Narrative web mapping for the restitution of a modeling work of animal mobility and associated risks of infectious disease transmission

-TEMPO Project-

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Abstract

This project's aim to implement an interactive narrative web mapping application to visualize the outcomes of the TEMPO project for wildlife and livestock managers in three Zimbabwean Wildlife and Livestock interfaces (WLI). The narrative web mapping application is implemented using database and GIS tools (PostgresSQL with PostGIS as a spatial extension and QGIS with QGIS server as a map server) combined with Internet technologies (Apache web server, Lizmap web mapping client and NAMO GeoWeb narrative web mapping platform). The implemented application describes, in association with a narrative, the key factors of animal mobility in the environment (land use, surface water, agricultural areas, savannah fires), animal mobility and contacts that determine the risk of transmission of pathogens.
The implemented web tool will allow users to easily access TEMPO project results by a web browser, although currently the platform is not compatible with smartphones. The dissemination of this information will promote improved herding practices and the implementation of best wildlife and livestock management practices in the studied interfaces.

Keywords: Animal behaviour, Wildlife, Livestock, African buffalo, Cattle, Mechanistic model, GIS, Geoprocessing, Client/Server technologies, Narrative Webmap, WebGIS, Cartographic atlas, One Health

Résumé

L'objectif de ce projet est de mettre en place une application cartographique web narrative interactive pour visualiser les résultats du projet TEMPO à l'attention des gestionnaires de la faune sauvage et domestique de trois interfaces aires protégées et anthropiques du Zimbabwe. L'application cartographique web narrative est implémentée en utilisant les outils base de données et SIG (PostgresSQL avec PostGIS en extension spatiale et QGIS avec QGIS server en server cartographique) combinés aux technologies Internet (Serveur web Apache, Client cartographique web Lizmap et Plateforme cartographique web narrative NAMO GeoWeb). L’application implémentée décrit en association avec un narratif, les facteurs clés de la mobilité animale dans l'environnement (utilisation des terres, eaux de surface, zones agricoles, feux de savane), la mobilité des animaux et les contacts qui déterminent le risque de transmission d'agents pathogènes.
L'outil web implémenté permettra aux utilisateurs d'accéder facilement aux résultats du projet TEMPO via un navigateur web. L’application n’étant pas actuellement responsive, elle ne peut s’adapter à la résolution des supports smartphones et tablettes. Cet outil permet de diffuser les résultats de la recherche à un public plus large, et favorise ainsi une meilleure compréhension de la mobilité des animaux dans les environnements d'interface, qui peut être prise en compte dans les pratiques de gestion de la faune et du bétail.

Mots-clés: Comportement animale, Faune sauvage, Bétail, Buffle Africain, Bovin, Modèle mécaniste, SIG, Géotraitement, Technologies Client/Serveur, Webmap narratif, WebGIS, Atlas cartographique, One Health

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Intitulé du projet : Cartographie narrative pour la restitution d'un travail de modélisation de la mobilité animale et des risques de transmission des maladies infectieuses associées
Échéance du projet : 01 avril au 30 septembre 2022

Contexte :
Dans le cadre du projet TEMPO, un modèle de mobilité animale a été développé pour deux espèces d'herbivores sympatriques (vaches et buffles) présentes à la périphérie d'aires protégées en Afrique australe. Ce modèle intégrant des variables environnementales issues de la télédétection (occupation du sol, surfaces en eau) ainsi que des variables de mobilité animale issue de la télémétrie, a été appliqué à trois zones d'étude au Zimbabwe. Les processus complexes de transmission de maladies en Afrique australe produits sous forme de résultats et de données, doivent être communiqués et valorisés auprès des acteurs.

Objectifs :
L'objectif de ce stage est de restituer les processus complexes liés à la transmission des maladies infectieuses dans les zones d'interface (parcs nationaux et zones communales) aux différents acteurs (gestionnaires de parcs, éleveurs, services vétérinaires, ...) et de diffuser les résultats du projet TEMPO en facilitant la compréhension de la démarche de modélisation et l'interprétation des cartes de risque obtenues par la mise en œuvre de la plateforme de cartographie narrative GeoWeb de NAMO. L'enjeu principal est la restitution des dynamiques paysagères (facteurs environnementaux clés de la mobilité animale) et des mobilités animales qu'elles déterminent. Cet enjeu peut être subdivisé en sous-enjeux suivant :

- Capitaliser et sécuriser les données et résultats de recherche du projet TEMPO et des projets précédents ayant alimenté en données le projet TEMPO ;
- Faciliter l'accès, la compréhension et l'interprétation de la démarche de modélisation et des résultats aux différents acteurs ;
- Visualiser et analyser les données et résultats du projet sur des bases géographiques ;
- Valoriser les travaux de recherche en facilitant l'accès aux données supports d'analyses spatiales ;
- Apporter une assistance aux utilisateurs non-initiés aux techniques des SIG.

Finalités : La finalité est d'implémenter une application cartographique web narrative qui fournira un récit cartographique et des outils de visualisation et d'analyse des données aux acteurs du projet TEMPO.

Livrables
Les livrables du projet sont :

- Récit cartographique;
- Base de données PostGIS;
- La plateforme de cartographie narrative du projet TEMPO.

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I.Introduction

I.1 Context, objectives, and challenges

Population growth and the juxtaposition of production and conservation around protected areas in southern Africa are increasing interactions between wildlife and livestock (Wittemyer *et al.*, 2008 ; Cleland et Machiyama, 2017 ; Rumiano *et al.*, 2020). This increased coexistence and interactions of varying nature and intensity increase the risk of transmission of pathogens and associated diseases and may impact on biodiversity conservation, local development, and livelihoods (Archibald et Bond, 2004 ; Mworia *et al.*, 2008 ; Andersson, 2013 ; Ogutu *et al.*, 2014 ; Mascia *et al.*, 2014 ; Lankester et Davis, 2016 ; Rumiano *et al.*, 2020).

Ecotones are an important ecological setting favoring the transmission of a few well-described zoonotic infections, such as yellow fever, where host or vector species congregate or otherwise occur in higher abundance than in either of the adjacent habitats (Despommier *et al.*, 2007 ; Rumiano *et al.*, 2021). These pathogens transmissions are considered as dynamic, diverse, and bidirectional with transmission phenomenon occurring freely within and between wildlife and livestock species at the WLI scale (Wells *et al.*, 2018 ; Rumiano *et al.*, 2021). As recommended by Mackenzie and Jeggo (2019) the 'One Health' collaborative and multi-disciplinary approach, cutting across boundaries of animal, human, and environmental health, is needed to understand the ecology of each emerging zoonotic disease to undertake a risk assessment, and to develop plans for response and control.

Funded by Montpellier University of Excellence, the project TElédétection et Modélisation sPatiale de la mObilité animale (TEMPO) means Remote Sensing and Spatial Modeling of Animal Mobility started in 2018 and ended in June 2022. Its objective was to model the use of the landscape by wild and domestic sympatric and conservation and production keystone ungulate species in Zimbabwe by using Earth Observation data (telemetry and satellite imagery) to better characterize the contacts between wild and domestic fauna by two focal species (buffalo and cattle) and their determinants in three different wild/domestic interfaces in southern Africa (Hwange National Park/Dete, Gonarezhu National Park/Malipati and Kruger National Park/Pesvi) and, to estimate the risk of transmission of pathogens and associated diseases

By using specific language OCELET, the developed model demonstrated the capacity to reproduce seasonal patterns of contact between buffalo and cattle, as observed by using telemetry data, in three different WLI by considering two main environmental variables (i.e., surface water and landcover) and livestock practices (F. Rumiano et al., 2021).

To improve zoonotic disease prevention and maintain human, animal, and environmental health, these TEMPO developed complex processes must be communicated to stakeholders (park managers, farmers, veterinary services) in a way to facilitate understanding at all, expanded knowledge, and changes in practice.

In this context of valorization of complex modeling process (Risks of transmission of pathogens and associated infectious diseases), the narrative web mapping is an adequate way that have an advantage to:

- Combine the story and the related maps in the way that both can be explored at the same time,
- Facilitate understanding of the parameters and complex phenomena modeled,
- Be an interactive and synthesis tool for stakeholders of various skills and roles,
- Be a decision support tool for these different roles and competences stakeholders,
- Be an updateable and perennial service for the target actors.

The main objective of this internship is to implement a narrative web mapping platform to restore to project stakeholders, the complex processes related to the transmission of infectious diseases in interface areas, and to disseminate the results of the previous modeling work by facilitating the understanding of the modeling approach and the interpretation of the risk maps obtained. The issue of the internship is the restitution of landscape dynamics (particularly water availability) and the animal mobilities that it determines.

The main expected outcome is the implementation of a narrative web mapping platform that will allow visualization of TEMPO developed model in the way to improve stakeholders understanding of the different environmental and climatic drivers and their impacts on wildlife/domestic contacts. Specifically, this consists of:

- Review of TEMPO project and elaborate narrative story,
- Cataloguing, collecting, and analyzing and processing data in a GIS project,
- Publish GIS project on the web,
- Create and set up a narrative web map by combining elaboration of narrative story and maps,
- Validate implemented narrative web map and publish.

The expected specifications of the narrative mapping application are:

- Completeness and fidelity of message to be communicated in relation to the related modeling work mentioned above and additional results or observations from related work done in the project,
- Read the Web Map Service (WMS) and load the Geographic Information System (GIS) project layers,
- Display various interactive maps in appropriate scrolls,
- Free and open-source solution to be reproducible with possibility of re-editing for improvement or additional information

And these specifications are all integrated in the Narrative and Modeling platform (NAMO GeoWeb for NArration and MOdeling GeoWeb platform) which allowing the production and distribution on the Internet of narrative maps for territorial knowledge and for the public (CIRAD, 2021).

The need being more that of communication, the narrative web mapping tool favors more the vizualization of information and data than the download and is designed in the working language of the targets which is English for better understanding.

I.2 Project resources and scope

The TEMPO project's existing resources are:

- Office, hardware, GIS, and Web GIS software, Database server, Cartographic Server, Web Server,
- Nextcloud for downloading and uploading documents and data,
- The TEMPO website: https://tempo.cirad.fr ,
- The bibliographic review of the project rich in published papers and master or PhD thesis,
- The dataset of spatial data produced or used in the implementation of the project. These spatial data are of several natures of which:
  - Telemetric data on the location of focal animal species,
  - The boundaries of parks and study sites data,
  - The satellite data for characterizing the environment animal mobility drivers: rainfall, savannah wildfire, land use and land occupation,
  - The basic environmental vector data such as rivers and infrastructure data such as towns, villages, roads, railways, etc.

All these data have been made available through the NextCloud of the MTD (Maison de la TéléDétection) and those missing, they have been collected through other sources. They are currently stored in the CIRAD Dataverse (https://doi.org/10.18167/DVN1/8I6MT0) to allow their security, access, and use by the public.

In order not to incur financial charges in the implementation of this mission, free and open source geomatic solutions are used, mainly:

- PostgreSQL as the relational database management system, with its spatial extension PostGIS,
- QGIS as the cartographic software,
- QGIS Server as the map server,
- Apache as the web server,
- Lizmap as the web client,
- NAMO GeoWeb as a narrative web map platform (https://github.com/GradelerM/NAMOgeoweb).

The purpose of this mission is defined by CIRAD (host company) and carried out in UMR TETIS for a duration of 6 months (from April to September 2022) as the second phase of my MS SILAT curricula.

II.Project management

II.1 Objective analysis

To achieve this need of implementing a narrative webmapping platform for project, the host organization proposed as the following steps:

- The bibliographic review and analysis of the problematic,
- The handling of the NAMO GeoWeb platform,
- The implementation of the platform for the narrative mapping of the TEMPO project in two phases,
- The writing of the internship report and presentation of the results to the partners.

To achieve the objective of this project, its reading identifies the need to use the narrative web platform NAMO GeoWeb as a visualization tool:

- To detail the context of wildlife management in Zimbabwe,

To describe the geographical specificities and remind the legal specificities of the study sites such as the membership of Transfrontier Conservation Areas (TFCAs), the substance of the legal and regulatory framework and their mix with local agreements as well as their shortcomings,

- To present the environmental factors influencing animal mobility and the importance of the impact of livestock practices such as cattle grazing in protected areas, as well as its main consequence, which is the occurrence of direct or indirect contact between the focal species that initiates a risk of transmission of infectious diseases and pathogens between the two species studied,
- To describe the animal mobility and contacts modeled through Ocelet,
- To show the ecological implications of the mobilities and occurrence (location, nature, frequency) of observed and simulated contacts.

The implementation of the project follows two simultaneous phases: “the project management” and “the development of the application”. The first aims to define the framework for the implementation of the project and to ensure its success within the deadlines and conditions defined with the sponsor, and the second aims to deliver the expected product. So, they have been constituted of the following methodological elements:

- Framing meeting and progress meetings,
- Literature review and elaboration of the cartographic narrative: which consisted in the selection, reformulation and validation of the text, maps, images, animations...
- Data collection, harmonization and GIS analysis project, and publication on web client,
- Development of the story map application of the TEMPO project,
- Validation and publication of the project story map application.

The stakeholder of this conducting project is:

- Sponsor: Supervisors,
- Supporting members: Sponsors associates to pedagogic tutor and associated technical support,

- End-users: academic community (researchers, students), park managers, herders, and veterinary services of studied protected areas in Zimbabwe.

As usual, the implementation of this project involves some opportunities and risks, which are described in the following section.

II.2 SWOT analysis

The main strengths of the project are:

- Profusion of free and open-source GIS and web mapping technology and an already developed web narrative platform for the project related needs,
- Availability of workspace, hardware, GIS, and web GIS softwares,
- Availability of cartographic and web servers necessary for the realization of the project,
- Mastery of methodological tools (project management and geomatic tools) for the implementation of the project,
- Organized management framework and realization of the project: Project committee, technical committee, ...
- Availability of the supervising sponsors,
- Support of the project by a large panel of partners with complementary skills:
  - Thematic and scientific skills: IRD UMR MiVEGEC, CIRAD UMR ASTRE, CIRAD UMR TETIS,
  - IT and software skills: CIRAD UMR TETIS (IT administrator, Designer of the narrative web platform).
- Institutional support of my host university by the attribution of a tutor.

The weaknesses of the project are related to the software, in particular the mobile version of the NAMO GeoWeb application is not yet available, which makes its use conditional on the computer and thus limits its current use by certain target users.

The opportunities are primarily:

- The development of experience in the implementation of web applications and the mastery of web technologies,
- The mastery of autonomous management of geomatic projects.

The threats to the project are:

- In the launch phase, the misinterpretation of the TEMPO project and its results can lead to a loss of time in the realization of project or communication of a truncated message to the target users. As a preventive measure, we have made the development and validation of the detailed cartographic narrative of the elements of dressing and maps before starting the implementation of the narrative web mapping application.
- In the production phase:
  - The mishandling of the data on the implemented platform caused a denaturation or deletion of the data. As a prevention, we made a test implementation and copy on a localhost server to replenish the remote server in case of loss of information,
  - Hacking of server,

- Changes of the sponsor's needs that could lead to a modification of the schedule and deliverables.

As a preventive measure, we made an elasticity in the calendar planning of the tasks and always use secure server connection with FTPS and Lizmap as proxy of the cartographic web narrative implemented application.

- In the publication phase, unuse, inaccessibility to the server due to failure, hacking or server shutting off with possible loss of data. As a preventive measure, IT did Backup copy of the server data.

II.3 Project managing

As stated during the scoping meeting and in the mission letter, the project is made up of a technical committee that will also assume the roles of the project steering committee. It will therefore be a guiding and decision-making authority whose responsibilities range from drafting the mission letter to validating the needs and products (see Annex 1: Mission letter). The said technical committee is composed of:

- Herman BANZA KONGOLO (CIRAD, UMR TETIS): MS SILAT geomatics project manager, with the role of project manager and responsible for implementation of the story web mapping,
- Annelise TRAN (CIRAD, UMR TETIS, UMR ASTRE): is the project sponsor and fills the role of supervisor, specifies the needs, and validates the products,
- Aurélie DOURDAIN (CIRAD, UMR TETIS): is the project sponsor and plays the role of supervisor, specifies the needs, and validates the products,
- Pascal DEGENNE (CIRAD, UMR TETIS): is the pedagogical tutor and plays the role of adviser and guidance.

As technical support, the project benefits from the assistance of Alain CLOPES, IT administrator of CIRAD, UMR TETIS and Maison de la TéléDétection (MTD) and Marie GRADELER, senior developer of the web platform NAMO GeoWeb.

To complete my GIS project management tasks, I used some project management tools such as meetings and timeline charts, as well as geomatics softwares such as QGIS, Lizmap plugin, and web cartographic technologies Lizmap webclient and NAMO Geoweb.

The project management was animated by bi-weekly meetings at the beginning and then monthly and more spaced out because of the recursive nature of the tasks. Thus, the first meetings were mainly aimed at framing the mission, validating the needs, the activity timeline (Gantt), amending and validating the narrative story to be implemented, following the implementation of the narrative web platform in localhost, and validating the test layout. Then followed support meetings to amend the information of the narrative map, the visual rendering of the maps developed, or comments to add specific information in the implemented web platform.

The Gantt chart below lists the major steps of the project and was used to tracking tasks throughout the project lifestyle. It helps to show the dependencies of interrelated tasks and focus on the start and completion dates for each specific task.

		April				May				June				July				August				September			
Task	Manager	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Project review	Herman B.	■	■	■	■																				
Narrative story writting	Herman B.			■	■	■	■																		
Data list elaboration	Herman B.				■	■	■																		
Collect and analyze TEMPO dataset	Herman B.					■	■	■	■																
Collects and analyzes related data	Herman B.							■	■	■	■														
GIS project and web publication	Herman B.							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Test implementation of the narrative map on localhost	Herman B.									■	■	■	■												
Implementation of the narrative map on a web server	Herman B.													■	■	■	■	■	■	■	■	■	■	■	■
Improvement of implemented web narrative application	Herman B.															■	■	■	■	■	■	■	■	■	■
Elaboration of data dictionary, complementary elements	Herman B.																	■	■	■	■	■	■	■	■
Elaboration of master thesis	Herman B.																		■	■	■	■			

Table 1 : Gantt chart

Due to the recursiveness of the tasks, the implementation required a rather flexible follow-up of the time schedule, especially after the implementation of the application on the localhost and the first implementation of the platform on the sponsor's server.

III.Application development

To meet the project's objective, the software and methodological tools choice are motivated by bibliographic review and analysis of existing software tools and web mapping solutions presented below.

III.1 Review

III.1.i Web mapping

Through its different stages of evolution since the beginning of the web and the first World Wide Web in 1994, the Web has gradually changed from a technological network of documents to a network where documents, data, people and organizations are interlinked in various and often unexpected ways (Hall et Tiropanis, 2012). The beginning was motivated by Al Gore's (1998) speech "The Digital Earth: Understanding our planet in the 21st Century" at the California Science Center shows the need to make geographic information accessible and easily understandable to all through the means of the internet (WWW) and, accelerates the enthusiasm to develop the web mapping as reported Veenendaal et al. (2017).

As Al Gore (1998) had intended, this technology was to be used for following purposes:

- Conducting virtual diplomacy to support peace negotiations or to create or wider peace corridor,
- Fighting crime by using GIS to detect crime pattern and gang activity,
- Preserving biodiversity in context of population growth,
- Predicting climate change by modeling global rate of deforestation and monitor land cover changes using satellite imagery, and
- Increasing agricultural productivity by precision farming.

The technologies, methods and tools making maps available on the web have evolved considerably related to both evolution dynamics of science and technology, and increased interest of domain experts and global citizens in consuming new kinds of maps created web mapping services (Veenendaal *et al.*, 2017). Huge volumes of geospatial data are available and daily being captured online and are used in web applications and maps for viewing, analysis, modeling and simulation (Veenendaal *et al.*, 2017).

Veenendaal *et al.*, (2017) ; Bert, (2016) lists three relevant and influential web mapping developments: basic online maps, web 2.0 interactive mapping and virtual globes. (Bert, 2016) describe them as:

- The Online maps enabled users to retrieve and share mapping data and information,
- The Web 2.0 enabled users to contribute to the map and the knowledge it was communicating,
- The Virtual globe growing the user base and generating a much more immersive environment to stimulate user engagement and collaboration.

Different authors defined web mapping in different way considering different aspects and boundary between web maps and web GIS is blurred as noted by (Neumann, 2008).

Related to Techopedia (2022), Web mapping is just the technique of utilizing maps that are obtained by an information system for spatial and geographical data and related to Wikipedia (2022), Web mapping or online mapping is the process of using maps delivered by GIS on the Internet, more specifically in the WWW. (Wikipedia, 2022) specify that a web map or an online map is both served and consumed, thus web mapping is more than just web cartography, it is a service by which consumers may choose what the map will show.

Related to Web GIS or Internet GIS, web mapping is the process of designing, implementing, generating and delivering maps based on the World Wide Web (WWW) and on a set of standards of the Open Geospatial Consortium (OGC) of which the Web Map Server (WMS) is the best-known (Neumann, 2008). It focuses on analysis, project-specific geodata processing, and exploratory aspects, deals mainly with technological issues, and additionally examines theoretical aspects such as the use and usability of web maps, the evaluation and optimization of techniques and workflows, social aspects, etc (Neumann, 2008).

(Caquard et Cartwright, 2014) complete by considering web mapping as a broad term that includes several aspects, but basically means digital mapping on the Internet. Thus, it is made of a set of technologies that rely on GIS for the creation and publication of digital maps on the Internet (Caquard et Cartwright, 2014). Given the speed of evolution and the multiplicity of web mapping tools and services, most definitions are partial (Veenendaal *et al.*, 2017) and web mapping is far beyond its literal meaning and seen from both the service and consumer point of view (Techopedia, 2022).

In the way to clarify these opinions, (Veenendaal *et al.*, 2017) distinguish web mapping from web GIS, internet GIS and GIS desktop by following characteristics:

- First, Web mapping uses the web to deliver maps, deals primarily with technological issues, and requires additional studies on cartographic theories. This means that web mapping not only follows various Internet protocols but also utilizes web specific protocols; and secondly it means that new technologies and cartographic principles are needed to effectively design maps for web mapping delivery.
- Second, differently from GIS desktop technologies, web mapping is mostly not an off-the-shelf solution, although many of its core technologies have already been well developed. It often requires some programming and demands breadth in terms of skills, knowledge, and organizational structures to deploy practical applications.

So shortly as shown if figure below, basically GIS is considering as a system composed of data handling tools (hardwares, softwares, data and human users) for capturing, storing, questioning, analyzing, displaying, and interpreting spatial data to understand relationships, patterns, and trends (Worbys and Duckham, 2004; Davis, 2001; Clarke, 2001) that are joined together in one computer (GIS Lounge, 2014). Using Local Area Network (LAN) these GIS handling tools were separated which born Distributed GIS. Development of the web technologies (WWW) allow separating GIS components for farther distances than LAN and this combination of GIS system with using Web technologies (server/client-side technologies) called Web GIS. Thus, Internet GIS is a broad GIS system using not only Web service like Web GIS but many of services of Internet. And at the end, Webmapping is the process or technics that enable map visualizing on the web and Geospatial Web (GeoWeb) is the merging of geospatial information with no geospatial information (photos, animations, stories, news, etc.) (GIS Sensing, 2020; Pinde Fu, 2016; Kurbanov, 2015; GIS Lounge, 2014; Moretz, 2008).

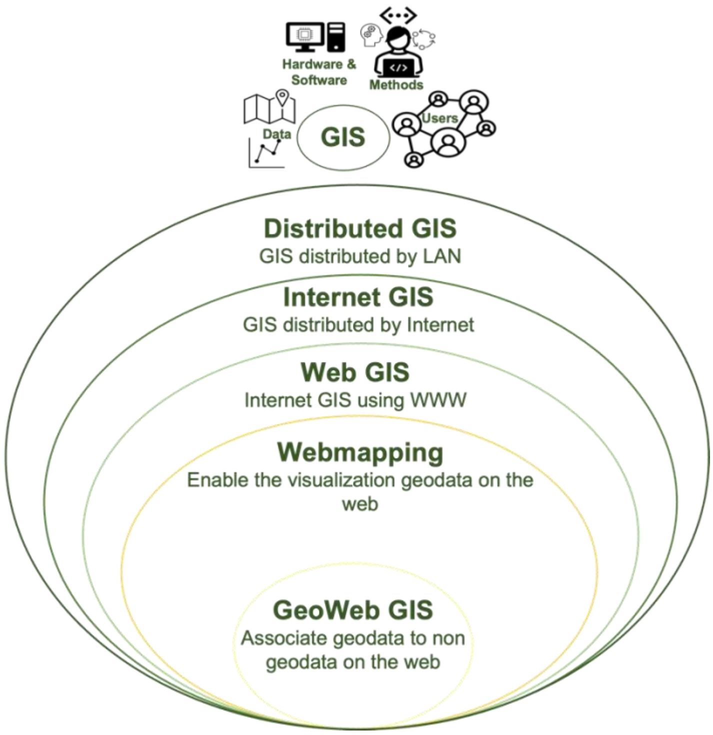

Figure 1: GeoWeb and Webmapping in relation to other related GIS terms

III.1.ii Narrative webmapping

Maps have not only been used to decipher and geolocate stories, but to tell them as well (Caquard et Cartwright, 2014). They conclude by emphasizing the need for the cartographic community to appreciate the power of employing narratives to better document the entire mapping process, from map production to its use in different contexts and says that it's central to post-representational cartography.

As its main words means, the "narrative webmapping" is the combination of "storytelling" and "maps" on the "web". Thus, it allows users to combine the graphic perception of information with contextual literature and increases the informative capacity of the maps.

Popularized by ESRI's ArcGIS StoryMaps, the tool is widely used to combine maps and narratives to tell historical stories, explain phenomena, etc. It's connecting the map with the complete mapping process through storytelling and by this way use narrative power of maps and mapping a story or process. It's also used to represent the spatiotemporal structures of oral, written, or audio-visual stories and their relationships with referential places (Caquard et Cartwright, 2014).

Story maps are generally for non-technical users (e.g., decision makers with limited spatial analysis skills) as it is a visualization tool only and does not require extensive GIS knowledge. A narrative map typically contains text, graphics, sound, images, or video to paint the portrait of the story. They are easy-to-use and set up with a range of tools and functionality to help tell the story in a visual and geographic way (GISGeography, 2021).

As Caquard and Cartwright (2014) and (Reuschel *et al.*, 2013) defined, the implementation of a narrative mapping of TEMPO project will be subject to a few basic requirements and challenges such as:

- Representing spatiotemporal sequences and events.
- Having to visualize the multiple scales at which processes unfold,
- To integrate the multiple scales and extent in which geographical phenomena are defined,
- Linking the narrative locations of the represented processes to the Euclidean structure of the reference map

Using the same web and GIS architecture and technologies, narrative web application is done using a Server-Side and a Client-Side technologies, and as said (Aurélie *et al.*, 2017), OGC Standards thus allowing the publication of geographic data on the web or the remote access to data stored on a web server.

III.1.iii Geographic web services and standards

Geographic web standards are developed by members until 2014 to make location information and services FAIR (Findable, Accessible, Interoperable and Reusable) to address specific interoperability challenges, such as publishing map content on the Web, exchanging critical location data during disaster response & recovery, and enabling the fusion of information from diverse Internet of Things (IoT) devices (OGC Standards and Resources, 2022).

The main standards OGC services are:

- Web Mapping Services (WMS): it provides a simple HTTP interface for requesting geo-registered map images from one or more distributed geospatial databases. it requests defines the geographic layers and area of interest to be processed. The interface also supports the ability to specify whether the returned images should be transparent so that layers from multiple servers can be combined or not.
- Web Feature Services (WFS): it's primarily a feature access service but also includes elements of a feature type service, a coordinate conversion/transformation service and geographic format conversion service.
- Web Coverage Services (WCS): Developed in 2005 for raster-based data, WCS offers multi-dimensional coverage data for access over the Internet. WCS Core specifies a core set of requirements that a WCS implementation must fulfill.

TEMPO implemented narrative web platform will use WMS standards.

III.2 Narrative storytelling elaboration

The narrative storytelling elaboration is the first step of narrative webmapping. This aims to write a story to tell, identify figures, charts, and table to insert in and at the end identify maps.

Stories are powerful; they can advocate for change, influence opinion, and create awareness (Brake, 2020). The elaborated narrative storytelling is based on review of TEMPO project literature such as PhD Thesis, Papers, websites, etc. As advised by Digital Storytelling and Brake (2020), elaboration of this geomatic project implies the identification of these three aspects:

- The story to tell: “Modeled infectious disease transmission processes and risk factors in Southern Africa”
- Target audience: Park managers, veterinary services, and herders
- General objective of the story map: to vulgarize the results of the TEMPO project to encourage stakeholders to make change decisions to adopt best practices.

These aspects apprehended in narrative storytelling elaboration provide a logical and fluid global flow of the narrative for the target audience, plan how the story will be told, and help identifying what media will be used (figures, graphics, video) and what maps to produce will be included and ending by calling target audience.

So, to better structure the overall content, flow, and formatting of the cartographic narrative, it was important to clearly define whether "maps are used to support the narrative" or vice versa. Because in the first case, it’ll be better to start by building the narrative with some scope to include the maps, and in the second case, it’ll be better to start by building the maps, to better frame the story around them.
In TEMPO narrative webmap project, "maps are used to support the story”, then and as recommended by (Caquard et Dimitrovas, 2017), we start by building and validating the narrative storytelling with some scope to include the maps.

The narrative storytelling was sent first to technic committee to integrate their wishes, be improved and was validated after final correction.
The validated narrative storytelling and selected media served more as a guide and example when implementing the narrative web mapping application. As narrative web maps are not readable in the same way as articles, problems that emerged during the implementation of the narrative web platform were corrected in the same way as the listed maps.

To present the aspects of the TEMPO project in a way that is comprehensive and potentially usable by the above-mentioned set of users, the communication strategy of the narrative map and its structure are detailed as follows:

1. Familiarize the reader with the study context and key concepts including:

- Geographic aspects: location and natural conditions,
- Socio-demographic aspects: increasing population density, urban sprawl and increasing protected area/anthropic interfaces, etc.
- Regulatory and practical aspects of wildlife and livestock management: membership of the protected areas of the study sites in transboundary conservation areas, mix of

state rules and agreements with livestock farmers influencing certain livestock practices (access to protected areas for cattle grazing, etc.)

2. Describe the data used (satellite images and telemetry data) and the methodological steps for information extraction
3. Present the outcomes of the TEMPO project studies and the ecological implications with a practical case study of the transmission of bTB from Kruger to Gonarezhou between 1990 and 2008 studied by Caron et al. (2010).

Although markdown has limited functionality for formatting text on a web page compared to HTML, for effective communication of information and animation of the reading of the narrative story, several formatting elements have been used including:
- Italics for species names,
- Hyperlinks for important bibliographic references, data sources and other resources,
- Twin hyperlinks for composite references such as Hwange-Sikumi,
- Bold and/or bold italics to highlight certain information,
- Blockquote to draw attention to aspects and to specify certain details,
- Simple lists or enumerated lists to list items.

For aesthetic reasons and to avoid confusion for users, the following is done:
- Only hyperlinks are underlined,
- Do not associate titles with hyperlinks because the latter gives an underlined and colored format that does not give a very aesthetic rendering in the publication.

Given the number of resources cited in different studies and the diversity of data external sources, it was also necessary to pay attention to certain details, such as the size of protected areas, which should be consistent with those reported by the IUCN protected areas database (WDPA OECM). If this is not the case, the reasons for the difference should be indicated in the text.

This part was done in two steps (in a narrative story and then on the implemented platform) gave as results:
- The cartographic story,
- The first data list,
- The graphics list,
- The list of figures and animations,
- The list of maps to produce.

III.3 GIS project

The objective of this phase is to prepare the data for publication on the narrative web platform to combine the strength of the elaborated narrative story with coherent cartographic information in a logical sequence. It's began by data census and collecting.

III.3.i Data compilation and collection

The data that feed the maps and the narrative (figure below) are of two categories:

- Non-geospatial data: figures, photos, animations, tables, etc.
- Geospatial data: Vectors and Rasters.

Data census starts by the identification of the data in a data-list, based on the validated narrative story, figures and maps have been selected. These figures and maps have been decomposed into lists of spatial layers necessary to realize them. These lists of data constitute basic elements preliminary to the development of the data dictionary with metadata and evolve during the implementation of the project. So, this overview facilitated the collection, evaluation, and validation of reliability before integration into the GIS.

To deduce guidelines for harmonization, formatting, and use of data on the maps, their analysis has revealed the following points:

- Data format: csv table, shapefile vector, geotiff raster, giff animation, etc.
- Spatial scope: data covers three protected areas, data covers three WLI and data covers Zimbabwe and Africa,
- In addition to the location, the type and nature of the values contained imply one or more possible representations:
    - Several data containing values in raw quantities that can be represented geometric object in proportion of size or in anamorphisms of geographical entities,
    - Several data containing values in proportions that can be ordered on a scale of variation or a gradient of colors in a representation.

The data is then mainly collected from the TEMPO project and after learning about the existing dataset, it was important to complement it with related data to better support the message to be communicated. Thus, as related data providers are mainly:

- IUCN WDPA OECM: for protected areas,
- OSM: for boundaries and limits,
- SADC TFCA for TFCAs and Peace Parks Foundation Open Data for TFCAs,
- Worldpop for population density,
- Gridded Livestock of the World (GLW v3), 2010 (FAO, ULB, ERGO, ILRI et UCL) for cattle density.

On the other hand, to make a cartographic representation of some of the facts stated in the bibliography, the creation of the data went through digitization followed using other geoprocessing. As an example, the case of the sprawl map around protected areas in southern Africa illustrates the increase in interfaces between protected areas and humans and highlights the increased risk of transmission of pathogens and associated diseases between wildlife, livestock, and humans.

Figure 2 : Diversity of data type and scale

This phase led to the drafting of a first draft of data dictionary with metadata that will be use in geospatial analysis or mapping.

III.3.ii Geoprocessing and layout

Mousnier (2015) defines "data" as a reality representation unit and "information" as the result of several data related queries. In the same way, as reminds O. Barge (Barge, 2003), "information" is not just data and not all data have the same "informative ability" to give users an understanding of studied object.

By these facts, the cartographic process is a serial interpretation of datasets, followed by their successive reductions into data, combining the choice of data with the choice of their representation and transformation into information. This implies a very deep investigation of the nature of the information to be represented, the analysis of the associated data and the consideration of the constraints of the graphic construction of the map. By this way the map designing becomes a set of choices guided by the knowledge of the subject to be mapped.

The processing of geodata was done according to the nature of each layer (vector or raster), its characteristics, the information to be communicated with this data and the maps in which it is intended to be used. Globally, this geoprocessing starts with creating QGIS projects with the collecting layers, the harmonization of data up to the most complex geoprocessing before saving project and publishing on the web.

The maps to be developed to be displayed in association with the narrative story have as challenge first to demonstrate in an intuitive, attractive, and informative way to the targeted users, secondly to communicate accurately the richness of the TEMPO data and the animal mobility and contact model developed in the TEMPO project, without exposing sensitive data such as the origin and identity of the cattle herds. Geoprocessing being a laborious and complex process to be completely described, a few examples of the treatments performed are mentioned below.

a. Anonymization of sensitive data

To prevent the identification of herds that have been observed as in contact with buffaloes in the modeling process, as show figure 3, some anonymization was done by:

- Deleting information about tracked herd identity and localization,
- Creating herd heatmaps or hull shapes,
- Creating contact hotspot to show occurred contact between focal animals.

Figure 3: Telemetry CSV files in 1 and 2, contact table and hull in 3 and, occurred contact frequency hotspot in 4

b. Map design and Semiology

As for all maps, the graphic semiology allows to capture the imagination of the user of the narrative web map. As said (Palsky, 2012), related the 'map design' developed by Arthur H. Robinson and 'graphic semiology' of Jacques Bertin, it's very important to consider the users point in the process of cartographic communication and to focus on graphical language and its efficiency.

First challenge of map design and semiology was rendering difference between GIS project and implemented narrative web application. Even if Lizmap use QGIS Server and QGIS render engine that normally allow to rightly replicate the QGIS project render on created webmap application, three kind of render challenge was founded: first the brightness render (figure 4), followed by the interpolated symbol label render issue (figure 5) and third native and created label difference (figure 6).

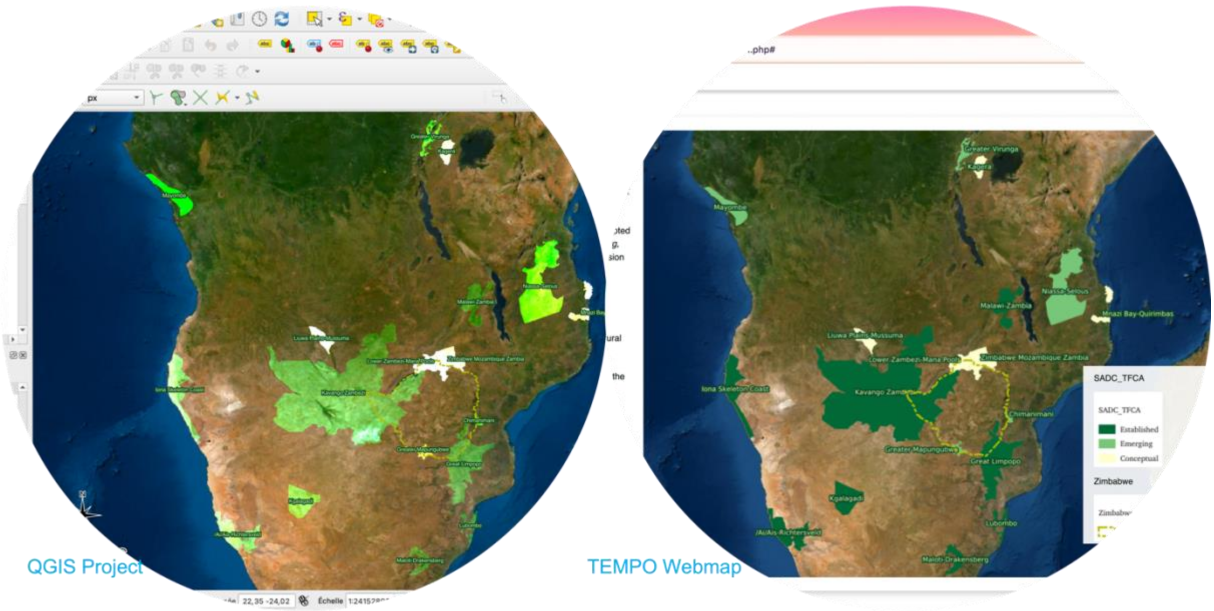

Figure 4: Brightness render difference of SADC TFCAs in built QGIS project and implemented TEMPO narrative webmap application

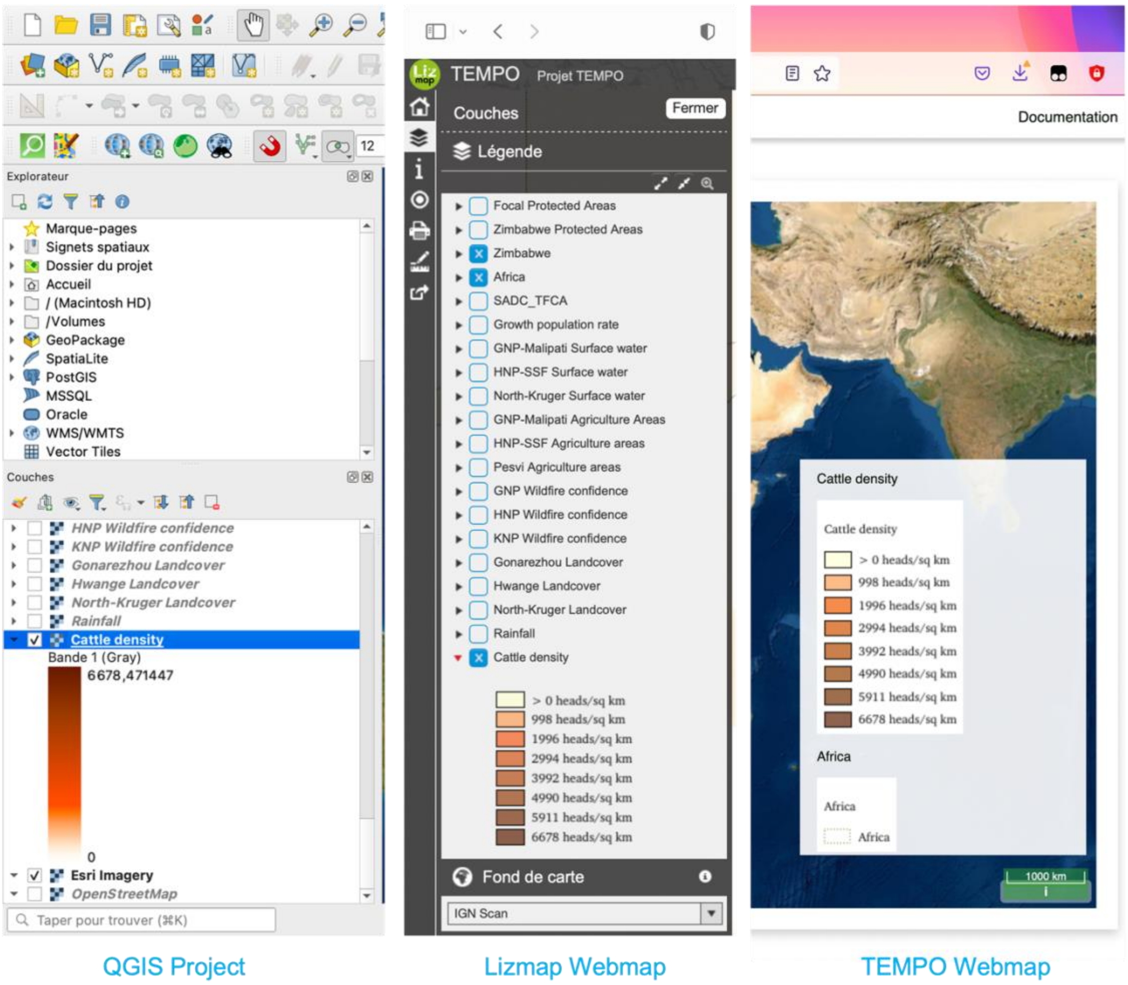

Figure 5: Interpolated symbol label render difference of Cattle density in Africa between QGIS project, created Lizmap webmap application and implemented TEMPO narrative webmap application.

Figure 6: difference in rendering between QGIS project and NAMO webmap of QGIS native and created labels.

c. *Multibackground compatible semiology*

When publishing maps on the web, several backgrounds can be used, in order not to overload the web map, the layers have been dressed and designed to be compatible with different background or have a multi-purpose semiology. The rendering of each layer has been tested in the scrolls that contain it and improved according to the evidence (figure 7).

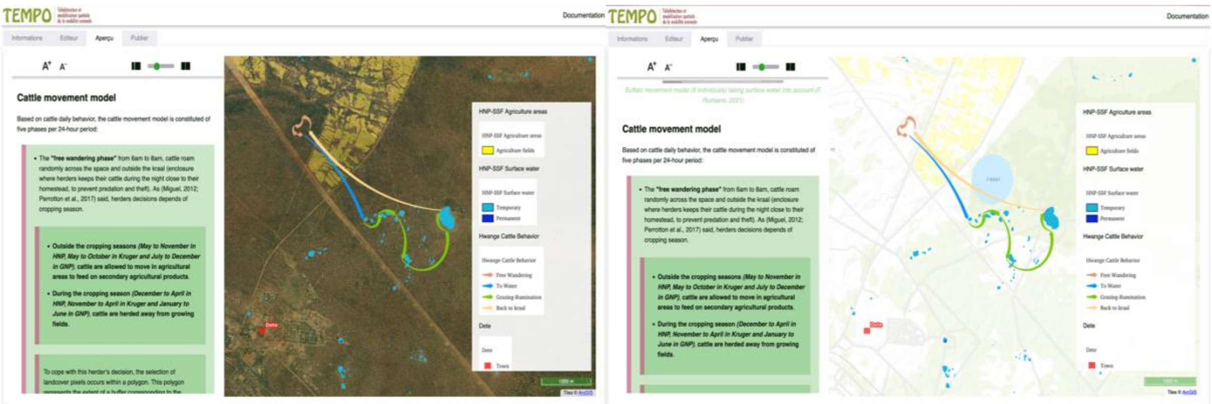

Figure 7: Multibackground compatibility semiology

d. Representation mode

Two kind of representation mode was designed: layer display mode with associated and related layers and, display of layer in different slide scale and, information detailed level (figure 8).

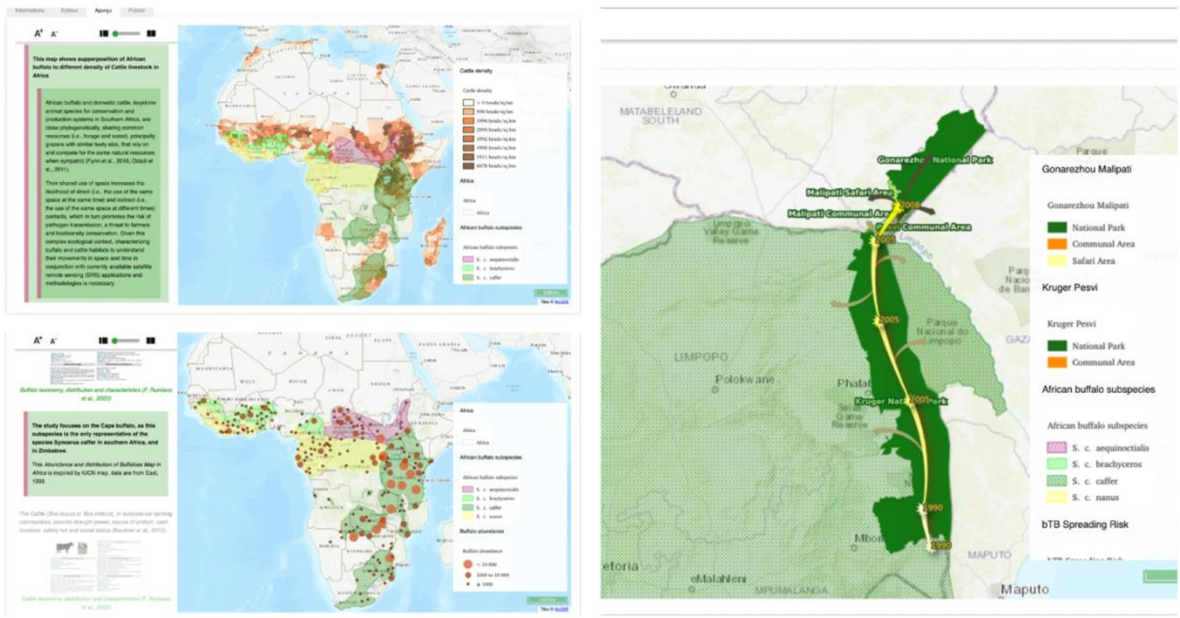

Figure 8: African Buffalo Subspecies layer symbol in different slide maps

Depending on the context of displaying of a geodata layer, specific representation mode may be more adapted than another one. Thus, it was important to analyze the representation mode of each geodata layer (generalist, detailed, contextualized or not) as well as the information to be used and communicate.

For example, the representation of protected areas was done according to protected area categories and grouped by similarity of management rules. Thus, protected areas with a conservation vocation (conservancy, sanctuary, wilderness area, wildlife management area) have been grouped into one. On the other hand, to help users understand the difference in context and management rules of their protected area belonging to one TFCA category belonging to another category, it was necessary to represent related to status contrary to the usual representation of TFCAs (figure 9).

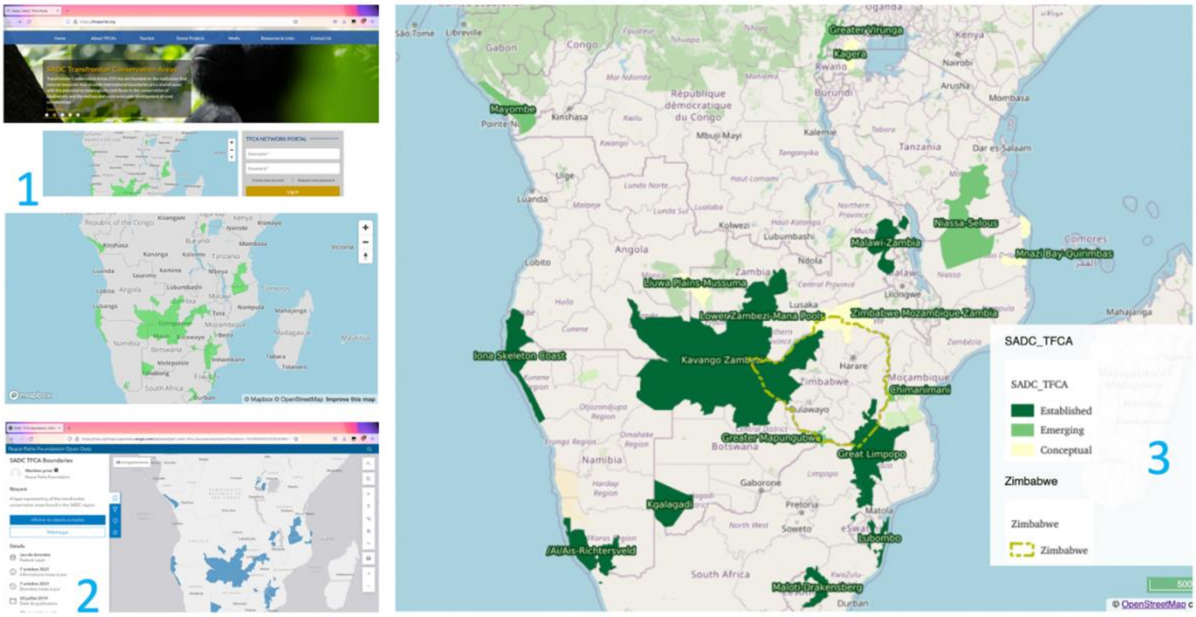

Figure 9: SADC TFCAs common representation (1 & 2) and TEMPO implemented narrative web application on 3

e. *Proximity analysis and flow maps*

Beyond the representation of observed, simulated (large) contact areas, it was relevant to analyze the data to extract the most recurrent contact areas and classify them by frequency. The representation of this final information gives the reader an indication of the most recurrent contact areas in the study areas. As this data was missing for the Gonarezhou and Kruger sites, it was useful to recreate them by proximity analysis including the temporal variable to establish an aspect of direct or indirect contact. Followed by clustering to assess the grouping of focal species herds.

To materialize the mobility flow that causes contacts between buffaloes and cows (figure below), a virtual layer joining the centrioles of the herds to the contact points was created through an SQL query.
First, the species locations from the telemetry data were separated into clusters giving groups of cattle and buffalo herds that are equidistant and expected to follow the same moving direction. Then, represent this cluster by an element, a centroid created for each group of buffalo and cattle in each study site and placed in a csv file.
These centroids are used as the flow origin for the buffalo and cattle herds and the previously constructed contact points (contact heatmap) are used as the destination for said cattle and buffalo herds.
For the creation of the virtual line layers joining the herds with their respective contact points, each element (entity) was saved in the csv file with the fields to create particular and conditioned joins: ID, Latitude, Longitude, Origin and Destination. The csv files have been saved:

- On one hand, with a spatial index for point layer (nodes) to provide geographic information of the Origin and Destination nodes and
- On the other hand, a non-spatial layer (edge) containing information about the flow weight (frequency of contacts) between the herds and the selected contact point.

The flow lines are then formatted according to the specific case, by a geometry generator or not. These flow maps produced, superimposed on the convex envelopes of the telemetry data and boundaries of the anthropic or protected areas, show the movements and contacts of both species between the two matrices: anthropic and protected areas (figure 10).

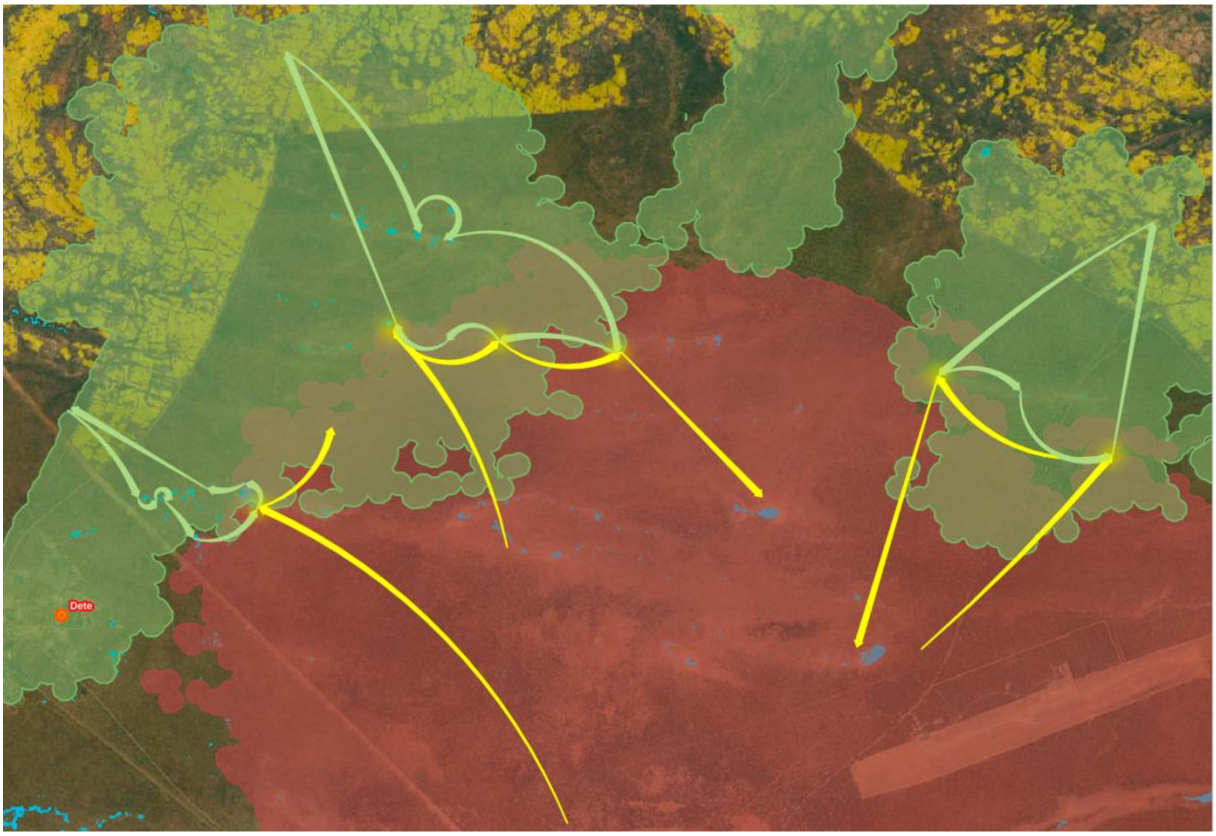

Figure 10: Hwange buffalo and cattle flowmap

With yellow arrows as buffalo flow mobility to contact point and green arrows as cattle flow mobility to contact point thar are bright green points. The transparent light-green spot is the shape of the cattle herds, and the transparent light-red spot is the envelope of the buffalo herds. The yellow-brown spot is the crop fields in the communal area and clearly bordering the protected area (Sikumi State Forest) in the satellite background.

f. The increasing interaction between protected and anthropized areas in southern Africa

The increasing interaction between protected and anthropized areas in southern Africa is reported as an important phenomenon creating challenges for biodiversity conservation and local development. With as main cited cause the sprawl of anthropized areas due to population growth, the multiplication of it may facilitate human-wildlife conflicts such as competition for natural resources, livestock predation, crop destruction by wildlife, and/or the risk of pathogen transmission between wild and domestic species.

To demonstrate the importance of the phenomenon, we conducted a population density dynamic between the years 2000 and 2020 using open and high resolution geospatial WorldPop data.

The used WorldPop gridded population count datasets are UN-adjusted numerical counts of the population density of Zimbabwe in 2000 and 2020 with a spatial resolution of 1km at the equator and WGS84 CRS. This means that the values are not in 256 grayscales as for the 8-bit coded images or another common satellites.
A subtraction between the two images was used to detect the change in population density and the detected density change was weighted to obtain a rate of decrease or increase density population that is easier to interpret than raw values.
To improve visual interpretation for users, the resulting raster was stretched to increase contrast and discriminating shades of population dynamics and, then the images were classified into 5 intensity levels:

- Less than 20% population decrease for exodus (the case of West Bulawayo),
- Between -20% decrease and 10% population change as a sign of recurrent population movement in and out, without sustainable settlement. For this reason, its symbology is masked to highlight the extremes of population dynamics,
- Between 10% and 40% for an average population increase,
- Between 40% and 70% for a strong population increase,
- More than 70% for a very high population increase.

As indicated in the bibliography and as shown in the obtained plot (figure 11), there is a general density population causing a sprawling of anthropized areas towards protected areas, which can be interpreted as an increasing of WLI contact interfaces and humans, that remind the above-mentioned consequences of these contacts including the risk of transmission of pathogens and associated infectious diseases.
This information overlaid on the protected areas studied by TEMPO shows the occurrence of the phenomenon for the WLI studied, in addition to the user's ability to view all of Zimbabwe's protected areas while operating the web narrative map. Given the size of the study area, the scale of visualization, and the demonstrated phenomenon, a halo is placed around the urban sprawl in the vicinity of protected areas to guide the user's reading.

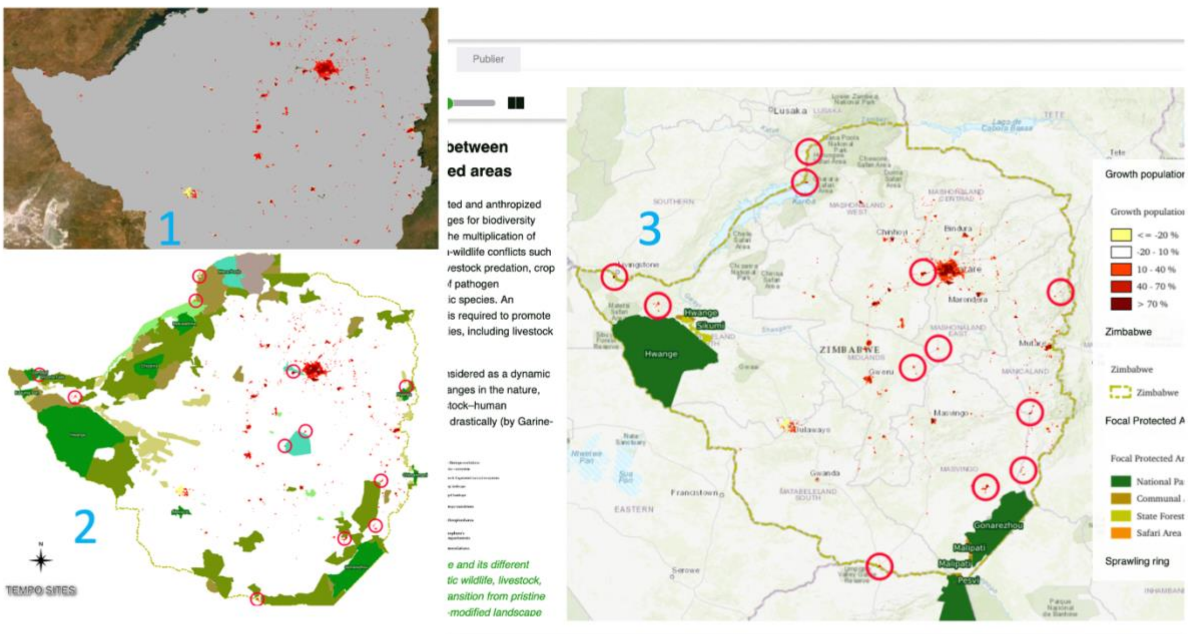

Figure 11: Anthropic area sprawl around protected areas to show increasing interaction between these two spatial matrices that increase the risk of transmission of pathogen between wildlife and livestock to human.

In this figure, 1 represent classified population dynamics from dynamic analyses of 2000 and 2020 WorldPop images, 2 represent increasing anthropic areas around protected areas of Zimbabwe and, 3 represent increasing anthropic areas near TEMPO project focal protected areas on implemented TEMPO narrative webmap application.

g. Representing pathogen and associated disease wildlife and livestock transmission risk as ecological implication

TEMPO project received dataset subtly representing the risk of transmission of pathogens, to illustrate this aspect, we have reconstructed maps (figure 12) and phenomena of bovine tuberculosis (bTB) transmission and risk of buffalo populations in the extreme south of the Kruger National Park to Gonarezhou National Parks between the years 1990 to 2008 by Alexandre CARON.

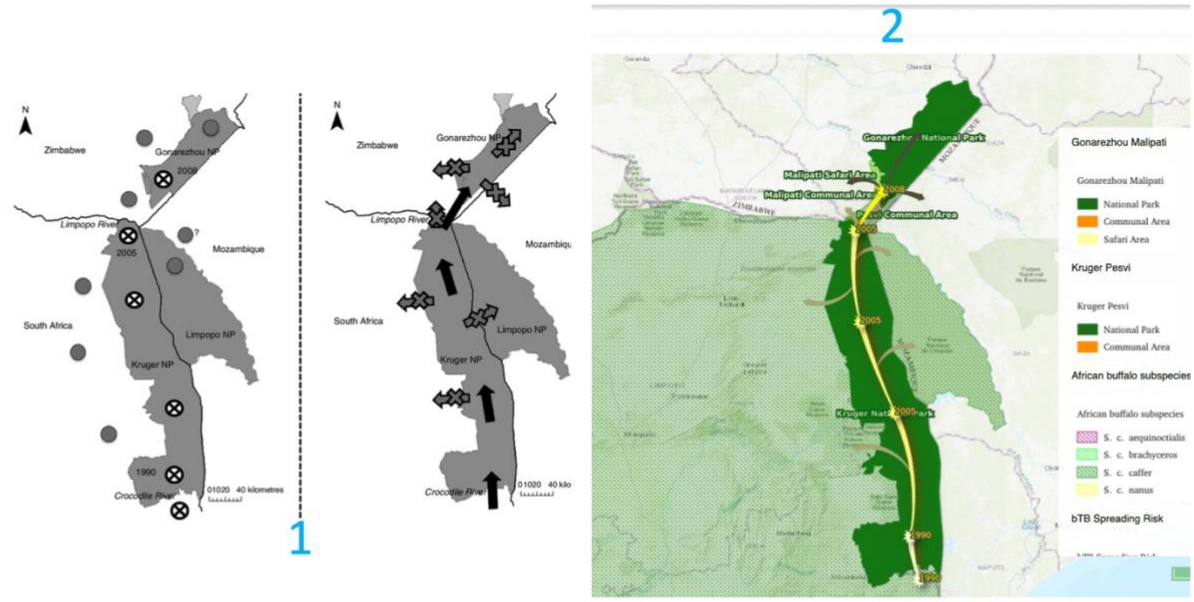

Figure 12: Spread and risk of spread of bTB in the Great Limpopo Transfrontier Conservation Area. In 1 it's made by A. Caron et al. (2010) to explain de phenomenon and in 2 made to show ecological implication as an example of risk of transmission of pathogen and associated disease in studied W/L interfaces.

Landcover required reclassification according to the classes defined in Florent's thesis and some classes converted. For example, Hwange contains temporary water while Gonarezhou and Kruger National Parks contain wetland instead. For certain representation needs in the narrative web map, the agriculture and water classes were extracted.

h. Another example of geoprocessing

To reduce the size of the raster files, a class with zero grayscale values was created in the reclassification of the rasters, all the pixels of this class were removed by deleting the class and the gaps created in the image were filled by generalizing the values of the pixels of the large and homogeneous regions on the neighboring minority gaps pixels as in an image enhancement with a low pass filter.

Using a series of TAMSAT rainfall images from 2018 over Africa, rainfall was averaged over Zimbabwe, with monthly data ranked on a scale from less than or equal to 30mm to greater than 130mm. The distribution of the savanna fire phenomenon using MODIS 2018 is categorized into three levels of fire intensity with all zero values removed.

III.3.iii Webmap design

Beyond the geoprocessing, as some authors point out, the presentation of data on a web interface requires certain artistic skills framed by the usual principles and rules of map design and graphic semiology. Given the variety of information to be presented, the use of visual variables to organize the communication was very important. The choice of colors, transparency, size, shape, orientation, amplitude as well as background, considering that the color of landscape elements (e.g., water, vegetation, etc.), the hierarchy of information layers on a map, never change.

Then, as the map is a graphical language, its design and layout are based on adequacy between information and graphic perception with a sobriety and simplicity and, ensuring it delivers the right message. Four criteria were used to develop the maps for our story maps:

- Fidelity to the argument of the published papers and master or PhD thesis,
- Completeness of the facts studied and demonstrated in related papers and PhD thesis,
- Crossing the spatial and temporal dimension of the phenomena of transmission of diseases and pathogens through the contacts in space and time of the animals studied (association of maps, text, animations ...),
- Intuitiveness of the users' understanding.

A choice to be made in the representation of anonymous flows is to limit oneself to the origin and direction of the flows (park - communal area or communal area - park), contact interface (in or out of the park) to the circumstances of contact or characteristics of the contact interface (open water areas or other land uses).

This is done through the sequencing of the narrative, the circumscription of the framework to be represented and especially the graphic semiology of the maps developed. For a good cartographic representation, a correct analysis of the data is necessary, from simple filters to the analysis of proximities to extract the areas of contact between the studied species, to the elaboration of flows etc. as we will see in the following section.

As advised by (Caquard and Dimitrovas, 2017), the choice of maps to be retained for the cartographic narrative must favor through a spatiotemporal analysis of the data and the narrative told, the depth of analysis and the intimate knowledge of the places and phenomena taking place there instead of the superficial and spectacular. Hence the necessity of a great fidelity of the messages to be transmitted from related papers and PhD thesis.

All layers being correctly prepared came the step of publishing the project on the web before the implementation of the narrative web platform

III.4 Web publishing

Implementing web mapping services uses both a client and server technologies in same architecture (figure 13). In this architecture, a program (the client) requests to another program (the server) and receives from the latter the requested data as table or map.

Any programming environment, programming language, and server-side framework can be used to implement web mapping projects. In any case, both server-side and client-side technologies have to be used (Neumann, 2008).

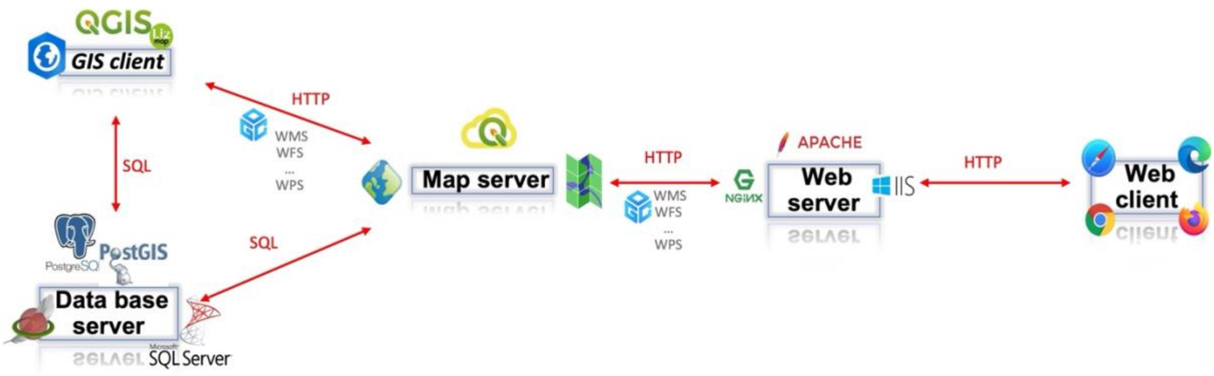

Figure 13: Overview of the web mapping client/server architecture and technologies

As show Figure 12, Relational Database Management System (Database server) store geodata with integrated data transmission protocols (TCP/IP or SSL) that are sent to GIS software (GIS client) by SQL query to build GIS project. For publishing this GIS project on web, these geodata are sent by HTTP protocols to Map server as OGC standard services. As a specific type of web server, Map server manage and distribute geodata between Database server and web interface. Then Web server serve files to websites on the www and, as intermediate between web client and server side, answer the www client request through HTTP or FTP protocols by sending an HTML file that will be visualize as map.

III.4.i Server-side technologies

A. The web server

Web server is a software used for serving files to websites on the Internet, so it’s the main link between server side and client side. It’s responsible for handling HTTP requests by web browsers and other user agents, and are also useful when developing complex real-time web mapping applications or web GIS (Neumann, 2008). Web servers also handle security, authentication, content negotiation, session management. Server-side includes Uniform Resource Locator (URL) rewriting, and forward requests to dynamic resources, such as CGI applications or server-side scripting languages (Neumann, 2008). Its functionality can be enhanced by modules or extensions.
The most popular web server is Apache with as main features (Stackscale, 2021):

- Free and open source,
- Module-based architecture,
- Easy configuration and customization,

- Regular updates and security patches,
- Big community of developers,
- Compatibility with IPv6.

B. The spatial database server

Spatial databases are usually relational, or object relational databases enhanced with geographic data types, methods, and operators. They are necessary whenever a web mapping application must deal with frequently changing dynamic data or with larger amounts of geographic data. Spatial databases allow spatial queries, filtering, coordinate transformations, and geometry manipulations and offer various import and export formats (Neumann, 2008 ; Aurélie *et al.*, 2017). It is useful to have at the heart of the information system a unique database that centralizes the data, to be sure that everyone uses the same data (Aurélie *et al.*, 2017). Some database server softwares:

- PostGIS is a spatial database extender for PostgreSQL one of the most useful open-source object-relational database in the scientific research field (Aurélie *et al.*, 2017). It adds support for geographic objects allowing location queries to be run in SQL (Neumann, 2008).

The advantage of the PostgreSQL solution is that it represents one of the most successful Opensource solutions used in the field of scientific research. Moreover, the geographical data is not treated separately, and we can therefore easily mix the geographical and numerical aspects in our queries with its multitudes of functions. Finally, this chosen solution has an easy-to-use administration, via its administration interface (PgAdmin) of the data stored in the DBMS.

- Oracle MySQL HeatWave is a fully managed database service, powered by the integrated HeatWave in-memory query accelerator. It's the only cloud database service that enables OLTP, OLAP, and machine learning directly inside a MySQL database, without complex, time-consuming, and expensive data movement and integration with a separate analytics or machine learning service(Oracle, 2022).

- SpatiaLite is an open-source library intended to extend the SQLite core to support fully fledged Spatial SQL capabilities (GAIA-GIS.IT, 2022). SQLite is intrinsically simple and lightweight:
    - a single lightweight library implementing the full SQL engine,
    - standard SQL implementation: almost complete SQL-92,
    - no complex client/server architecture,
    - a whole database simply corresponds to a single monolithic file (no size limits),
    - any DB-file can be safely exchanged across different platforms because the internal architecture is universally portable,
    - no installation, no configuration need.

SpatiaLite is smoothly integrated into SQLite to provide a complete and powerful Spatial DBMS (mostly OGC-SFS compliant) like PostgreSQL can deploy PostGIS.

C. The map server

The map server is a software that stores information as geographical information with coordinates, an attribute table in the case of vector data, a symbology, etc... This allows to make attribute or location queries on the data .

A map server is a specific type of web server for managing and distributing geographic data. It is the intermediary between the spatial database (PostGIS or Oracle for example) and the web interface. It allows to distribute OGC streams services (WMS/WMTS/WFS) to visualize information (Conte, 2020).

WMS servers are specialized web mapping servers implemented as a CGI application, Java servlet, or a web application server. They either work as a standalone web server or in collaboration with existing web servers or web application servers. WMS Server can generate maps on request, using parameters, such as map layer order, styling/symbolization, map extent, data format, projection, etc. The OGC defined the WMS standard, including the map requests and allowed return data formats (Neumann, 2008). Some map server and capabilities detailed in the table 1 below:

Features	**QGIS Server**	**Geoserver**	**Mapserver**	**ArcGIS Server**
Since	2006	2001	1994	1999
License	GPL	GPL	X/MIT	Commercial
Commercial support	Multiplatform	Multiplatform	Multiplatform	ESRI & its network
Technology	C++/python	Java/GeoTools	C/C++/CGI	C++
Tile cache	Yes	via GeoWebCache)	yes	yes
3D	No	No	No	Yes
Querying	FES (2.0) and OGC (1.0) filters	CQL and OGC filters	Embedded SQL Query	OGC filters
Report generation	Yes	Yes	Yes	Yes
Server administration	via third parties (LizMap, QWC2, etc.)	web + API REST	web + API REST	web + API REST
GIS project	via QGIS	via web interface	no	via Esri solutions
Main OGC standards	WMS, WFS, WCS, WMTS	WMS, WFS, WCS, WPS, WMTS	WMS, WFS, WMC, WCS	WMS, WFS, WCS, WMTS, WPS

Table 2: Map server software

III.4.ii FTP client

An FTP client is a software that allows to connect to an FTP server to exchange files. The data published in this way are accessible from the address of the publishing website.

A. FileZilla

Compatible with all major platforms (Windows, Mac, and Linux), this fully open-source software is one of the most popular FTP clients of all. Beyond the simplicity of use, its advantages include support for secure transfer protocols (FTPS and SFTP), a site manager with a transfer queue, a file name filter, synchronized directory browsing and remote file search/editing.

III.4.iii Client-side Technologies

A. The web client

Only web browsers are required as client-side technologies (Neumann, 2008).

B. The GIS client

The GIS client is any GIS software that displays geographic data and allows to interact with it for editing data, changing the scale, displaying the legend, etc.

C. The cartographic web client

- Lizmap: Is a python plugin for QGIS by 3Liz, is a complete solution to publish webmaps from a QGIS project. Free and open-source, Lizmap consists of an application to be installed on a map server (e.g., QGIS server) and a web client that generates dynamic maps. It has an easily modifiable interface, a map server, rich interactive maps, and rights management. Lizmap is also a proxy to the web services used to build the maps. It is therefore possible to use WMS or WFS requests pointing to Lizmap. It is thus possible to secure access to web services for access in QGIS. It also allows to share these web services addresses with cataloging systems and to acquire a better interoperability.

Developed jointly with QGIS, it has the same rendering engine and allows to configure maps directly with QGIS (symbols, labels, visibility scales, etc.) without having to manually edit configuration files.

- OpenLayers: open-source software (BSD license), with the most features, provides a core functionality-oriented implementation of flexible web mapping client applications. It's a modular, high-performance, feature-packed library for displaying and interacting with maps and geospatial data. The library comes with built-in support for a wide range of commercial and free image and vector tile sources, and the most popular open and proprietary vector data formats. With OpenLayers's map projection support, data can be in any projection.

- Leaflet: is the leading open-source JavaScript library for mobile-friendly interactive maps. It's used by OpenStreetMap and a very active community.

III.4.iv Narrative webmapping applications

Caquard et Dimitrovas (Caquard et Dimitrovas, 2017) identified three families of web cartographic applications:

- Applications that use the map primarily to organize a story into a simple, linear spatial structure, brief to visualize stories (e.g., Tripline and Google Tour Builder). They allow the user to represent stories in a uniform way by geocoding locations easily, to link the locations, especially in the form of trajectories, and to associate different kind of media to the locations such as photos or videos. These applications are best designed for representing stories of trips or other non-fictional stories where locations and routes are clearly identified.

- Applications that are more sophisticated and more linked with the GIS world, allowing not only the telling of stories with maps but also the spatiotemporal analysis of stories. Multifunctional applications that can both tell stories with the assistance of a map as well as map stories for analytical purposes. They have been designed to improve the communication and diffusion of the results of spatial analysis i.e. MapStory and ArcGIS StoryMap (Caquard et Dimitrovas, 2017). These applications distinguish themselves from the previous ones on several levels: they offer the possibility of importing shapefiles, of representing quantitative data, of creating maps collaboratively, of representing different stories on the same map (even if this might require a few adjustments) and of representing different types of links between places. These applications therefore offer a greater diversity of options for representing the diversity of experiences associated to the places that mark these stories.

- Finally, applications geared primarily for research that employs stories as databases that can be analyzed to help better understand places, their intimate and personal geographies, as well as the structure of the stories that refer to those places (i.e., Atlascine and Neatline).

ArcGIS StoryMaps offers more options for representing a wide range of stories (Caquard et Dimitrovas, 2017), but NAMO GeoWeb have the advantage of first being free and open-source, and second possibility to collaborate on the same project, managing rights (Marie Gradeler et Jean-Pierre Chery, 2021)

To centralize and validate data with free and open-source solutions, two previous projects have fed the reflections and choice of tools for this geomatics project:

A. EcoFoG Paracou valorization of geospatial data

Lizmap webmapping solution was used to publish webmapping application for centralizes and valorize UMR EcoFoG data: environmental layers, inventory plots, forest inventory parameters, satellite images. These digital data was collected in the GuyaFor database (PostGIS) under SQL Server 2008 (as a web cartographic server) and hosted on the EcoFoG database server (Aurélie *et al.*, 2017).
QGIS server used as the map server in QGIS as GIS client. Apache 2 used as web server, the code allowing to query PostGIS/PostgreSQL and to call SQL Server (via CGI) and to execute R scripts (via rApache) was written in PHP5.
Lizmap as mapping client application. The database and its project Lizmap are hosted on the CIRAD server in Montpellier for reasons of accessibility on a large scale, the internet speed in Guyana being uncertain. Through an R script, an automated weekly data transfer and updates done between the GuyaFor database on SQL Server in French Guiana and the EcoFoG (CIRAD Montpellier PostGreSQL/PostGIS) database server for weekly data updates.

B. RestEAUr’Lag project

The cartographic need of this project was to "Explain the modalities of ecological restoration of Mediterranean lagoon socio-ecosystems" through:

- centralization and consultation of the cartographic data of the project
- valorization and diffusion of these maps
- collaboration for the members of the project
- extensible platform to add new modules built on the cartographic data

With as target:

- For research community
    - addition and consultation of the cartographic data
    - collaboration for writing and publishing narrative maps
    - development of new modules
- For public
    - consultation of data and narrative maps

Technological solution used was NAMO GeoWeb with in back-end (Debian, PostgreSQL/PostGIS, Apache, PHP, Docker) and in front-end (OpenLayers+ol-ext, JQuery+JQueryUI, Remarkable, D3, DataTables).

So, to meet the objective of the project, the publishing of the TEMPO narrative webmap will be done in two steps: the first is the publication of the TEMPO project on the Lizmap web client and the second is the implementation of the narrative map on NAMO GeoWeb. As well as software technologies, this geomatic project use:

- QGIS: for the development of the GIS project,
- QGIS Server: as a map server,
- Apache: as a web server,
- PostgreSQL: as DBMS server,
- Lizmap: as cartographic web client and WMS proxy for NAMO GeoWeb,
- NAMO GeoWeb: as a narrative web mapping platform.

The system set up allows to create web mapping applications on Lizmap from QGIS and to use the rendering engine of QGIS and QGIS server for a publication with the same rendering on the web. Then to get this project through a WMS flow on Lizmap to publish the elements on the narrative web platform NAMO GeoWeb and then the visualization of the modeled processes and for those who wish, the distribution of data through the Lizmap web client (if requested and connected) or on the CIRAD dataverse.

III.4.v TEMPO web publishing

Setting up TEMPO QGIS project for Lizmap began by installing the Lizmap plugin through the official QGIS project repository as any other QGIS plugin.

The QGIS project was saved in QGS format (Lizmap does not read QGZ format) in the same directory as the Esri shapefile and Tiff layers (because Lizmap does not read database formats such as geopackage). This project and its layers were loaded in QGIS Server and with the help of the Lizmap plugin, it was loaded on the Lizmap web map server. Via the FTP client FileZilla, the project and layer files were uploaded to the web server. Then, Lizmap was used as a proxy to the web services used to build the project maps in the NAMO GeoWeb narrative web platform.

Thus, the narrative webmapping platform uses requests from the geoservices (WMS or WFS) pointing to Lizmap and the access to the web services by the web client (browser) in QGIS Server or QGIS is not direct and is therefore secure. The Apache web server (with PHP) and Lizmap take care of sending the requests to QGIS Server and transmit the result. This also makes it possible to share the web services address with cataloging systems.

An IGN background key has been configured in the Lizmap plug-in to provide users with diverse and rich backgrounds. Moreover, the OSM background (free) has also been configured as well as ESRI.

The Lizmap provided WMS flow of the project to TEMPO narrative webmap application is https://qgsrv.teledetection.fr/index.php/lizmap/service/?repository=projtempo&project=TEMPO_Lizmap&SERVICE=WMS&VERSION=1.3.0&REQUEST=GetCapabilities

III.4.vi Implementation of narrative GeoWeb platform

After publishing the QGIS TEMPO project on Lizmap web client and pushing project and layers on NAMO GeoWeb, began designing implementation of platform. The basic for a right narrative storymap design, as (Brake, 2020) said, is to:

- Clearly define the message to be communicated
- Make a relevant choice of layers and simple symbology, pop-ups, and labels

And the elements to consider when designing the web narrative map, Brake (2020) he completes:

- Polish the visual elements (theme, cover design, fonts, navigation options) because these they set the overall tone of the story being told and have an impact on users
- Remove unnecessary content doesn't support the story or may distract viewers
- Think about display devices and interaction with targets
- Consider the possibilities of updating with new information or developments that introduce new features.
- Take the time to revisit the map narrative to make any necessary updates or changes related to the introduction of new features or conceptual elements.

First a test implementation was performed on the localhost of the working machine. This test implementation allowed to evaluate the matching between the narrative, the rendering of the maps and the logical-intuitive-completeness association of the whole narrative map by the sponsor before publishing on a CIRAD server, open on the internet.

The image upload on the platform is done in jpeg format allowing to have a background, ideal in case of zoom on image for easy reading. The PNG format being vectorial is without background, it was used for the logos.
For a perfect overlay of the layers on the GeoWeb platform, the ZIndex of the layers has been structured in 5 levels of overlay mainly according to transparency characteristics combined with basic overlay principles as follows:

- Point,
- Line,
- Polygon without background,
- Polygon with background,
- Raster.

Implemented TEMPO webmapping platform contains 95 layers, the majority of which are displayed in several maps, 42 maps and scrolls, 31 figures and 2 animations and about 82 links classified in 8 classes: Organism, Contributors host organism, Projects, Resources & reports, Papers, Masters and PhD Thesis, External data sources, Satellite images, Software & modeling languages. These data are published on the CIRAD dataverse, to make them open to all.

Implemented TEMPO narrative GeoWeb application (figure below) is found at https://tempo.teledetection.fr/map/storytool.php# and users will access the mapping applications with their web browser and use the maps and tools provided by the editor.

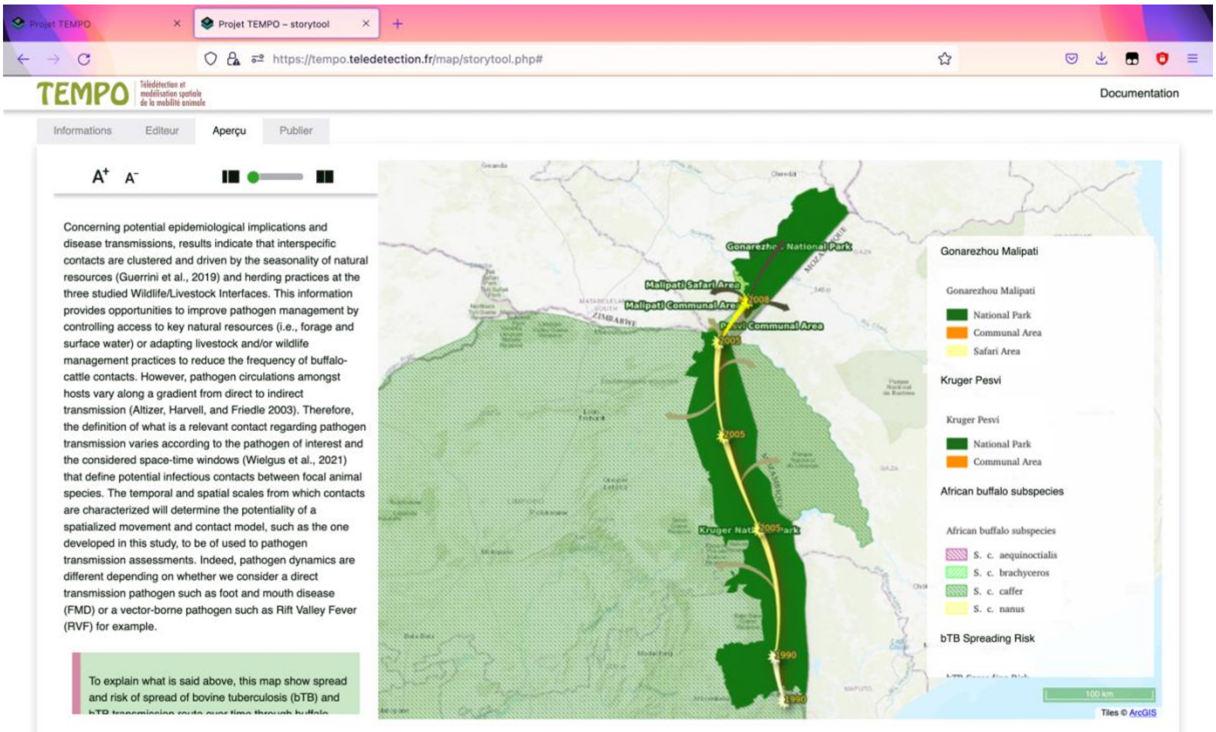

Figure 14: TEMPO implemented narrative web map application

IV.Limits

Narrative web mapping being a data storytelling tool, must achieve a certain objectivity as stated (Chopin, 2018). The communication strategy of this narrative map was to contextualize (geographical framework), explain, analyze, and argue the phenomena observed on the territory and highlight the risk of transmission of pathogens and associated infectious diseases between buffaloes and cows. This story map can therefore be evaluated on its pedagogical aspect by asking the following questions:

- Are the mechanisms of transmission of infectious diseases and associated pathogens faithfully transmitted in the image of the doctoral thesis and other work of the TEMPO project and exhaustive?
- Are the narrative maps (narrative and unfolded maps) consistent, logical, and unambiguous in the messages communicated.

The difficulties encountered during its development are:

- Working on a new but equally exciting theme for me,
- The artistic side of the cartographic representation which requires a very developed sense of graphic semiology, common sense, and a sharp imagination,
- Iterative approach consisting of continuous review, inspection, and adaptation of the elements of the narrative mapping to deliver an application that meets the needs of the sponsor and the users. This approach required great flexibility and speed in the execution of the tasks.
- The difference in richness of brightness rendering and labelled symbols between the built GIS project on desktop software QGIS and the implemented platform NAMO GeoWeb, cause by lower rendering quality in Lizmap despite its use of the QGIS and QGIS Server rendering engine (Appendix IX.1.v and IX.1.vi).
- The limitations of the platform in not being able to display two or more views on the same rendering, not supporting the Time Manager, the limitation of the text formatting as the justification of the text in the story,

The overcoming of these limits would greatly contribute to a better formatting of the narrative webmap and to an integration of a timelapse animation of the layers on a rendering.

V.Conclusion

As its name indicates, TElédétection et Modélisation sPatiale de la mObilité animale (for Remote Sensing and Spatial Modeling of Animal Mobility), the TEMPO project aimed to characterize the landscape use (mobility and contact) of two sympatric species buffalo and cattle, and the factors determining it, to estimate the risk of transmission of pathogens and associated infectious diseases in interface areas. The main objective of this geomatic project was to implement a narrative mapping platform to restore to stakeholders (park managers, farmers, veterinary services, ...) the complex processes related to the transmission of infectious diseases in interface areas, and to disseminate the results of the previous modeling work by facilitating the understanding of the modeling approach and the interpretation of the risk maps obtained.

Inspired by various works of the TEMPO project, and particularly the PhD thesis on "The combined use of remote sensing and spatial modeling for animal movements - Application to the study of wildlife-livestock contacts and pathogen transmission risk in Southern Africa" by Florent Rumiano et al. (2021), with the aim of providing an intuitive understanding of wildlife management in Zimbabwe, this narrative map sets out the context of wildlife and livestock management in Zimbabwe, the landscape use factors of the species studied, the pattern of animal mobility and resulting contacts, and the risks of transmission of associated pathogens and infectious diseases.

It aims to contribute to improved understanding of the contexts and complexities modeled by wildlife management stakeholders in Zimbabwe, for prevention of pathogen and associated infectious disease transmission risks through improved wildlife and domestic management practices using a ‘One Health’ approach.

As an example, it can be used in the case cited above, that of exchanges between local communities and government authorities on the issue of extending the area of incursion by pastoralists to graze their livestock.

This geomatics project is conducted at UMR TETIS for CIRAD as an internship for the SILAT specialized master's degree. As integrated in this master thesis, the realization of this project gave me the opportunity to exercise the double competence of geomatic project manager: the geomatic methods expertise and project management.

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Table list

Figure list

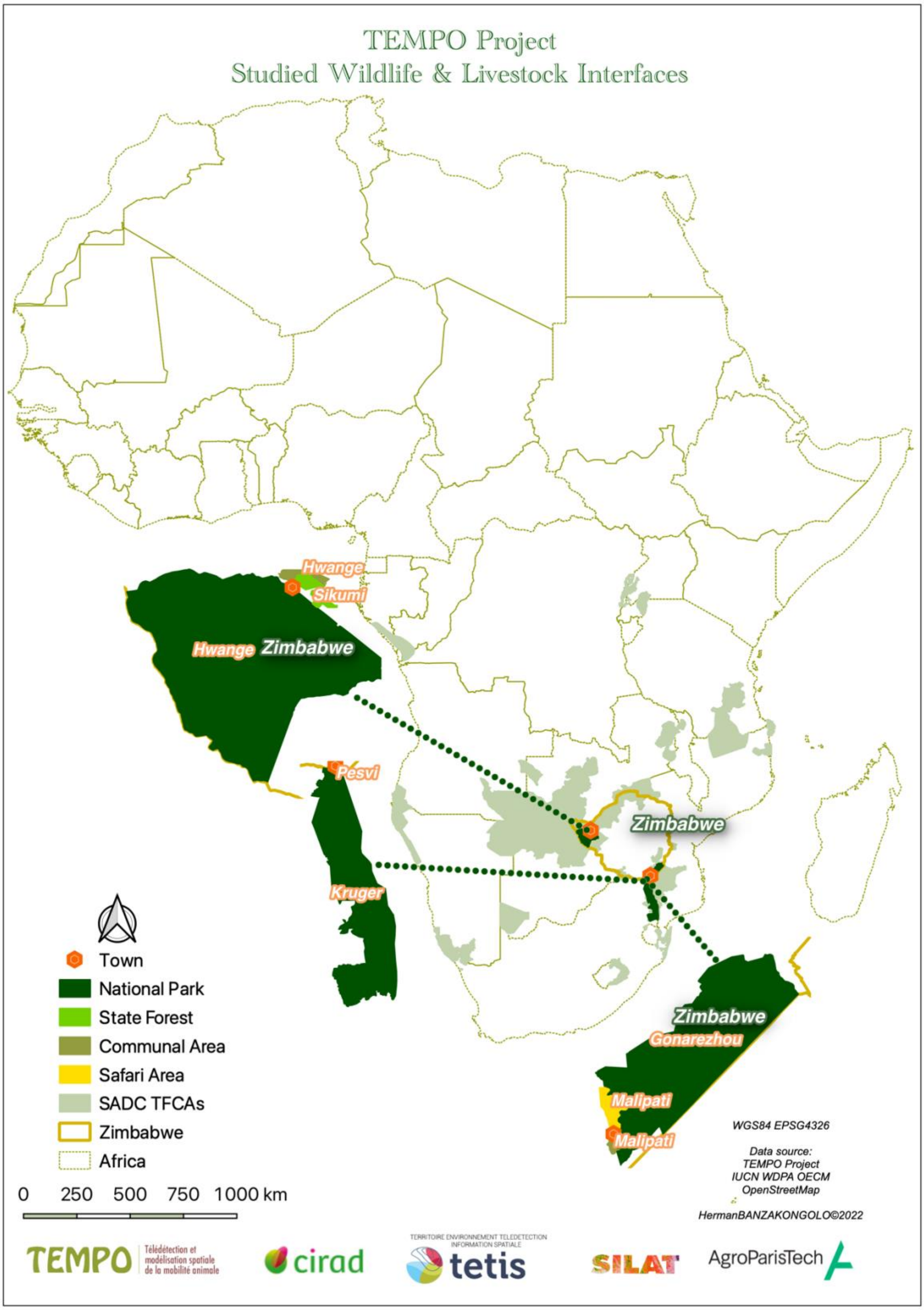
Acronym list

bTB: bovine TuBerculosis
CGI: Common Gateway Interface
CIRAD: The French Agricultural Research Centre for International Development
CRS: Coordinate Reference Systems
CSV: Comma-Separated Values
DBMS/RDBMS: DataBase Management System / Relational DataBase Management System
ERGO: Environmental Research Group Oxford
FAO: Food and Agriculture Organization of the United Nations
FTP/FTPS/SFTP: File Transfer Protocol / File Transfer Protocol Secure / Secure SHell File Transfer Protocol
GIS: Geographic Information System
GLW v3: Gridded Livestock of the World version 3
GPS: Global Positioning System
HTML: HyperText Markup Language
HTTP: Hypertext Transfert Protocol
ID: IDentity
IGN: Institut Géographique National
ILRI: International Livestock Research Institute
IoT: Internet of Things
IRD : Institut de Recherche pour la Développement
IUCN: International Union for Conservation of Nature
MiVEGEC : Unité Mixte de Recherche Maladies infectieuses et Vecteurs Ecologie Génétique Evolution et Contrôle
MODIS : Moderate Resolution Imaging Spectrorediometer
MS SILAT: Master Spécialisé Système d'Informations Localisées pour l'Aménagement des Territoires
MTD: Maison de la TéléDétection
NAMO GeoWeb: NArration and MOdeling GeoWeb platform
OGC: Open Geospatial Consortium
OLAP: Online Analytical Processing
OLTP: Online Transaction Processing
OSM: OpenStreetMap
PhD: Philosophiæ Doctor
PHP: Hypertext Preprocessor
QGIS : Quantum GIS
RestEAUr'Lag : Restauration Ecologique des socio-éco-systèmes lagunaires méditerranéens
SADC: Southern African Development Community
Shp: Esri Shapefile
SQL: Structured Query Language
SSL: Secure Socket Layer
TAMSAT: Tropical Applications of Meteorology using SATellite data
TCP/IP: Transmission Control Protocol/Internet Protocol
TEMPO: Telédétection et Modélisation sPatiale de la mObilité animale
TFCAs: Transfrontier Conservation Areas
UCL: Université Catholique de Louvain

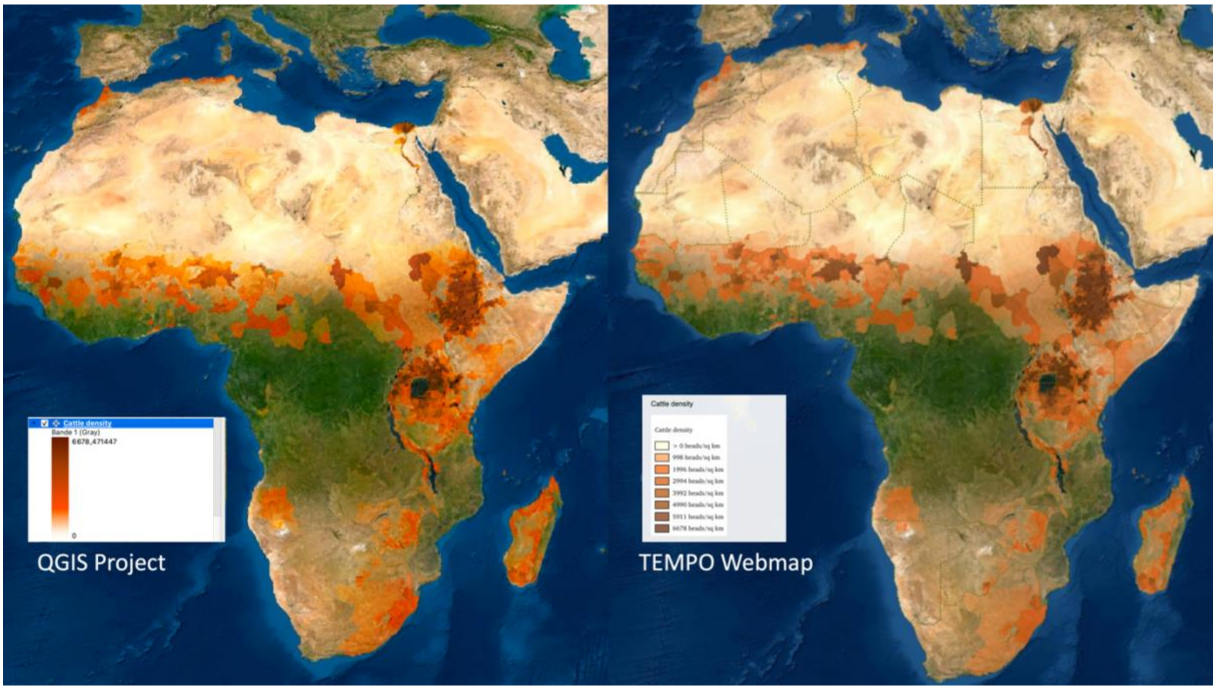
ULB: Université Libre de Bruxelles
UMR ASTRE: Unité Mixte de Recherche Animal Santé Territoires Risques Ecosystèmes
UMR EcoFoG: Unité Mixte de Recherche Ecologie des Forêts de Guyane
UMR TETIS: Unité Mixte de Recherche pour les Territoires et l'Environnement par la Télédétection et l'Information Spatiale
URL: Uniform Ressource Locator
W/L: Wildlife and Livestock
WLI: Wildlife and Livestock interfaces
WCS: Web Coverage Service
WD-OECM: World Database Other Effective Area-Based Conservation Measures
WDPA: World Database of Protected Area
WFS: Web Feature Service
WGS: World Geodetic System
WMS: Web Map Service
WMTS: Web Map Tile Service
WWW:World Wide Web

VII.Appendix

VII.1.i TEMPO studied Wildlife and Livestock interfaces



VII.1.ii Brightness and interpolated symbol label rendering difference between QGIS project and implemented TEMPO narrative webmap application



VII.1.iii Narrative story

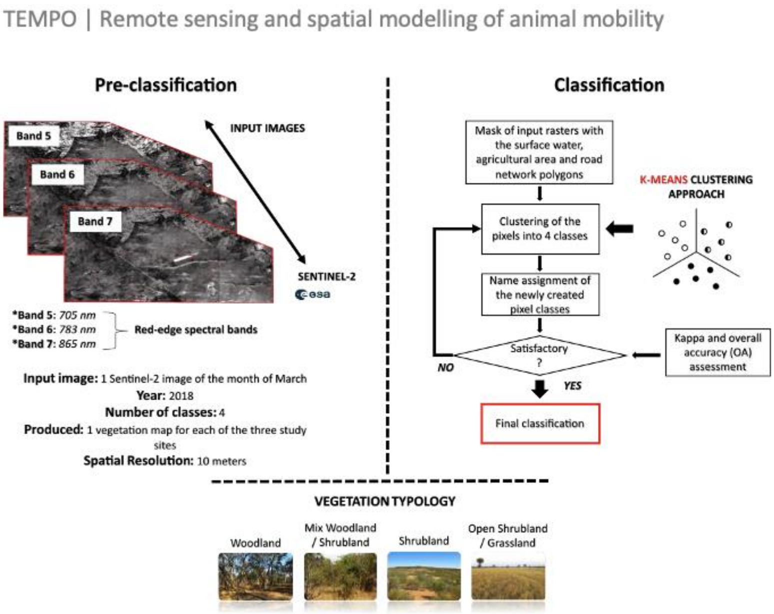
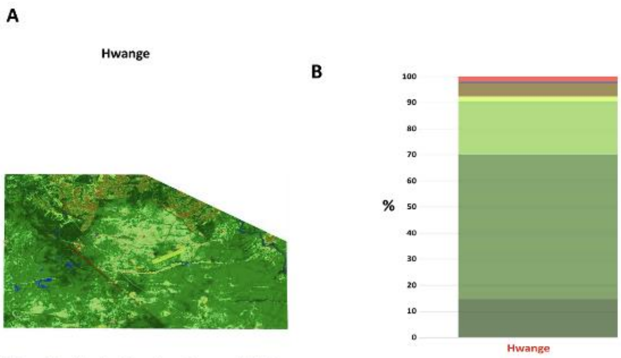


Figure 12: Landcover classification methodology

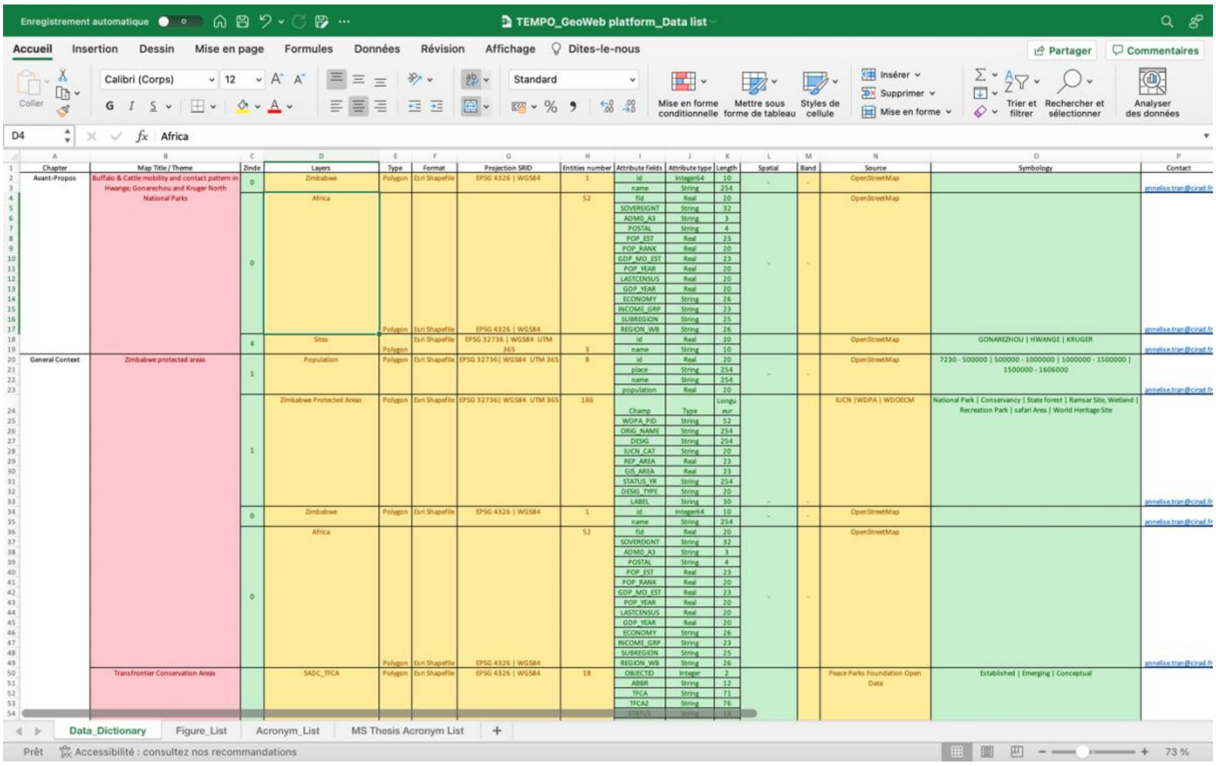
The landcover maps for the three study sites highlight a contrast in the landscape spatial configuration and intrinsic composition between Hwange/Dete from one hand and Gonarezhou/Malipati and Kruger/Pesvi.
In Hwange/Dete the landcover is more wooded across the mapped area and is composed of mostly closed landscapes, except for areas in closed proximity with surface water where the vegetation opens. The woodland covers an area of 175,5 km² and the mixed-woodland shrubland covers an area of 660.4 km², representing 14.7% and 55.5 % of the total classified surface area respectively.



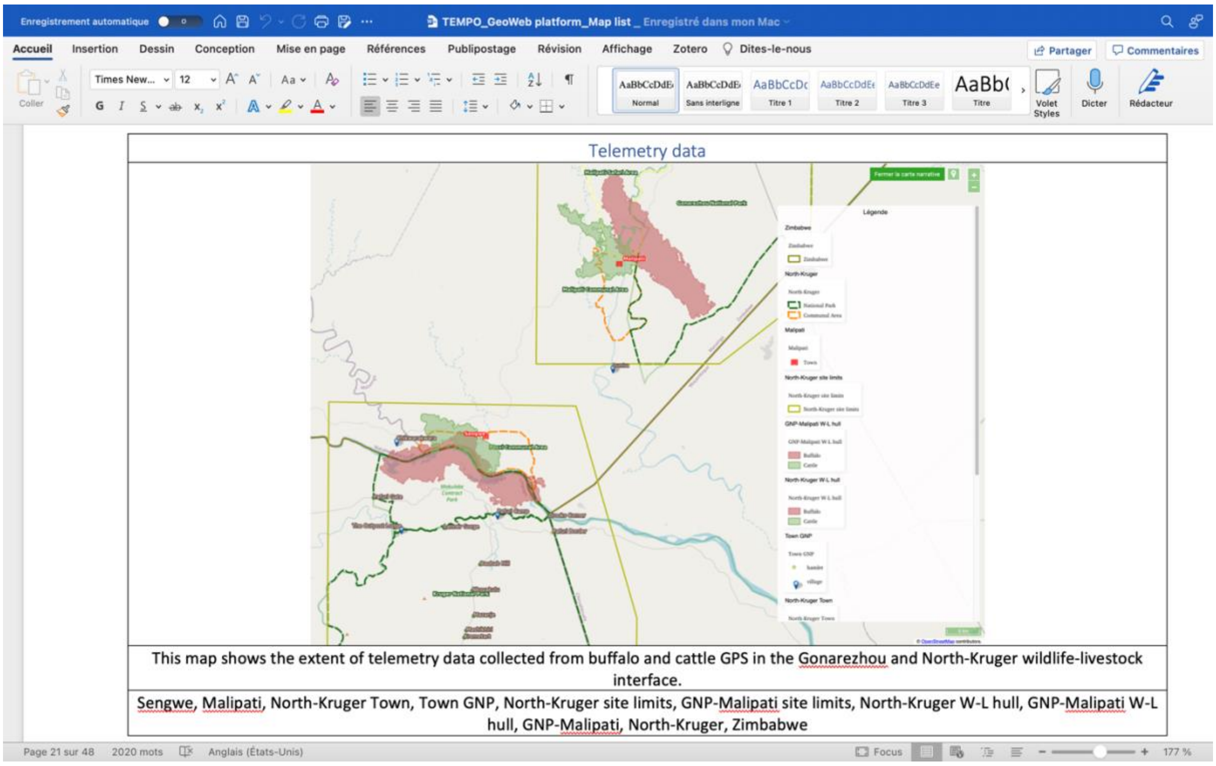
Map 14: Study sites Landcover: HNP

In Gonarezhou/Malipati, the landcover changes drastically whether the observed landcover is located on the eastern or western side of the Mwenezi river that flows from north to south. On the eastern side of the river, the landscape is more wooded as “woodland” and “mixed woodland shrubland” composed the majority of the landcover types present in this

VII.1.iv TEMPO GeoWeb platform data dictionary



VII.1.v TEMPO GeoWeb platform map dictionary



VII.1.vi CIRAD dataverse

VII.1.vii TEMPO GeoWeb platform map list

1. Buffalo & Cattle mobility and contact pattern in Hwange, Gonarezhou and Kruger North National Parks
2. Zimbabwe protected areas
3. Transfrontier Conservation Areas
4. Increasing intercations between protected and anthropized areas
5. Distribution and ecology of African buffalo & Cattle
6. Buffalo subspecies & abundance
7. Cattle density
8. Study sites
9. Hwange national park
10. Hwange/Dete study site
11. Gonarezhou national park
12. Gonarezhou/Malipati study site
13. Kruger national park
14. Kruger/Pesvi study site
15. Methodology & data
16. Telemetry data
17. Satellite data
18. Environmental drivers influencing cattle and buffalo mobility
19. Rainfall
20. Wildfire regimes
21. Surface water
22. Agricultural areas
23. Hwange surface water & agriculture areas
24. Gonarezhou surface water & agriculture areas
25. North-Kruger surface water & agriculture areas
26. Landcover
27. Hwange landcover
28. Gonarezhou landcover
29. North-Kruger landcover
30. Buffalo & Cattle contact model and pathogen transmission risks
31. Buffalo movement model
32. Cattle movement model
33. Buffalo & Cattle contact model
34. Hwange MCP
35. Hwange buffalo & cattle contact
36. Gonarezhou MCP
37. Gonarezhou buffalo & cattle contact
38. Kruger MCP
39. Kruger buffalo & cattle contact
40. Epidemiologic implication
41. Conclusion
42. Logo Partners

VII.1.viii TEMPO GeoWeb platform figure list

33. TEMPO CIRAD (https://tempo.cirad.fr/)

VII.1.ix TEMPO GeoWeb platform acronym list

ANR: The French National Research Agency
bTB: bovine TuBerculosis
CIRAD: The French Agricultural Research Centre for International Development
CNRS : Centre National de Recherche Scientifique
EVI: Enhanced Vegetation Index
FAO: Food and Agriculture Organization of the United Nations
FMD: Foot and Mouth Disease
GL-TFCA: Great Limpopo Transfrontier Conservation Area
GLTP: Great Limpopo Transfrontier Park
GLW v3: Gridded Livestock of the World version 3GNP: Gonarezhou National Park
GPS: Global Positioning System
HNP: Hwange National Park
HNP-SSF: Hwange National Park - Sikumi State Forest
HWC: Hyphal Wall Components
IGF: Institut Génomique Fonctionnelle
IUCN: International Union for Conservation of Nature
IUCN ESARO: IUCN Eastern and Southern Africa Regional Office
KAZA-TFCA: KAvango-ZAmbezi Transfrontier Conservation Area
KNP: Kruger National Park
MCP: Minimum Convex Polygon
MiVEGEC: Unité Mixte de Recherche Maladies infectieuses et Vecteurs Ecologie Génétique Evolution et Contrôle
MNDWI: Modified Normal Difference Water Index
MODIS: Moderate Resolution Imaging Spectrorediometer
MOU: Memorandum of Understanding
NCAS: National Centre for Atmospheric Science
NCEO: National Centre for Earth Observation
NDVI: Normalized Difference Vegetation Index
NDWI: Normalized Difference Water Index
NPWLMA: National Parks and Wildlife Management Authority
Ocelet DSL: Ocelet Domain Specific Language
OSAVI: Soil Adjusted Vegetation Index
PhD: Philosophiæ Doctor
RISDP: Regional Indicative Strategic Development Plan
RP-PCP: Research Plateform-Production and Conservation in Partnership
RVF: Rift Valley Fever
SADC: Southern African Development Community
SRS: Satellite Remote Sensing
SSF: Sikumi State Forest
SWIR: Short-Wave Infrared
TAMSAT: Tropical Applications of Meteorology using SATellite data
TEMPO: Teledétection et Modélisation sPatiale de la mObilité animale
UHF: Ultra-High Frequency
UMR ASTRE: Unité Mixte de Recherche Animal Santé Territoires Risques Ecosystèmes

UMR TETIS: Unité Mixte de Recherche pour les Territoires et l'Environnement par la Télédétection et l'Information Spatiale
UNEP-WCMC: United Nation Environment Program - World Conservation Monitoring Centre
WLI: Wildlife and Livestock interfaces

VII.1.x TEMPO GeoWeb platform link list

1. Organism

- European Spatial Agency (ESA) https://www.esa.int
- French Agricultural Research Centre for International Development / CIRAD https://www.cirad.fr/
- CNRS https://www.cnrs.fr/fr/page-daccueil
- IGF https://www.igf.cnrs.fr/index.php/fr
- SANParks https://www.sanparks.org
- FAO https://www.fao.org/home/fr)
- ANR SAVARID https://www.rp-pcp.org/projects/completed/anr-savarid
- Peace Parks Foundation Open Data https://new-ppfmaps.opendata.arcgis.com/datasets/ppf::sadc-tfca-boundaries/explore?location=-14.113470%2C25.643077%2C5.00
- UNEP-WCMC (2022). Protected Area Profile for Zimbabwe from the World Database on Protected Areas, July 2022 https://www.protectedplanet.net/country/ZWE
- Britanica / Britanica 2022 https://www.britannica.com/place/Hwange-National-Park
- SADC https://www.sadc.int/
- IUCN-ESARO / IUCN Eastern and Southern Africa Regional Office https://www.iucn.org/our-work/region/eastern-and-southern-africa
- Montpellier Université d'Excellence (I-SITE MUSE) https://muse.edu.umontpellier.fr/li-site-muse/
- French National Research Agency (ANR) https://anr.fr/en/
- Territories, environment, remote sensing, and spatial information (UMR-TETIS) https://umr-tetis.fr/index.php/fr/
- Research Plateform – Production and Conservation in Partnership (RP-PCP) https://www.rp-pcp.org/

2. Contributors and host organism

- Eve MIGUEL, MiVEGEC https://www.ird.fr/umr/mivegec / IRD https://www.ird.fr
- Victor DUFLEIT, UMR TETIS https://umr-tetis.fr/index.php/fr / CIRAD https://www.cirad.fr
- Florent RUMIANO, UMR TETIS https://umr-tetis.fr/index.php/fr / CIRAD https://www.cirad.fr
- Herman BANZA KONGOLO, UMR TETIS https://umr-tetis.fr/index.php/fr / CIRAD https://www.cirad.fr
- Alexandre CARON ASTRE https://umr-astre.cirad.fr / CIRAD https://www.cirad.fr
- Marie GRADELER, IFAD
- Alain CLOPES, UMR TETIS https://umr-tetis.fr/index.php/fr / CIRAD https://www.cirad.fr
- Pascal DEGENNE, UMR TETIS https://umr-tetis.fr/index.php/fr / CIRAD https://www.cirad.fr
- Aurelie DOURDAIN, UMR TETIS https://umr-tetis.fr/index.php/fr / CIRAD https://www.cirad.fr
- Annelise TRAN, ASTRE https://umr-astre.cirad.fr / CIRAD https://www.cirad.fr

3. Project

- Télédétection et Modélisation sPatiale de la mObilité animale (TEMPO) / TEMPO project https://tempo.cirad.fr/en
- EU-PARSEL project https://www.rp-pcp.org/projects/completed/eu-parsel

4. Resources & reports

- SADC Protocol on Wildlife Conservation and Law Enforcement (1999) https://www.sadc.int/document/protocol-wildlife-conservation-and-law-enforcement-1999
- SADC Protocol on Forestry (2002) https://www.sadc.int/document/protocol-forestry-2002
- SADC Protocol on Shared Watercourses (2002) https://www.sadc.int/document/revised-protocol-shared-watercourses-2000-english
- SADC Regional Biodiversity Strategy (2006) https://www.sadc.int/document/sadc-regional-biodiversity-strategy
- SADC Regional Indicative Strategic Development Plan (RISDP) https://www.sadc.int/document/sadc-regional-indicative-strategic-development-plan-risdp-2020-2030
- SADC Programme for TFCAs https://tfcaportal.org/sites/default/files/public-docs/SADC%20Programme%20for%20TFCAs%20%28English%29.pdf
- IUCN, 2020 / IUCN Eastern and Southern Africa Regional Office, 2020) / IUCN ESARO (2020) The state of protected and conserved areas in Eastern and Southern Africa. State of Protected and Conserved Areas Report Series No.1. Nairobi, Kenya https://portals.iucn.org/library/node/49133

5. Papers or Master & PhD Thesis

- Alexandre Caron from 2008 to 2011 on buffalo and cattle https://agritrop.cirad.fr/563802
- Spread and risk of spread of bovine tuberculosis in the Great Limpopo Transfrontier Conservation Area. A. Caron et al. (2011) https://www.researchgate.net/figure/Spread-and-risk-of-spread-of-bovine-tuberculosis-in-the-Great-Limpopo-Transfrontier_fig2_256442318
- Eve Miguel from 2009 to 2012 on buffaloes and cattle https://www.theses.fr/2012MON20064
- Hugo Valls-Fox from 2012 to 2015 on cattle https://theses.fr/2015MONTS130
- Hugo Valls Fox, 2015. To drink or not to drink? the influence of resource availability on elephant foraging and habitat selection in a semi-arid savanna https://theses.fr/2015MONTS130 [PhD thesis]
- Elodie Wielgus in 2020 https://e-space.mmu.ac.uk/627391/1/Elodie%20Wielgus%20-%20FINAL%20VERSION%20THESIS.pdf
- Elodie Wielgus, 2020. The social dynamics of the Cape buffalo
- and the epidemiological implications https://e-space.mmu.ac.uk/627391/1/Elodie%20Wielgus%20-%20FINAL%20VERSION%20THESIS.pdf [PhD thesis]

- Alexandre Caron, 2011. Describing and understanding host-pathogen community interaction at the wildlife/domestic interface https://agritrop.cirad.fr/563802/ [PhD Thesis]
- Eve MIGUEL, 2012. Contacts et diffusion de pathogènes des ongulés sauvages aux ongulés domestiques Africains https://www.theses.fr/2012MON20064 [PhD Thesis]
- Elodie Wielgus, 2020. Are fission–fusion dynamics consistent among populations? A large-scale study with Cape buffalo https://hal.archives-ouvertes.fr/hal-02917348/ [Papers]
- Florent RUMIANO, 2021. Combined use of remote sensing and spatial modeling: when surface water impacts buffalo (*syncerus caffer caffer*) movements in savanna environments https://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XLIII-B3-2021/631/2021/ [Papers]
- Florent RUMIANO, 2021. Remote Sensing of Environmental Drivers Influencing the Movement Ecology of Sympatric Wild and Domestic Ungulates in Semi-Arid Savannas, a Review https://www.mdpi.com/2072-4292/12/19/3218 [Papers]
- Florent RUMIANO, 2021. The combined use of remote sensing and spatial modelling for animal movement : Application to the study of wildlife/livestock contacts and the risk of pathogen transmission in Southern Africa https://tel.archives-ouvertes.fr/tel-03607859/document [PhD thesis]
- Victor Dufleit, 2021. Modélisation des mouvements des buffles du cap (**Syncerus caffer caffer**) en fonction de la disponibilité en eau et de l'occupation du sol https://tempo.cirad.fr/content/download/4168/31580/version/1/file/Rapport+de+stage+Victor+Dufleit+2021.pdf [Master's thesis]
- Le Pioufle N, 2022. Modélisation et prédiction des dynamiques de surfaces en eau en périphérie des aires protégées au Zimbabwe https://agritrop.cirad.fr/601275/ [Master's thesis]

6. Data sources

- SADC TFCAs / The Southern African Development Community Transfrontier Conservation Areas (SADC TFCAs) https://tfcaportal.org
- IUCN, 2020 https://portals.iucn.org/library/node/49133
- Zimbabwe biggest cities / Zimbabwe OpenStreetMap https://www.openstreetmap.org/relation/195272
- IUCN WDPA, 2022 https://www.protectedplanet.net/1104
- Livestock.geo-wiki website https://livestock.geo-wiki.org/Application
- WorldPop https://www.worldpop.org
- WorldPop Zimbabwe 2000 https://hub.worldpop.org/geodata/summary?id=43848
- WorldPop Zimbabwe 2020 https://hub.worldpop.org/geodata/summary?id=43868
- Protected areas
- Hwange / HNP https://www.protectedplanet.net/1991
- Sikumi State Forest / SSF https://www.protectedplanet.net/20357
- Kruger / North-Kruger / Kruger-Pesvi https://www.protectedplanet.net/873
- Gonarezhou / GNP https://www.protectedplanet.net/1104
- KAvango - ZAmbezi- (KAZA-TFCA) https://tfcaportal.org/node/51
- Great Limpopo Transfrontier Park (GLTP) / Great Limpopo TFCA / Great Limpopo (GL-TFCA) https://tfcaportal.org/node/23

- Limpopo National Park https://www.protectedplanet.net/20295
- Zimbabwe Protected Areas https://www.protectedplanet.net/country/ZWE

▪ Satellite images

• Sentinel-2
  - Sentinel-2 / Sentinel-2 images https://www.esa.int/Applications/Observing_the_Earth/Copernicus/The_Sentinel_missions / https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-2
  - Sentinel-2 satellite images in level 1C https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-2-msi/level-1c-processing
  - Sentinel-2 satellite images characteristics https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-2
  - 10 m spatial resolution https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-2/Instrument)
  - 13 spectral bands https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-2/Plant_health
  - 290 km swath width https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-2/Instrument
  - 100 km Tile size for orthorectified products (Level-1C and Level-2A) https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/overview
  - 5 days revisit time https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-2/Satellite_constellation
• TAMSAT http://192.171.139.10/about
• MODIS https://modis.gsfc.nasa.gov / https://modis.gsfc.nasa.gov/about
  - Climate Division of the National Centre for Atmospheric Science (NCAS) https://ncas.ac.uk
  - National Centre for Earth Observation (NCEO) https://www.nceo.ac.uk

7. Software and Modeling languages

▪ QuickOSM plugin https://plugins.qgis.org/plugins/QuickOSM
▪ QGIS https://www.qgis.org/fr/site
▪ Ocelet / Ocelet DSL http://www.ocelet.fr