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MapX: An open geospatial platform to manage, analyze and visualize data on natural resources and the environment

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ABSTRACT

This paper describes MapX, a spatial data infrastructure that aims to support the sustainable use of natural resources and the environment by increasing access to the best available geospatial information and related monitoring technologies. MapX is supported by an online platform that provides authoritative spatial data at local, national and global scales, an authentication data integrity framework using a scorecard and a set of on-line tools to visualize, analyze and access geospatial data. Originally created for stakeholders involved in the extractives sector, MapX has recently expanded to other fields where spatial data can help inform stakeholder dialog, prioritization of investments and impact monitoring such as disaster risk reduction, chemicals management, biodiversity planning, renewable energy and environmental security. This paper describes the open source software stack of the platform, its key functionalities as well as its planned features and concludes by capturing some of the key lessons learned.

Code metadata

Current code version	1.5.6
Permanent link to code/repository used of this code version	https://github.com/fxi/map-x-mgl
Legal Code License	GPL-3
Code versioning system used	GIT
Software code languages, tools, and services used	Languages: R, HTML, JavaScript Build tools: Docker, Webpack, Bash R packages: shiny, RPostgreSQL, memoise, jsonlite, magrittr, parallel, curl, xml2, pool JS packages: https://github.com/fxi/map-x-mgl/network/dependencies Data services: OpenStreetMap data provided by Mapbox as vector tilesets
Compilation requirements, operating environments & dependencies	Docker, Webpack
If available Link to developer documentation/manual	https://github.com/fxi/map-x-mgl
Support email for questions	https://github.com/fxi/map-x-mgl/issues

Software metadata

Current software version	1.5.6
Permanent link to executables of this version	app.mapx.org
Legal Software License	GPL-3
Computing platforms/Operating Systems	Web-based
Installation requirements & dependencies	Web-based
User training material	https://www.mapx.org/knowledge_base
Support email for questions	https://github.com/fxi/map-x-mgl/issues

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1. Motivation and significance

Extractive resources can have a transformative impact on the development trajectory of a country [1]. They can generate jobs, revenues to fund basic government services and stimulate economic growth. However, harnessing these opportunities, presents numerous challenges as the extractives sector is often plagued by opaque contracts, inequitable sharing of benefits, and poor mitigation of risks and decisions taken without public consultation. These challenges tend to undermine the positive development impact of the extractives sector and often contribute to mistrust, unmet expectations and social conflict [2,3]. Addressing this challenge fundamentally depends on improving stakeholder access to and use of information on the economic, social and environmental performance of extractive sector projects so that benefits and risks can be shared in a more equitable, sustainable and transparent manner [4].

While a number of global and national initiatives are promoting transparency on the economic, social and environmental performance of the extractives sector [3,5–8], the vast range of data and information that is generated is not being effectively used to support stakeholder dialog and decision making. In many cases, this data is out-dated, fragmented, inaccessible, inconsistent or contested.

Some of these initiatives are supported by online platforms of geospatial data, but most of them (e.g. see [9]) are however restricted to one country or one aspect of the sector (such as only financial transparency). Most of the geospatial platforms in the field of extractives do not provide analytical tools or metadata about the layers of information and none have a data integrity framework. Other platforms are restricted to the display of a few layers of information as is the case for the Mining Cadastre Portal of the Democratic Republic of the Congo (DRC) [10] that shows industrial mining concessions, protected areas and geology.

To address these shortcomings, UN Environment and GRID-Geneva established in 2014 a joint initiative known as MapX. More specifically MapX is an online information and engagement platform that aims to:

- **Aggregate** data at various geographical scales (site, national, regional, global);
- **Authenticate** data integrity using a scorecard;
- **Visualize and analyze** this data using both service and client side applications;
- **Communicate this data** using dynamic story maps and data dashboards as the basis for prioritization and action.

It is available from: https://app.mapx.org

The MapX partnership was initially based on the request from the g7+ group of 20 conflict-affected states to help them map and monitor progress in sustainable development of their extractives sector. However, other stakeholders dealing with natural resources and environmental challenges soon realized the wider applicability of MapX and asked for customized front-end applications that could also meet their needs. As a result, in September 2017 the scope of MapX was expanded to all natural resources and related environmental issues that can be mapped and monitored.

2. Software description

2.1. Requirements

User requirements have been collected continuously since the beginning of the platform development in 2015. Various types of end-users of the application and potential clients have been consulted from the public and the private sector, non-governmental organizations and academia. Stakeholder consultation workshops were conducted as well as inventory of technical capacity (e.g. in DRC and in Afghanistan), webinars were given on the potential and use of the platform, and User Interface/User Experience (UI/UX) testing was achieved by selected early adopters. The high heterogeneity of data types and quality, the various intended functionalities, the foreseen scale-up of the platform to accommodate the needs of several new countries and organizations over the coming years, and the need to customize some of the modules and functions to users' specific needs, have directed the MapX software architecture to be built with a stack of existing open source libraries and in-house developed modules. This stack has been deployed on a Docker infrastructure hosted on a cloud platform. A strong requirement from users was the ability to combine different types of geospatial layers on the fly, for instance to identify where mining concessions are overlapping protected areas. User friendliness was another strong request from users, as many of them do not have advanced expertise in Geographic Information Systems (GIS). Many comments were made on the necessity to have a visually attractive application. The capacity to tell stories was perceived by users as a key functionality of the platform, as well as multiple language support. The necessity to assess the integrity of data before their publication was raised several times, especially by data customers from governmental agencies (e.g., in DRC and Afghanistan). From a technical perspective one of the main challenges encountered was the low Internet connectivity in the targeted countries. Another technical requirement was the necessity for MapX to be able either to host data (in case end-users do not have this capacity) or to stream existing data through Web services or Application Programming Interfaces (APIs). The necessity to have fast client-side algorithm for data processing, and responsiveness to various types of screen resolutions – especially for visualizing story maps – was also a strong constraint that guided some of the technological choices.

2.2. Software architecture

In line with the above requirements, MapX is an online open-source application, currently available in four languages (French, English, Dari and Pashto). It has a graphical user interface and no programming capacity is required for accessing geospatial data, conducting data analysis, and building story maps. The code was entirely developed in-house and it is provided under the GPL-3 license. The MapX website, from which the application can be launched, is available on www.mapx.org

MapX has been optimized for low Internet bandwidths and connectivity, with a light interface that is less than 1.5 MB and that is transferred to the client when the application loads in a browser. MapX has been developed following interoperability standards, notably to harvest data through existing standardized Web services such as Open Geospatial Consortium (OGC) Web Map Services (WMS) [11] as well as APIs when available. To achieve smooth and fast display of information, vector tiles are used for map rendering. MapX software architecture is composed of a stack of existing open source libraries and in-house developed functions, as shown in Fig. 1:

- **Docker** [12] is an open platform for developers and sysadmins to build, ship, and run distributed applications through

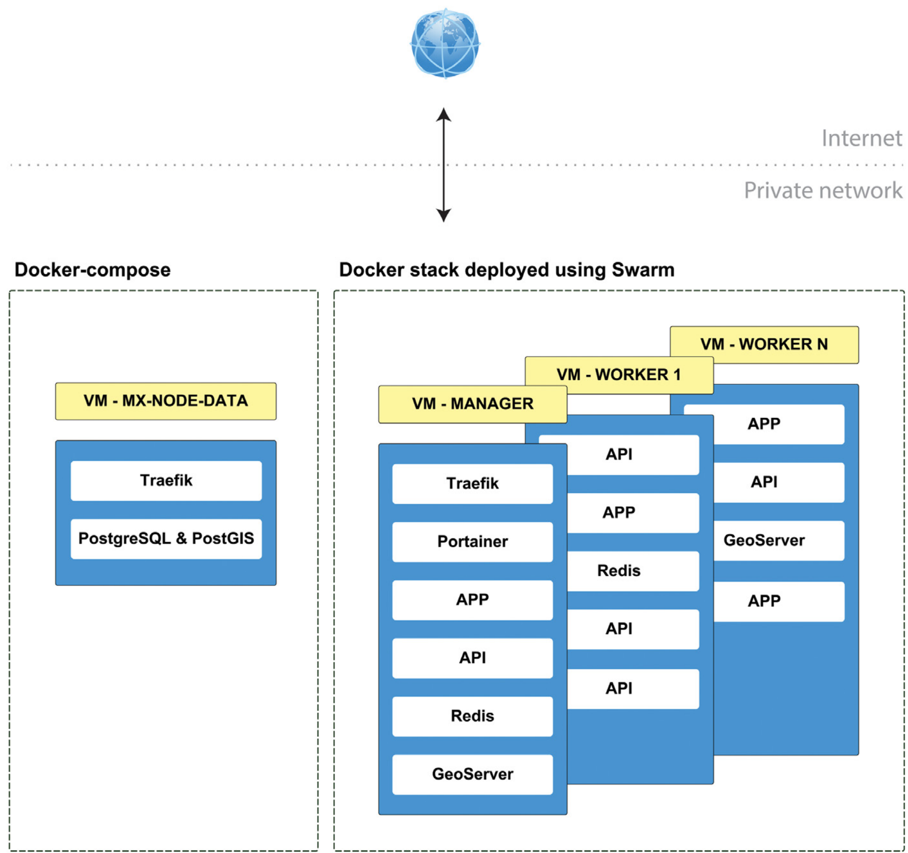

Fig. 1. Simplified architectural overview of the platform.

operating-system-level virtualization (containerization). Docker implements a swarm mode for natively managing a cluster of Docker Engines called a **Swarm**.

- **Traefik** [13] is a reverse proxy and load balancer. It integrates with MapX Docker infrastructure.
- **Portainer** [14] is a management solution for Docker.
- **PostgreSQL** [15] is used for storage of vector data.
- **PostGIS** [16] adds support for geographic objects allowing location queries to be run in SQL. PostGIS is used on the server side for vector analysis such as area calculation, univariate statistics and overlap analysis.
- **Turf.js** [17] is used on the client side to quickly approximate vector tiles analysis such as calculation of features areas, centroids and extents.
- **MapX APP** is a custom R-Shiny and JavaScript application that provides a bidirectional interaction between the backend and the frontend. It is composed of a client-side program written in JavaScript using Mapbox GL JS and a server-side program written in R that maintains a session per-user and handles all server-side interaction. **R** [18] is the language used for data analysis, database connection, and for server-side logic. **R shiny** [19] is a web framework for building interactive reports and visualizations using R. **Mapbox GL JS** is a JavaScript library that uses WebGL to render interactive maps from vector tiles and **Mapbox styles** [20].
- **Redis** [21] is used on the server side for caching vector tiles.
- A **GeoServer** instance enables potential GIS specialists to discover and directly access data through OGC services.
- **JavaScript**, **HTML**, **CSS**, **JSON Editor** and **Highcharts** are used in the frontend of the application and for vector rendering.
- **MapX API** is a custom **Express Node.js** [22] application that provides backend services, such as upload, download, vector tiles creation, encrypted SQL queries to PostgreSQL/PostGIS, user authentication, IP validation and emailing.

In terms of user management system, MapX features multiple and flexible user access levels to story maps, datasets and tools. Each user is assigned a role of "public", "member", "publisher" or "admin". A role defines the access to the application's different components. This role also grants permissions to read, publish, and edit content. Internally, users are grouped based on their role. This enables per-role varying permissions to modify user profile settings and administer the user groups. "Members" of a particular project can share datasets in a dedicated space, which can be public or private. By default, a MapX user is public and has limited privileges on maps, data and tools. To be upgraded, a public user must self-register. This only involves sending their email address but no additional information. A one-time password token is automatically generated by MapX and sent to the user. The password token is not saved in a database. Rather, it only exists in the memory of the application, in a temporary session and it automatically expires after 20 min. This approach to password management was deemed more secure than user-managed passwords, which can be more easily hacked depending on the complexity of the password used. To remember the user, an encrypted cookie (in AES-128 bits) is saved in the browser, with a 30-day lifespan.

2.3. Input data

The testing of the MapX platform in DRC in the extractives sector has confirmed that it can build on existing national processes to support stakeholders to consolidate, analyze and visualize various key datasets such as:

1. Extractive concession boundaries including owner, resource type and activity status;
2. Company-level financial information linked to concessions disclosed through the EITI [23];
3. Other contextual information such as: armed groups involved in mining exploitation and trade [24], development indicators [25,26], watersheds [27] and land cover maps [28];
4. Concession or site-specific monitoring data covering benefit sharing, production volumes, grievances and environmental quality [29,30] (Fig. 2);
5. Information disclosed through sustainability reporting or through compliance with environmental and social performance standards (e.g. Global Reporting Initiative, Equator Principles, International Finance Corporation Performance Standards);
6. Global datasets of interest to natural resource management, including the World Protected Areas Database [31], the Global Risk Data Platform [32], global forest loss [33], conflict data from the Armed Conflict Location and Event Data Project (ACLED) [34] and great apes range and carbon stock corridors [35].

Where feasible this information is dynamically served into MapX through standards such as WMS or using scripts developed by the authors (e.g., R scripts to extract conflicts data from the ACLED online database).

2.4. Software functionalities and user interface

The key MapX functionalities are presented below. It is important to note that the data shown might not reflect the latest available online information:

Proportional symbols and color ramps

MapX has the ability to display proportional symbol maps and color ramps in order to help users visualize hotspots and important environmental quality thresholds, e.g. below target levels (green point in Fig. 2), above target levels (blue point in Fig. 2), above intervention levels (red points in Fig. 2).

Aggregation, consolidation, visualization and overlay of locally stored layers, WMS layers with high-resolution satellite imagery in background [36].

As an online geospatial platform, MapX can easily aggregate and consolidate a large amount of datasets, and makes it easy to search for and overlay several layers. Viewing filtered legends, metadata and the ability to interrogate (by click pointing) any object from any layer are standard features.

Spatial overlap analysis

Any two-vector layers can be analyzed for spatial overlap through a fast client-side algorithm. Interesting overlap examples are between mining concessions and protected areas [37,38] (Fig. 3), indigenous territories, agricultural areas, pastoral lands or

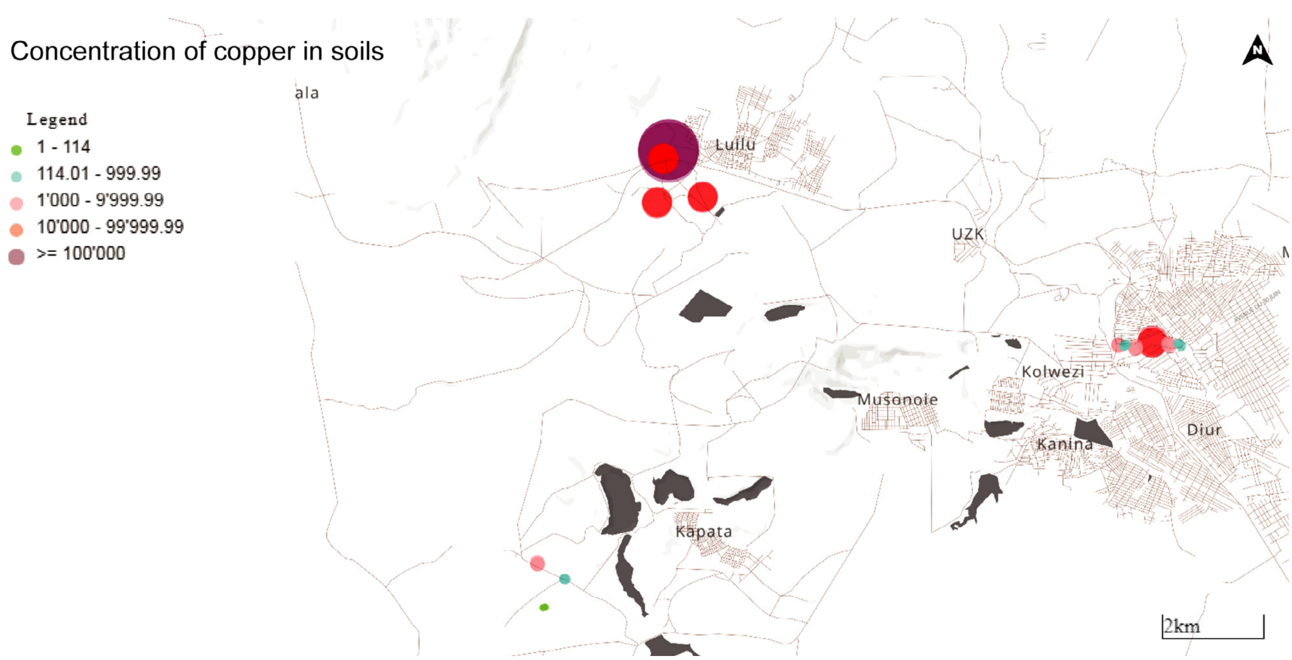

Fig. 2. Site-specific monitoring data: environmental sampling study in selected sites in Kolwezi, DRC, depicting poisonous concentrations of copper on a river bank. *Source:* https://app.mapx.org?project=MX-MMN-3EH-CLM-KI7-EG9&views=MX-RUPXK-487AQ-LMTLC.

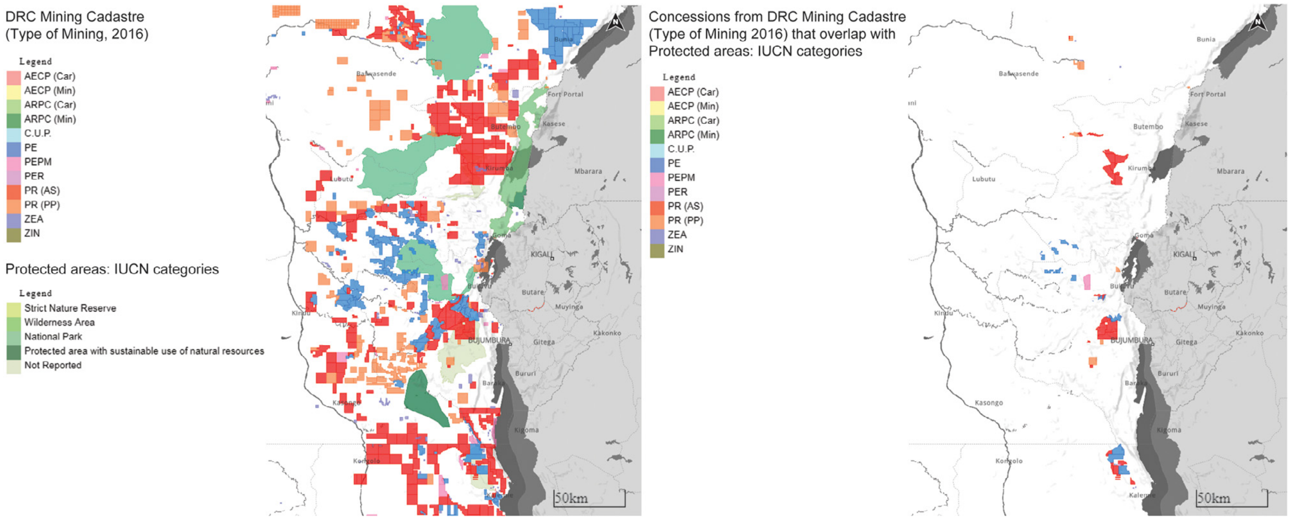

Fig. 3. Overlap analysis between mining concessions and protected areas in DRC, with overlay of the two layers (left) and results of the overlap analysis (red areas on the right).
Source: https://app.mapx.org?project=MX-MMN-3EH-CLM-KI7-EG9&views=MX-OD60Y-0XHH1-NUQLJ,MX-1LCIL-QRNLH-0CF2L,MX-NAXHL-ZRS68-RNVJA.

natural hazard risks. This function also computes the surface of the currently visible overlapping areas.

Time slider

For any data attribute that has a standardized time-stamp component, MapX can automatically link it to a time slider allowing users to visualize changes over time, e.g. mining concessions granting date.

Data upload, styling and publication

With the right access level, users can upload their vector datasets, style the legend from within MapX, and publish it on the platform.

Story map editor

A story map is a combination of narrative texts, photos, multimedia, graphs, and real-time information [39]. Story maps are accessed linearly by scrolling down in the browser or clicking on the slide numbers while the narration is connected to geographical locations that update automatically (Fig. 4). A key feature in story maps is to allow readers to unlock maps in order to dynamically navigate geospatial information and interrogate it while reading the narrative. MapX features a full developed in-house story map engine and an on screen story map editor allowing users to easily construct story maps from within MapX interface. When the live

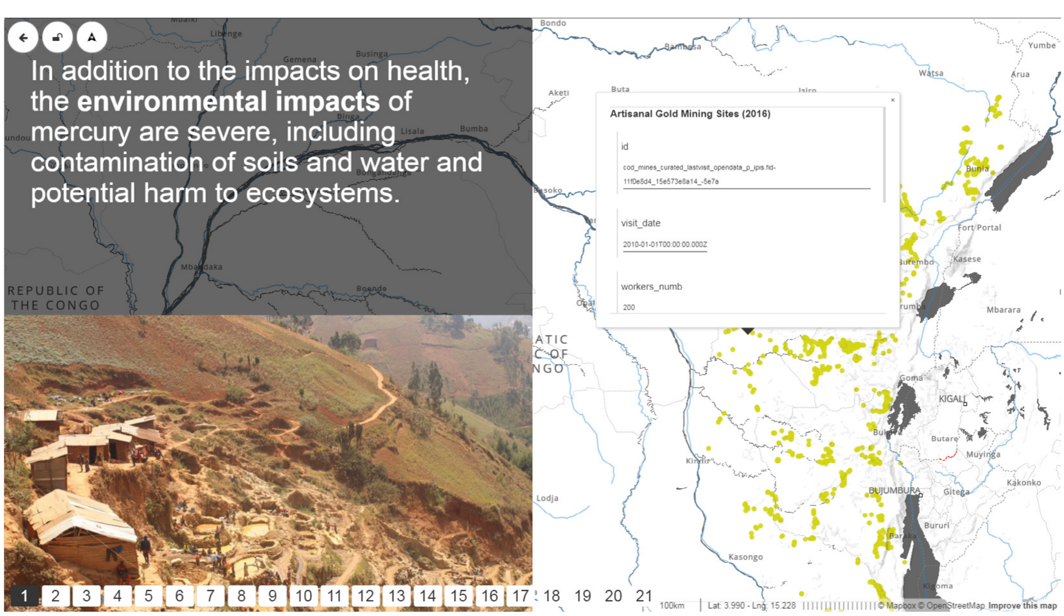

Fig. 4. Example of MapX story map with narrative, picture and dynamic map, aiming at improving the understanding of a field work assessment of the consequences of mining actions driving mercury pollution of sediments and water in DRC.
Source: https://app.mapx.org?project=MX-IY9-QCF-ILZ-UVO-07Y&views=MX-CUPUZ-QMWZT-3XD3K.

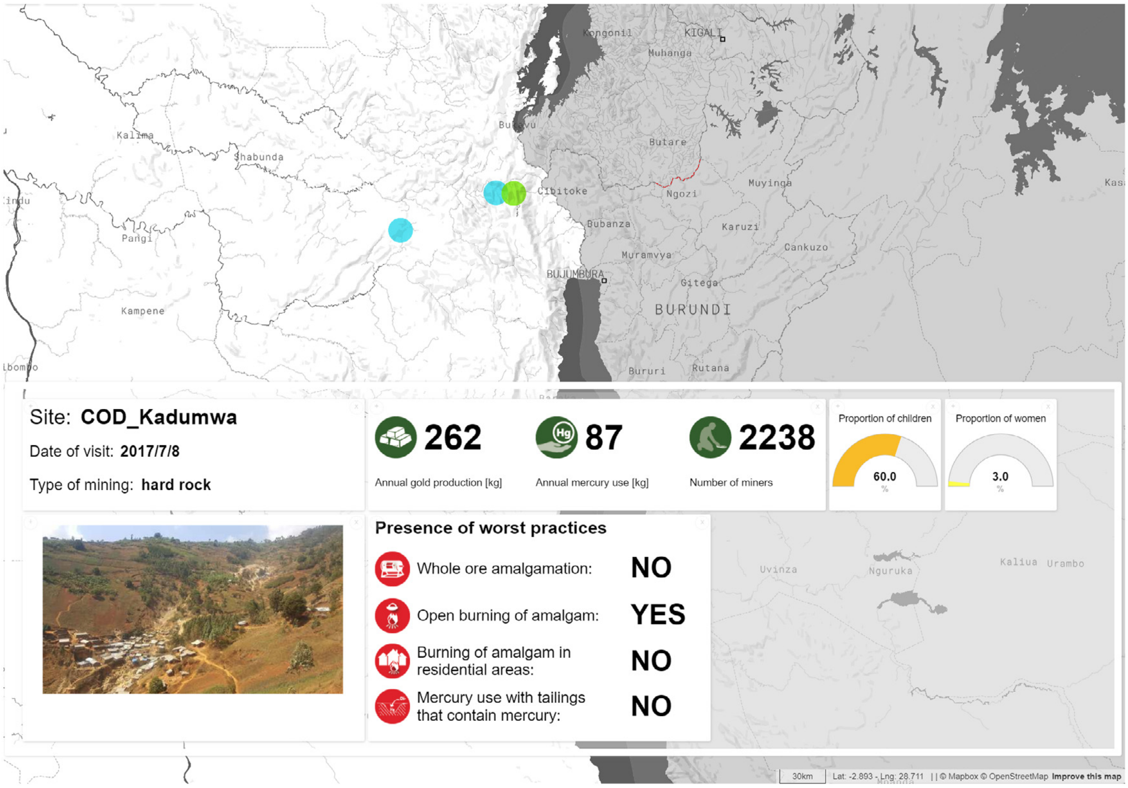

Fig. 5. Example of MapX site dashboard based on UNITAR data for Artisanal Small-Scale Gold Mining (ASGM) sites in DRC showing key figures, indicators and practices on mercury consumption.
Source: https://app.mapx.org?project=MX-IY9-QCF-ILZ-UVO-07Y&views=MX-W8SQB-SM644-QVQXV.

data layers that contribute to a story map are updated in the platform — the story map is also automatically updated.

Dashboards showing key figures and indicators

A MapX dashboard is a separated informative environment associated to a layer that complements or synthesizes the information shown on maps. It is composed of widgets that can contain charts, text or media and can be used to show the temporal evolution of data as well as photos and underlying site fact sheets (Fig. 5). A dashboard can show information from the attribute tables of MapX datasets and can also fetch external information via URLs (e.g. pictures, video, GeoJSON). A dashboard code editor is available from within MapX to connect graphic libraries (e.g. HighCharts, D3.js) with available datasets. Widgets can simultaneously target datasets at different scales (e.g. global, national, site) and can interact in two ways with the map: by clicking on specific features, which reports the exact value of the selected feature, or through zooming in or out, which returns a dynamic statistical analysis on the features shown on map.

Data download

Data download is available in various formats such as shapefile, GeoJSON, DXF and SQLite. Download is authorized by the data manager based on the underlying license requirements of the dataset. For example, data that cannot be redistributed from MapX are not authorized for download.

2.5. Data quality assurance/quality control (QA/QC)

In terms of data quality insurance, MapX uses a data integrity assessment framework (DIAF). In order to assess the integrity of the data, a data inventory is initially conducted that lists the source, custodian and quality of existing data together with key data policy and capacity gaps and level of compliance with international standards for geospatial data. This inventory forms the basic input to a data integrity scoring system that assesses the integrity of the data in four categories: data reliability, technical accessibility, data openness and data sustainability. The framework consists of a 4×4 framework of four major components and four questions within each component. Responses are designed to be yes, no, or partial compliance. When implemented in MapX along with a graphical dashboard, the DIAF will allow users to monitor progress in data transformation and population within the MapX platform. It will also help them to understand the level of data integrity and the issues preventing publishing datasets in a sustainable manner. A complete description of the DIAF is presented on the website of the application.

2.6. Pilot testing

The MapX platform has been pilot tested in DRC, Afghanistan, Haiti and Somalia at a national level, in Colombia, Indonesia, Nigeria and Cote d'Ivoire at sub-regional level, and in Afghanistan at a mine-site level. In DRC, MapX has been developed in close cooperation with the Extractive Industries Transparency Initiative (EITI) Multi stakeholder group (MSG). Other pilots have started recently, in Iraq, Sudan and South-Sudan. Pilots have also been developed to support the Minamata Convention on Mercury for gathering, displaying and analyzing mercury use in Artisanal and Small-scale Gold Mining (ASGM) sites, and to support baseline data management and progress reporting by countries in the frame of the Stockholm Convention on persistent organic pollutants (POPs). Finally, MapX is collaborating with the United Nations Development Program (UNDP) through the UN Biodiversity Lab (unbiodiversitylab.org) to support countries in making use of global biodiversity indicator methodologies and available spatial data, in order to report progress on meeting the Aichi Biodiversity Targets in their sixth National Reports to the Convention on Biological Diversity (CBD).

2.7. Upcoming developments

Now that MapX has been pilot tested "in the wild" in different countries, consultations with users and stakeholders have provided useful insights on how to improve the user experience and how to prioritize future features moving forward.

In terms of data integrity, future developments will consist of implementing a function that will enable users of the platform to provide their own ratings (on a scale of five) for different datasets as well as formally challenge some aspect of a layer. This function can be useful for example in the context of company claims on access to services, jobs, or revenue sharing that are disputed by community members. The system will keep track of how the challenge has been opened, solved, when and by whom.

A strong request from user is the online definition a geographic area of interest. This function will be able to support numerous scenarios. For example, a villager or a member of the civil society (e.g., local NGO) is interested in monitoring an area of interest where she lives, or because it is of ecological importance. The user would like to be alerted by email in case a new concession is granted or if an existing concession has a new status.

3. Illustrative examples

A general presentation is available in [40]. It consists of a story map that exemplifies key features such as: overlay between locally stored layers and satellite imagery, spatial overlap analysis between mine sites and protected areas, heat maps, visualization of landscape degradation between two dates, embedding of multimedia content (images and videos) in online maps, and dashboards showing contamination by mercury at various geographical scales (global, national and site levels).

4. Impact

Based on the existing applications of MapX, we expect five major impacts:

1. Democratize access to essential spatial data: building a global public catalog of high-quality spatial information that is managed by a neutral actor could reduce information asymmetries among stakeholders and support evidence-based decision-making. Such a data pool could be leveraged for artificial intelligence and mobile applications.

2. Prioritization of investments and monitor impact: the platform is providing an evidence-based of best available data that could help decision-makers and stakeholders understand the trade-offs or co-benefits of different environmental options to prioritize investments and monitor impact.

3. Open data norms and interoperable data: MapX can help to broker and depoliticize the sharing of environmental information between stakeholders and countries using a neutral and non-commercial information platform combined with strong interoperability standards.

4. Interconnection between spatial data producers and consumers: MapX can help to match producers of spatial data with consumers of spatial data to answer specific questions and assess the landscape of solutions.

5. A more integrated view of transparency: MapX can help to expand the application of transparency from financial considerations only – to both social and environmental performance – thereby allowing communities, companies and governments to more accurately assess development impact of mining projects.

One of the major challenges faced to transform expectations into reality is the expansion of the use of MapX inside and outside the current community. The technical developments initiated towards that direction include extending the list of export formats for data to GML, GPKG and CSV, and enabling the importation of Styled Layer Descriptor (SLD) files into MapX. In line with this objective, the list of supported cartographic reference systems by the application is being extended (from WGS84 to other major global systems and local ones) to facilitate the export of vector data by local communities. The quality of maps that can be produced in MapX is also being improved to encourage users to include maps in their reports, e.g. when reporting to the CBD or to the Minamata convention. Finally a strong effort is being made to enable embedding MapX into external applications in order for users to navigate in their geospatial layers from a customized application rather than directly from MapX. The UN Biodiversity Lab (www.unbiodiversitylab.org) is a very good example of integration of MapX into an external website. Powered by MapX, the UN Biodiversity Lab includes an online platform that shall encourage building partnerships among data providers and data users to ensure that governments have access and capacity to use cutting-edge spatial data to make key conservation and development decisions. MapX is the backend of this platform, while unbiodiversitylab.org is the frontend. For now the integration is done through iFrames but the extension of the MapX API will facilitate this type of integration in future.

5. Conclusions

Effectively protecting the planet's ecosystems whilst allowing for the sustainable development of natural resources requires an actionable evidence base that can be easily understood by decision-makers. Today, the on-going digital revolution is generating more information than ever before on the state of the planet: a combination of mobile phones, satellites, sensors and drones are collecting planetary information in real time that can inform decision making on natural resources and democratize access to data. However, the sheer size and scale of the various data streams overwhelms the capacity of many stakeholders to use this wealth of information. Indeed, while the quantity of available data is doubling on an exponential basis every year, is it not yet structured in an actionable format. Stakeholders are challenged by the fragmented nature of various data streams, the uncertain quality and a lack of tools to analyze, visualize and communicate the data to inform policies and decision-making.

As outlined in this paper, MapX is our proposed solution to these problems. MapX is a UN-backed geospatial information platform that aims to map and monitor natural resources and environmental risks in real time using best available data and emerging digital technologies. It is the first UN attempt to consolidate the range of spatial information into a single impartial cloud platform, provide incentives and algorithms to match data producers with consumers, while also offering tools and dashboards for analysis, visualization and storytelling. Ultimately, MapX aims to help decision-makers and other stakeholders understand the trade-offs and co-benefits of different land use options in order to prioritize investments and actions.

Developed on a stack of open-source libraries, with code integration that gives particular attention to low connectivity settings, MapX has the potential to reach a large user base. Its open model will likely encourage other developers and institutions to engage with the platform for improving and expanding its functionalities, and even for deploying the stack for other usages than natural resources management.

Acknowledgments

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Conflict of interest

The authors declare that there is no conflict of interest.

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