads; $u_i$ are residual specific factors that determine that part of each of the analyzed parameters, which cannot be explained by common factors, and also
include errors of parameters measurement; \( p \) is the number of latent factors; \( N \) is the number of parameters.

Factor analysis structures the system and highlights the basic (or common) factors [3,18-20], characterizing the variation of all parameters. These factors are also responsible for a lot of private statistical relationships. The generalized scheme of parameter relationships provides ample opportunities for solving applied problems, in particular the selection of those parameters that are most sensitive to independent factors. They can be considered as parameters of the system condition and be used for monitoring purposes.

4. Results
The detailed factor analysis revealed that the run-off composition is determined by five factors. Table 2 shows a matrix of factor loads, which have the form of correlation coefficients and show crowded links between the identified factors and initial parameters. The last column shows the dispersion (\( h^2 \)) of corresponding parameters, which determines how fully each basic parameter is reflected in six latent factors.

| Parameter | 1          | 2          | 3          | 4          | 5          | Estimated communality |
|-----------|------------|------------|------------|------------|------------|-----------------------|
| Col_1     | -0.0616994 | -0.0429373 | -0.568721  | 0.218194   | 0.258078   | 0.443306              |
| Col_2     | 0.833744   | -0.0227502 | -0.0219291 | 0.122402   | -0.0576693 | 0.714435              |
| Col_3     | 0.191804   | 0.0735992  | -0.100162  | 0.715979   | 0.056992   | 0.568112              |
| Col_4     | -0.0419907 | 0.976199   | 0.14113    | 0.0427701  | 0.0673741  | 0.981014              |
| Col_5     | -0.00876344| 0.965407   | -0.0740577 | 0.0316468  | -0.0450817 | 0.940605              |
| Col_6     | -0.0814807 | 0.238633   | 0.596459   | 0.0231774  | 0.353842   | 0.545089              |
| Col_7     | 0.886397   | -0.0187968 | -0.0186053 | 0.0913577  | -0.0634828 | 0.798776              |
| Col_8     | 0.396773   | -0.00121385| -0.0945099 | -0.0302464 | 0.55012    | 0.469909              |
| Col_9     | -0.177661  | 0.0275514  | 0.0247992  | 0.00445879 | 0.779759   | 0.640981              |
| Col_10    | 0.852627   | 0.0012935  | 0.0213493  | 0.0058559  | 0.0515754  | 0.730124              |
| Col_11    | 0.0899332  | -0.0226824 | 0.216226   | 0.647702   | 0.167386   | 0.502892              |
| Col_12    | 0.0216316  | 0.0380539  | 0.791175   | 0.204445   | 0.0807986  | 0.676200              |
| Col_13    | -0.0192512 | -0.0629176 | 0.445261   | 0.0673031  | -0.0296185 | 0.207994              |
| Col_14    | -0.101954  | -0.0793451 | 0.324073   | 0.355074   | 0.349097   | 0.369661              |
| Col_15    | -0.00695584| 0.0364527  | 0.0386763  | 0.628629   | -0.183684  | 0.431788              |
| Col_16    | 0.75071    | -0.0188751 | 0.00077661 | 0.0459898  | -0.014418  | 0.566246              |

Analysis of the factor load matrix shows that the most comprehensive factors reflect such parameters as dry residue (by 98.1%), chlorides (94%), ammonium (79.8%), and zinc being the weakest factor (20.7%).

On the basis of the factor analysis, the researchers divided the factors and obtained the following subsets: of four parameters (BOD\(_{\text{fall}}\), ammonium ion, phosphates, ASS), of two parameters (dry residue, chlorides), of four parameters (pH, sulfate, copper, zinc), of four parameters (suspended substances, iron general, aluminum, petroleum products) and two Parameters (nitrites, nitrates).

To confirm the results of the factor analysis, the authors grouped the factors by methods of cluster analysis. As a result, the hierarchical classification (by the method of near neighbor) of surface run-off quality parameters was obtained (see Figure 1). Structural organization of the analyzed data reflects the nonlinearity of the dependence "adhesion distance (Euclidian square distance) – step agglomeration" (see Figure 2), which should be monotonous. At the distance level of about 1.8, the monotony of the function is abruptly disturbed. This value can be considered to be a boundary that defines the minimum number of classes in which objects differ significantly from each other.
Thus, the cluster analysis made it possible to define two subgroups: of four parameters (BODfull, ammonium ion, phosphates, ASS) and two parameters (dry residue, chlorides), which are completely identical in composition with the results of factor analysis.

Taking into account the conditions of formation and types of surface run-off flowing into rainwater drainage, the following interpretation of the received factors is offered:

The first factor is the general sanitary condition of water catchment area, as well as the presence of the household flow in the network.

The second factor reflects such interrelated parameters as dry residue and chlorides. This factor is determined by the composition of soils on the territory of the watershed where sediments infiltration and run-off formation take place.

The third factor characterizes the existence of industrial enterprises water discharge. It has a maximum impact on total run-off pH and heavy metals content.

The fourth factor reflects the state of the road network in the water catchment area.

The fifth factor characterizes the existence of drainage waters from residential areas and the internal state of wastewater disposal system.
The analysis allows to identify representative parameters. They are parameters that have the greatest factor load [20]. Thus, the data presented in Table 2 makes it possible to put forward the following representative diagnostic set of parameters: suspended substances, dry residue, ammonium ion, nitrates, copper.

To determine the indicative value of other parameters, depending on the data obtained during monitoring while using the diagnostic kit, regressional dependences are defined. These dependences are given in Table 3.

**Table 3.** Regressional dependences used to determine run-off composition parameters.

| Parameter | Regression model | Middle error |
|-----------|------------------|--------------|
| Col_1     | 7.87604 + 0.00143964*Col_3 + 0.00568626*Col_9 - 5.09274*Col_12 | 1.0 |
| Col_2     | 4.08923 + 1.9081*Col_7 | 28.7 |
| Col_5     | -131.496 + 0.389522*Col_4 | 14.1 |
| Col_6     | 67.5511 + 2340.61*Col_12 + 6.23307*Col_9 + 0.0433907*Col_4 | 8.5 |
| Col_8     | 0.113385 + 0.0122869*Col_7 + 0.0166627*Col_9 | 16.1 |
| Col_10    | 0.104066 + 0.0501426*Col_7 | 18.5 |
| Col_11    | 0.0955907 + 13.273*Col_12 + 0.0189089*Col_3 + 0.0189023*Col_9 | 22.1 |
| Col_13    | 0.0677745 + 1.03666*Col_12 | 31.5 |
| Col_14    | 0.00874571 + 0.0045321*Col_9 + 0.000207649*Col_3 + 1.12134*Col_12 | 63.1 |
| Col_15    | 0.0110613 - 0.00396523*Col_9 + 0.00875592*Col_3 | 129.7 |
| Col_16    | 0.0489477 + 0.0280248*Col_7 | 62.5 |

5. Conclusion

The research yielded the following conclusions:

1. The quality of surface wastewater from the territory of Samara is subject to considerable fluctuations.
2. It is proved that the run-off composition is mainly determined by five factors. These factors control allows to minimize wastewater negative impact on the environment.
3. To monitor the run-off composition in Samara, a representative diagnostic set of quality parameters of surface wastewater was identified: suspended substances, dry residue, ammonium ion, nitrates, copper.
4. The introduced regressional dependences make it possible to determine the surface run-off composition according to all parameters. It is done on the basis of wastewater quality monitoring while using a representative set of parameters.

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