Application of the algorithm for calculating the boundaries of built-up areas from satellite images to calculating the areas of flooded land and the environmental potential of the territories of settlements

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Abstract. The processes of flooding of the territory of settlements cause significant economic damage to the national economy. Up-to-date space information provides research on flooding over large areas. Analysis of the dynamics of flooding in the Khabarovsk Region for 2016-2019 using remote sensing methods and statistical data analysis showed that the optimal software product for processing multi-time satellite images is the MapInfo Professional GIS application. It is established that the dynamics of the areas of flooded land in settlements has similar trends, significantly differing in quantitative indicators. The most favorable year was 2017, when the least amount of land was affected by flooding. In 2019, the amount of flooded land was the maximum. 2016 and 2018 occupy an intermediate position. The proportion of flooded land was the highest in large and medium-sized cities, the lowest in rural settlements, and the small towns occupied an intermediate position due to the landscape and geographical features of the research objects. The relative decline in the value of the territory environmental potential (EFP) was also the highest in large and medium-sized cities, and the lowest in rural areas. According to the years, the increase in the temporary decline in EFP due to flooding and withdrawal from economic use of land is as follows: 2017-2016-2018-2019, which is due to the dynamics of the hydrological and climatic characteristics of these years.

1. Introduction
Flooding of land by river waters during high water is a serious natural and anthropogenic danger that hinders the proper life of the people and the development of territories located in areas subject to these negative processes. In this study, the analysis of the capabilities of the MapInfo Professional geoinformation system (hereinafter – GIS) for calculating the areas of flooded lands (flood zones) is carried out by the example of a logically constructed series of settlements of different sizes in the Khabarovsk Region, located on the river Amur, whose territories are managed at the municipal level by local self-government bodies [4].

This largest hydrological object of the region and the country plays a crucial role in the food and material well-being of the inhabitants of the settlements located on its banks, representing a significant storehouse of various resources, but at the same time being a serious threat to them due to periodic floods that lead to temporary flooding of the land.
The aim of the work was to study the dynamics of land flooding in the cities of Khabarovsk, Komsomolsk-on-Amur, Amursk, villages of Troitskoye, and Yelabuga, which are large, medium-sized, small cities and two rural settlements. The analysis of the negative process of flooding corresponds to the local general level for cities and to the local level of land monitoring for villages, corresponding to the mainstream of landscape research [1, 7, 9].

2. Baseline information
To achieve this goal, the initial materials provided by cadastral data, statistical and other documented information about the declared research area, as well as remote sensing materials (satellite images) were collected.

In accordance with the data of the state statistical reports, the area of the land fund of the Khabarovsk Region as of 01.01.2019 was 78,763.3 thousand hectares. The distribution of the land fund by land categories is shown in Table 1.

| Name of the land category                                      | Square, thousand ha | Share, % of the total area |
|---------------------------------------------------------------|---------------------|---------------------------|
| 1. Agricultural land                                          | 399.7               | 0.5                       |
| 2. Lands of settlements                                        | 421.5               | 0.5                       |
| including:                                                    |                     |                           |
| urban settlements                                             | 157.9               | 0.2                       |
| rural settlement                                              | 263.6               | 0.3                       |
| 3. Industrial and other special purpose lands                  | 269.9               | 0.4                       |
| 4. Lands of specially protected territories and objects        | 1 646.4             | 2.1                       |
| 5. Forest fund lands                                           | 73 706.7            | 93.6                      |
| 6. Water fund lands                                            | 961.4               | 1.2                       |
| 7. Reserve lands                                              | 1 357.7             | 1.7                       |
| Total                                                         | 78 763.3            | 100.0                     |

3. Research progress and methodological aspects
Satellite images were digitized and decrypted to obtain flood maps. To determine the boundaries of settlements and other terrain objects from space images, a specially written algorithm for contour selection in the MATLAB programming language was used. The idea of the algorithm is that in the MATLAB environment, the original space image is opened, then the brightness values for a specific object of the terrain are entered, and the size of the mask (it is possible to enter the mask value 3, 5, 7, 9). Based on a specific brightness value, the mask compares the pixel values across the entire image with the specified brightness value of the object. If a particular pixel falls under the specified value, then it falls within the boundaries of the selected object, if not, then it is not included in this area of interest. In this way, the desired objects are highlighted in the original space image. In the present study, the algorithm was mainly used to identify the boundaries of settlements to form the corresponding layer in the MapInfo Professional GIS application, and to superimpose the "aqua" thematic layer on it. Below is the code of the algorithm. Algorithm code:

```matlab
% program for edge detection
% clc; clear all; close all;
% read an image
[filename, pathname, filterindex] = uigetfile( ... 
{ '*.tif', 'TIF (*.tif)'; ... 
'*.,*', 'All Files (*.*)'}, ... 
...);`
'Choose image(s) to be processed', ...
'MultiSelect', 'off');
%
if filterindex==0, break;end
filename=cellstr(filename);
y= imread(horzcat(pathname,char(filename))); 
mm=input('Input your threshold between 0 and 255    ');
wsz=input('Введите размер окна    ');
% convert color image to gray scale
x=y;
% mapshow(x, R);
imshow(x);
[r,c]=size(x);
max=0;
min=0;
rsize = round(wsz/2)-1;
for j=1+rsize:r-rsize
    for i=1+rsize:c-rsize
        p=i-rsize;
        q=i+rsize;
        a=j-rsize;
        b=j+rsize;
        d1=abs(x(j,i)-x(j,p));
        d2=x(j,i)-x(j,q);
        e1=x(j,i)-x(a,i);
        e2=x(j,i)-x(b,i);
        f1=x(j,i)-x(a,p);
        f2=x(j,i)-x(b,q);
        g1=x(j,i)-x(a,q);
        g2=x(j,i)-x(b,p);
        if (d1 < 0)
            d1=d1*(-1);
        end
        if (d2 < 0)
            d2=d2*(-1);
        end
        if (e1 < 0)
            e1=e1*(-1);
        end
        if (e2 < 0)
            e2=e2*(-1);
        end
        if (f1 < 0)
            f1=f1*(-1);
        end
        if (f2 < 0)
            f2=f2*(-1);
        end
        if (g1 < 0)
            g1=g1*(-1);
        end
        if (g2 < 0)
            g2=g2*(-1);
        end
    end
end
if (g2 < 0)
g2=g2*(-1);
end
if (d1 >= mm) && (d2 >= mm)
x(j,i)=255;
elseif (e1 >= mm) && (e2 >= mm)
x(j,i)=255;
elseif (f1 >= mm) && (f2 >= mm)
x(j,i)=255;
elseif (g1 >= mm) && (g2 >= mm)
x(j,i)=255;
else
x(j,i)=0;
end
end
figure
imshow(x);
BW = im2bw(x, 0.90);
figure
imshow(BW).

The visual identification of flood-affected areas and the calculation of their squares are carried out in the MapInfo Professional GIS application. The authors thank N. Y. Gorbashov, B.Sc. (in Land Management and Cadaster) and M. S. Strulnikov, B.Sc. (in Land Management and Cadaster) for their assistance in the work.

At the first stage, an image of the original map material was obtained, visualized on a monitor screen, which was digitized by converting a bitmap image into a vector image and forming layers of a digital map [2, 3, 8].

The original map materials were differentiated by content elements, highlighting the following sublevels within each element:

a) polygon (objects that represent a polygon);
b) arc (objects that represent arcs);
c) point (point objects).

The MapInfo Professional GIS application allows you to place several different types of elements, including text, on a single layer. Creating layers is performed on already created tables, previously activated in the "Manage Layers" dialog box by selecting the checkbox in the "Edit" window. Layers are created on top of the bottom layer, which is the raster base.

The "aqua" layer of flooded land is digitized as a layer of area features, so that the area of polygons can be determined in the future.

Figure 1 shows an example of a decoded satellite image on the territory of a settlement (red lines – the boundaries of the settlement) with the allocation of flood zones (blue lines).
Figure 1. A fragment of a satellite image of the city of Amursk with the boundaries of flooded lands (2016).

The results of the calculation of the flooded lands of Khabarovsk are presented in Table 2.

| Year | Total land area of the city, ha | Area of flooded land, ha | Area of flooded land, % |
|------|--------------------------------|--------------------------|-------------------------|
| 2016 | 38635                          | 7825                     | 20.3                    |
| 2017 | 38635                          | 7847                     | 20.3                    |
| 2018 | 38635                          | 7855                     | 20.3                    |
| 2019 | 38635                          | 9355                     | 24.2                    |

For the entire study period, the number of flooded lands was minimal in 2017, as in 2016 and 2018. In 2018 as in 2016, the city suffered in the West because of the flood (lands designated for mining of mineral resources); on the South-West and North-West of the affected lands for the placement of production and administrative buildings, structures and objects that serve them; on the North-East – lands, designed to accommodate social and domestic purposes.

In 2019, the highest level of flooding was recorded. The main part of the city suffered in the West due to the flood of the river (land for mining of mineral resources, as well as for gardening), in the South-West and North-West, lands intended for industrial facilities were flooded, and in the North-East, lands intended for social and municipal facilities were flooded.
The results of the calculation of the flooded lands of Komsomolsk-on-Amur are presented in Table 3.

Table 3. The area of flooded land in Komsomolsk-on-Amur.

| Year | Total land area of the city, ha | Area of flooded land, ha | Area of flooded land, % |
|------|--------------------------------|--------------------------|------------------------|
| 2016 | 32510                          | 4090                     | 12.6                   |
| 2017 | 32510                          | 3637                     | 11.2                   |
| 2018 | 32510                          | 5745                     | 17.7                   |
| 2019 | 32510                          | 9719                     | 29.9                   |

For the entire period of the study, the amount of flooded land was the lowest in 2017. In 2018, as in 2016, there was a water spill in Lake Mylka, small reservoirs and rivers overflowed their banks, and the A-376 highway was flooded, but without obvious damage. In the eastern part of the city, the coastal line of the Amur River was flooded, the lands of settlements intended for gardening were affected. In the northern part, the shoreline of Lake Horpy was flooded, and the lands intended for agriculture were damaged.

In 2019, the highest level of flooding was recorded. The entire southern part of the city was flooded. Lake Mylka overflowed its banks, and the flooding of the A-376 highway caused significant damage to it. In the eastern part of the city, the lands of settlements intended not only for gardening, but also for the placement of transport facilities, individual residential buildings, communal and warehouse facilities were affected. Lake Horpy overflowed its banks, and lands for farming and for gardening were damaged.

The results of the calculation of the flooded lands of the city of Amursk are presented in Table 4.

Table 4. The area of flooded land in the city of Amursk.

| Year | Total land area of the city, ha | Area of flooded land, ha | Area of flooded land, % |
|------|--------------------------------|--------------------------|------------------------|
| 2016 | 14664                          | 1657                     | 11.3                   |
| 2017 | 14664                          | 1233                     | 8.4                    |
| 2018 | 14664                          | 1827                     | 12.5                   |
| 2019 | 14664                          | 2873                     | 19.6                   |

For the entire period of the study, the amount of flooded land was the lowest in 2017. In 2018, as in 2016, in the southern part of the city, the shoreline of Lake Padali was flooded; the lands of settlements intended for recreation of the population, for industrial activities and for the berth of small vessels were affected. In the eastern part, the coastal line of the Amur River was flooded, the lands of settlements intended for gardening by citizens, as well as for agriculture, were affected.

In 2019, the highest level of flooding was recorded. In the southern part of the city, there was a significant flooding of the shoreline of Lake Padali; the lands of settlements intended for recreation of the population were affected. The water completely flooded the highway leading out of the city, effectively cutting off the entrance and exit from the south of the city. The lands of settlements intended for placement of individual residential development, for industrial activity and for the berth of small vessels were affected. In the eastern part there was a strong flood of the river Amur, the lands of settlements intended for gardening, for farming and for recreation of citizens were affected.

The results of the calculation of flooded land of the village Troitskoye are presented in Table 5.
Table 5. The area of flooded land in the village of Troitskoye.

| Year | Total land area of the village, ha | Area of flooded land, ha | Area of flooded land, % |
|------|-----------------------------------|--------------------------|-------------------------|
| 2016 | 1368                              | 7                        | 0.5                     |
| 2017 | 1368                              | 4                        | 0.3                     |
| 2018 | 1368                              | 13                       | 1.0                     |
| 2019 | 1368                              | 16                       | 1.2                     |

For the entire period of the study, the number of flooded lands was the lowest in 2017.

In 2018, as in 2016, in the northern part of the village, the Amur River coastline was flooded. The lands of settlements intended for the berth of small vessels were affected. In addition, in 2018, damage was caused to the lands of settlements intended for the location of the emergency prevention and response facility.

In 2019, the highest level of flooding was recorded. In the northern part of the village there was a significant flooding of the coastline of the Amur River. The lands of settlements intended for berthing small vessels were seriously damaged. The material damage to the lands where the objects of the Ministry of the Russian Federation for Civil Defense, Emergency Situations and Elimination of Consequences of Natural Disasters are located was much higher than in other years.

The results of the calculation of the flooded lands of the village of Yelabuga are presented in Table 6.

Table 6. The area of flooded land in the village of Yelabuga.

| Year | Total land area of the village, ha | Area of flooded land, ha | Area of flooded land, % |
|------|-----------------------------------|--------------------------|-------------------------|
| 2016 | 402                               | 5                        | 1.2                     |
| 2017 | 402                               | 4                        | 1.0                     |
| 2018 | 402                               | 23                       | 6                       |
| 2019 | 402                               | 31                       | 8                       |

For the entire period of the study, the amount of flooded land was the lowest in 2017.

In 2018, as in 2016, in the West and North-West, due to the flood of the Amur River, land for personal subsidiary farming and gardening were affected, in the West – for the placement of communal, warehouse facilities. Lands for personal farming were affected in the South.

In 2019, the highest level of flooding was recorded. In the North-West of the Amur River, lands for housing communal and storage facilities were affected. In the West, lands for personal farming and gardening were affected. In the South and South-West, lands for personal farming were flooded.

As the cornerstone of the work, a meaningful analysis of the seasonal decline in the value of the environmental potential (hereinafter-EFP) of the territory of the cities of Khabarovsk, Komsomolsk-on-Amur, Amursk, the villages of Troitskoye and Yelabuga, caused by periodic flooding of lands, was carried out. The principles and calculation algorithms for calculating the EFP were described earlier [5, 6, 10], the initial value of the regional specific EFP of the territory was taken as 800 points/m²; the results are summarized in Tables 7 and 8.
Table 7. The total environmental potential of the territory of the settlements of the Khabarovsk Region, million points/m².

| Settlements             | EP of the territory without considering its flooding (2016) | EP of the territory considering flooding (2016) | EP of the territory considering flooding (2017) | EP of the territory considering flooding (2018) | EP of the territory considering flooding (2019) |
|-------------------------|-------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Khabarovsk              | 309 080                                                     | 246 480                                         | 246 304                                         | 246 240                                         | 234 240                                         |
| Komsomol'sk-on-Amur     | 260 080                                                     | 227 360                                         | 230 984                                         | 214 120                                         | 182 328                                         |
| Amursk                  | 117 312                                                     | 104 056                                         | 107 448                                         | 102 696                                         | 94 328                                          |
| Village of Troitskoye   | 10 944                                                      | 10 888                                          | 10 912                                          | 10 840                                          | 10 816                                          |
| Village of Yelabuga     | 3 216                                                       | 3 176                                           | 3 184                                           | 3 032                                           | 2 968                                           |

Table 8. Calculated specific environmental potential of the territory of the settlements of the Khabarovsk Region, points/m².

| Settlements             | CSEP of the territory without considering its flooding (2016) | CSEP of the territory considering flooding (2016) | CSEP of the territory considering flooding (2017) | CSEP of the territory considering flooding (2018) | CSEP of the territory considering flooding (2019) |
|-------------------------|-------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Khabarovsk              | 800                                                         | 638                                             | 638                                             | 637                                             | 606                                             |
| Komsomol'sk-on-Amur     | 800                                                         | 699                                             | 711                                             | 659                                             | 561                                             |
| Amursk                  | 800                                                         | 710                                             | 733                                             | 700                                             | 643                                             |
| Village of Troitskoye   | 800                                                         | 796                                             | 798                                             | 792                                             | 791                                             |
| Village of Yelabuga     | 800                                                         | 790                                             | 792                                             | 754                                             | 738                                             |

The seasonal decrease in the value of the EFP is proportional to the area of flooded land. In the case of a specific survey implemented in this paper, the maximum relative decrease in the value of the EFP was annually in large and medium-sized cities, the minimum – in rural settlements, the small town occupies an intermediate position, which is associated with the landscape and geographical features of the objects of study. Every year, the increase in land flooding and, accordingly, the temporary decrease in the EFP are as follows: 2017-2016-2018-2019, which is due to the dynamics of the climatic characteristics of these years.

4. Conclusions
The processes of flooding of the territories of settlements cause significant economic damage to the national economy. During such emergencies, many industrial, transport, municipal and social infrastructure facilities, residential and industrial buildings, and structures are damaged and destroyed, large tracts of agricultural land are flooded, leading to the death of crops, and the health and life of the people, as well as domestic animals, are threatened.
Modern space information provides research on the consequences of flooding over large areas. Remote sensing, replacing expensive and relatively slow field methods, provides the ability to safely collect data from the Earth's surface without physical contact with monitoring objects. Remote sensing technologies allow us to find appropriate solutions for emergency situations and their consequences, the ability to accumulate data on a large area of the earth's surface in a short period of time, and the ability to take pictures of hard-to-reach areas and make measurements regardless of weather conditions and time of day, and also to increase in labor productivity and reduce economic and time costs due to a decrease in the volume of field research, due to an increase in cameral work, and measurement accuracy by reducing the influence of atmospheric factors and automating measurements.

The study of the dynamics of flooding in the Khabarovsk Territory for 2016-2019 using remote sensing methods, statistical data analysis and data processing in the MapInfo Professional software product showed that the dynamics of the areas of flooded lands, characterized by the example of five settlements of the Khabarovsk Region, has similar trends, but its quantitative indicators are markedly different.

For all localities, 2017 is the most favorable year, with the least number of lands affected by flooding during the entire study period. In 2019, the number of lands affected by flooding is the maximum. 2016 and 2018 occupy an intermediate position.

The proportion of flooded land was the highest in large and medium-sized cities, the lowest – in rural settlements, the small towns occupied an intermediate position (closer to the medium-sized city), which is due to the landscape and geographical features of the objects of study.

The relative decline in the value of the MFP was also the highest in large and medium-sized cities, the lowest in rural settlements, and the small towns occupied an intermediate position. According to the years, the increase in the temporary decline in MFP due to flooding and withdrawal from economic use of land is as follows: 2017-2016-2018-2019, which is due to the dynamics of the hydrological and climatic characteristics of these years.

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