Mapping of soil properties using geographic information systems (on the example of Tashkent region)

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Abstract. The article analyzes the options for mapping soil properties using GIS systems. The perspectives on the use of GIS in the efficient mapping of soil mechanical content, agrochemical, and salinization characteristics are given. The study is conducted for irrigated sierozem soils of the Parkent district of Tashkent region. The basis of the research is the analysis of soil map data of the study areas, and the generalization of the results of soil-cartographic, laboratory, and cameral-analytical studies, which were conducted by commonly use methodological instructions. As a result of the research, digital thematic maps were created for the selected areas, such as various thematic maps, such as soil mechanical composition, soil nutrient status, and salinity maps.

1 Introduction

Today agricultural production and the provision of food to the population are one of the most pressing issues in the world. This is due to the high increase in the world population, various environmental problems (land degradation, soil erosion, quantitative and qualitative changes of water resources, climate change), and many other socio-economic issues.

Agriculture is one of the oldest branches of human economic activity. The application of modern information technologies in this area is very important. However, the effectiveness of the application of innovative technologies and innovations in agriculture is not very high. Of course, the mechanization of the sector has significantly increased the efficiency of agricultural labor, but agriculture lags far behind the rapidly growing industrial production sectors. Nevertheless, today innovative projects are being implemented in this area to bring production to a new level. It is clear that the application of information technology in the industry should begin with a clear account of available production resources. Since the main resource of agriculture is land, such information is, of course, of a spatial nature. This, in turn, makes the use of modern Geographical Information Systems (abbreviated as GIS) one of the primary tools in this sector.

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The application of GIS technologies is also important in the study of soils, which are the main valuable resources of agricultural lands. It is known that one of the most important properties of soils is soil productivity, so it is necessary to study its level and condition. The analysis of the spatial distribution of soil fertility properties serves as a basis for measures aimed at maintaining and increasing soil productivity.

In the 1970s and 1980s, the first attempts were made to describe the spatial patterns of soil properties by interpolation [1], attempts were made to determine the characteristic scales of spatial variation of soil cover and the size of soil individual [2], aerospace methods were developed for studying soil [3]. The concept of the structure of the soil cover [4] was actively developed in Russian soil science, which later became the basis for digital soil mapping.

In 1992, the discipline called pedometric was defined as a separate branch of soil science, which deals with the use of mathematical and statistical methods for studying the distribution and genesis of the soil [5]. Already in the 90s, ideas were expressed about the need to specify models for carrying out soil surveys [6], including models based on expert knowledge [7]. At the end of the 20th century, a great number of knowledges was obtained in application of the methods of geostatistics in ecology and soil science [8].

The development of computer technology has led to the emergence of a new trend in soil cartography, labelled as Digital Soil Mapping (DSM) [9]. DSM is computer-borne development of a soil spatial information systems making use of numerical modeling of spatial and temporal variability information of soils and their properties based on field survey data and on soil formation factors [10]. The methods of DSM are based on the models, which were developed on the basis of the factors of soil formation [11].

2 Materials and methods

Geographically, Parkent district is located 48 km east of Tashkent, in the western foothills of the Chatkal mountain range in the Middle Tianshan, surrounded by mountains. Due to the fact that the relief consists of foothill plains, hills, and mountainous areas, the climate of the district is divided into vertical zones and is characterized by a variety of features.

Relief. The surface of the region is more complex and gradually decreases from northeast to southwest to the Syrdarya. The highest lands are located in the northeast and east of the region. The southwestern part is flat [10].

Climate. The geographical location and topography of the Chirchik-Ahangaron region have a great impact on its climate. In the southwestern part of the region, the impact of cold, warm and humid air masses from the Arctic are significant. Even the northeastern mountainous part of the region can be easily washed away by wet and warm westerly winds. Therefore, the north-eastern mountainous parts of the region are wetter. Summer in the Chirchik-Ahangaron region, especially in the plains, is hot and almost always clear. The average temperature in July is 26-27 ºC in the plains and 20-24 ºC in the mountains. The maximum air temperature in summer can rise to 42 ºC and even 44 ºC [12].

Soils. Sierozem soils are distributed in the valleys of the Chirchik and Akhangaron valleys, on the banks of the Syrdarya. Soil cover varies with elevation: light sierozem soils are scattered at altitudes of 300-400 m above sea level. Light sierozem soils contain 1-1.5% humus, and normal gray soils contain 1.5-2.5% humus. The lands where the sierozem soils are scattered are almost completely irrigated, cotton, hemp, vegetables, and melons are grown, and there are gardens [12].

Coordinates: geographical location of the chosen observation sites and of the soil samples were marked with a Garmin ETrex-60 type GPS instrument.

Methods such as comparative-geochemical, comparative-geographical, laboratory-analytical, data accumulation, spatial analysis, and modeling on the basis of geoinformation systems make up the fundaments of the research methods.

Soil samples were taken from sierozem-meadow soils in the area. Field surveys were carried out on the basis of "Instruction on soil survey and soil mapping for the State Land Cadaster".

Laboratory-analytical and cameral studies were developed and conducted on the basis of commonly used techniques developed by the Research Institute of Soil Science and Agrochemistry [13, 14]. The mechanical content (texture) of soils was analyzed by the pipette method of N.A. Kachinsky. Amount of salts and ion content in the soil were analyzed using the aqueous absorption method, degree, and chemistry (type) of salinity - by L.P. Lebedev methods.

GIS analyses were carried out using ArcGIS 10 software and its Geostatistical Analyst modules.

3 Results and discussion

3.1 Mechanical composition of soils

Typical irrigated sierozem soils studied in the Parkent district of Tashkent region consist of light, medium, and heavy clay mechanical composition. The amount of physical clay (<0.01 mm) in these soils fluctuates over a wide range and is 16-18% in light mechanical sands, 21-30% in light loams, 32-45% in medium loams, and 45-58% in heavy loams. Silt fractions (<0.001 mm) are observed in the amount of 1.4-3.3% to 13-16%.

The plow layer of soil (0-35 cm, the top layer of the soil, which is normally turned in plowing) of the Parkent district of Tashkent region consists mainly of light and medium clay in lower horizons (layers) with heavy clay mechanical composition. The total amount of physical clay particles (<0.01 mm) in the plow layer is 10.4-40.1%, and heavy clay is 26.2–43.3% in the lower layers.

3.2 Agrochemical properties of soils

The amount of humus in the plow layer of irrigated soils of key areas of the Parkent district of Tashkent region varies at 0.93-1.71%, forming groups with low (0.5-1.0%) and moderate (1-2%) humus content. According to the analysis of agrochemical data, the irrigated sierozem-meadow soil of the studied massifs constitutes moderately supplied soil groups (Table 1).

The amount of humus in the subsurface horizons is significantly reduced, at 0.66-0.93%. In some sections, which characterize irrigated sierozem-meadow soils, relatively high amounts of humus are observed to a depth of 50-90 cm.

The total nitrogen content of the plow layer of irrigated soils studied in the Tashkent region varies in the range of 0.072-0.099% and decreases downwards along the soil section. The maximum amount of gross nitrogen is 0.099%. The total nitrogen content in the topsoil of these soils is 0.095%, decreasing with increasing depth depending on the lower layers.

Soils selected from irrigated lands of the Tashkent region vary in the range of 0.115-0.423% of total phosphorus in the plow layer, so it was observed that the soils of this region are rich in total phosphorus. These soils form groups that are poorly supplied with mobile phosphorus. The amount of mobile phosphorus in the plow layer of these soils is 3.98-12.71 mg/kg.

The total potassium content in the plow layer of irrigated soils of the Tashkent region is not high (1.44-1.67%). These soils form low-supply (100–200 mg/kg) groups according to the amount of potassium that plants can assimilate.

3.3 Salinization processes in soils

According to the salinity level, in the irrigated typical sierozem soils of the studied area, samples from unsalted (washed out of salts, with salt content less than 0.3%), moderate (1-2%), and strongly saline (2-3%) were noted.

According to a detailed analysis of the obtained data, irrigated soils of the Parkent district of Tashkent region are mainly medium or strong by salinity, and the total amount of water-soluble salts in the soil profile is a wide range, 0.275-4.895% of soil. The total quantity (HCO3 content) varies between 0.021-0.043%, chlorine ion content between 0.021-0.843%, and sulfate ion content in the range of 0.117-2.402%. According to salinity chemistry, the main soil samples consist of chloride-sulfate and sulfate salinity characteristics.

3.4 GIS analysis of soil texture

Soil texture defines various physical-chemical properties of soils. Consequently, the amount of physical clay in the content of the soil is an important factor in defining soil fertility. Humus content, amount of nutrients, and its physical-chemical properties change depending on soil texture. On the basis of obtained data, the distribution map of physical clay (<0.01 mm) in the plow layer of the soil of the study area was created with the method of interpolation (Figure 1).

3.5. GIS analysis of soil salinity

It is known that soil salinity is considered one of the main factors, which has a negative influence on soil fertility. Soil salinity has a negative impact on the development of agricultural crops, and decreases harvest significantly. Soil salinity is one of the most urgent problems, in particular, in our study areas, and most parts of the irrigated lands of the Sirdarya region are considered as less and medium saline soils.

In creating maps of the parameters of the salinity block of the soil fertility model, solid residues and the amount of sulfate and chlorine salts were determined. Based on these indicators, soil salinity maps were created with GIS by applying the interpolation method (Figure 2).

3.6. GIS analysis of agrochemical properties

To create a digital soil map of the amount of humus and nutrients, the corresponding belonging to this section were entered into the soil quality determination points of the study area. Based on these values, the spatial distribution of the amount of humus and nutrients in the soil in the study area was determined. For this, the kriging interpolation method available in the Geostatistical Analyst (GA) module of the ArcGIS program was used in Figure 3.

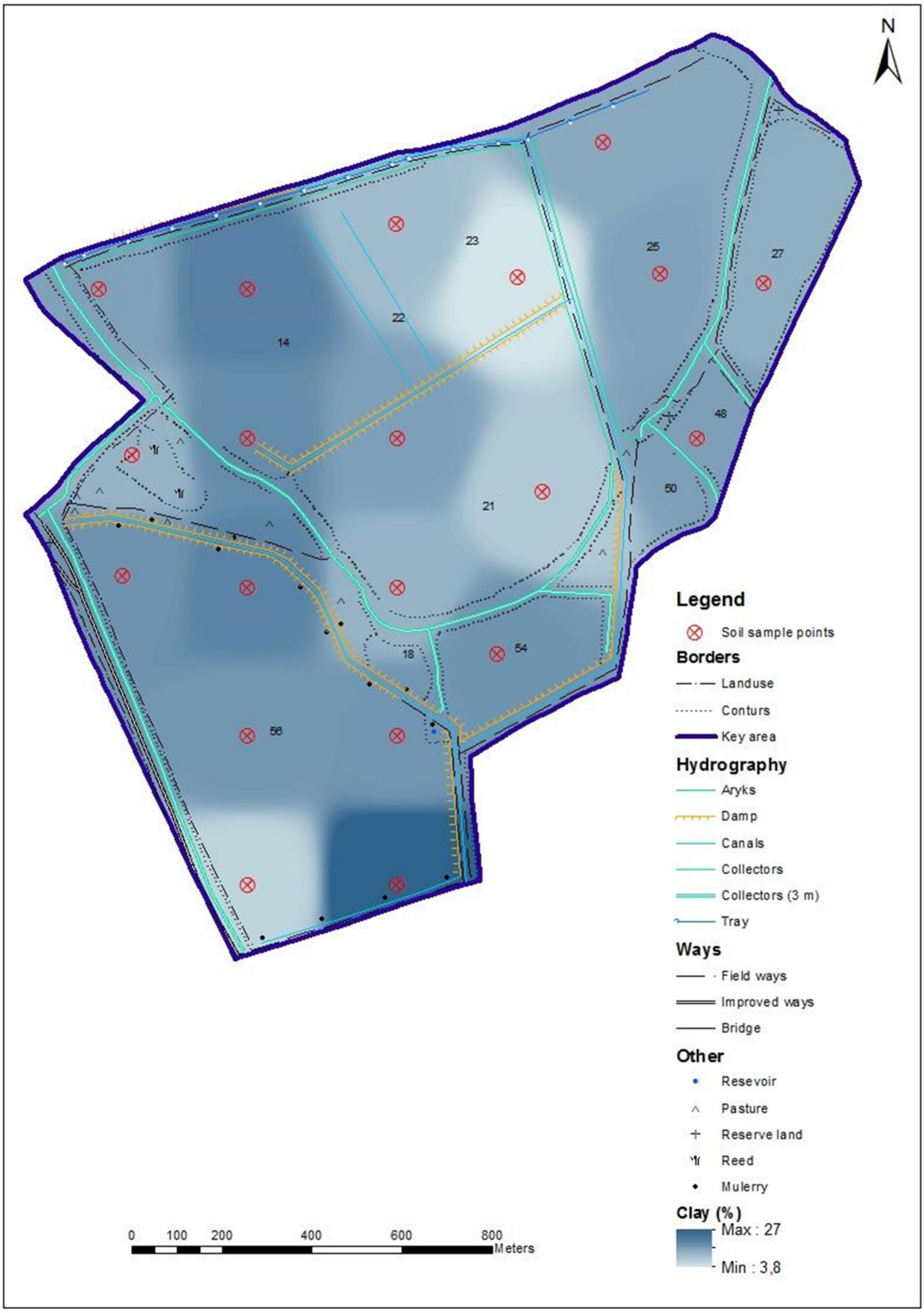

Fig. 1. Texture maps of irrigated soils of the Parkent district in Tashkent region by physical clay.

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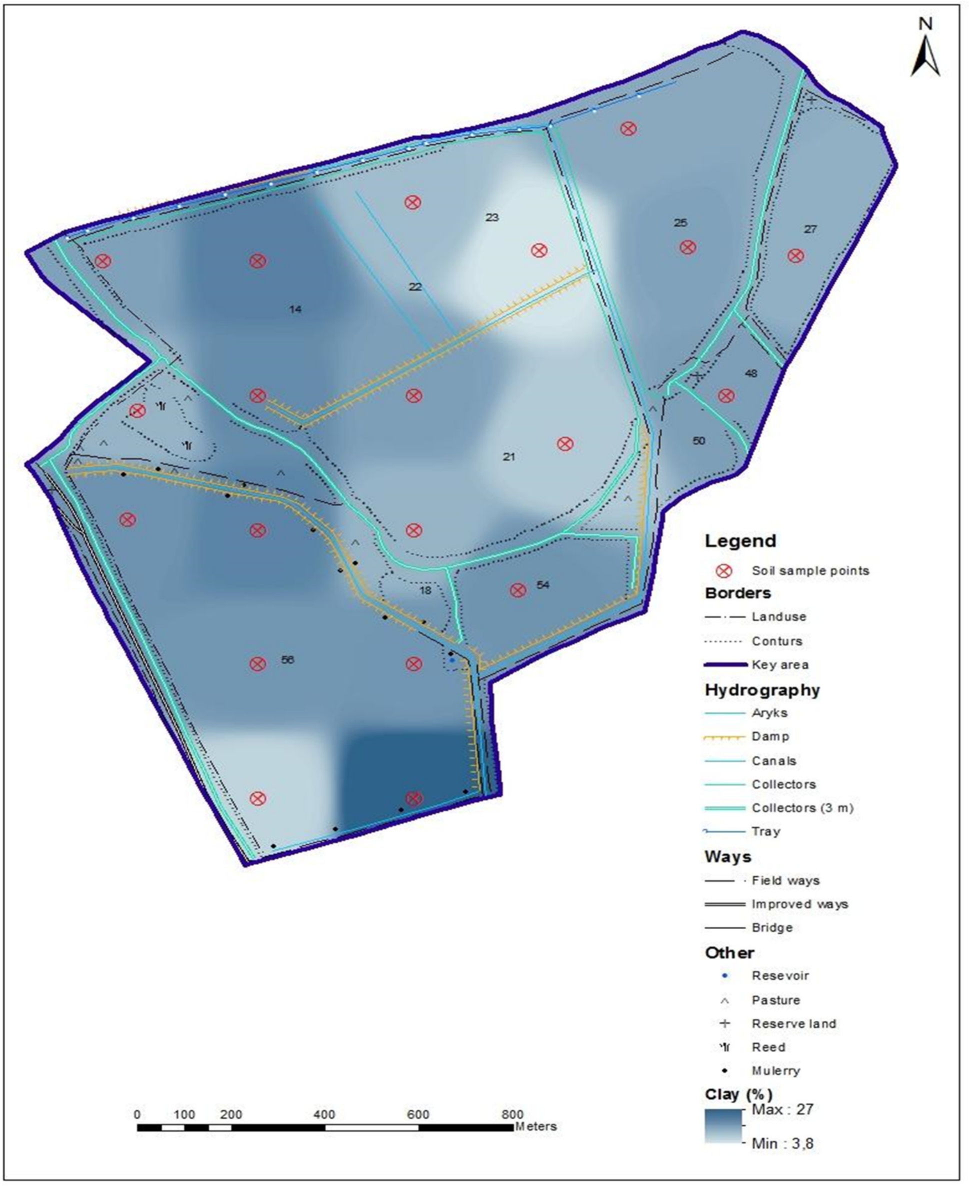

Fig. 2. Soil salinity map of the irrigated soils of Parkent district in Tashkent region.

Humus content - despite the relatively low amount of humus in irrigated soils in desert and semi-desert zones -, its impact on soil formation and fertility is very high. Humus plays an important role in the formation of processes, changes, and properties of the soil. Organic matter in the soil has the ability to accumulate and retain large amounts of nutrients and moisture due to its high-water absorption capacity.

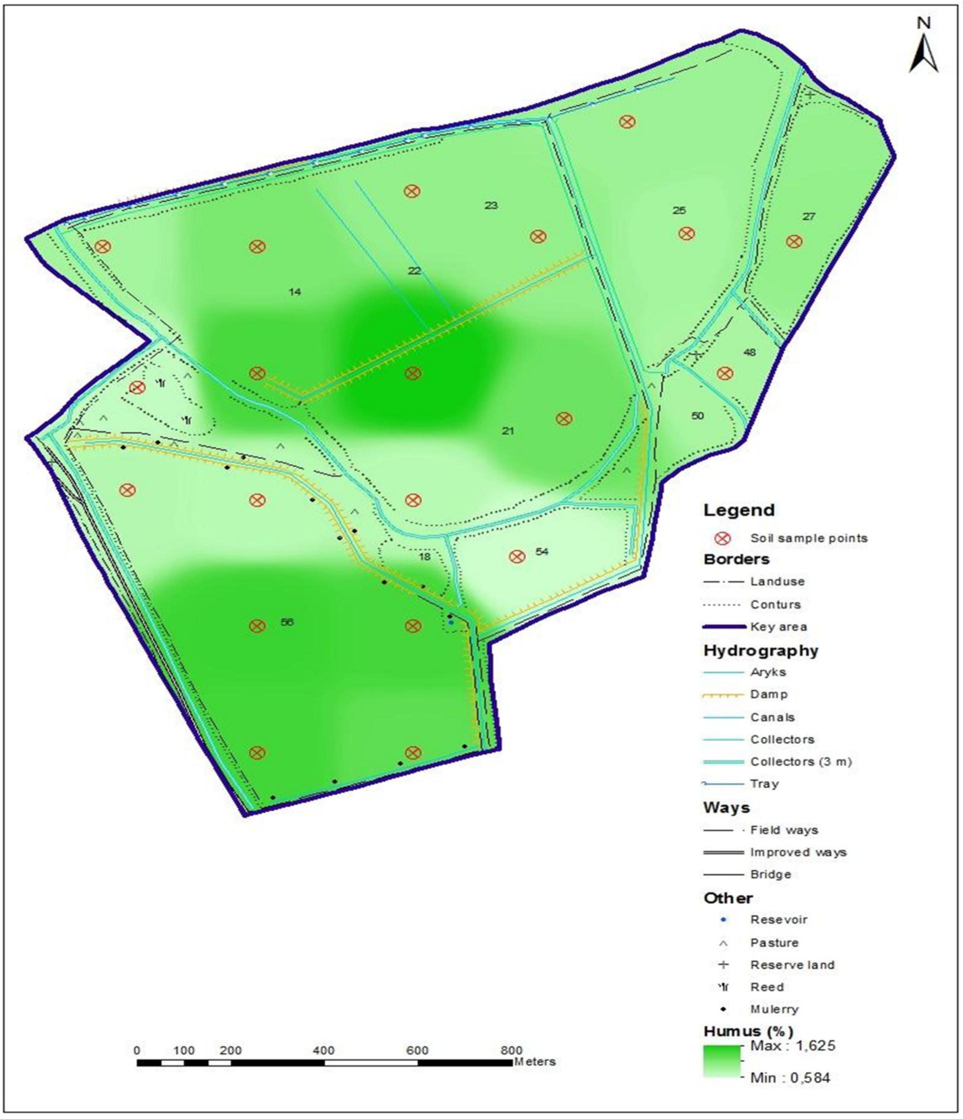

Fig. 3. Map of humus distribution in irrigated soils of Parkent district of Tashkent region.

Phosphorus is present in all organs of plants and energy metabolism. Consequently, the amount of P2O5 compounds play a major role in photosynthesis and respiration. Optimal phosphorus nutrition in the initial period of cotton development allows intensive development of the root system and rapid ripening of the crop. The total amount of phosphorus in irrigated soils of Uzbekistan is around 0.1-0.3%. Most of it is in the form of phosphates of alkaline earth metals, iron, and aluminum. Despite the relatively high content of phosphorus in irrigated soils, the proportion of water-soluble compounds, which are a direct source of plant nutrients, is small. This explains the high efficiency of phosphorus fertilizers in irrigated agriculture, especially in cotton. Work on this property of the soil was carried out as described above. A digital map of P2O distribution in the soils of the experimental field was created in Figure 4.

4 Conclusions

The soils of the study area consist of all mechanically compacted soils from heavy sand to sandstone in terms of mechanical components.

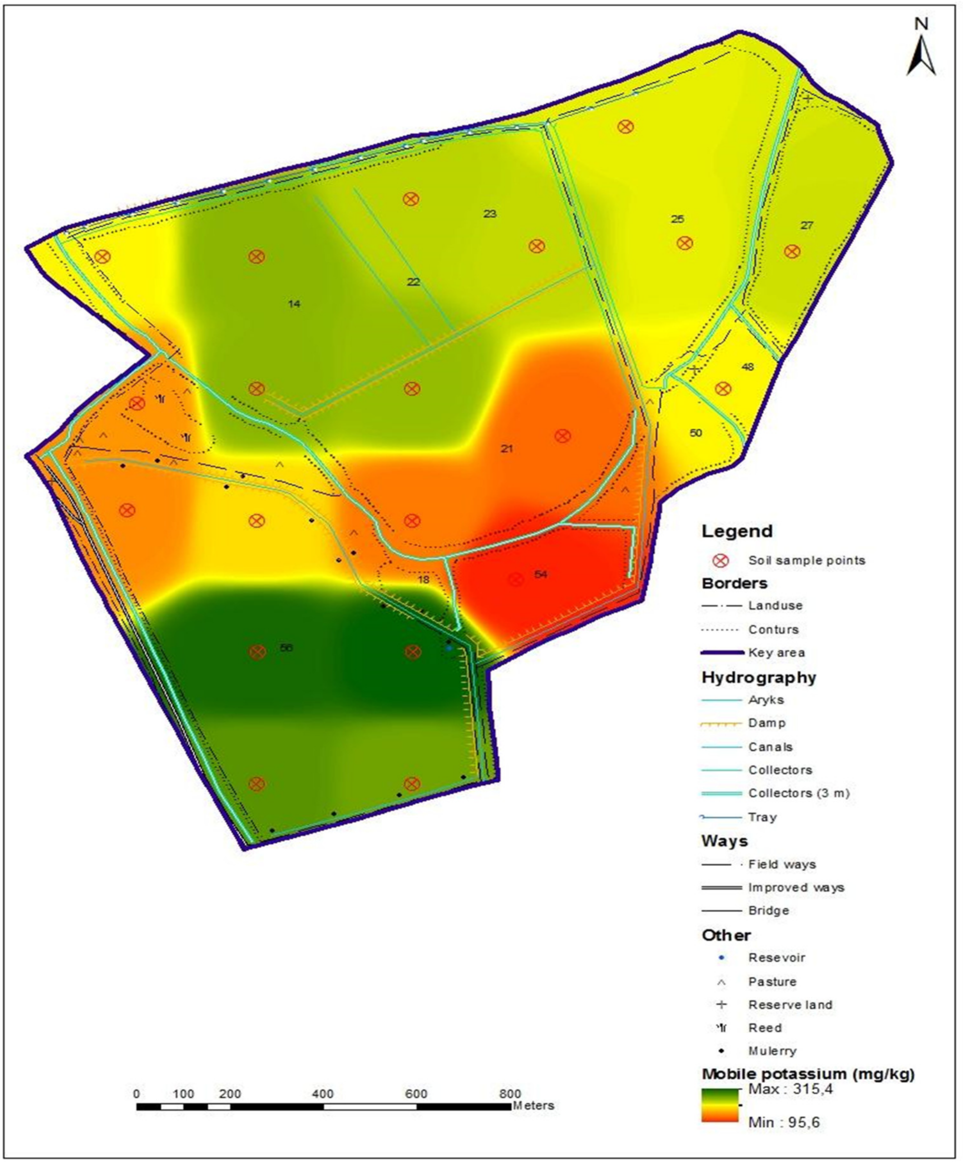

Fig. 4. Map of distribution of potassium in irrigated soils of Parkent district of Tashkent region.

One of the indicators of productivity is low and medium with humus, low, medium, and sometimes high supply groups with mobile phosphorus and exchangeable potassium from agrochemical indicators. One of the factors that negatively affect irrigated soils is the number of water-soluble salts, which are the determinants of salinity, and in the study area, there is mainly chloride-sulfate and sometimes sulfate type for irrigated soils. In these soils, mainly low, moderate, and strong salinity is observed in some soil separations.

It is recommended to use scientific data on the mechanical composition, agrochemical properties, and salinity of soils in determining the measures aimed at maintaining and increasing the fertility of soils of agricultural lands of Parkent district of Tashkent region. It is also advisable to carry out the use of appropriate soil quality assessment maps, agrochemical cartograms, and salinity cartograms to determine the norms of application of stratified fertilizers for the soils of the region, the timing and norms of saline leaching and other reclamation measures to increase soil fertility.

As a result of the research, some options for researchers to create thematic maps based on the soil research results using the Spatial Analyst and Geostatistical Analyst modules of ArcGIS software are determined.

In summary, it should be noted that the use of modern geoinformation technologies in the effective management of land resources can provide accurate and timely information, increasing the operational processing and storage capacity, and creating a relevant database, which can ultimately provide an excellent tool for an analysis on the state of the land resources.

The thematical digital maps developed using geospatial analysis in GIS systems, illustrated its agroecological conditions, soil properties, and relevant agro-meliorative measures for the study areas recommended as a scientific basis for the placement of agricultural crops, calculating the land value, and determining crop yields.

In order to efficiently manage soil fertility, it is recommended to apply a complex of measures that improve soil fertility - systems for the graduated application of mineral and organic fertilizers at optimal rates and soil washing in saline soils based on fertility models.

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