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SMARTAGRIHUBS FIE20 - GROUNDWATER AND METEO SENSORS AND EARTH OBSERVATION FOR PRECISION AGRICULTURE

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Abstract.

The solution developed under the SmartAgriHubs project in the scope of the Flagship Innovation Experiment (FIE20) Groundwater and meteo sensors is an expert system to support farmers in decision-making process and planning process of field interventions. This FIE20 solution integrates various data sources and different analytical processes in a complete system and provides users an easy-to-use web map application as a common user interface. The FIE20 solution utilizes components of the SmartAgriHubs Digital Innovation Hub. The FIE20 solution integrates different types of data – local sensor data and online analysis based on this data, Earth Observation and remote sensing data, farm and regional thematic spatial data, weather model and forecast data – to be visualized in web application and used in set of implemented analytical functions. Available analytical functions provide decision-support results oriented on fields status and conditions, support based on long-term data from EO observations, weather models and measurements. The web map application provides weather forecasts for the locality of the farm and different analyses based on the weather forecast and the forecast model data. Various analytical functions based on spatial and EO data are available in the web map application, these analyses provide information oriented on fields and crops on fields in different stages. Data layers providing – yield productivity zones delimitation from the long time-period data, fertilizers variable application maps and NDVI index daily average trend from short time-period data represent products of EO data and analytical functions. The main agricultural challenges that the FIE20 solution is addressing can be divided in three parts. Firstly, the challenge is to integrate various and heterogeneous data from different sources to one system and to present this integrated data *in a usable and understandable form to farmers. Secondly, utilization of integrated data in combination with external services in a set of analytical functions to provide farmers enough information as a support of decisions. And finally, the way how to visualize and present results of analyses to extract information and added values by the most of users of the solution. The solution utilizes a combination of cartographic visualizations, interactive charts, and diagrams.*

Keywords.
Sensors, Ground Water, Earth Observation, Precision Agriculture, Web Map Application

Introduction

The solution developed during the Flagship Innovation Experiment (FIE) is a solution targeted on different types of farmers, agronomists, and agriculture advisors. The main target group are farmers because the design of the FIE20 solution allows them to integrate different data and services from various systems. It allows farmers to step by step minimize the need of individual applications providing particular tasks and analyses. The highly modifiable FIE20 solution allows to prepare an instance of the application according to needs and specification up to individual farmers. When adding analytical functionality focused on long-term series analyses and assessments the FIE20 solution can be targeted on agronomists and agriculture advisors. Extending functionalities by implementing services from larger platforms and e-Infrastructures capability of the solution can grow to larger regions.

The software solution developed during the FIE20 experiment utilizes the advantages of Digital Innovation Hubs (DIHs) as a web platform for its hosting on one side and data services and functions provided by different DIHs for its analytical functions on the other side.

The architecture of the FIE20 solution follows the 3-tier architecture design. It has the data access layer represented by the central database and the cloud storage for Earth Observation (EO) data. The logic layer provides all functionalities of the application and analytical functions. Components of the logic layer of the solution are developed as modular components providing scalability and interoperability of the solution. Presentation layer is represented by a web map application with individual components for visualization of sensor data, analytical functions, and layer management.

The FIE20 solution uses an open-source component called SensLog (Kepka et al., 2017) as a sensor data management component that integrates data from meteostations, soil sensors and groundwater nodes deployed on fields to own data storage. These sensor data can be integrated from sensors directly or from sensor manufacturers' clouds. The SensLog solution provides integrated sensor data by system of web services to other components of the solution.

Remote sensing (RS) data are represented by utilization of the ESA Copernicus programme products, namely Sentinel-2 data, and different vegetation indices. These RS data are used mainly as inputs for analytical functions and partly as thematic products for visualization. The FIE20 solution provides analyses based on short-time – represented by the NDVI daily average trend (Šnevajs et al., 2022) as well as the long-time period of RS data – represented by the yield productivity zones delimitation (Jurečka et al., 2018). The analyzes utilizing RS data are implemented using the Jupyter Notebook platform and components of the EUXDAT e-Infrastructure. This part of analytical components is easily scalable and modifiable due to running on the WirelessInfo Innovation Hub[1].

The FIE20 solution utilizes weather forecast and weather model data for visualization of weather forecast on given locality for 7- and 14-days period. It provides visualization of weather model data corrected by measurements to provide information about the current situation in the locality. Long-time series of weather data in combination with current forecasts are used for analyses supporting interventions planning – namely soil trafficability, sowing and spraying windows, frost risk prediction, crop weather risk etc. Deep learning methods are used in the background of these weather data analyses.

The presentation FIE20 solution to users is done through a web map application based on the open-source web mapping library HSLayers NG[2] for spatial data visualization (Charvát et al., 2018). This web map application contains the main map window visualizing available spatial data and geometrical results of analyses and additional portlets for current and historical sensor data visualization and interface for individual analytical functions.

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[1] https://www.agrihub.cz/

[2] https://ng.hslayers.org/

Addressing the agriculture challenge

The innovative aspect of the FIE20 solution is mainly represented by integration of various data from different providers in one web map application together with analytical functionalities and tools provided by different platforms and DIHs. Sensor data is downloaded to the central data storage in harmonized data model from different data providers infrastructures and interfaces. These integrated sensor data are provided by a set of web services to other components of the solution or by standardized interface based on the OGC SensorThingsAPI specification (OGC 15-078r6) to other third parties' components.

ESA Copernicus programme products are utilized for analyses on regional and on the field level, not only visualization of time-series of vegetation indices are provided, but these EO data are used for analytical functions. On a regional level, differences of vegetation indices during the growing season are regularly calculated and visualized in the form of charts. Characteristics of fields in the locality from the yield productivity aspect are calculated from the long-term series of satellite data. These characteristics are utilized for calculations of application maps during vegetation seasons. Utilization of weather forecast and weather model data for analytical functions providing predictions is supporting interventions planning on farms.

The FIE20 solution supports sustainability of agriculture by several aspects, but mainly by efficiency of resource consumptions. Utilization of field characteristics based on long-term EO data provides data source for calculations of variable application maps for application of pesticides and fertilizations. Calculation of yield productivity zones provides input for effective application of fertilizers on additive or compensatory methods. Utilization of short-term EO data in combination with weather forecast provides supporting information for intervention planning in the next few days. Available analyses based on weather forecast and weather model data provide important information for planning of optimal time period for field interventions and reducing cases of non-effective utilization of resources.

The developed FIE20 solution is designed as easily modifiable and can be run on local data in different regions and countries not only in Europe.

Design and development of the FIE20 solution

The FIE20 solution as an integrated application was developed in the last 3 years, but some individual components and services used by the FIE20 solution were developed during previous projects and activities in the last 7 years and were integrated in the FOODIE Innovation Hub.

Sensor data management is realized by utilization of the SensLog solution that is developed by a team of several entities for more than 10 years (Kepka et al., 2017). This SensLog component is utilized by several research and technical projects as well as by commercial activities in different domains – agriculture monitoring, agriculture machinery telemetry, long-time groundwater monitoring, collecting of VGI data in fields etc. This solution continuously improves its interoperability by implementing different interfaces according to specifications and standards.

Weather forecast and local weather information provided by the company Swiss company meteoblue[3] AG have been developed since 2006 when an independent commercial computing infrastructure and product development was established. Meteoblue is using proprietary modeling to generate locally adapted forecasts for surface and atmosphere.

Processing and analytical functions utilizing EO data were designed and developed for more than 5 years starting during previous technical and research EU projects FOODIE[4], DataBio[5] and

[3] https://www.meteoblue.com/
[4] https://cordis.europa.eu/project/id/621074
[5] https://cordis.europa.eu/project/id/732064

EUXDAT[6]. Development of the product yield productivity zones (Jurečka et al., 2018, Řezník et al., 2020, Charvát et al., 2021) started during the project FOODIE and was validated by several projects during the last 5 years and is commercially used in the Czech Republic. Derived products from the yield productivity zones data are utilized for variable rate applications in precision farming and for generating characteristics of individual fields. The function calculating the NDVI daily average trend is a newly developed function with high potential for regular monitoring of crop status during the whole season from open services and datasets. The field blocks geometries and attributes are stored partly using the FOODIE data model (Řezník et al., 2015; Řezník et al., 2016). Field blocks are used not only for visualization of the locality but as a data source for analytical inputs.

Visualization of data is realized as a responsive web map application based on the HSLayers NG web mapping library developed by a consortium of partners for almost 12 years. This library is used by many projects and products as a multipurpose visualization library implementing cartographic methods of spatial data visualization as well as explanatory visualization in form of charts and diagrams annotated using Vega[7] visualization grammar for better interoperability.

System architecture

The architecture follows a 3-tier design with storage layer, data management layer and data visualization layer. Modularity of the architecture is ensured by using stable components with defined interfaces using standardized APIs where available and proprietary APIs otherwise. Developed components are provided as standalone blocks deployed using Docker images and communicating using defined APIs. Interoperability with other data sources is managed by using the system of Connectors. The last architecture scheme is shown in Figure 1.

[6] https://cordis.europa.eu/project/id/777549
[7] https://vega.github.io/vega/

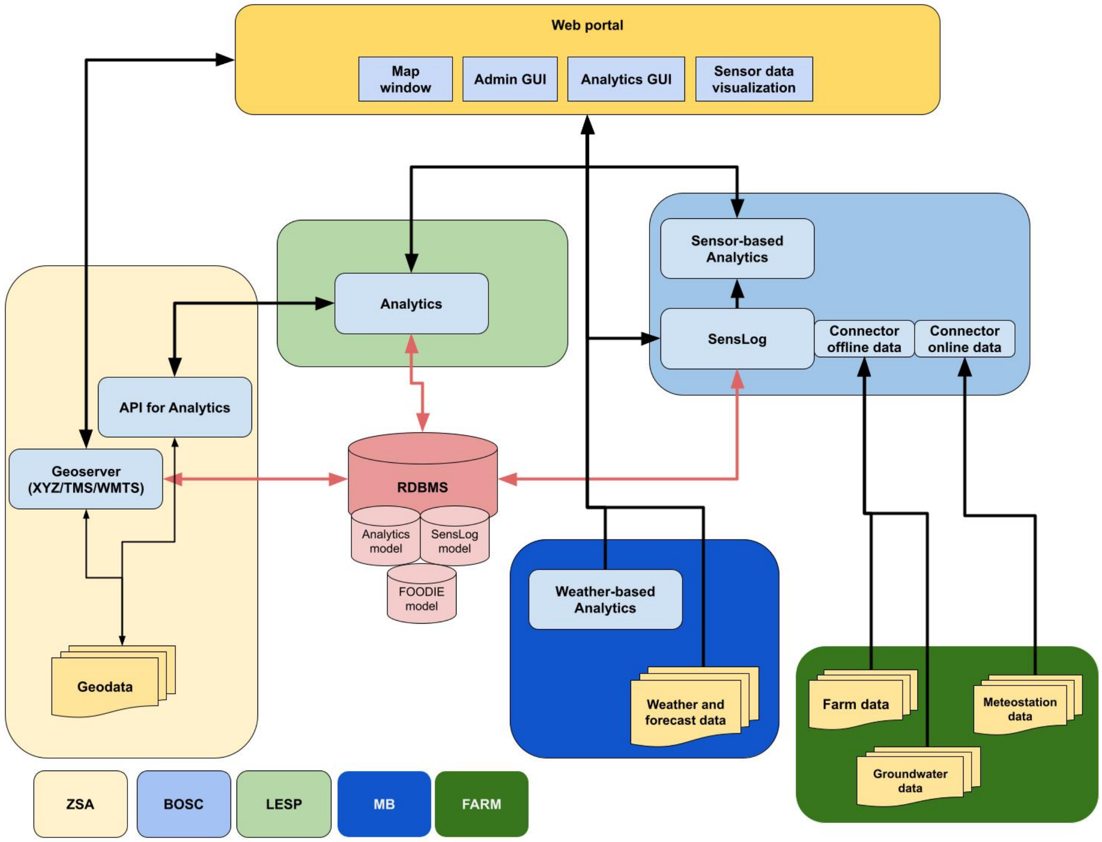

Figure 1 – Schema of the FIE20 solution architecture

System is using sensor data measured by meteostation, soil sensors or groundwater sensors. Data is downloaded from the sensor manufacturer cloud (FieldClimate) via online Connector ("FieldClimate Connector") on a regular basis or downloaded manually and imported to the system by the offline Connector. Sensor data management is realized by the SensLog system and storage is realized by the SensLog data model in RDBMS.

SensLog component is managing and integrating sensor data from different sources. SensLog is publishing sensor data for analytical functions and for visualization in the application. SensLog Connectors are pulling data from particular systems – Field Climate and offline exports from groundwater nodes. SensLog Analytics is providing analytical functions based on sensor data. It provides basic statistical analyses – min, max, sum, average, threshold checking – reaching defined threshold value of an observed phenomenon, conditions checking – checking combination of values for defined time period. Analytics components provide analytical functions based on spatial and EO data. Weather Analytics provides analytical functions based on weather model and forecast data.

Different types of geodata are used in the system. Mainly satellite data and thematic spatial data are stored on file systems and provided by a set of Web Services. Geodata and layers provided by components of the system are provided by the standardized WMS and WFS services. Web services are provided with different data formats for visualization as well as for processing.

Visualization layer of the system is represented by the web portal and individual web applications integrated into the web map application. Web portal provides an environment for application deployment and user access management. Web portal contains an instance of the web map application with demo access providing content for the pilot farm and an instance with authorized access providing secured content and data for a particular user/farm. These include protected API access or spatial data such as yield statistics, field boundaries, soil data or any other spatial data annotated in map composition format.

Development

The main FIE20 web map application is available online at https://groundwater.smartagro.lv/. The initial page of the application allows users to enter as a guest user to the demo version of the application or under authorized access to the authorized instance containing user-specific data. The main web map application provides spatial data visualization with sensor observations and analytical capabilities. The application provides additional functionality for sensor data visualization, meteorological data, and analyses.

Web map application allows users to turn on and off different thematic layers. The map window contains general base layers, general thematic data (soil, land value, Natura2000, hydrography, field blocks borders etc.). Important content of the layers list is built by vegetation indexes and satellite imagery data (optical, infrared, NDVI, MSAVI2 etc.). Example of the map window is shown on Figure 2.

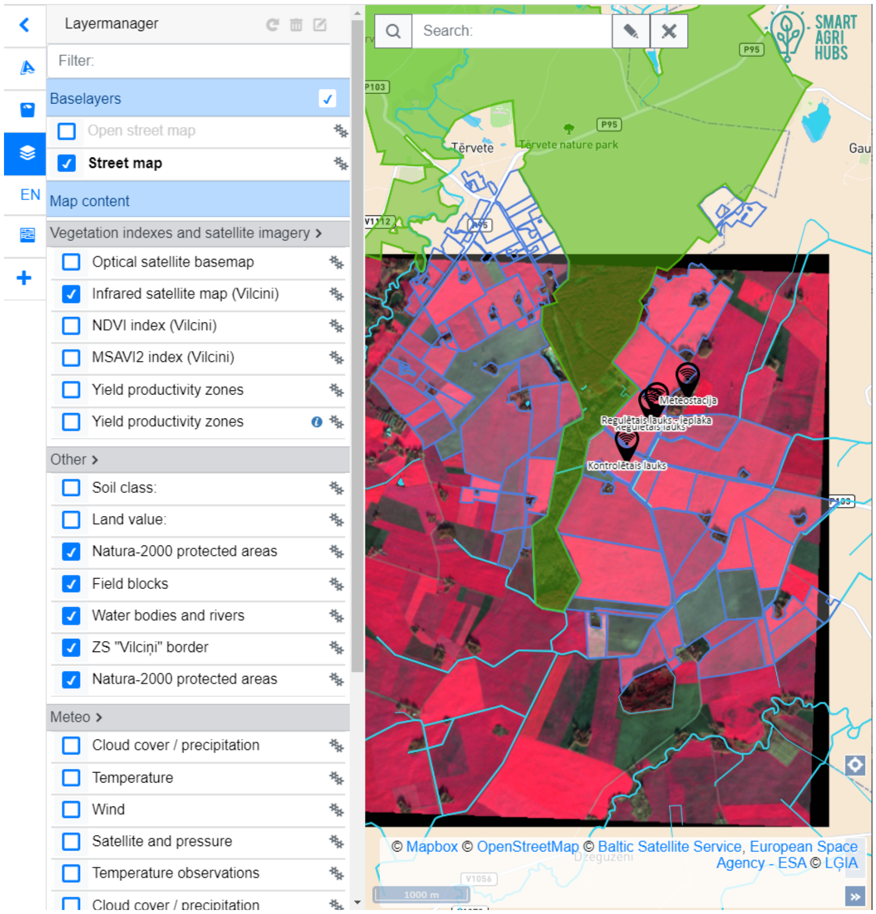

Figure 2 – Layer manager and layer selection

Integration and visualization of sensor data in combination with other spatial data layers is one of important benefits for farmers. Farmers can see sensor unit positions on the map and select particular sensors to see details and measured values in the form of charts. Users can select different time periods – last day, last week, last month, last 6 month or their own defined time period by beginning and end date. The sensor data visualization is shown on Figure 3.

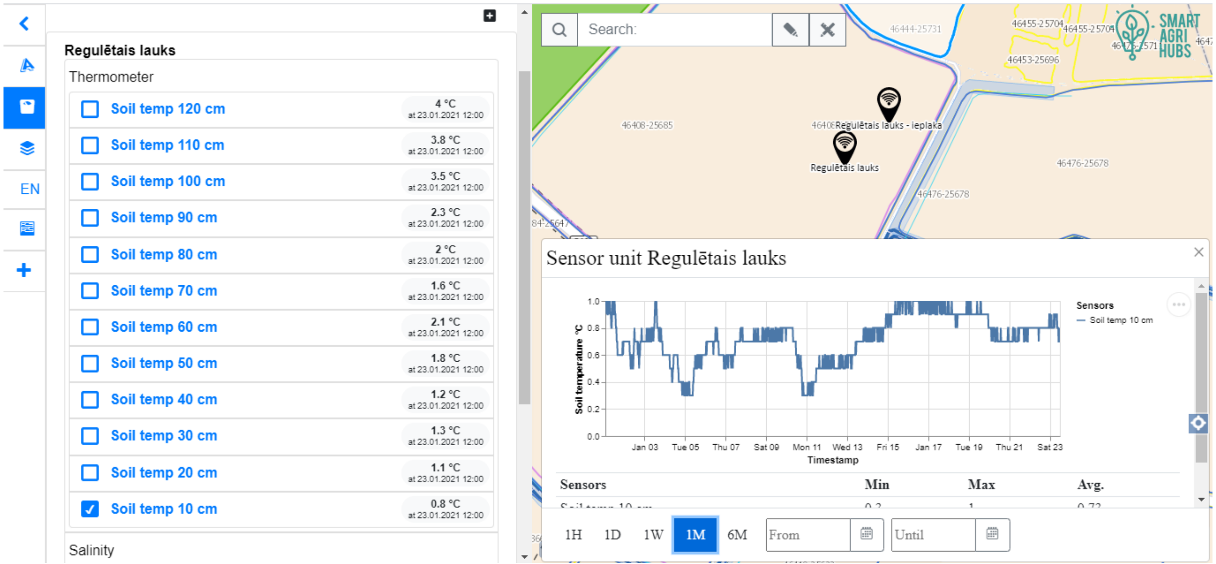

Figure 3 – Sensor data visualization

Analytical functions for the FIE20

The FIE20 application provides an Analysis panel where users can run predefined analyses which provide results in the form of diagrams or spatial layers. It contains weather forecasts and meteograms as well as agricultural analyses based on the model data and particular weather forecasts.

A set of meteograms containing 7-days meteogram Agro that shows the development of the weather with diagrams of air temperature, wind velocity and direction on the ground, as well as precipitation, clouds, spraying windows and evaporation. The data are valid for the forecast area of a model grid cell, without indicating special conditions of the selected place (e.g., differences in height). And the 14-day meteogram that shows the weather forecast for the next fortnight with weather symbols, a range of maximum, average and minimum temperatures, precipitation amounts, as well as the precipitation probability for each day.

A set of meteo model analyses containing the meteogram Agro Trafficability (see Figure 4) shows the capacity of the soil to support moving vehicles based on the development of water content in the topsoil (0-10cm). The soil trafficability development is calculated for four types of soil. Sand, Silty Loam, Silt and Clay, each of which has a different water holding capacity and reacts differently to weather conditions.

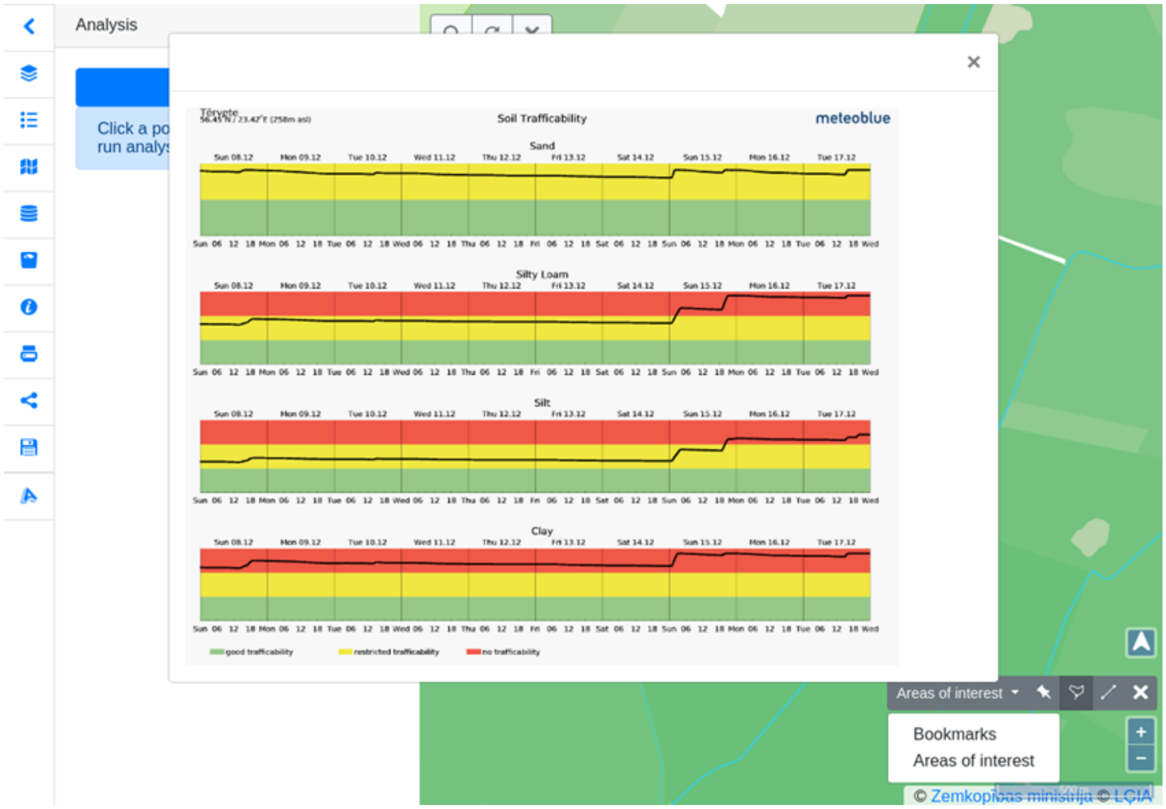

Figure 4 – Example of the Soil Trafficability meteogram

The meteogram Agro Sowing shows the development of soil temperature and precipitation for 7 days. Additionally, it includes sowing windows for maize, wheat, barley, rapeseed, potato, and sugar beets. Another example is meteogram Agro Spraying that shows the forecasts of the temperature and precipitation for 7 days and it includes the spraying window. The spraying window helps identify suitable periods for crop protection.

Based on long-term weather data and climatic models are implemented two analyses. The Frost risk, which is the probability of cold events, defined as temperatures below a certain temperature threshold lasting for a certain time. It shows the likelihood of a cold event per day and per week, periods of tolerable risk and the occurrences of cold events for each year in the last 30 years. And the Crop weather risk monitoring and prediction that allows to monitor the drought and frost risks for a particular crop at a particular location during its growth period. Data include the current season's weather to date, a 7-day forecast, and a seasonal forecast. In addition, single or multiple reference years can be included for comparison. This service supports operational decisions such as when to plant, fertilize, irrigate, etc. The growth phases are calculated from accumulated growing degree days – GDD – at a particular year.

Based on thematic spatial data and remote sensing data another set of analyses was implemented. It contains Protected areas analysis that provide a layer where interventions with chemicals are not permitted/recommended due to distance from water resources. It calculates buffer zones where interventions are not allowed. The analysis *NDVI Average daily change* provides (see Figure 5) information about the average daily change of the NDVI index during a selected period. It can provide the farmer information about the result of some interventions or other events that happened in recent days. Or it can identify spots where an intervention is necessary to support growing or flowering of crops. With the granularity of the layer, it can identify spots with some irregularities in the field. The layer shows average change of index between spots captured on subsequent images without clouds – it is the current one and nearest previous one without clouds, but the maximum time span between 2 non-cloudy images is 2 weeks.

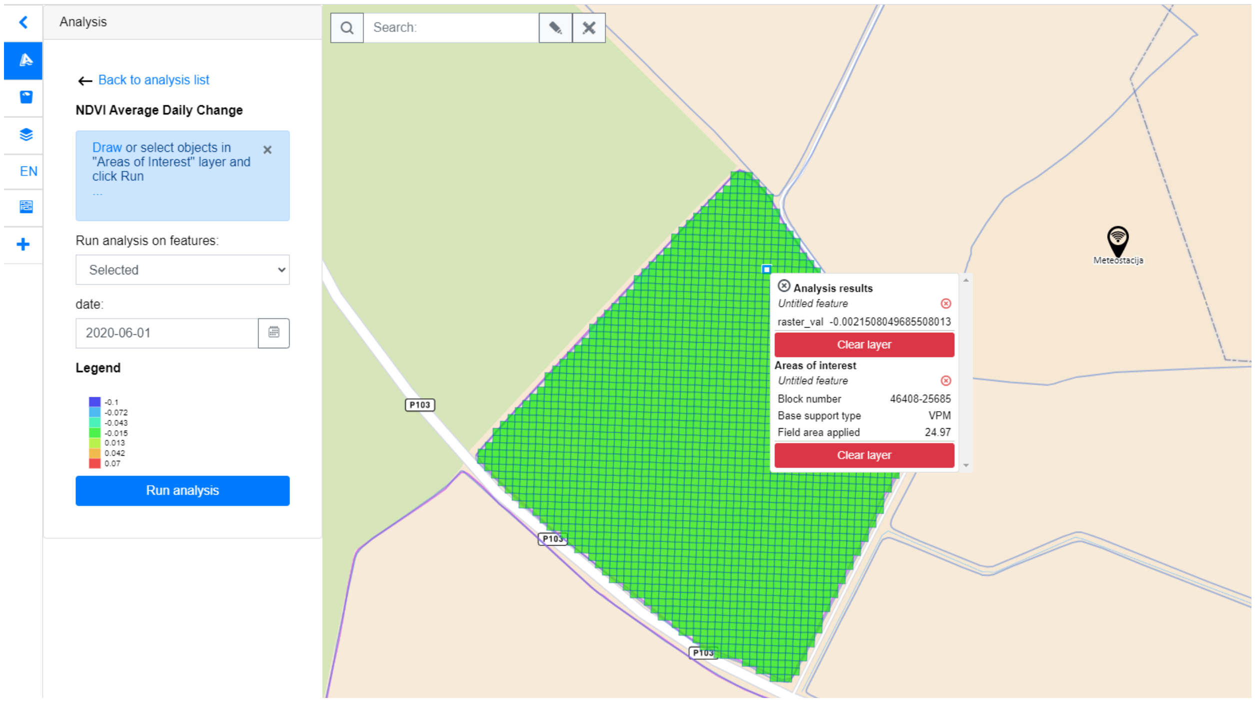

Figure 5 – Example of the NDVI Average Daily Change analysis

An initial analysis producing an important product for farmers as well as a source for further analyses is the Yield productivity zones analysis. The Yield productivity zones analysis provides information about segmentation of fields with similar characteristics and similar production level – a variety of management zones approach. Example is shown in Figure 6. The yield productivity zones calculation uses multispectral images for the last 8 years' time series (Landsat or Sentinel-2), atmosphere corrections, EVI index, borders of fields (LPIS), optionally crops in the period. It describes the heterogeneity of fields based on the status of vegetation in the selected time period. Number of zones corresponds with the heterogeneity of the field. But it is not possible to compare two fields with each other, values are calculated only for each field separately during the time period.

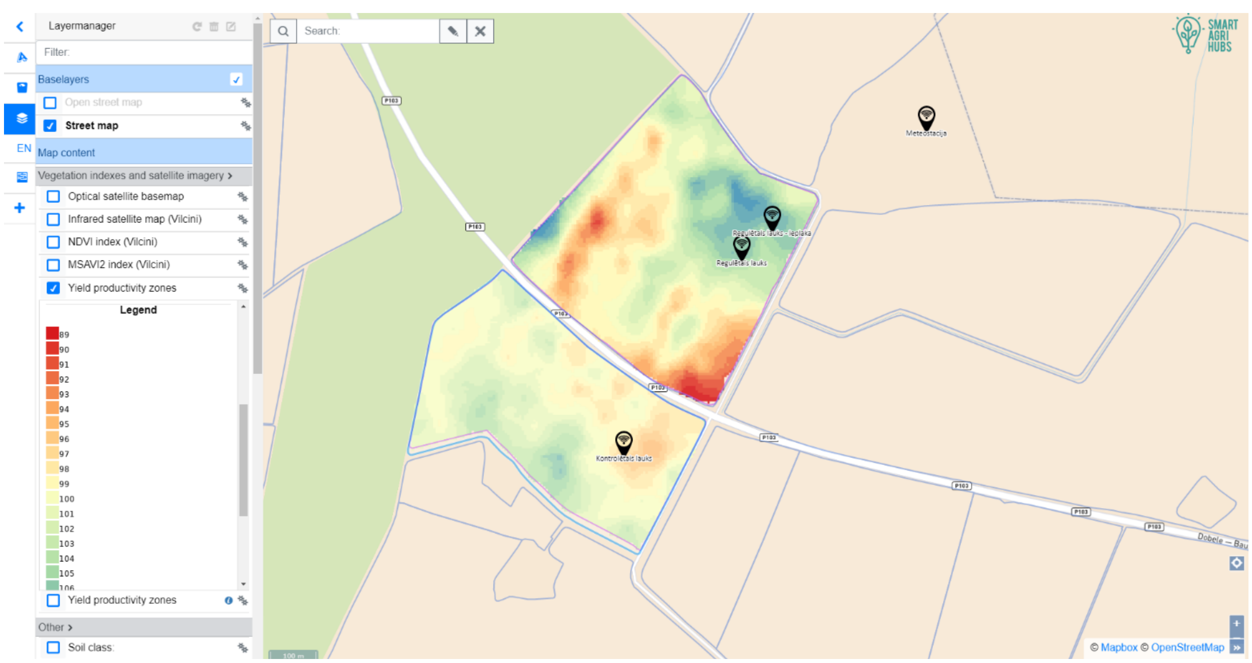

Figure 6 – Example of result of the Yield productivity zones analysis

Based on the heterogeneity of the field, a variable rate application map can be calculated to distribute fertilizer on a particular field effectively. Analysis Fertilization map calculates areas where to apply more or a smaller number of inputs. When the application map is calculated based on the layer "yield productivity zones", it is time stable during the season based on the regulations of applications themselves. If weather conditions are appropriate for the intervention, other analyses could be considered – Soil trafficability, Spray window. It can be used for both types of fertilizers – pre-planting fertilization, nitrogen fertilization. Output is an application map providing a recommended amount of fertilizer per square meter that can be downloaded in different GIS formats.

Feedback

The FIE20 solution was presented in several workshops during the running period of the experiment in several stages of development. We were collecting feedback by asking users to fill in questionnaires. These results from questionnaires were used for the application improvements and adding further functions users would like to have. Most of the responders have mentioned the advantage of availability of data and analytical functions in one web application, variability of the solution to be adopted to the needs of farmers and application is more user friendly and contains necessary explanations of the represented data layers.

Discussion and future steps

The focus will be now on marketing and commercialization of the solution on a larger scale. Due to the used data, the FIE20 solution is easily replicable. The technical objectives of the FIE20 solution are mainly focused on further extension of analytical functions and available datasets suitable for farmers. We plan to integrate additional datasets like ESA Copernicus Sentinel-1 data. First experiments were already realized, and results look promising. The main advantage of Sentinel-1 data is that Sentinel-1 is independent of clouds and could be used for all seasons. Successful integration of this type of data can increase possibilities for preparing thematic layers and analyses. We plan also to integrate commercial data from commercial satellites, the first expected data source is PLANET. Resolution of this data can increase possibilities for small fields and can help to bring these services also to developing countries. Another alternative is to integrate data from drones. We plan to also integrate more Copernicus-based services. The derived product from Copernicus atmospheric services is now calculated for all Europe using the EUXDAT e-Infrastructure. We will also cooperate with other projects e.g., H2020 STARGATE and in cooperation with this project provide commercialization of their services. Further direction of data integration is to integrate services from Agroclimatic atlas (Jedlička et al., 2021) to provide farmers overview of agroclimatic factors in specific locality and involve these factors in the analytical functions. And the standalone direction of development is the integration of telemetry data from agriculture machinery utilized on the farm and to provide application maps for such machinery directly from the application or to plan the trajectory for particular operations.

Conclusion

Presented FIE20 solution provides an example of an integral expert system for supporting the decision-making process on the level of a farm by providing valuable data and analytical support in the form of modern web map application. The application combines the common environment of the web map application and adds visualization of sensor measurements and analytical results. Analytical functionality covers weather forecasts and climatic models analyses as well as spatial thematic data with remote sensing data and products-based analyses.

The advantage of the FIE20 solution is the modularity and emphasis on the interoperability of the application. The application can provide services for small farmers as well as medium scale organizations. The solution is designed not only as an end application but can be connected to other farm management systems based on the set of web services on the back end.

Further development of the application will be mainly focused on the extension of the analytical functionality incorporating remote sensing data and their products to improve the recommendation of variable applications of inputs to improve the effectiveness of interventions.

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