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STANDARDIZATION OF COLOR VISUALIZATION FOR SOIL AGROCHEMICAL MONITORING GEOSPATIAL DATA IN A GIS ENVIRONMENT

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Annotation. *The article substantiates the necessity of standardizing the color visualization of geospatial soil agrochemical monitoring data within a GIS environment. The study aims to develop a unified approach to the color coding of thematic maps, atlases, geodatabases, and geoportals for the agrochemical passportization of agricultural land. Discrepancies between subtractive print color models (CMYK, Pantone) and additive digital display models (RGB, HEX), as well as design models (HSL/HSV), caused by the different color gamuts of display devices, were analyzed. The transition from verbal color descriptions in regulatory documents to the creation of technical specifications and a reference color matrix (Cartographic Design System) with dual encoding of values – sRGB for web services and Coated FOGRA39 for printing–is substantiated, allowing to avoid oversaturated shades, reduced contrast, and violations of accessibility requirements (WCAG 2.1). Based on the "Methodology for Agrochemical Land Passportization of Agricultural Purpose", 6-level spectral scales of soil nutrient availability and 6-level scales of heavy metal contamination have been formalized. A unified classifier of cartographic display styles for agrochemical and ecotoxicological indicators is proposed, distinguishing a warm palette (deficiency), a green palette (optimal state), and a dark palette (contamination), along with a conceptual separation of the data storage layer and the visualization layer in accordance with database normalization principles (1NF/3NF) and the OGC SLD standard.*

***Keywords**: visualization standardization, geodatabase, agrochemical monitoring, reference color matrix, color spaces (RGB/CMYK/HEX), geoportal, QGIS Atlas, PyQGIS, mapping automation, style files (.qml), Cartographic Design System.*

Problem statement. Cartography was historically developed for print, whereas contemporary GIS systems and geoportals operate in a digital environment. In methodological guidelines or technological standards, colors are often described verbally (e.g., relief in brown, vegetation in green) or by paint numbers from the PANTONE or CMYK scales, whereas web-GIS applications employ the digital HEX and RGB models.

In practice, when visualizing geodata, developers of cartographic materials frequently encounter the problem that the same verbal color description is interpreted differently by different developers of thematic maps, atlases, and geodatabases. In order to prevent each contractor from developing separate styling libraries that would ultimately diverge from one another, it is necessary to develop a technical standard (specification). Such a standard may be presented in the form of a table with precisely fixed HEX, RGB, CMYK, and Pantone values and the corresponding names of visualization elements.

On the basis of such specifications, it becomes considerably easier to create digital style libraries for QGIS (.qml or .xml files), for ArcGIS Pro (.stylx files), or for web-geoportals (Mapbox GL Style JSON / OGC SLD styles). In addition, automatic conversion must be ensured to ensure consistency between print and web versions, fixing the color profiles involved (e.g., sRGB for screens and Coated FOGRA39 for print). To standardize the approach and fix a single color code for each name, it is best to develop a reference color matrix (a Cartographic Design System).

The principal discrepancy arises from color spaces and display environments. The same color has an entirely different range of available shades in different color spaces (a different color gamut). A color space, as a mathematical and physical model describing how colors are generated, measured, and reproduced on a particular device (a monitor screen, a printing press, or paper), therefore presupposes different technologies for producing the required color shades. In cartography and GIS, it is essential to understand the distinction between three principal color spaces. The first is the additive model – RGB (Red, Green, Blue). It is applied to monitor screens, smartphones, geoportals, and digital cartographic web services (Leaflet, Mapbox). Its operating principle consists in the emission of light through the mixing of three base beams: red (R), green (G), and blue (B). The HEX format essentially corresponds to RGB but employs a different notation for web-development encoding; for example, RGB(0, 153, 220) corresponds to #0099DC. The subtractive model CMYK (Cyan, Magenta, Yellow, Key/Black), used in printing houses and topographic plants for printing paper maps and atlases, makes it possible to visualize given colors on paper while accounting for the absorptive properties of the inks. The application value of each of the four inks is measured as a percentage (from 0% to 100%). Thus, the physical ink used in printing does not cover the entire color gamut represented in the RGB model and cannot reproduce colors as bright and pure as those emitted by a monitor screen. Consequently, the purer and more neon-bright a color appears on screen, the duller, dirtier, or darker it will appear on paper after printing.

The design model HSL / HSV / HSB (Hue, Saturation, Lightness / Value / Brightness) is used in the interfaces of GIS software (QGIS, ArcGIS) for selecting balanced palettes, as it was created for convenient human perception. Brightness in the HSV/HSB model (Value/Brightness) denotes the maximum brightness of the color itself (a pure color), rather than white; to render it white, saturation must be decreased. Therefore, the specification should separately clarify the measurement units for Lightness and for Value, since GIS software (in particular QGIS and ArcGIS) more often uses a percentage range from 0% (black) to 100% (white or bright).

If the color-visualization standard fixes only the CMYK code, then, when it is displayed in a web-GIS, the computer will automatically convert it into RGB, which may produce an unexpectedly dirty or excessively dull shade. Conversely, if only the RGB/HEX value is fixed (for instance, a bright cyan for a river), this color will become duller when printed on paper, since printing ink is physically incapable of reproducing it. The specification for each map element should therefore provide a verified pair of values – a code for screen display (HEX/RGB) and a correct code for print (CMYK/Pantone) – rather than a mere automatic conversion between them.

It is important to avoid hyper-saturated color shades with maximum possible brightness and saturation (Saturation close to 100%), which are not typically found in real nature, as they create a glowing effect or cause eye strain. This effect also occurs during the transition from printed materials to web maps, owing to the difference between the CMYK (print) and RGB/HEX (screen) color models. Furthermore, standard topographic maps are designed for a white-paper background, whereas on geoportals the base layer may be a satellite image or a dark map background.

The need to adapt maps for pleasant visual perception is backed by a number of justifications. First of all, a user will not be able to work with a map for a long time if large areas (forests, water bodies, urban blocks) are colored with hyper-saturated shades, as this leads to rapid eye fatigue. Excessive saturation of the map layers' color background distorts contrast and impairs essential elements (for example, the legibility of text labels deteriorates, route lines become indistinct, or other focal points are lost). European standards must take accessibility into account (Accessibility & WCAG 2.1), including the technical parameters of visualization for people with color-perception impairments (color blindness), while modern geoportals are required to comply with contrast requirements. Accordingly, a rule of cartographic design is applied whereby large areal objects (forest polygons, water, built-up areas, etc.) are always rendered in pastel, muted, or softened tones, while bright, saturated colors are used exclusively for small accents – point objects, boundaries, and the like.

Analysis of recent research and publications. The regulatory support for soil survey and mapping in Ukraine is based on a number of specialized DSTU standards that govern the methodology of data collection and processing, yet do not define color coding of the results. In particular, the procedure for electronic mapping of soil cover by multispectral scanning is established by DSTU 7849:2015 [2], developed by the Technical Committee for Standardization "Soil Science" (TC 142) jointly with the O.N. Sokolovsky National Scientific Centre "Institute for Soil Science and Agrochemistry." Indicators of soil fertility and the procedure for their use in monitoring and agrochemical certification of agricultural land are defined by DSTU 4362:2004 [3], which also provides for the creation of soil-agrochemical databases. The classification framework is supplemented by DSTU 3866-99 [4] on the degree of secondary soil solonetzicity and DSTU 7827:2015 [5] on soil quality classification. National topographic standards have also been developed that define stylistic rules for the design of conventional symbols on cartographic materials, including: conventional symbols for topographic maps at scales of 1:10,000, 1:25,000, 1:50,000, and 1:100,000; specifications of the State Scientific Production Enterprise "Kartographia"; geoinformation classifiers; and standards of the National Research Institution (NIGD). It has been established that these standards form a system of classes and gradations of agrochemical indicators, yet none of them contains a prescriptive color scale for their cartographic representation.

The tradition of agrochemical mapping proper in Ukraine constitutes an established practice that has taken shape within the national cartographic school: agrochemical cartograms are defined as thematic maps depicting the spatial distribution of the degree of soil supply with nutrient elements through the shading of contours with identical indicators [6]. It has been demonstrated that this tradition functions as a conventional, de facto established practice of color coding rather than as a formalized and approved standard, which accounts for the variability of color solutions among different contractors and departmental cartographic services.

International directives and specifications exist that concern the styling of geospatial objects and their visualization. In particular, clear rules for the styling and encoding of geospatial data layers in Europe are set out in the INSPIRE standard (EU);

the standard describing symbology used in GeoServer, MapServer, and QGIS is established by the Open Geospatial Consortium (Styled Layer Descriptor / Symbology Encoding); and Cynthia Brewer's cartographic standard for selecting visually balanced and contrasting palettes is ColorBrewer 2.0. Geoinformation technologies further provide standard style libraries in ArcGIS Pro (.stylx) and QGIS (.qml, .xml). The INSPIRE Data Specification on Soil (D2.8.III.3) [7] was developed by the Thematic Working Group TWG-SO. This specification defines a data model based on the ISO 19156:2011 standard (Observations and Measurements) for parametric soil characteristics and ISO 19123 (Coverages) for the raster representation of thematic soil maps, and it recommends the application of the WRB (World Reference Base for Soil Resources) classification scheme to ensure semantic interoperability [7]. It has been established that this specification exhaustively regulates the structure and semantics of the data, yet places the issue of their visual (color) representation outside its own scope of regulation.

The issue of cartographic portrayal of geodata proper is regulated by the ISO 19144-2 standard [9] and the OGC Symbology Encoding (SE) specification, which provides mechanisms for the areal classification of data, in particular the construction of choropleth maps through corresponding cartographic stylization techniques. At the same time, the study by Bocher and Ertz [8] demonstrates that even within the INSPIRE infrastructure, portrayal rules are defined only at a basic level, largely as recommendatory color tables without deeper cartographic substantiation, which constitutes a systemic problem for thematic geoportals in general [8]. This conclusion directly confirms the existence of a gap between the technical infrastructure of color encoding, which has already been standardized at the OGC/ISO level, and its substantive, subject-oriented content for the purposes of agrochemical soil monitoring.

A separate distinction exists between the color standardization of the soil itself as a physical object and the color legend of a thematic map of agrochemical indicators. An established international instrument is the Munsell Soil Color Chart, based on three coordinates (Hue, Value, Chroma), which has been used by soil scientists for decades to record the natural color of samples. Recent studies confirm the integration of this scale into digital methods of soil-color mapping based on satellite spectral data [10]. It has been established that the Munsell system addresses the task of objectively recording the natural color of a soil sample and is not applicable to the coding of classes of agrochemical indicators (the content of mobile phosphorus, potassium, humus, etc.).

Thus, no approved, agreed-upon selection of colors for the thematic mapping of soil agrochemical indicators within a GIS environment currently exists. The available sources form three independent and mutually unconnected components: a system of classes of agrochemical indicators [3], a technical infrastructure for color encoding devoid of subject-specific content [9], and an established yet formally unfixed national cartographic convention. This substantiates the expediency of developing and specifying a dedicated, standardized color system that synthesizes the aforementioned components within a unified GIS-oriented approach.

The purpose of the study is to standardize the visualization of thematic maps when working with the database of agrochemical certification of agricultural land, atlases, thematic maps, and geoportals.

Materials and methods of the study. The standardization of visualization is carried out for the purposes of research conducted under contract with the Ministry of Education and Science of Ukraine No. DZ/168-2025 of 12.02.2025, "Study of the agrochemical condition and the impact of military operations on agricultural land to ensure sustainable agricultural production (Zhytomyr, Kyiv, Sumy, Kharkiv, Kherson, and Chernihiv oblasts)," using survey materials within Kherson Oblast.

The normative-methodological basis for the formalization of intervals and gradations was the Methodology for Agrochemical Certification of Agricultural Land [1]. The study processed the following indicators:

soil acidity and alkalinity – a 10-level scale;

macroelements and organic matter – 4–6-level scales;

mobile forms of trace elements according to the ammonium-acetate buffer at pH 4.8 and the oxalate buffer at pH 3.3 – 6-level supply scales;

heavy metals and toxicants – 6-level scales; radionuclides ^{137}Cs and ^{90}Sr – 3-level contamination scales; and HCH and DDT – exceedance of maximum permissible concentrations.

To eliminate the subjectivity of verbal color description, the method of reference cartographic profiling (Cartographic Design System) was applied. Conversion between the additive (sRGB, HEX), subtractive (CMYK/Coated FOGRA39, Pantone), and design (HSL/HSV) color models was carried out with account taken of the color gamut of the display devices. The assessment of contrast and visual accessibility of the developed palettes for users with color-perception impairments was performed in accordance with the international WCAG 2.1 standard (Accessibility) and the cartographic design principles of ColorBrewer 2.0.

Cartographic modelling, visualization, and testing of the developed styles were carried out in the QGIS geoinformation system environment (version 3.32.1).

To comply with database normalization requirements (1NF/3NF) and to ensure time-series monitoring (Time-Series Analysis), a conceptual distinction was applied between the data-storage layer (Data Layer) and the visual-presentation layer (Presentation Layer/OGC SLD). All primary numerical values of the indicators are stored in a single attribute table together with metadata (extraction method, units of measurement, DSTU/regulatory document), while their semantic division into zones ("deficiency," "optimal condition," "contamination") is implemented at the level of style classifiers (.qml files).

Research results and discussion. Analysis of the Methodology [1], developed by the State Institution "Derzhgruntokhorona," makes it possible to establish a clear system of grouping soils by agrochemical indicators together with the regulated colors for their cartographic representation. The basis of visualization in the Methodology is agrochemical cartograms, which characterize agricultural land by the degree of acidity and alkalinity, humus content, and the level of nutrient supply.

The number of groups and the corresponding colors depends on the specific agrochemical indicator. In particular, for assessing the degree of soil acidity and alkalinity, a maximum of 10 groups is provided – from very strongly acidic ($pH < 4.1$) to very strongly alkaline ($pH > 8.5$). A separate color, ranging from red to brown, is assigned to each group.

By humus content, soils are divided into 6 groups: very low, low, medium, elevated, high, and very high. Six groups are likewise provided for mobile compounds of phosphorus and potassium and for mobile sulphur.

Particular attention in the Methodology is devoted to the assessment of soil nitrogen regime. Various methodological approaches are used for its characterization, including the determination of easily hydrolysable nitrogen content by the Cornfield method, which uses a division into four groups, and soil nitrification capacity by the Kravkov method, which uses six.

By the content of easily hydrolysable nitrogen, determined by the Cornfield method, soils are divided into four groups: very low level – less than 101 mg/kg of soil; low – 101–150 mg/kg; medium – 151–200 mg/kg; and elevated – more than 200 mg/kg. According to the adopted system of cartographic representation, these levels correspond to red, orange, yellow, and green colors respectively. Separate gradations for high and very high supply levels are not provided for this method.

For assessing soil nitrification capacity by the Kravkov method, a six-group scale is used. Nitrification capacity is considered very low at a nitrogen content of less than 5.0 mg/kg of soil; low at 5.1–8.0 mg/kg; medium at 8.1–15.0 mg/kg; elevated at 15.1–30.0 mg/kg; high at 30.1–60.0 mg/kg; and very high at more than 60.0 mg/kg. For the cartographic representation of these gradations, red, orange, yellow, green, light blue, and blue colors are applied respectively (Table 1).

Table 1.

Soil fertility classes based on agrochemical elements for 6 groups

Group	Content Value	Color in the Methodology	The Role of Color (Perception)
I	very low	red	alarm signal / shortage
II	low	orange	warning / needs to be entered
III	average	yellow	moderate
IV	elevated	green	optimal / normal state
V	high	sky blue	well-off
VI	very high	blue	excess / specific condition

For trace elements, in particular Mn, Zn, Cu, Co, B, and Mo, six supply groups are likewise provided – ranging from very low to very high. For these indicators, a six-color gradation is applied: red, orange, yellow, green, light blue, and blue. At the same time, the approach to assessing their content as heavy metals differs from the system used for assessing nutrient-element supply. For heavy metals, the background content, corresponding to the upper limit of the supply range, is taken into account, together with six levels of contamination: weak, moderate, medium, elevated, high, and very high.

A separate principle of cartographic representation is likewise applied to characterize the radioactive contamination of soils. For the density of contamination by the radionuclides ^{137}Cs and ^{90}Sr, distinct ranges and color gradations are used, making it possible to visually distinguish territories with different levels of radioactive load.

The principal problem of this Methodology for web-GIS applications and geoportals, as with most Ukrainian normative-methodological documents, is the absence of standardized cartographic conventions. The text contains verbal descriptions of colors rather than digital codes ("red," "orange," "yellow-green," "blue"). The appendices provide graphic samples of cartograms for printing, but no digital color code is fixed anywhere. In the absence of precise codes under the HEX/RGB/CMYK standards, in practice, when applying the Methodology, each user selects "green" or "yellow" at their own discretion in QGIS or ArcGIS. As a result, a phosphorus cartogram produced by one contractor will appear bright and neon, while one produced by another will appear dull or in different shades altogether.

To translate this methodology into a unified digital standard for geoportals (RGB/HEX) and for the printing of agrochemical certificates (CMYK), it is necessary to fix a reference matrix.

Such a duality of interpretation of the same elements, depending on the assessment task – either as indicators of plant nutrient supply or as indicators of soil contamination – creates a potential problem when representing them in digital geodatabases, geoinformation systems, and geoportals. In order to standardize the cartographic representation of these indicators and to avoid confusion between classes that are close in color perception, it is proposed that a unified classifier of cartographic-representation styles for agrochemical and ecological-toxicological soil indicators be developed.

A geodatabase is developed to address specific managerial and production tasks. For an agronomist or farmer, what matters is determining the soil's nutrient supply and substantiating the need for micronutrient fertiliser application. For environmental control and monitoring bodies, and for institutions making managerial decisions concerning the environmental safety of land, the priority is the opposite characteristic – identifying territories with an excessive content of potentially hazardous elements. In this case, it is appropriate for the unified style classifier to employ a separate, visually distinct, attention-drawing color scale – for example, a transition toward magenta and violet tones for high contamination levels and exceedances of regulatory values. This would prevent a situation in which the same color, across different thematic layers, denotes fundamentally different processes – element deficiency versus its excessive, environmentally hazardous content. Dark, saturated colors would not be confused with the red color denoting deficiency, while visually conveying a sense of severity and toxic loading on the soil. At the same time, it is appropriate to distinguish exceedance of the maximum permissible concentration (MPC) not merely as another level on the gradation scale, but as a separate, normatively significant category. The Methodology provides that the level of contamination is assessed by comparing the actual concentration of an element with the MPC, or, in the absence of such a standard, with the natural background value. Where the MPC is exceeded, the Methodology provides for corresponding restrictions on the agricultural use of the land.

At the level of cartographic visualization, in particular within the structure of geoportals, it is advisable to provide for at least two separate thematic modes or tabs. The tab for the agrochemical status of plant nutrient supply would use the six-color scale established by the Methodology – from red for very low supply to blue for very high supply. The tab for ecological contamination status would represent the background condition and the six contamination levels using a separate, contrasting scale, visually distinct from the nutrient-supply scale. In this case, it is advisable to additionally mark MPC exceedances with a special color, hatching, or warning symbol, independent of the contamination class number. Such an approach would make it possible to unambiguously interpret the same chemical element depending on the target task of the geoinformation analysis – either as a resource for plant mineral nutrition or as a potential factor of environmental risk.

The simultaneous separation of the semantics of indicators from the styles of their representation is an important precondition for the standardization of agrochemical geodata and its correct use in specialized geoportals. Separating primary physical data into different attribute tables contradicts database normalization (1NF/3NF), undermines the integrity of geodata, and complicates time-series monitoring (Time-Series Analysis). All measured absolute values (for example, copper content in mg/kg according to the AAB method) must be stored in a single attribute field.

Ensuring the integrity and interpretability of geospatial data requires a conceptual distinction between the data-storage layer (Data Layer) and the layer of their visual representation (Presentation Layer/Styles). This approach is consistent with the general logic of geoinformation systems, whereby source spatial and attribute data are stored independently of the rules governing their cartographic design; in particular, the OGC SLD standard provides for a separate definition of the rules of symbolization and color representation of geospatial data.

To eliminate this duplication and create an intuitively comprehensible cartogram, it is advisable to divide the color space into three logical zones. The first zone would represent nutrient-element deficiency, the second – optimal or acceptable supply, and the third – excessive content and contamination levels. It is advisable to convey the transition between classes not only through a change in color hue, but also through changes in lightness and saturation (Lightness/Value and Chroma), which would make it possible to visually reinforce the degree of deviation from the optimal state (Table 2).

In this connection, it is appropriate to speak not merely of storing all measured indicators in a single attribute table, but of forming a unified, structured database in which, alongside the numerical value, the indicator identifier, units of measurement, determination method, extraction type, and other necessary metadata are stored together. This is particularly important for trace elements, since their agronomic and ecological-toxicological assessment may be carried out using different extraction methods. For example, Table 5.16 of the Methodology uses an ammonium-acetate buffer solution at pH 4.8 for Mn, Zn, Cu, and Co, an oxalate-buffer solution at pH 3.3 for Mo, and water for B; at the same time, Appendix 6 provides for the assessment of contaminant elements both in a 1N HCl solution extract and in an ammonium-acetate buffer solution at pH 4.8.

Table 2.

Classification System for Cartographic Representation of Agrochemical and Ecotoxicological Soil Indicators

Group	Title According to the Methodology	Color rendering	HEX (sRGB / Web)	RGB (Screen)	CMYK (Print FOGRA39, %)
Supply level					
1	red		#ff5656	255, 86, 86	0, 81, 65, 0
2	pink		#ffd1dc	255, 209, 220	0, 26, 6, 0

3	orange		#ffd6a5	255, 214, 165	4, 19, 39, 0
4	yellow		#fdffb6	253, 255, 182	5, 1, 36, 0
5	bright green		#e2f0cb	226, 240, 203	13, 3, 25, 0
6	green		#caffbf	202, 255, 191	19, 0, 26, 0
7	sky blue		#9bf6ff	155, 246, 255	31, 0, 10, 0
8	blue		#a0c4ff	160, 196, 255	40, 19, 0, 0
9	violet		#bdb2ff	189, 178, 255	33, 31, 0, 0
10	brown		#d4a373	212, 163, 115	11, 36, 57, 10
back ground	hatching 45°		#afafaf	175, 175, 175	34, 26, 26, 6
Pollution level					
1	low		#e0bbe4	224, 187, 228	16, 32, 1, 0
2	moderate		#d291bc	210, 145, 188	18, 52, 4, 2
3	average		#338384	51, 131, 132	76, 20, 40, 25
4	elevated		#948079	148, 128, 121	42, 45, 45, 17
5	hight		#1a247c	26, 36, 124	98, 91, 0, 18
6	very hight		#37474f	55, 71, 79	80, 55, 47, 53

All colors in the reference matrix are given at 100% opacity. When compositing multi-layer maps in QGIS, layer transparency may be set within the range of 75–85%. A visual representation of the proposed classification is shown in Figure 1.

Consequently, the formation of a single, continuous numerical series "deficiency – optimal supply – contamination" is possible only for those indicators determined by a comparable method and expressed in identical units of measurement. In other cases, the database must retain separate indicators, with their semantic integration carried out only at the level of the classifier and cartographic representation.

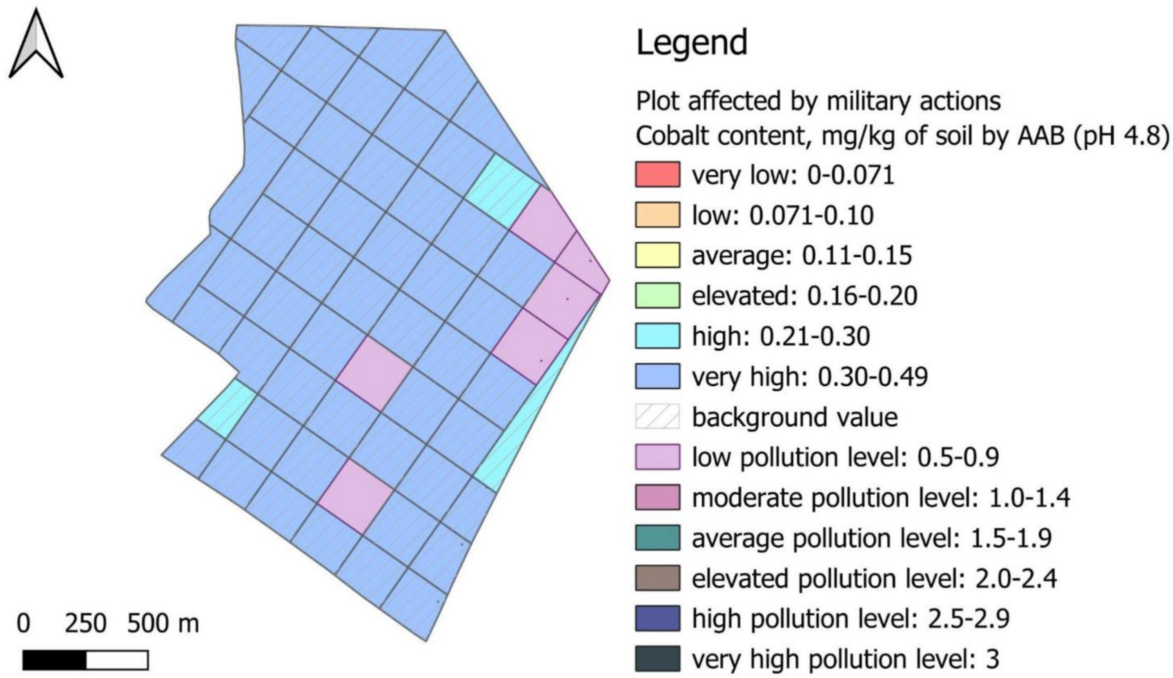

Fig. 1. Application of the proposed classifier of cartographic representation styles for agrochemical and ecological-toxicological soil indicators

At the same time, it must be taken into account that violet is already used in the Methodology to denote strongly alkaline soils; therefore, for the ecological block, it is advisable to apply not the same pure violet hue, but a specially selected dark magenta-burgundy palette with different brightness and saturation parameters. Such an approach would make it possible to minimize the visual blending of thematic layers and to establish a stable color semantics: red-orange tones – deficiency; green tones – acceptable or optimal condition; dark tones – excess and potential toxic loading.

Conclusions. The system of visualizing agrochemical indicators in the Methodology for Agrochemical Certification of Agricultural Land is built on the principle of a discrete color-scale gradation, whereby each defined value interval of an indicator, or each supply group, corresponds to a separate color. The number of such groups is not constant across all indicators and depends on the specific characteristics of the given agrochemical parameter and its determination method. Therefore, when developing digital agrochemical maps and cartographic-visualization systems, it is advisable to retain the grouping ranges established by the Methodology and the correspondence between the numerical ranges of indicators and the colors used to represent them.

In the proposed unified classifier of cartographic-representation styles for agrochemical and ecological-toxicological soil indicators, warm colors – red and orange – signal a deficiency of a nutrient element; the green range – from light to dark green – represents the optimal or safe level and background values, depending on the type of indicator; dark burgundy, plum, and deep magenta-violet shades are used to denote elevated content and various contamination levels. Owing to their greater saturation and darker tonality, these shades form a visually distinct "alert" zone that does not blend with the red-orange range denoting deficiency. Thus, the user is provided with a single, consistent logic for interpreting the cartogram: warm, bright shades – deficiency; green – optimal or background condition; dark magenta-burgundy – excessive content and contamination. To ensure the unambiguous interpretation of colors, such a system must be accompanied by a legend indicating the classes, numerical boundaries, and units of measurement.

The proposed system does not alter the primary numerical data or the regulatory limits; it standardizes only their cartographic representation. This makes it possible to apply different styles to the same set of geodata depending on the user's task – agronomic, ecological, or managerial. Such an approach will ensure the efficient operation and integrity of the geodata, since all monitoring measurement results will be stored in a single, structured database attribute table. The source numerical values will remain unchanged, while their classification and color representation will be determined separately at the level of visualization styles.

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СТАНДАРТИЗАЦІЯ КОЛІРНОЇ ВІЗУАЛІЗАЦІЇ ГЕОДАНИХ АГРОХІМІЧНОГО МОНІТОРИНГУ ГРУНТІВ У СЕРЕДОВИЩІ ГІС

Анотація. *У статті досліджено проблему стандартизації колірної візуалізації геопросторових даних під час ведення бази даних агрохімічної паспортизації земель сільськогосподарського призначення, розробки тематичних карт, атласів та функціонування геопорталів. Проаналізовано розбіжності між традиційними субтрактивними колірними моделями друку (CMYK, Pantone) та цифровими адитивними моделями екранів (RGB, HEX), а також моделями дизайну (HSL/HSV). Обґрунтовано необхідність переходу від словесного опису кольорів у нормативних документах до створення технічних специфікацій та еталонних колірних матриць (Cartographic Design System) із подвійним кодуванням (sRGB для веб-сервісів та Coated FOGRA39 для поліграфії). Це дозволяє уникнути виникнення наднасичених відтінків, втоми очей та забезпечити дотримання вимог контрастності та доступності (WCAG 2.1).*

Відповідно затвердженої Методики проведення агрохімічної паспортизації земель сільськогосподарського призначення формалізовано 6-рівневі спектральні шкали забезпеченості ґрунтів поживними речовинами та 6-рівневі спектральні шкали забруднення.

Ключові слова: *стандартизація візуалізації, база геоданих, агрохімічний моніторинг, еталонна колірна матриця, колірні простори (RGB/CMYK/HEX), геопортал, QGIS Atlas, PyQGIS, автоматизація картографування, файли стилів (.qml), Cartographic Design System.*