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Methodology for urbanized watersheds parameters ascertainment

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Abstract. The paper presents elaborated methodology for Saint Petersburg and its outskirts watersheds parameters ascertainment. The methodology is based on usage of the digital terrain model, which was created as result of topographic maps digitalization. Usage of the most popular global digital terrain models such as SRTM, ASTER GDEM makes difficulties under the conditions of big cities. The models were processed on the base of Earth surface radar mapping. Therefore, the altitude values have distortions due to the radar signal reflection from roofs, structures, trees, scrubs, and so on. Thus, the global models include noisy data. The distortions can lead to mistakes at determination of the watersheds boundaries. Topographic maps digitalization allows elaborating of digital terrain models without distortions of the altitude values. The watersheds boundaries ascertainment was carried out by means of the ArcGIS tool Watershed. In addition, we use for the ascertainment and determination of the catchments areas structure some tools of Quantum GIS (QGIS) and SAGA.

1 Introduction

St. Petersburg hydrographic network includes 47 watercourses [1]. All the watercourses are located within the Baltic Sea watershed. Evaluation of the sea contamination is one of the most important ecological problems for countries of the Baltic region for last decades. The Baltic Sea anthropogenic eutrophication takes place due to nitrogen and phosphorus intake with yield of the drainage basin. The eutrophication can lead to “blooming” and deterioration of the water quality, appearance of anaerobic zones, the biocoenosises structure destruction, and disappearance a number of hydrobionts species, including commercially valuable fish. Blue-green algae during the intensive “blooming” exude top-rank toxins such as alkaloids, low-molecular-weight peptides, and so on. The toxins pose hazard to life of alive organisms and human life or health. The toxins concentration increases at rising on the trophic pyramid from the lowest storeys up to the highest ones.

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Eating of the contaminated by the toxins food can lead to such human diseases as hepatic cirrhosis, dermatitis, poisoning and death of animals [1].

Incoming into the Finnish Gulf with the rivers outflow nitrogen and phosphorus compounds of the anthropogenic origin are one of the causes of the Baltic Sea anthropogenic eutrophication [2]. The Baltic Sea is characterized by very slow water exchange with the North Sea. The full water exchange period is equal to 40–50 years. The natural singularity is the reason of extreme responsitivity of the Baltic Sea ecosystem to the anthropogenic impacts [3]. The Baltic Sea contamination became the serious ecological problem of the region at the end of XX century [4], due to increase of economic development within the Baltic region [5]. Decision of the Baltic Sea eutrophication problem demands participation of the all countries of the Baltic region [2]. International co-operation is necessary requirement for successful saving of the Baltic Sea environment. For this reason, ministers of environment protection of the Baltic countries 15.07.2007 in Krakow made consistent of the Baltic Sea Action Plan [2].

According to the Plan international responsibility, Russia must monitor the state of the surface water within the Baltic Sea watershed. North-Western Department for Hydrometeorology and Environmental monitoring (St. Petersburg, Russia) carries out regular observations of aquatic objects water quality [6]. The Department on a monthly basis monitors the water quality of 13 watercourses within St. Petersburg. Evaluation of the total nitrogen and phosphorus income into the Neva Bay and the eastern part of the Finnish Gulf with the St. Petersburg rivers outflow is carried out on the base of the monitoring results. However, the figure 1 demonstrates that the evaluation takes into account only outflow of the Neva River and its binnacles. However, there are more than 25 additional watercourses, which enter into the Neva Bay and the eastern part of the Finnish Gulf from the St. Petersburg area. Amounts of the total nitrogen and phosphorus income into the water areas with the watercourses outflow are unknown. Thus, the current evaluation of the total nitrogen and phosphorus income into the Neva Bay and the eastern part of the Finnish Gulf from the St. Petersburg area with the rivers outflow is not full and precise one.

For this reason goal of our research consists in elaboration of methodology for evaluation of the biogenic elements outflow unit discharges from the watersheds, which are not taken into account in evaluation of the total nitrogen and phosphorus income into the Neva Bay and the eastern part of the Finnish Gulf from the St. Petersburg area.

2 Methodology

Figure 2 demonstrates flow graph of the methodology for evaluation of the total nitrogen and phosphorus income into the Neva Bay and the Finnsh Gulf from the watersheds which are now missed out in the assessment of the biogenic elements intake in the water areas. Digitization of topographic map hypsographic curves is carried out at the first stage of our research according to the methodology. We used topographic map of St. Petersburg and Leningrad Region issued in 2001 with scale 1:200000.

By means of the hypsographic curves digitization we produced shapefile of polyline objects. The shapefile attribute table contains altitudes of the curves. With the use of some Quantum GIS tools we located points objects along the polylines in each 100 meters. The point objects layer attribute table contains values of the hypsographic curves altitudes. The digital terrain model was produced in ArcGIS by the «Universal kriging» method. The model raster cells dimension is 100 per 100 meters.

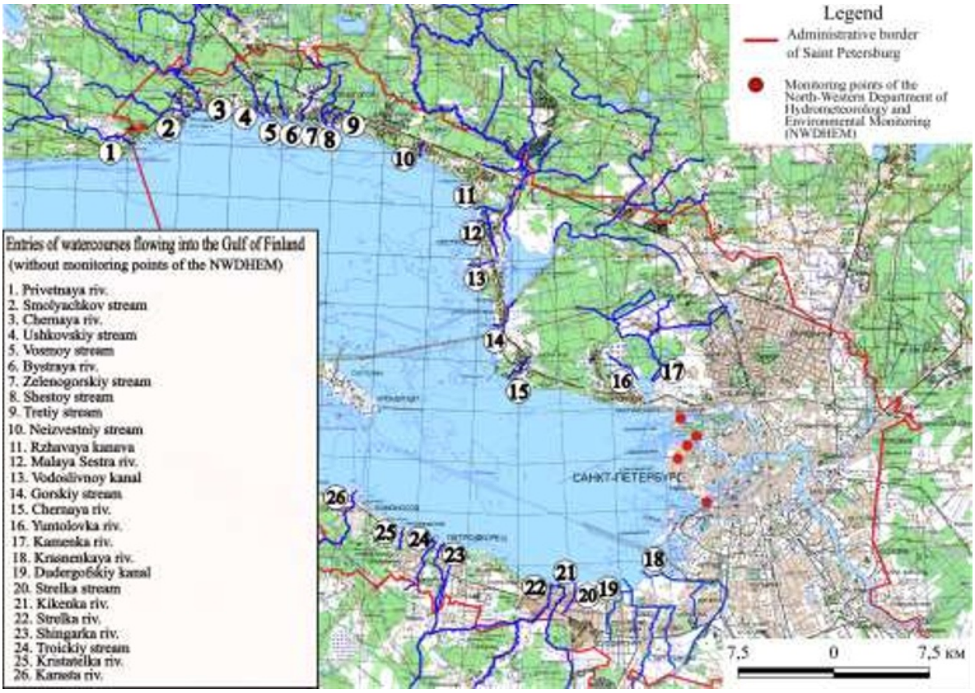

Fig. 1. Monitoring of total nitrogen and phosphorus income with outflow of Saint Petersburg watercourses

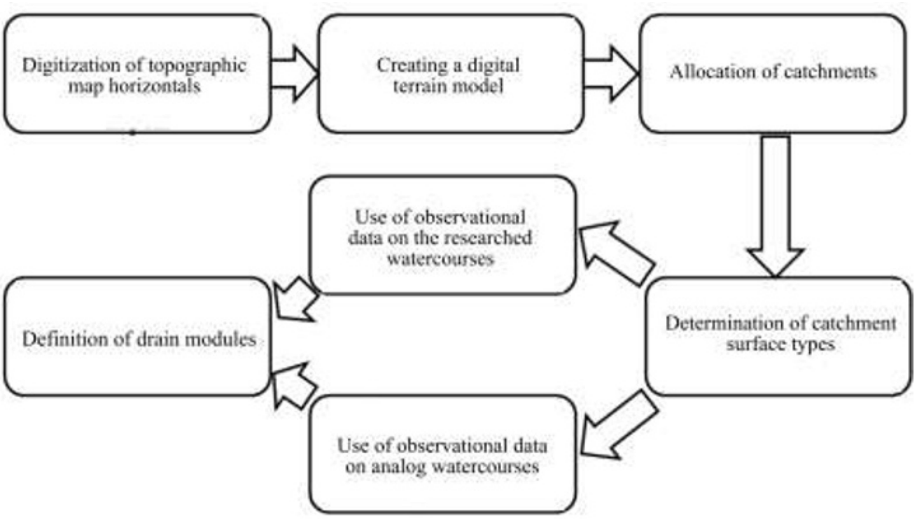

Fig. 2. Action diagram of the outflow modules evaluation methodology

The terrain model raster was upgraded. There were produced buffer zones of the watercourses 100 meters wide. The raster values within the buffer zones were decreased by 10 meters for easement of the watercourses catchment areas ascertainment processing. Afterwards the terrain model raster was upgraded by the ArcGIS tool «Fill», and then the ascertainment was produced by the ArcGIS tool «Watershed». At first, we produced raster of the runoff directions «Flow Direction». Then we manually located nodes in the watercourses outfalls. The watersheds are ascertained on the base of the «Flow Direction» rasters up-stream the nodes. The tool produced new rasters with information of the cells belonging various partial watersheds. The next stage of the processing is the rasters conversion into vector polygon layers by means of the ArcGIS tool «Conversion tools». Afterwards the polygons of the partial watersheds were aggregates into polygons of the watercourses catchment areas.

The next stage of the methodology is ascertainment of various types of surface within the watercourses watersheds. We applied for this purpose computer supervised classification by means of the Quantum GIS module "Dzetsaka classification dock" on the base of composite images. We used for the images production combination of red (B4), green (B3), and nearest infrared (B8) bands of Sentinel-2 satellite images. Spatial dimension of the initial images and the result rasters is equal to 10 per 10 meters.

For the supervised classification, we produced vector layer of regions with known types of the surface:

1. Grass and shrub vegetation;
2. Ground surface;
3. Asphalt surface;
4. Green zones (parks, gardens, garden squares and so on);
5. Roofs;
6. Water surface.

After the classification, we carried out verification of its results, and vectorization of the result raster for calculation of areas of various surface types. The verification was consisted in comparison the produced polygon layer of the surface types with layers of the Open Street Map of St. Petersburg for the areas with the known surface types.

Calculation of total nitrogen and phosphorus income values into the Neva Bay and the Finnish Gulf was carried out according to the formula 1 [6]:

$$Q=31,5 \bullet C_c \bullet R_c \quad (1)$$

Here Q – income of some substance in metric tons per year; C_c – average concentration of the substance in the water, g/m^3; R_c – average river runoff for the temporal duration, m^3/s.

Unit runoff rates of total nitrogen and phosphorus are calculated by the formula 2:

$$M=Q/W \quad (2)$$

Here M – unit runoff rates, metric tons/(year•km^2), Q – substance income, metric tons/year (see formula 1), W – area of the watershed, km^2.

There are no regular hydrochemical monitoring on the bulk of watercourses, which enters the Neva Bay and the eastern part of the Finnish Gulf. There is a number of the watercourses with hydrochemical observations by water users, which make business activities within the watersheds. The observations are carried out according to industrial ecological control.

However, there are watercourses without any data about the hydrochemical parameters and the runoff values. In this case, we propose to apply the data of analogue watercourses. The analogue watercourses must have morphometric parameters, which are close to ones of the watercourses under investigation. Runoff of the analogue watercourses are formed due to processes, which are analogues ones for the watercourses under investigation. The catchment areas of the analogue watercourses must have parameters, which are close to the watercourses under investigation watersheds characteristics.

Location of the analogue watercourses is presented in the figure 3.

Fig. 3. Schematic map of the analogue watercourses spatial location

Bulletins of inland surface water quality, Annual data of inland surface water regime and resources, Yearbooks of inland surface water quality contain hydrochemical data and information about river runoff for the analogue watercourses. We used the data for 1980-1989 and 2010-2021. The data processing was produced in Department of State data Fund of North-Western Department for Hydrometeorology and Environmental monitoring. The data for 1980-1989 correspond days of sampling or runoff measurements. The data for 2010-2021 are presented as average readings.

The analogue watercourses data will be used for future calculations. The averaged unit discharges of the total nitrogen and phosphorus outflow from the catchment areas within St. Petersburg will be evaluated according to the analogue watercourses data.

3 Results and discussion

Values of the total nitrogen and phosphorus unit discharges have been evaluated for the Volkovka River and Okhta River catchment areas. These amounts exceed the maximum permissible discharges for the Finnish Gulf catchment area according to the HELCOM recommendation (Table 1). Some researches [1, 2] derived exceedance of the unit discharges from urbanized catchment areas over the HELCOM norms.

Table 1. Unit discharges of the biogenic elements, tons / square kilometre

Place	Total phosphorus	Total nitrogen
Volkovka River	0.104	1.295
Okhta River	0.134	1.799
Maximum allowable values for the Finnish Gulf catchment area according to the HELCOM recommendation [1]	0.011	0.236

The elaborated methodology will be used for evaluation of the total nitrogen and phosphorus unit discharges from St. Petersburg catchment areas. At the research first stage, we have ascertained the catchment areas on the Neva Bay south shore (fig. 4).

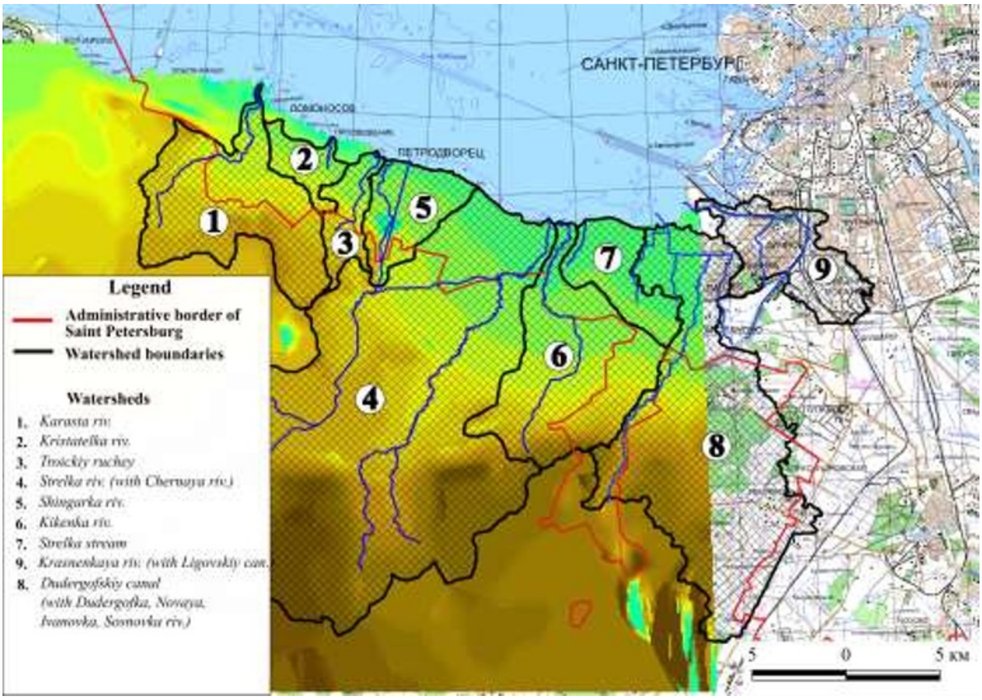

Fig. 4. Boundaries of the watersheds, watercourses of which inflow into the Neva Bay from the south

4 Conclusions

Determination of the catchment areas boundaries is the first stage of the methodology. There are considered possibilities of usage for the purpose achievement global terrain models such as ASTER GDEM, SRTM, WorldDEM. ASTER GDEM is the most applicable terrain model for usage in the research. We elaborated the model upgrading for increase of the watersheds boundaries ascertainment accuracy. The upgrading consists in filtration of true altitude values and in decrease of the altitude values within the buffer zones of the watercourses. However, the upgrading demands significant labour inputs and individual approaches for each watershed. We propose to produce digital terrain models for urban areas by digitalization of hypsographic curves in images of topographic maps, location of point objects along the curves, and usage the point objects for interpolation of the altitude values by means of ArcGIS tools. Hydrological functions of ArcGIS were applied for the catchment areas ascertainment.

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