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Kenyan-German Centre of Excellence for Mining, Environmental Engineering and Resource Management (CEMEREM)

Spatial Data and Technologies for Geomonitoring of the Mining Environment and Competing Land Use within System Dynamics Modelling: A Case Study of Taita Taveta

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Webinar presentation 30.04.2020

AGENDA

01 Background

Mineral resource scenario in Africa, Kenya, and Taita Taveta – **case study**

02 Where are the skills gaps?

Global skills index survey

Key areas of focus to cause change – **data governance**

03 Mining Sector Governance Challenge

The role of quality **geodata** and knowledge

04 Mining and SDGs

Interconnectedness, multistakeholder partnerships

05 Research Gap & Methods

Scale limitations – **spatial metrics**

Systems Thinking - **System Dynamics Model**

06 Findings and Implications

Threatened ecosystems

Policy simulations for decision support

The Global Mineral Reserves – African Countries

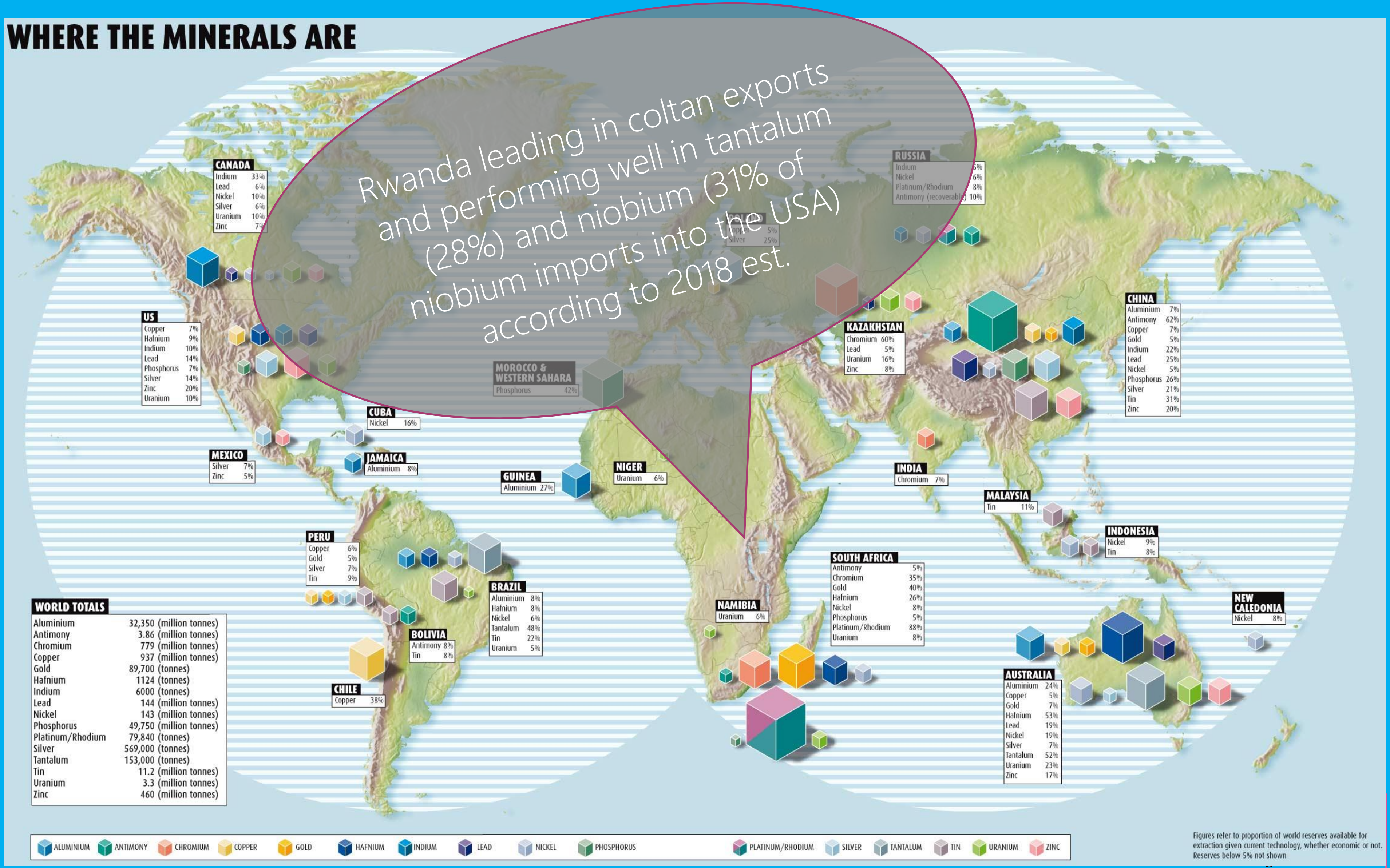
88% South Africa
Platinum

49% Congo
Cobalt (**64% of** 2018 global production / **39%** of Tantalum production

42% Morocco & West Samara
Phosphorus

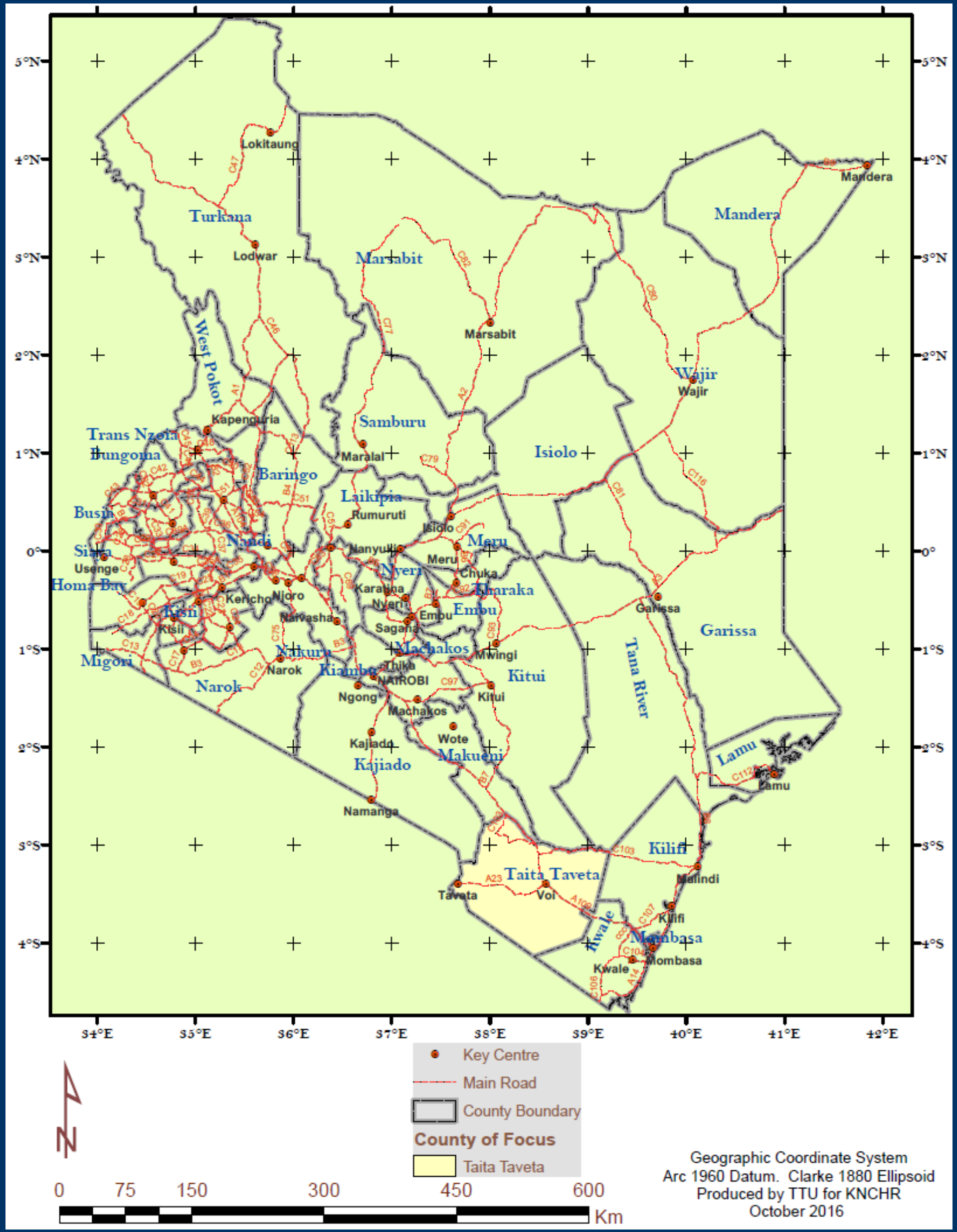
27% Guinea
Aluminium

6%/ 6% Namibia/Niger
Uranium



Source: USGS, 2019; visual.ly; InfoMine

Precious stones in the coastal mineral belt – Taita Taveta



Kenya: 3rd in the world for soda ash; 8th for fluorite

13 large-scale mining companies, 5 foreign-owned

Taita Taveta has mainly ASM (Zurura; Zama Zama)

Mining and quarrying activities in Kenya – mainly surface mining

Wanjala Mines
(Iron ore)

Rare earths minerals project in the coast

Source: Base Titanium Ltd site, the largest mining project in Kenya

Contribution to Kenya's GDP by Sector

<1% Mining contributes <1% to Kenya's GDP

Statistical Abstract 2018 (KNBS, 2019)

Key Issues in Africa’s Mining Sector

Land Rights

- Land ownership conflicts and historical and spatial injustices of cadastral nature retard progress on mining and other projects

Benefits Sharing

- Contested royalties and sharing formula with communities

Safety – personal, public, environmental

- Poor infrastructure service linkages and poor working conditions and environments put workers at risk
- Environmental degradation by unregulated mining activities especially from surface mining

Children and Gender Issues

- Child labour in artisanal mines
- Discrimination against female workers in the mines

The Governance Challenge

Regulation

- Policy enforcement gaps, compliance monitoring
- Incoherent, inconsistent policy decisions & actions

Strategy and Operations

- No transparent, standardised, inclusive and predictable decision and assessment framework to implement policy and regulations and monitoring compliance
- Low emphasis on sustainable long-term goals

Community Engagement

- Local communities not actively involved in decision-making on mining. Information asymmetry - exploitation of artisanal miners by intermediaries

Productivity - data and information ecosystem, knowledge, technology

- No systematic resource mapping, setback to spatial framework. Data gaps, incompatibilities and duplications.
- Low digitalisation and challenges of geodata management retard data integration and technology adoption

Mining-Environment Goals: Interconnectedness

SDG 7

Affordable, reliable, sustainable, modern energy for all

- Cleaner fossil fuel technologies

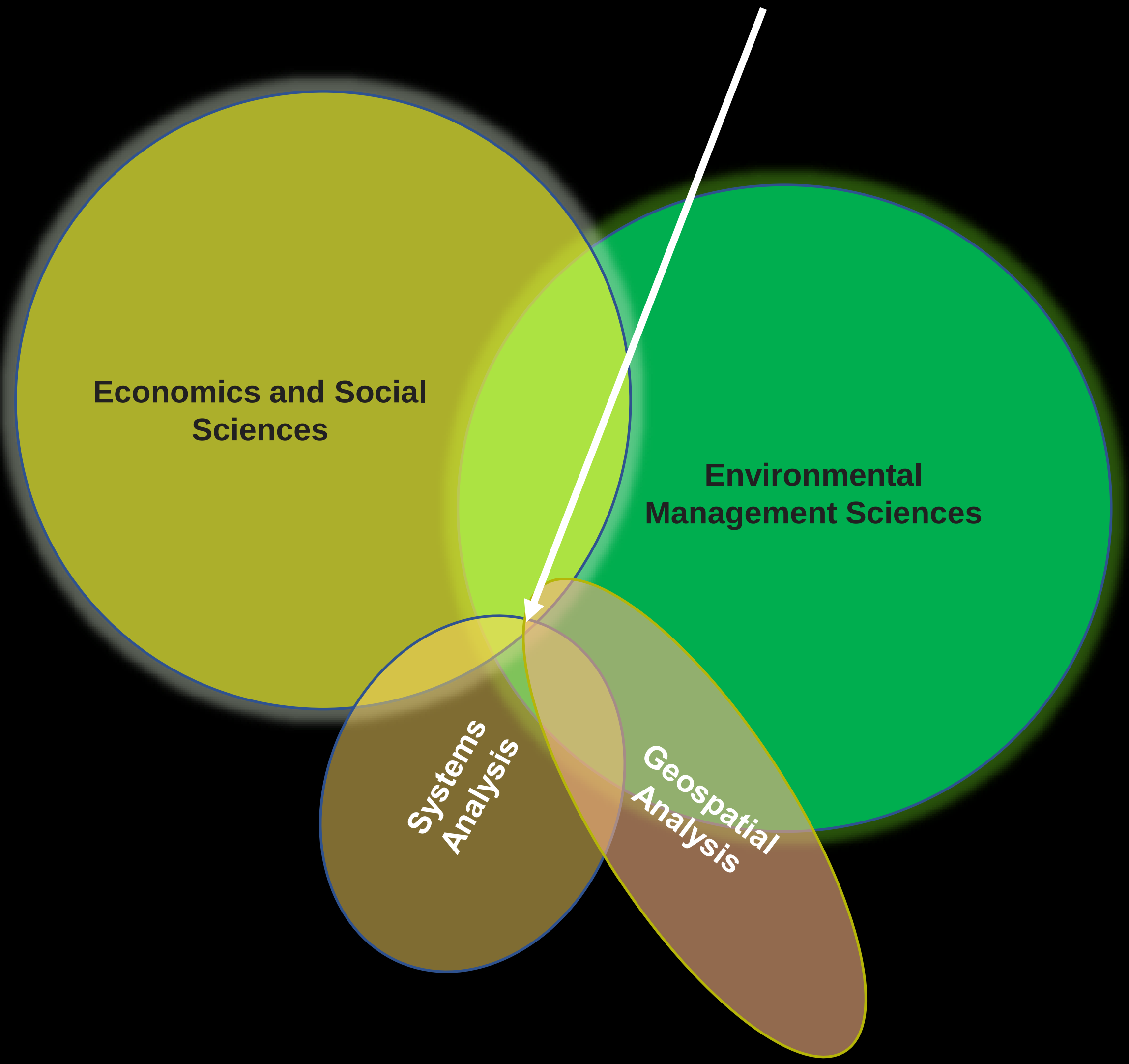
SDG 9, 11,13, 14, 15

Interrelated SDGs

- Infrastructure, industrialisation, innovation
- Sustainable cities and communities
- Combat climate change
- Ocean and marine resources
- Protect, restore, promote terrestrial ecosystems – forests, land conservation, biodiversity

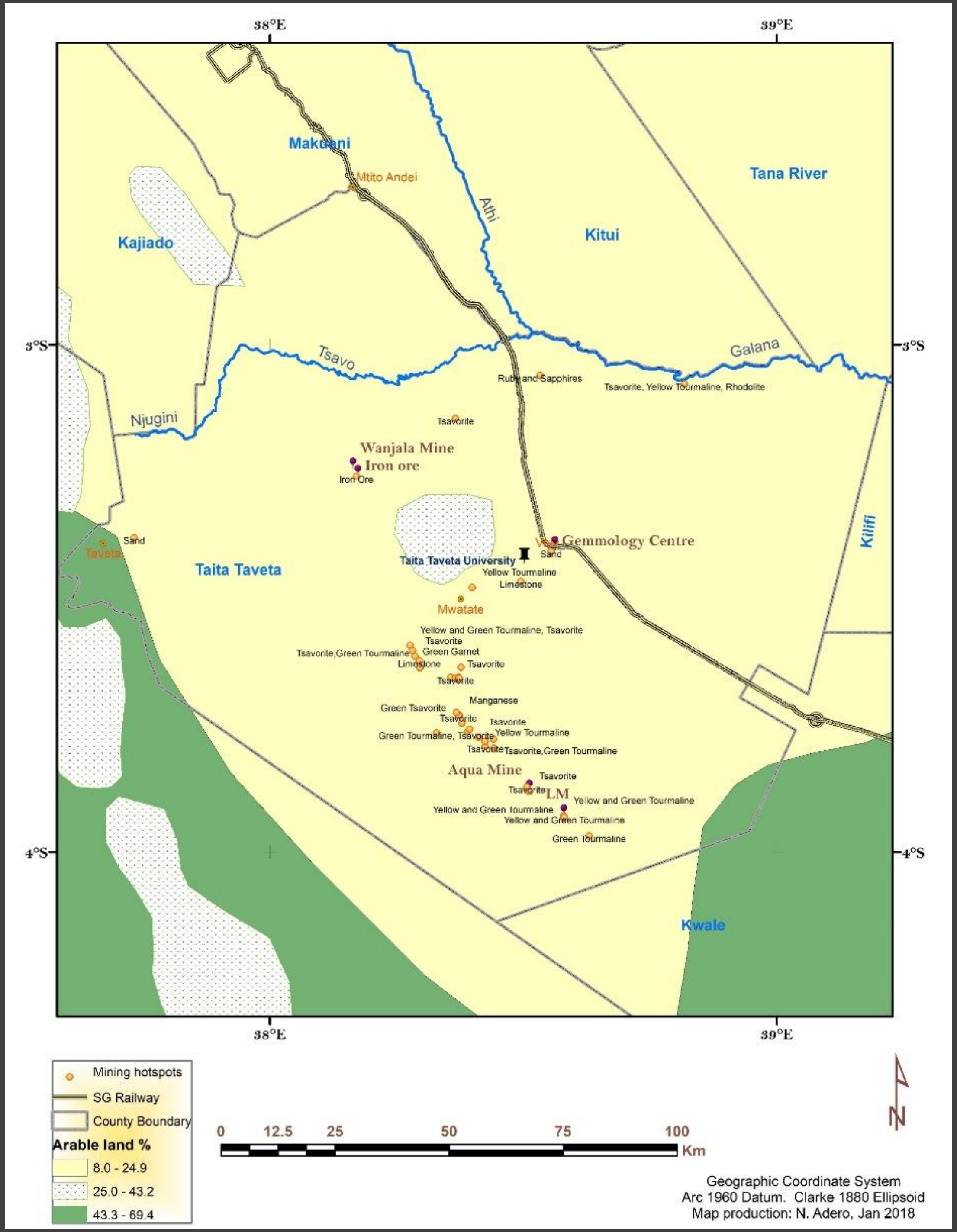
Research area intersection

- Inadequacy in spatial metrics – to replace binary dummies (e.g. near/far, within/outside)
- Limited spatial scale – to move from project level to community-wide scale



Taita Taveta is rich in gemstones and industrial minerals and has pockets of agroecological zones which are more than 25% arable

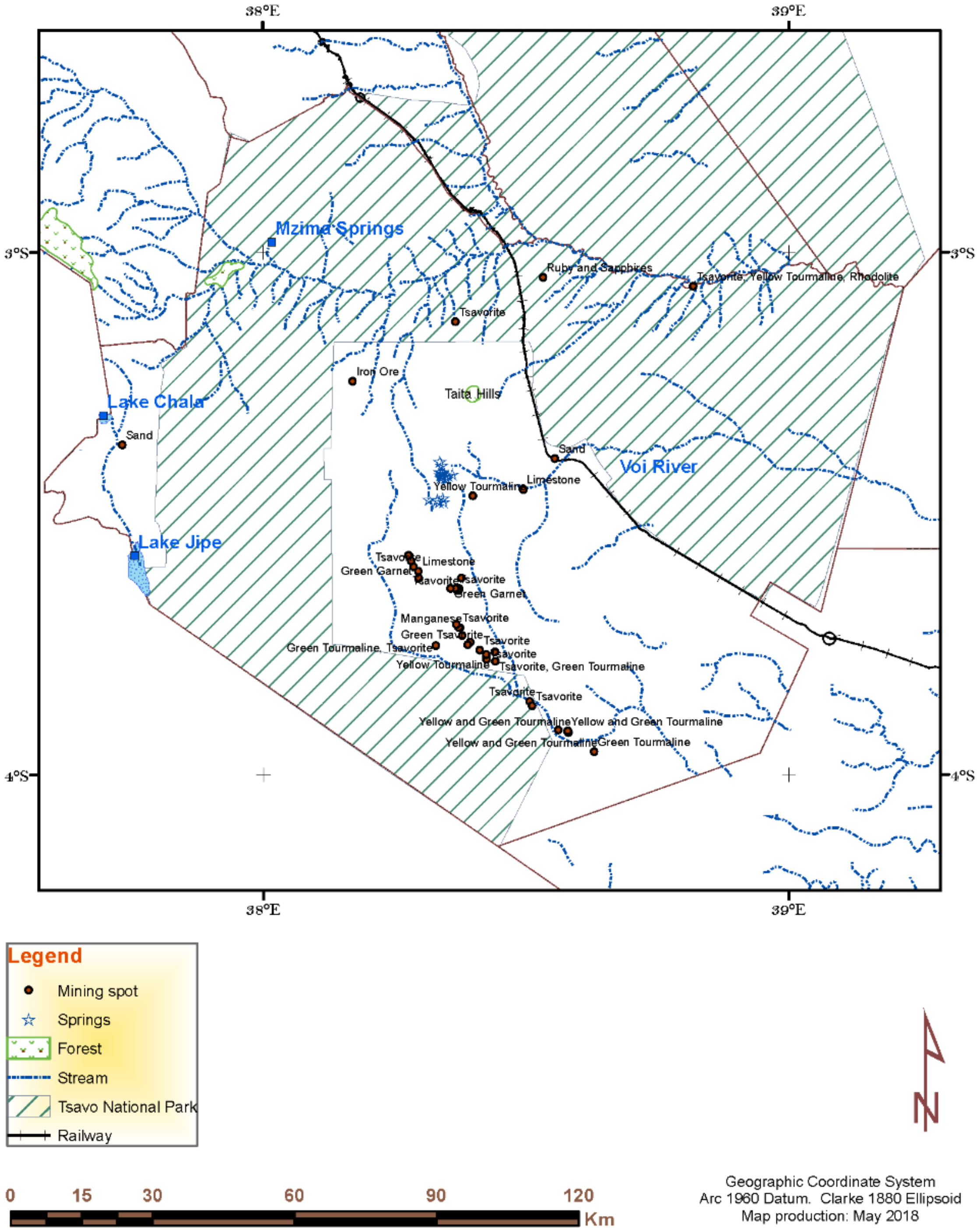
- Sisal farms
- Many (group) ranches in the region
- Land and mining rights compete/conflict with agricultural and biodiversity conservation interests



GPS and GIS analysis and map compilation, Adero (2018)

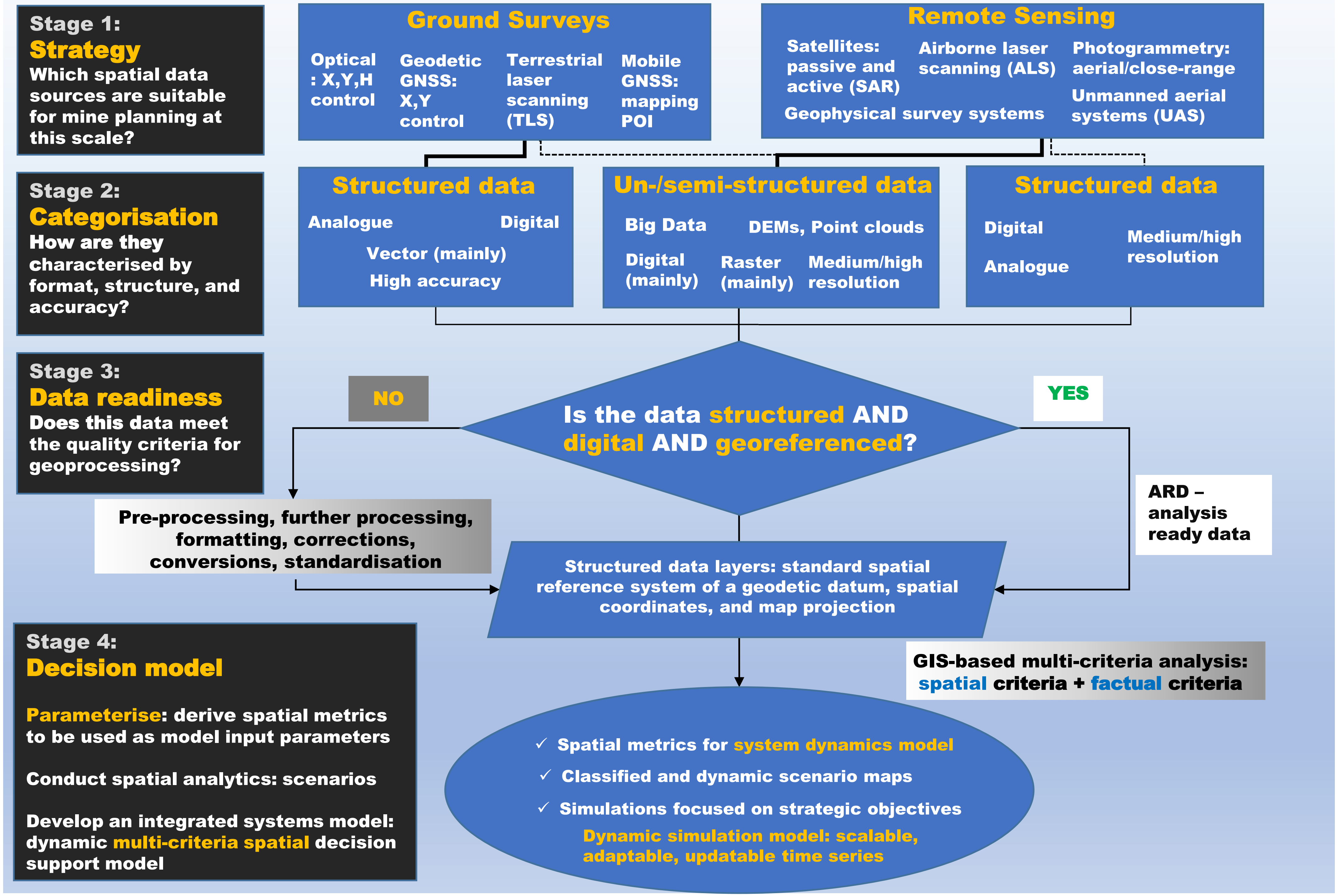
Tsavo National Park claims more than 60% of the area of Taita Taveta

Human-wildlife conflict is common

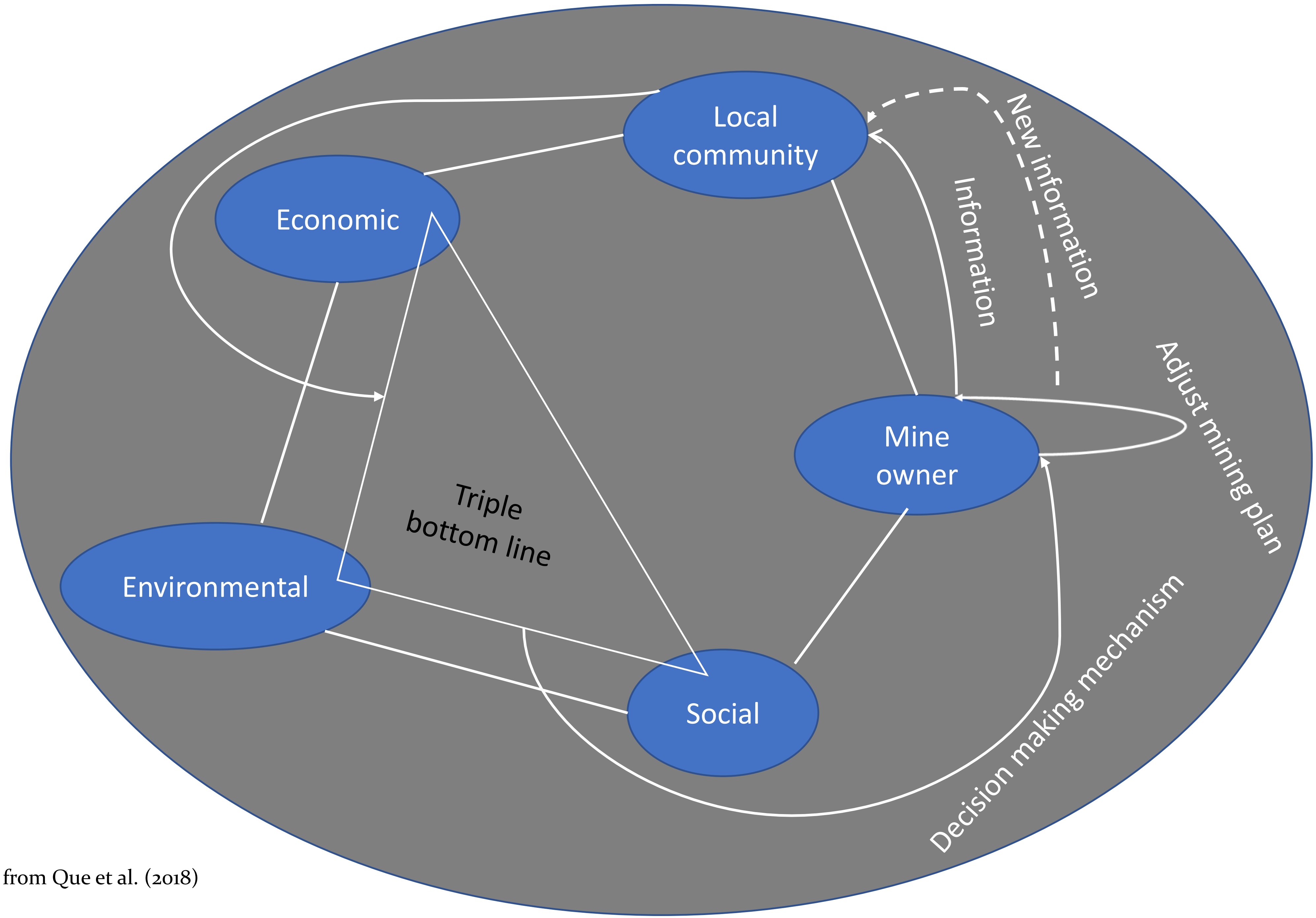


GPS points and map compilation, Adero (2018)

Proposed systems approach	Traditional linear approach
System-focused: Considers the big picture with stocks, flows and feedbacks which constitute a *nexus of interconnectedness.*	**Sector-focused:** Fragmented treatment of individual sectors with little consideration of their interconnectedness.
Boundaries are seen as zones of interrelationships: interconnections, interdependence, and dynamic interactions.	**Boundaries** are seen as zones of separation between problem spheres or silos.
Irreducible model: Time-delayed *non-linear* thinking and a *synthesis* of diverse views and variables in *iterative* and *cyclical* processes to promote *adaptive* responses in a complex web of *reciprocal causality.*	**Reductionist model:** *Linear* thinking engaging *analysis* of views and variables in a *unidirectional* cause-effect relationship.
Solution-seeking: Seeks out *holistic* solutions which address the root causes inherent in *mental models*. Explores *high-leverage* intervention points.	**Problem-oriented:** Tends to patch *isolated* problem spheres, manifested in *events*. High-leverage intervention points remain elusive.
Predictive and proactive: Applies *dynamic simulation* to anticipate *covert* problems and design possible solutions.	**Curative and reactive:** Mainly a *static* approach led by the urgency to address significant and *overt* problems.
Regular and strategic: Establishes a regular and continuous review regime with predictable standards and long-term objectives.	**Sporadic and short-term:** Irregular, needs-based, and discharging short-lived interventions.

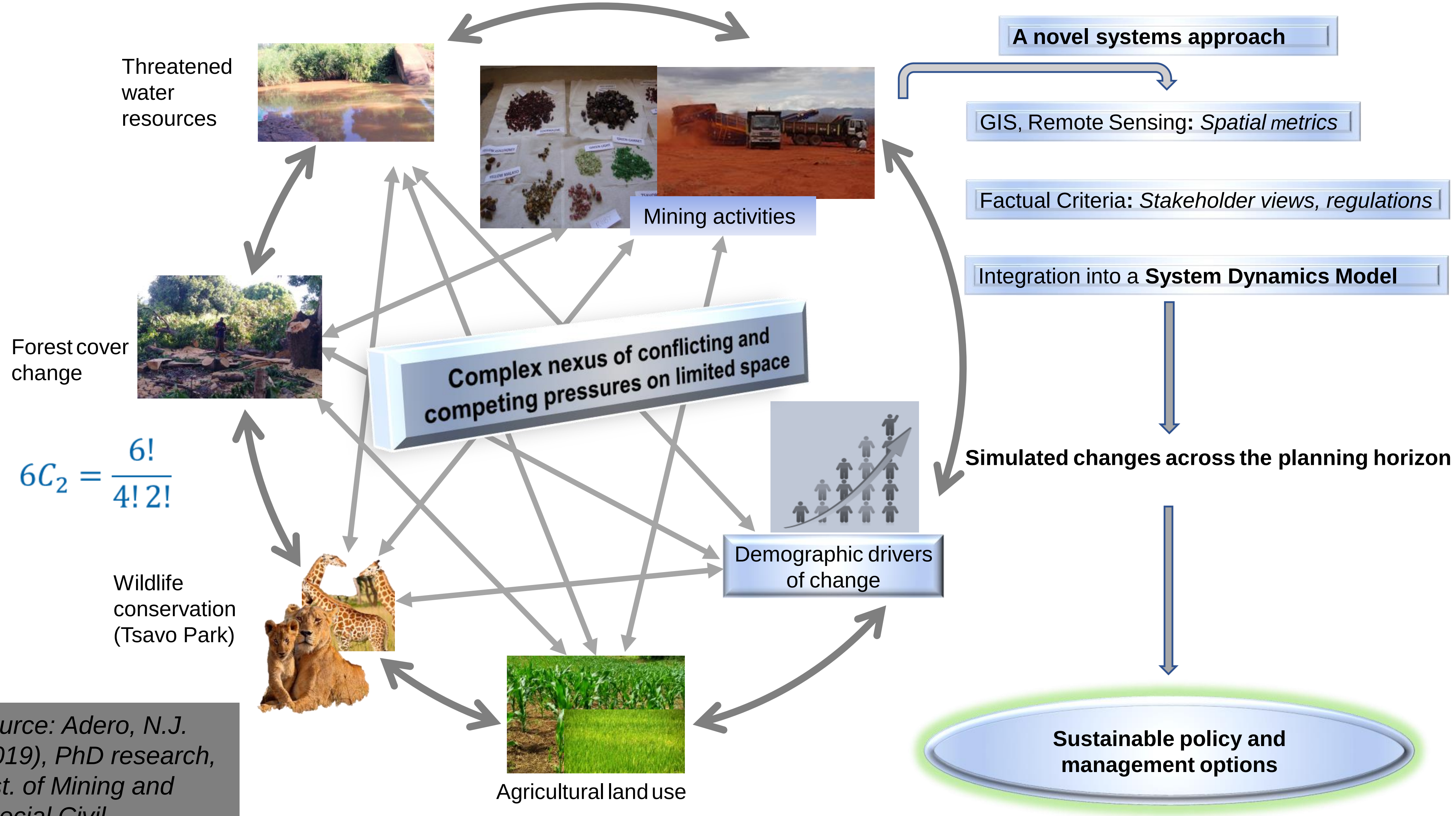


Stage 1:
Strategy
Which spatial data sources are suitable for mine planning at this scale?
Ground Surveys
Optical: X,Y,H control
Geodetic GNSS: X,Y control
Terrestrial laser scanning (TLS)
Mobile GNSS: mapping POI
Remote Sensing
Satellites: passive and active (SAR)
Airborne laser scanning (ALS)
Photogrammetry: aerial/close-range
Geophysical survey systems
Unmanned aerial systems (UAS)
Stage 2:
Categorisation
How are they characterised by format, structure, and accuracy?
Structured data
Analogue
Digital
Vector (mainly)
High accuracy
Un-/semi-structured data
Big Data
DEMs, Point clouds
Digital (mainly)
Raster (mainly)
Medium/high resolution
Structured data
Digital
Analogue
Medium/high resolution
Stage 3:
Data readiness
Does this data meet the quality criteria for geoprocessing?
NO
YES
Is the data structured AND digital AND georeferenced?
ARD – analysis ready data
Pre-processing, further processing, formatting, corrections, conversions, standardisation
Structured data layers: standard spatial reference system of a geodetic datum, spatial coordinates, and map projection
Stage 4:
Decision model
Parameterise: derive spatial metrics to be used as model input parameters
Conduct spatial analytics: scenarios
Develop an integrated systems model: dynamic multi-criteria spatial decision support model
GIS-based multi-criteria analysis: spatial criteria + factual criteria
✓ Spatial metrics for system dynamics model
✓ Classified and dynamic scenario maps
✓ Simulations focused on strategic objectives
Dynamic simulation model: scalable, adaptable, updatable time series



Source: Modified from Que et al. (2018)

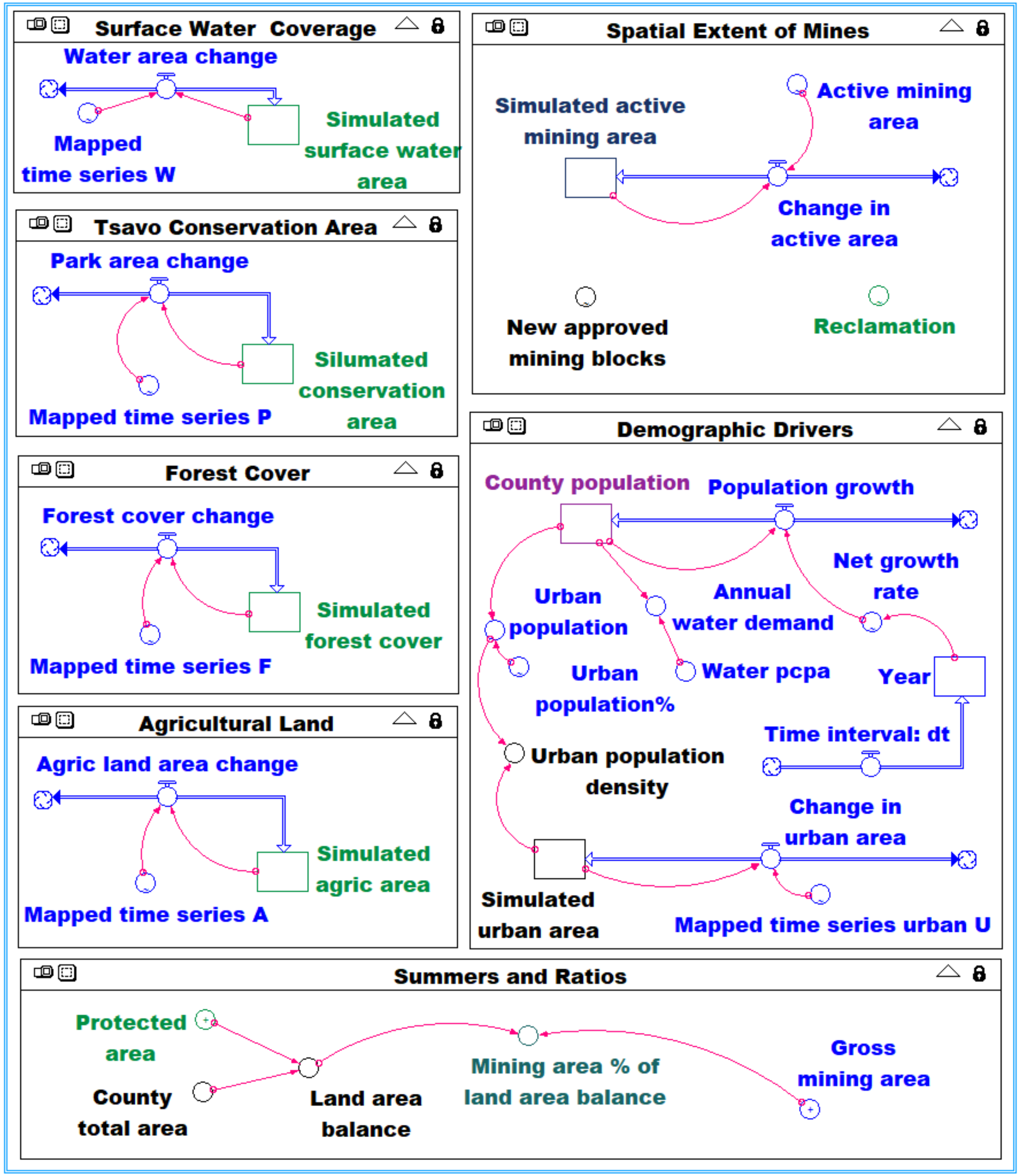
Conceptual model of the complex nexus of reciprocal causality



$$6C_2 = \frac{6!}{4!\,2!}$$

Source: Adero, N.J. (2019), PhD research, Inst. of Mining and Special Civil Engineering, TuBAF

Formalised scalable, adaptable systems model



Model Equations Layer - Examples

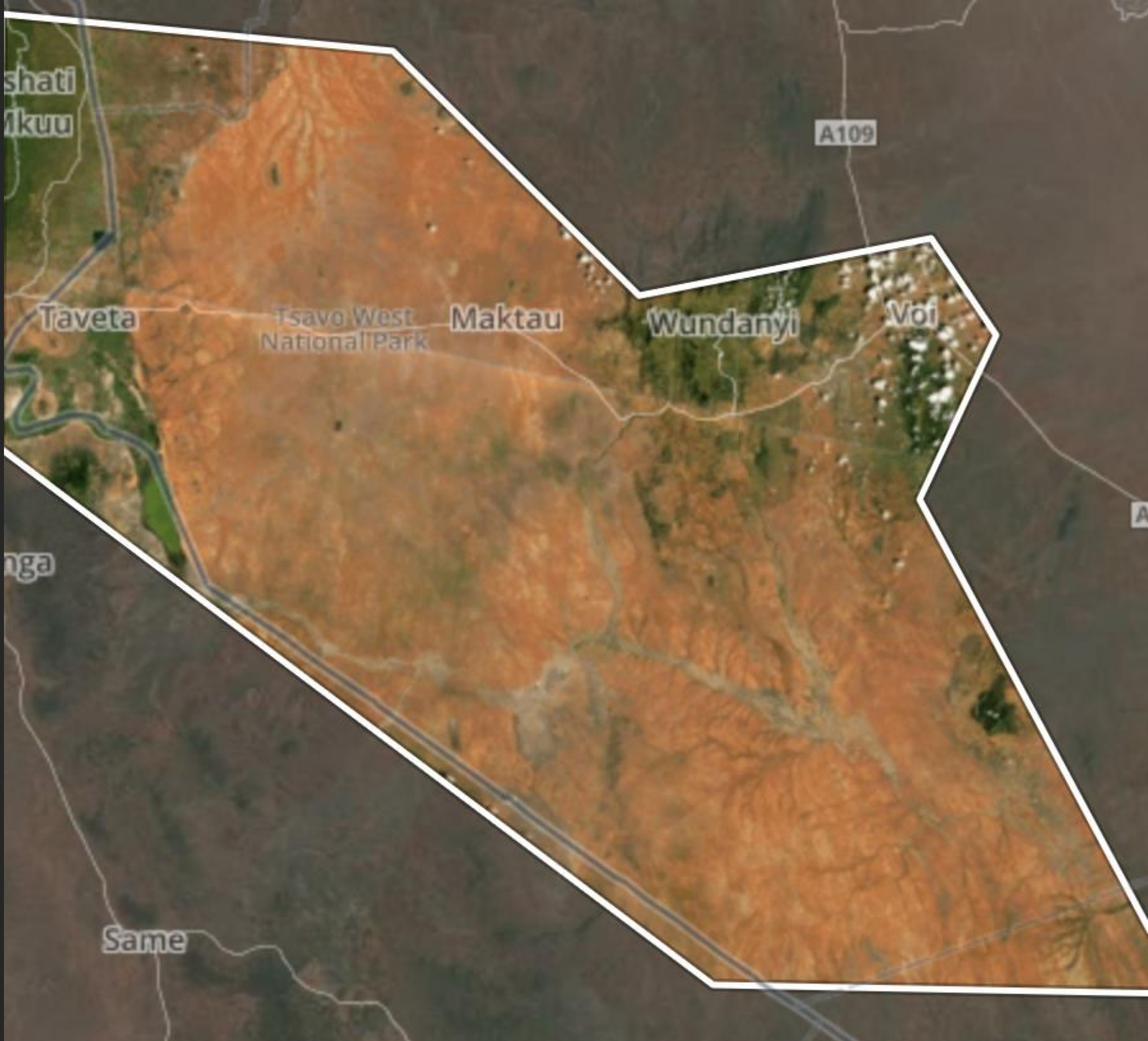
```
County_population(t) = County_population(t - dt) + (Population_growth) * dt
INIT County_population = 147597
INFLOWS:
Population_growth = County_population*Net_growth__rate
Simulated__urban_area(t) = Simulated__urban_area(t - dt) + (Change_in__urban_area) * dt
INIT Simulated__urban_area = 600
INFLOWS:
Change_in__urban_area = Mapped_time_series_urban_U-Simulated__urban_area
Year(t) = Year(t - dt) + (Time_interval:_dt) * dt
INIT Year = 1979
INFLOWS:
Time_interval:_dt = 1
Annual__water_demand = County_population*Water_pcpa
Urban_population_density = Urban__population/Simulated__urban_area
Urban__population = County_population*Urban__population%/100
Water_pcpa = 0.000073
Mapped_time_series_urban_U = GRAPH(TIME)
(0.00, 600), (5.00, 616), (10.0, 649), (15.0, 652), (20.0, 653), (25.0, 655), (30.0, 660),
(35.0, 676), (40.0, 688), (45.0, 697), (50.0, 700)
Net_growth__rate = GRAPH(Year)
(1979, 0.034), (1984, 0.034), (1989, 0.03), (1994, 0.019), (1999, 0.018), (2004,
0.0144), (2009, 0.0144), (2014, 0.0326), (2019, 0.035), (2024, 0.033), (2029, 0.03)
Urban__population% = GRAPH(TIME)
(0.00, 2.00), (5.00, 2.50), (10.0, 5.00), (15.0, 9.00), (20.0, 11.0), (25.0, 14.0), (30.0,
17.0), (35.0, 20.0), (40.0, 25.0), (45.0, 28.0), (50.0, 30.0)
```

Forest Cover

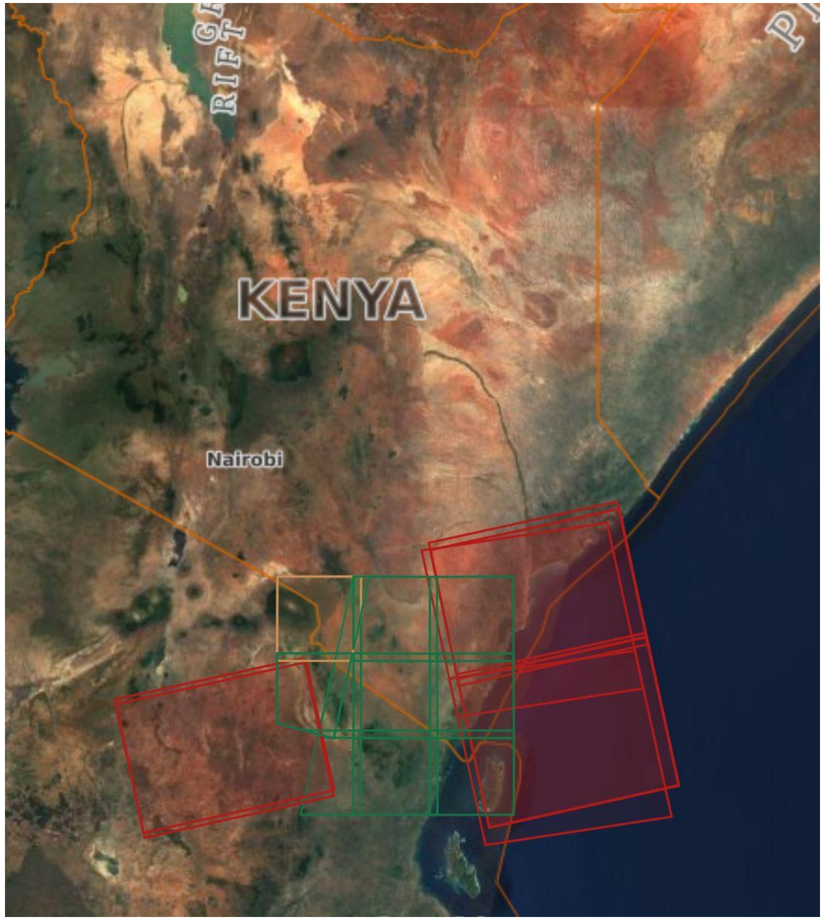
```
Simulated__forest_cover(t) = Simulated__forest_cover(t - dt) + (Forest_cover_change) * dt
INIT Simulated__forest_cover = 200
INFLOWS:
Forest_cover_change = Mapped_time_series_F-Simulated__forest_cover
Mapped_time_series_F = GRAPH(TIME)
(0.00, 200), (5.00, 201), (10.0, 198), (15.0, 198), (20.0, 195), (25.0, 194), (30.0, 191),
(35.0, 181), (40.0, 180), (45.0, 179), (50.0, 180)
```

Study area

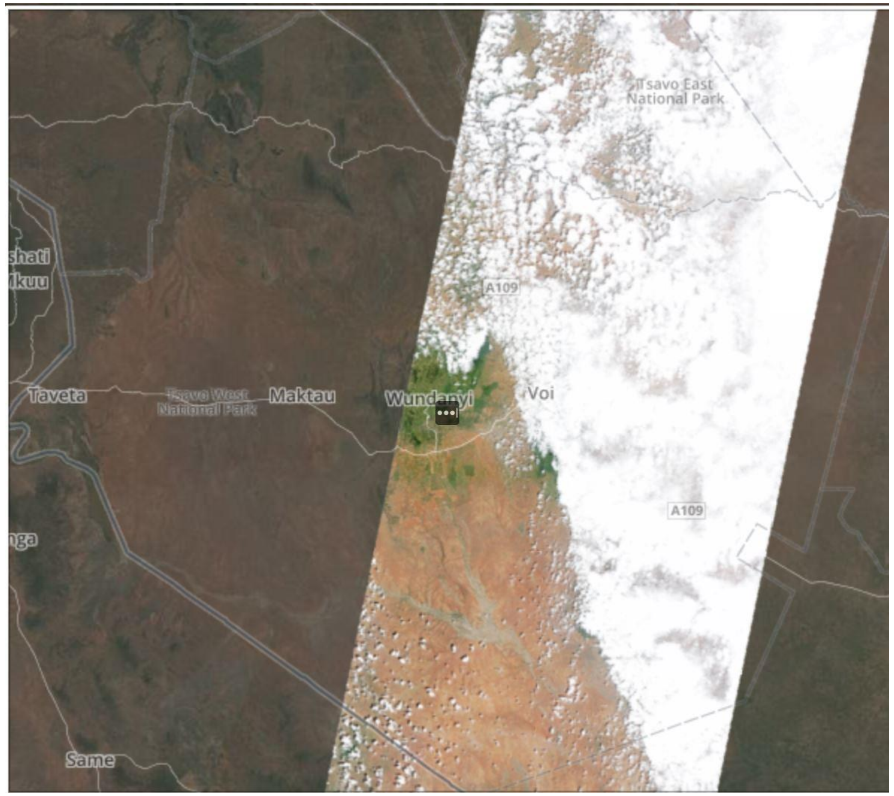
Landsat 8



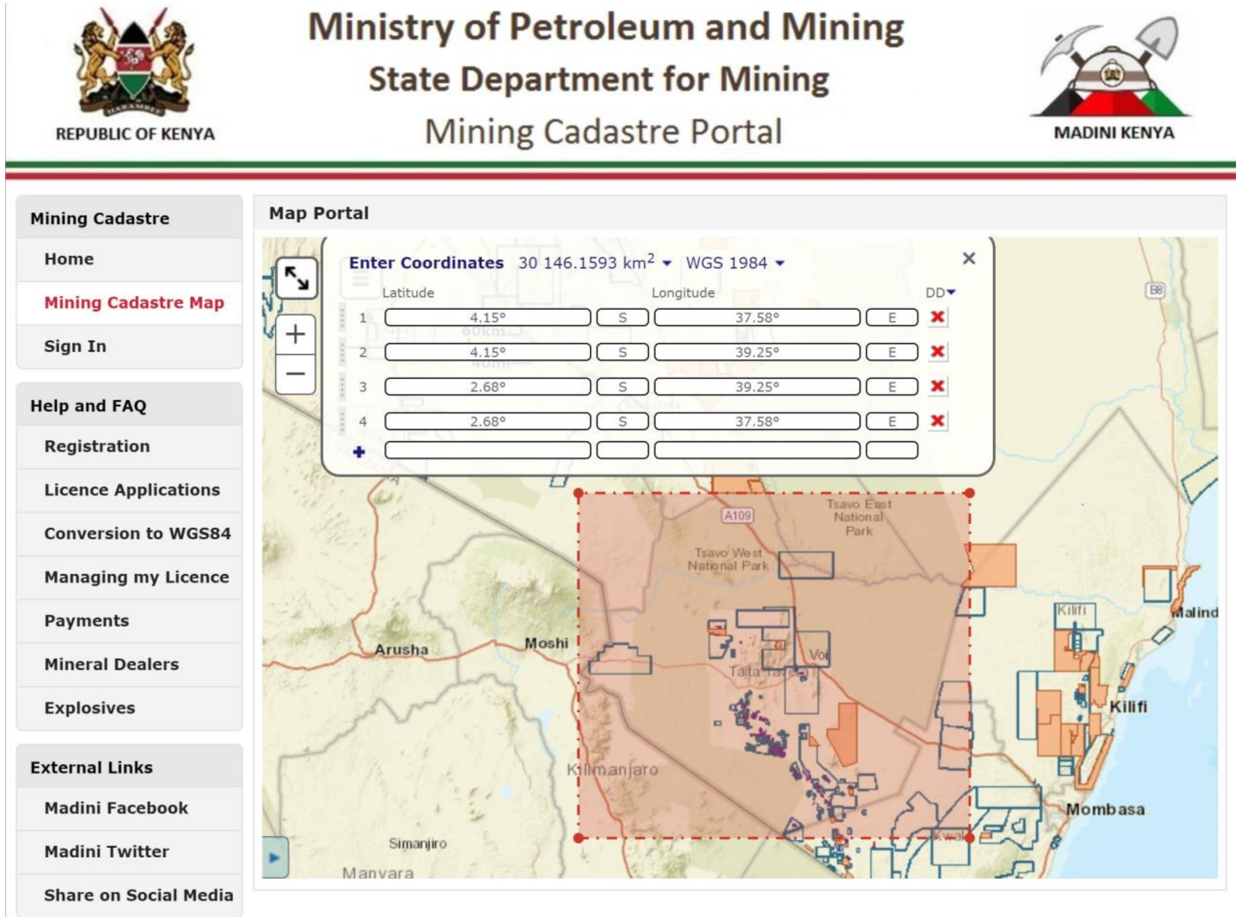
Sentinel 1, 2



Rapid Eye



Mining Cadastral Portal - National



Results: Satellite image classification and land use simulations

PlanetScope 3-m satellite imagery showing human activities encroaching onto the dormant **Wanjala Mines** to the north, and clearance around the active **Gregory Mine** near Mwatate

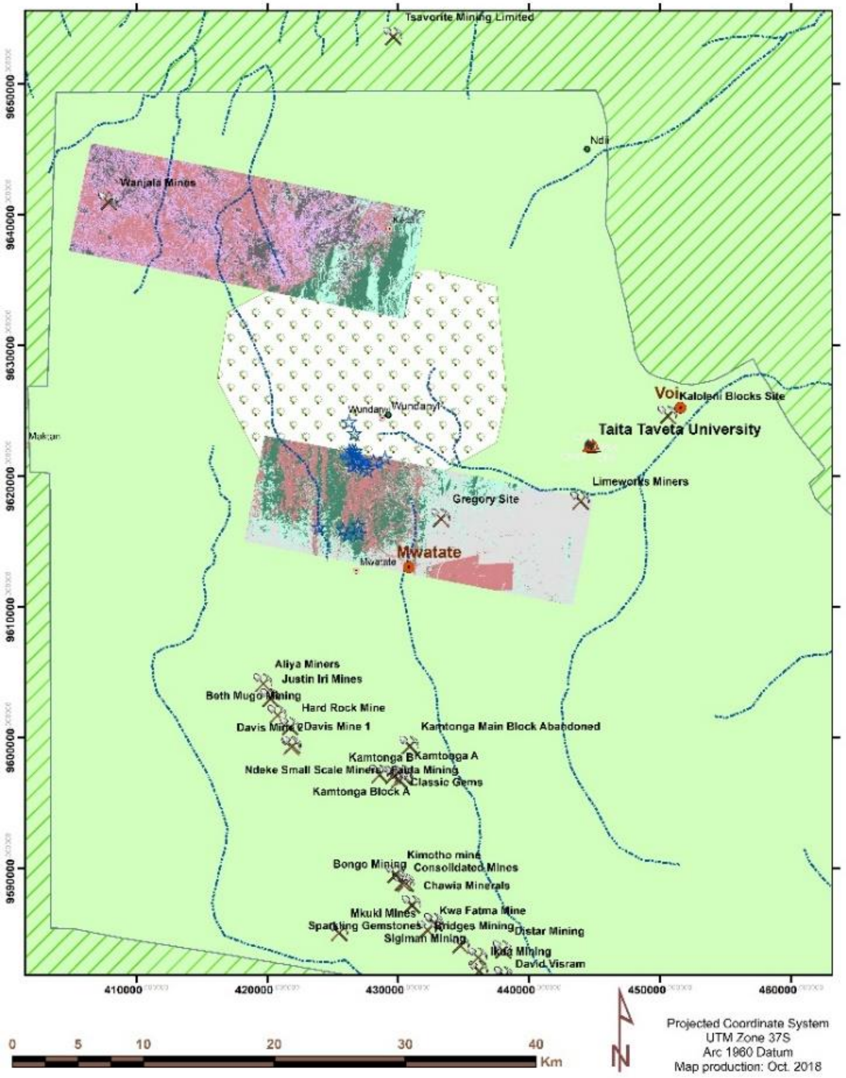
Legend

2017 LULC CLASS

- Dense Forest/Vegetation
- Sparse Forest/ Vegetation
- Cropland
- Bare Farmland
- Cropland/Builtup Area

2018 LULC CLASS

- Dense Forest
- Cropland/Dense Vegetation
- Sparse Vegetation
- Bare Land/Builtup Area



Source: Based on PlanetScope satellite imagery

Legend

Mining_Spots_TT

TaitaTavetaLULC

Class_Name

- Grassland
- Built-up Land
- Developed
- Bare
- Forest
- Mixed Forest
- Shrubland

Classes

Class_Name

- Developed
- Forest
- Planted / Cultivated
- Shrubland
- Bare

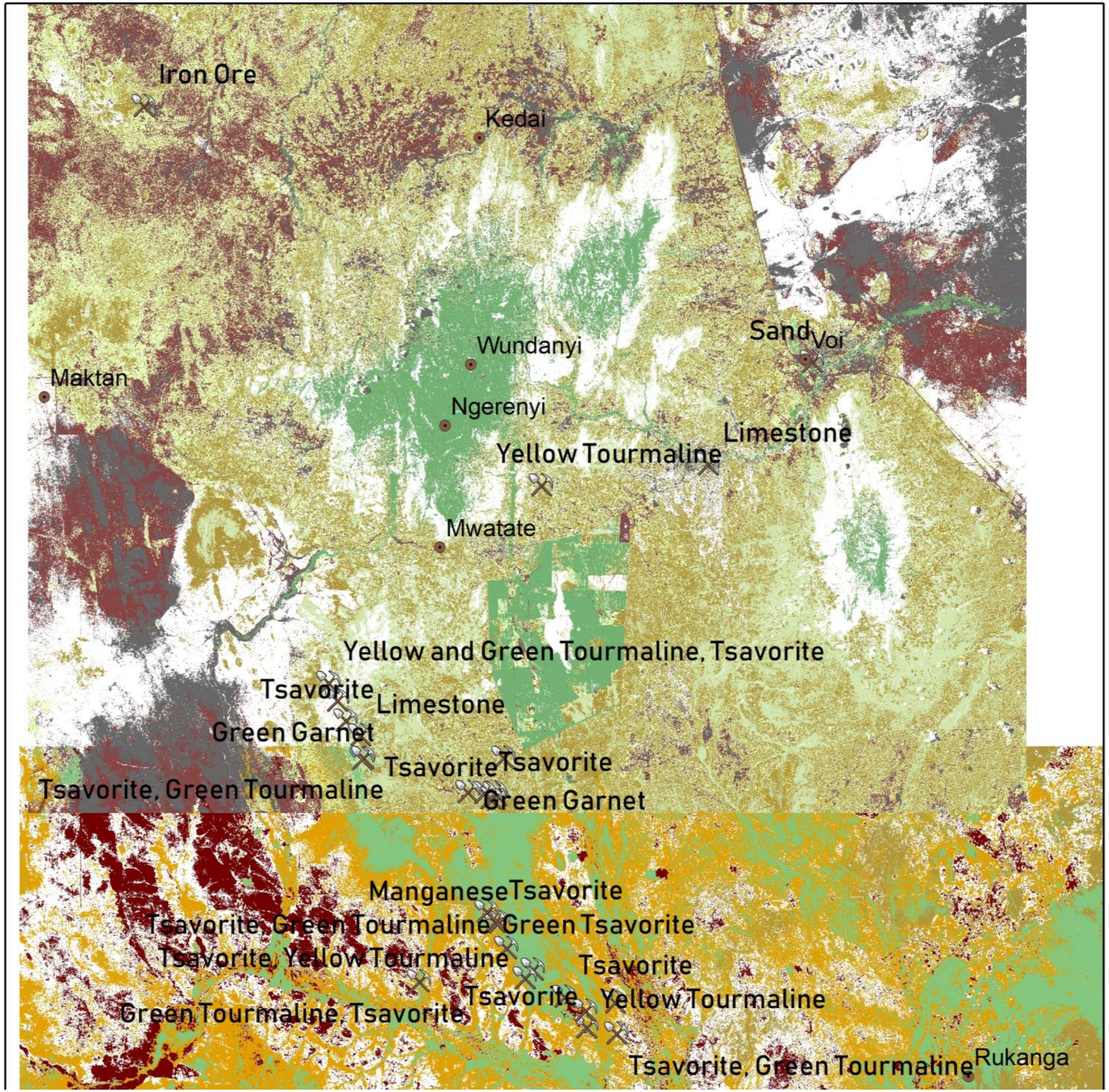
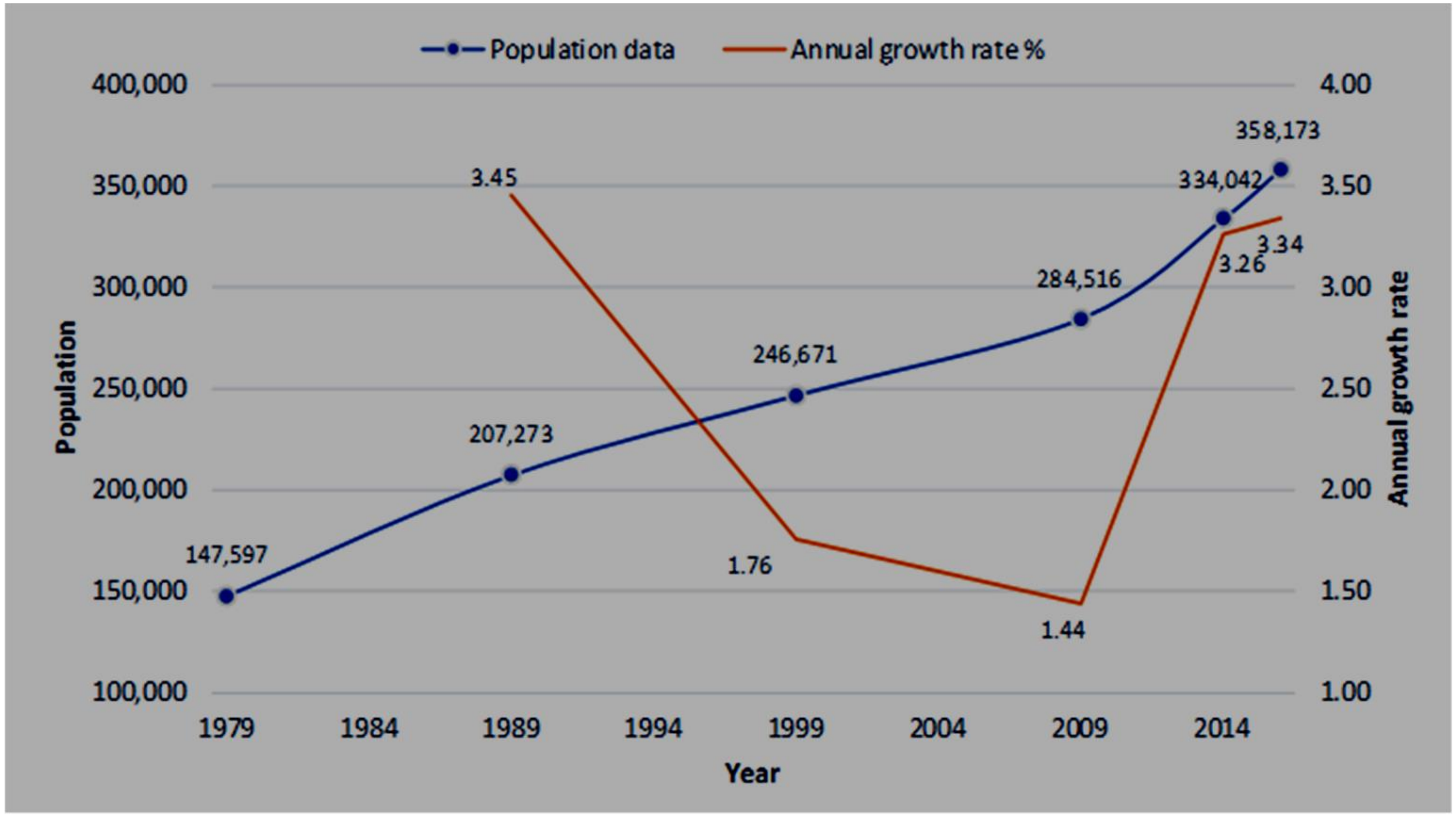


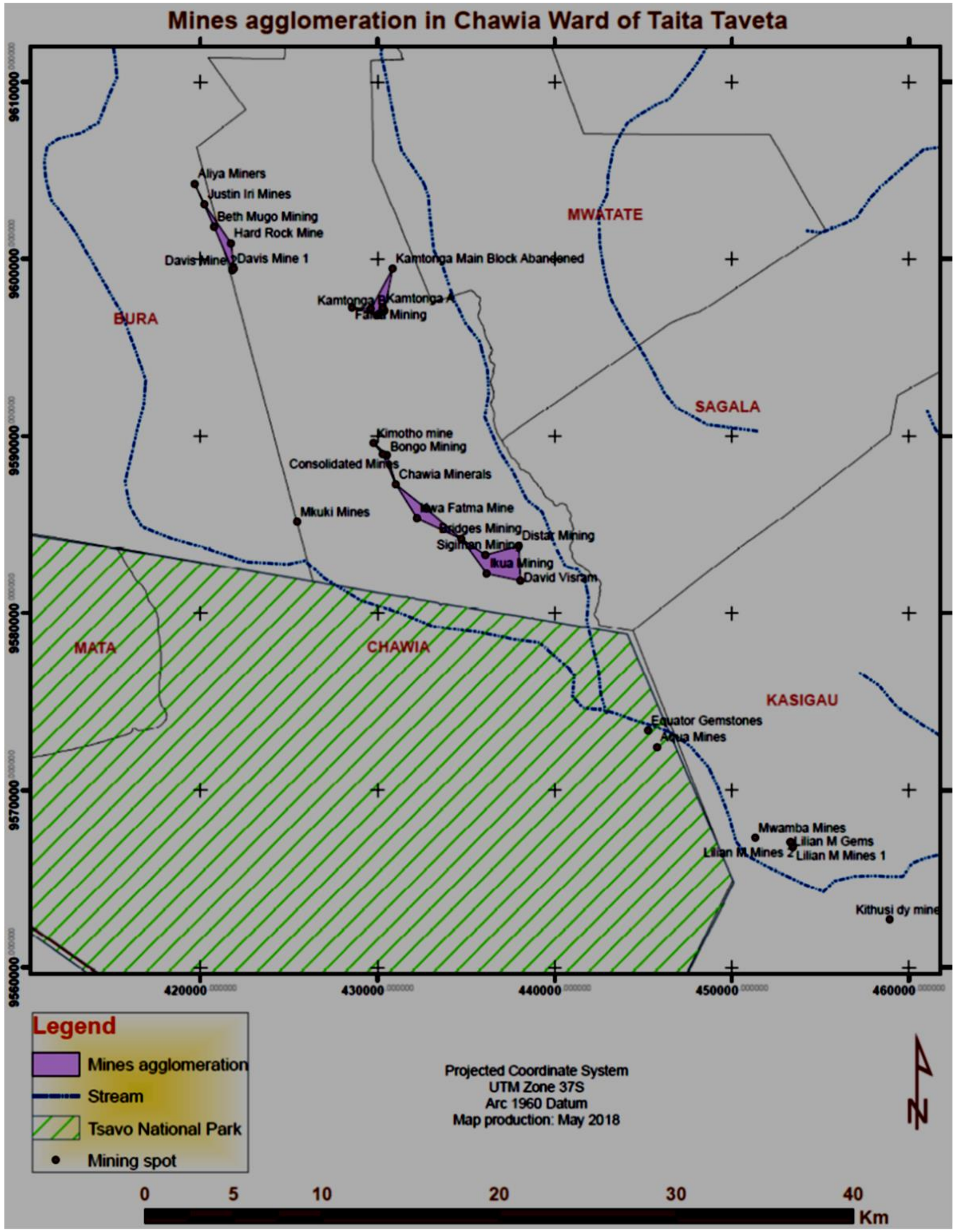
Image classification of Taita Taveta land use land cover from multispectral Sentinel 2 satellite imagery (10 m spatial resolution) showing land development and clearance around active mining areas

Taita Taveta population growth based on KNBS (2015) and Brinkhoff (2018) data



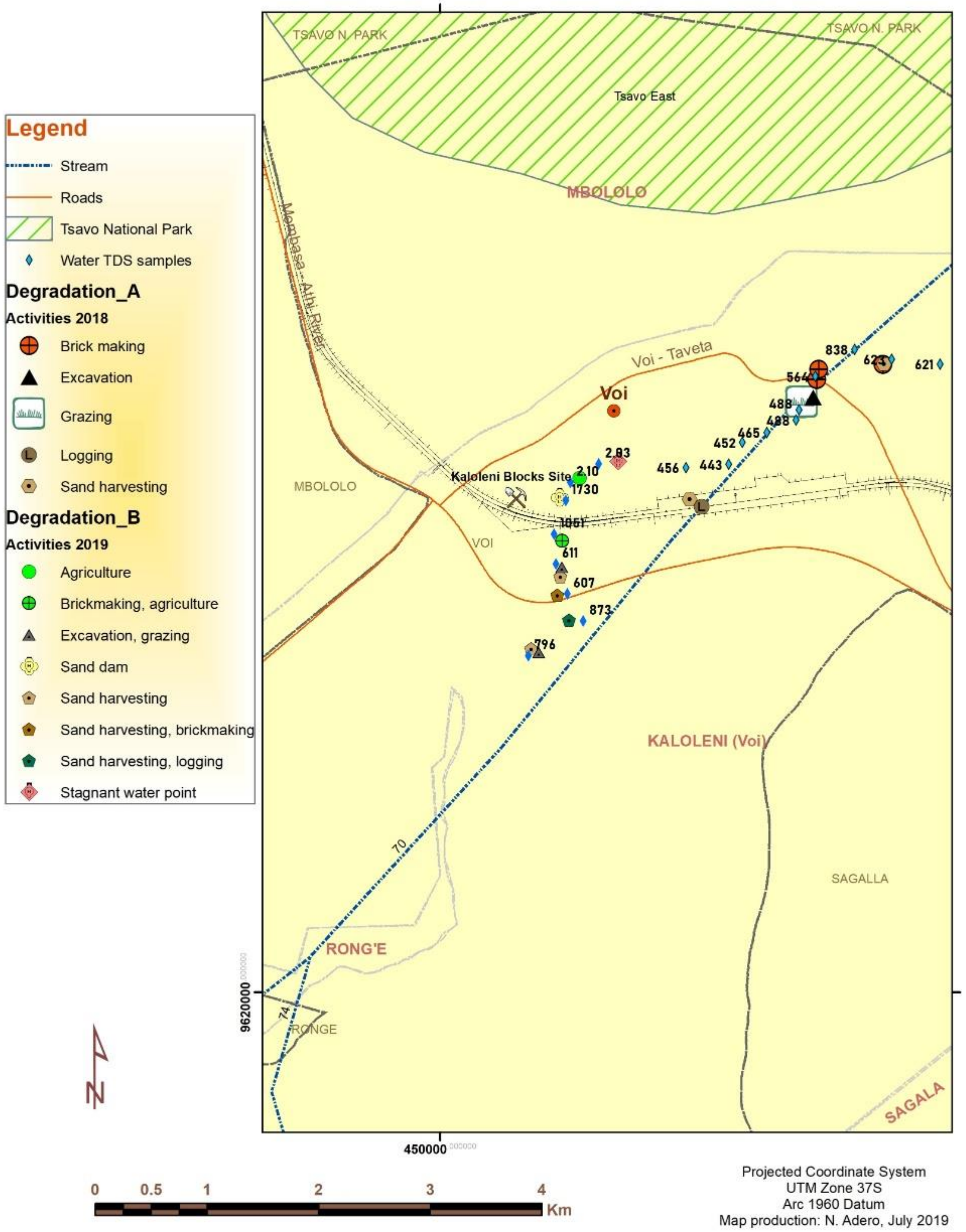
Agglomeration of mines in Chawia (795ha from cartographic generalization tool in ArcGIS)

GIS analysis based on GPS locations of mines and county spatial data



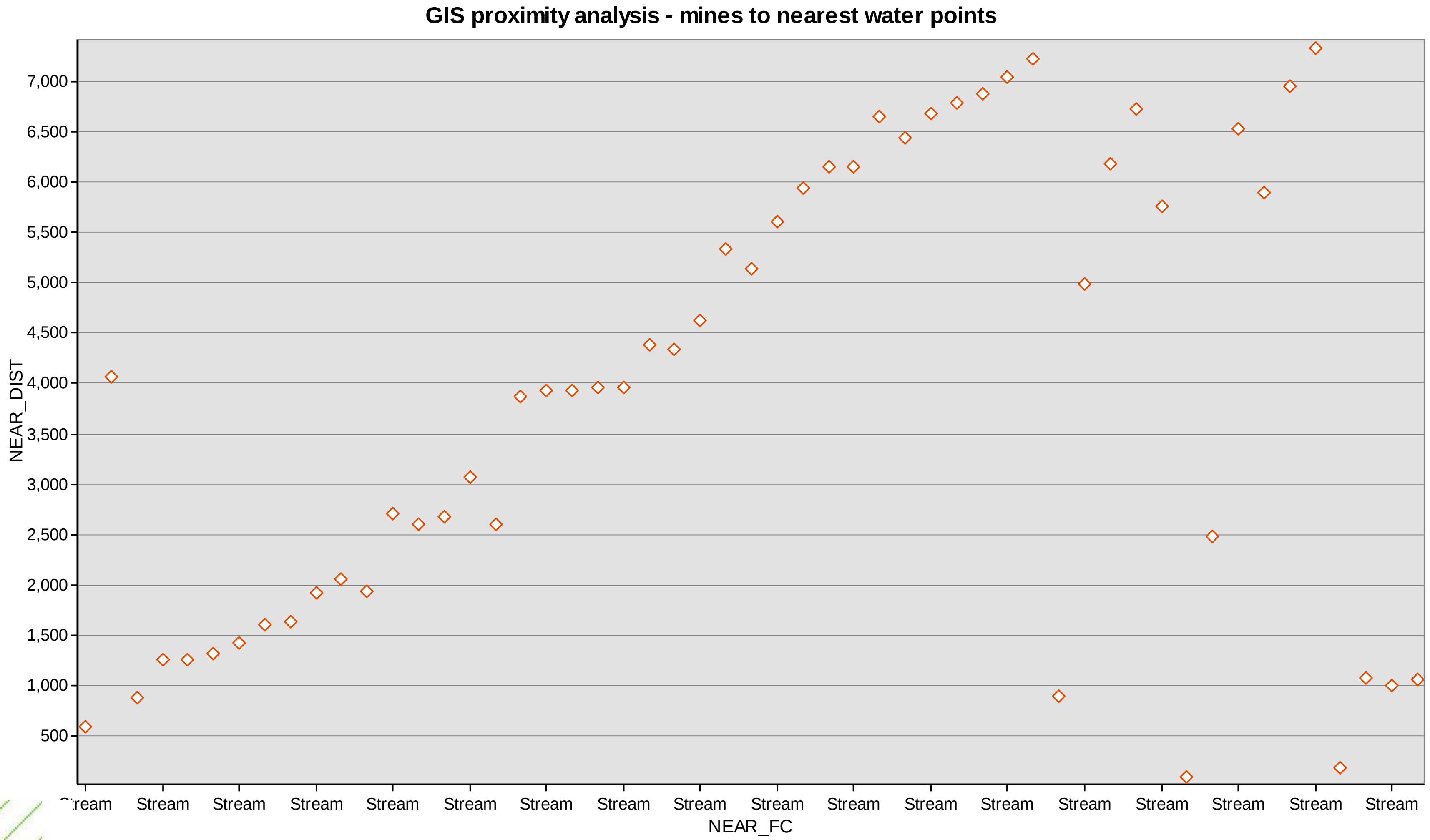
Additional water samples mapped 09 – 11 July 2019 along Voi River

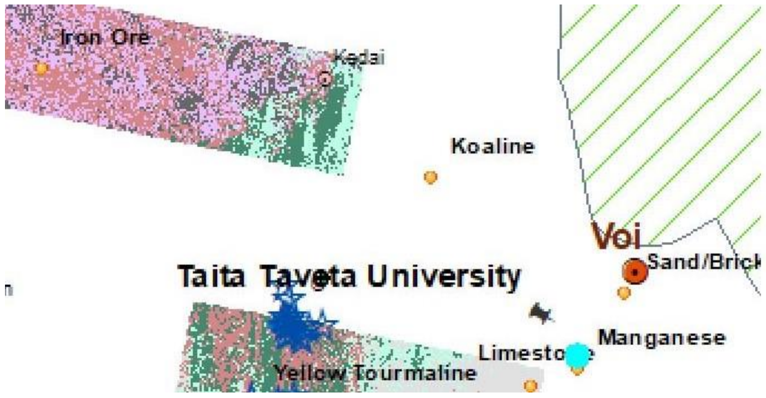
- Unregulated sand harvesting degrades Voi River further
- Excavation leaves pits which attract pools of water and grazing animals (see map)
- TDS generally increasing downstream (400 – 838 ppm)



53% **Mines within 4 km from water points** (mainly streams)

28 /53 mines in Taita Taveta region





X-axis: Near feature. Y-axis: Distance of the mine from the feature in metres

Source: Adero, N.J. (2019), PhD research, Inst. of Mining and Special Civil Engineering, TuBAF

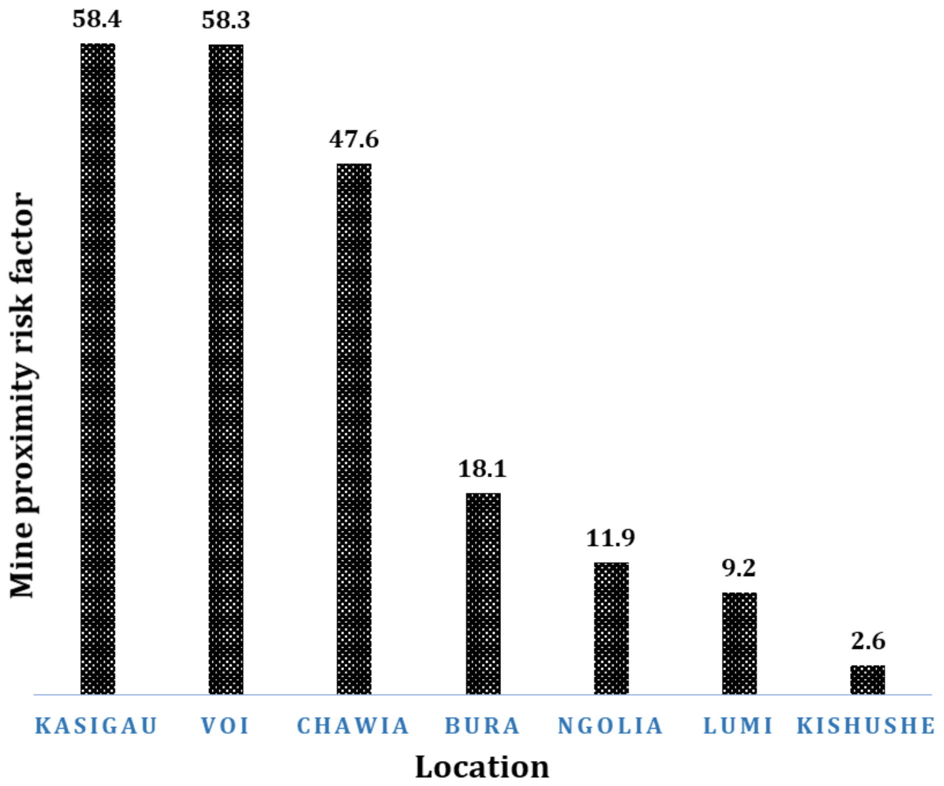
Geoprocessed mine proximity risk factor analysis

$$D\_mine = \sum_{i=1}^{n} \frac{Q_i}{Di}$$

n = total number of mines

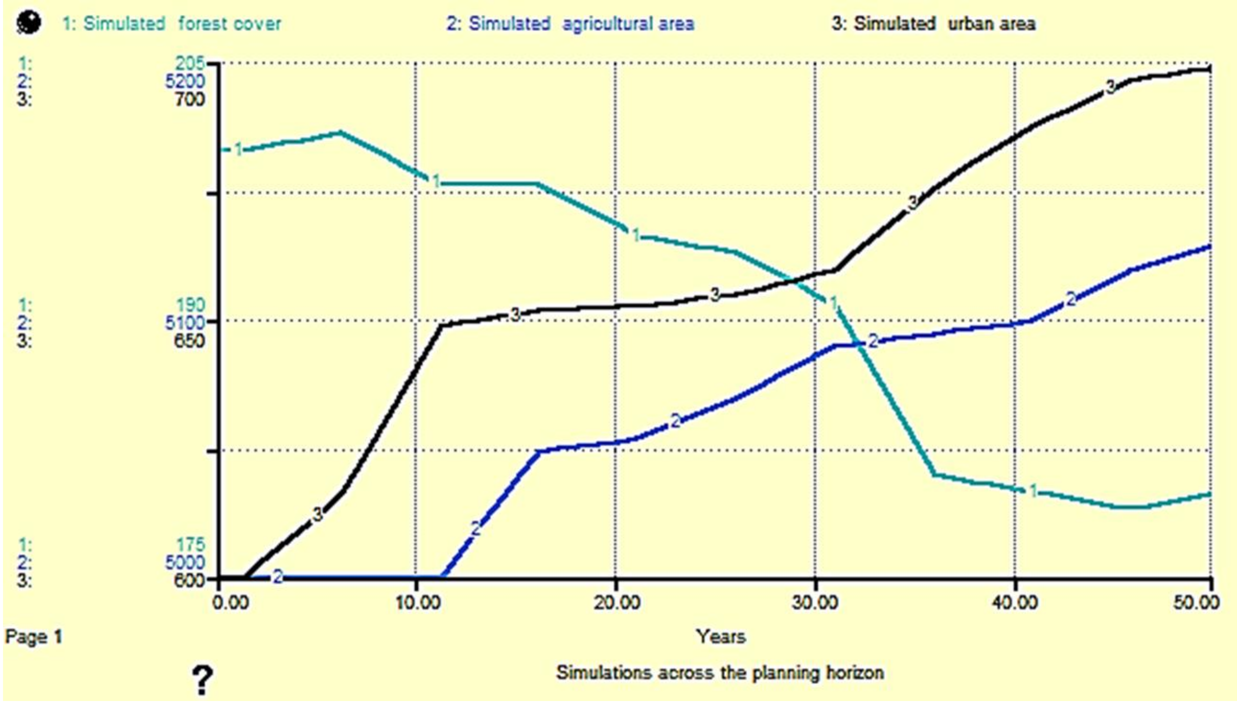
Di = distance metric from a mine to the nearest water point

Qi = Index for the impact of mining activity in a given mine, i, on the nearest water points



Stakeholders in the wards validated the general order of perceived risk in August 2018

Forest cover, agriculture and urban areas scenarios (1979 – 2029)



Forest (km²):

200

180

Agricultural area (km²):

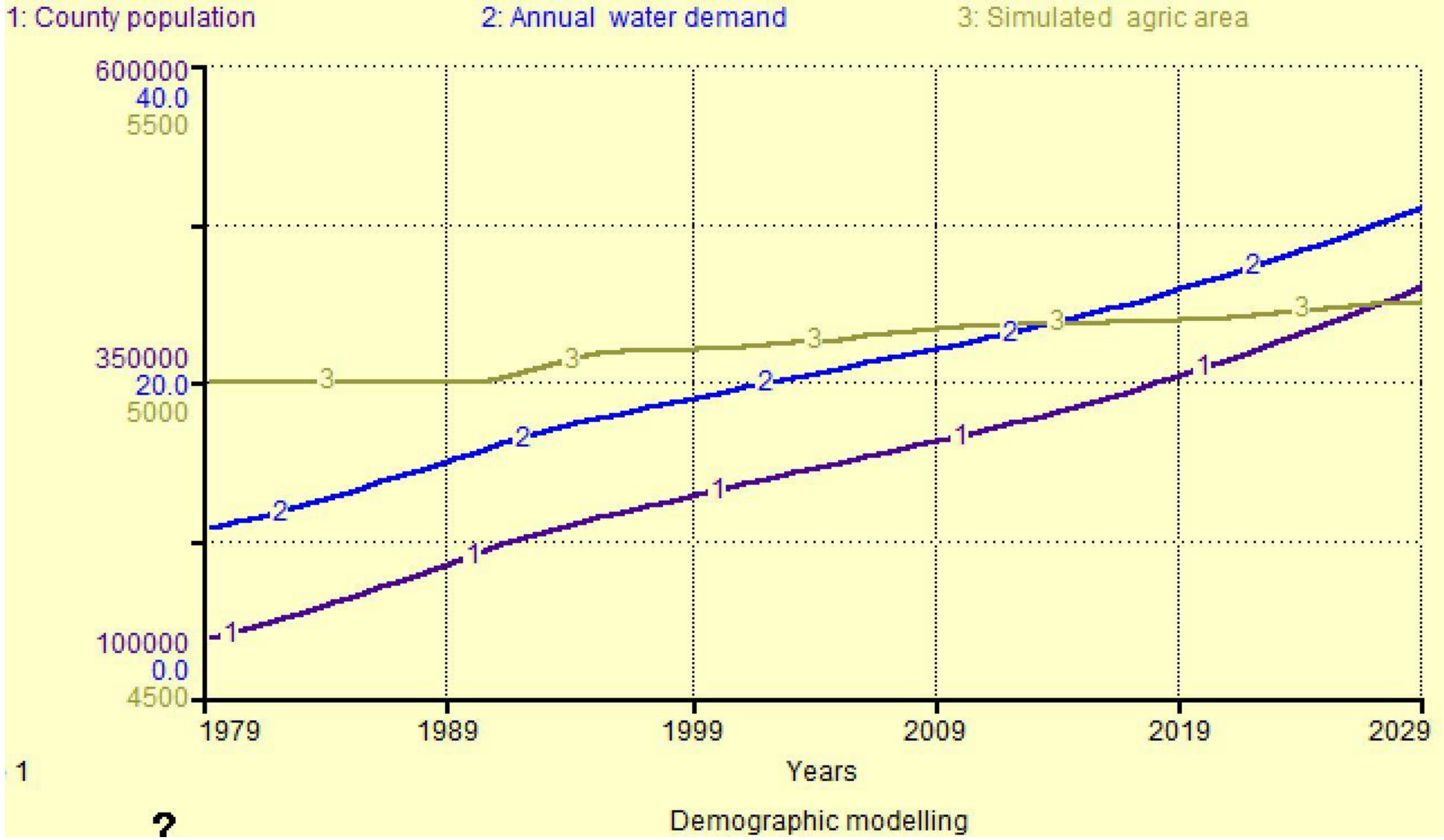
5,130

5,000

Urban area (km²):

700

600



County population growth and water demand scenarios (1979 – 2029)

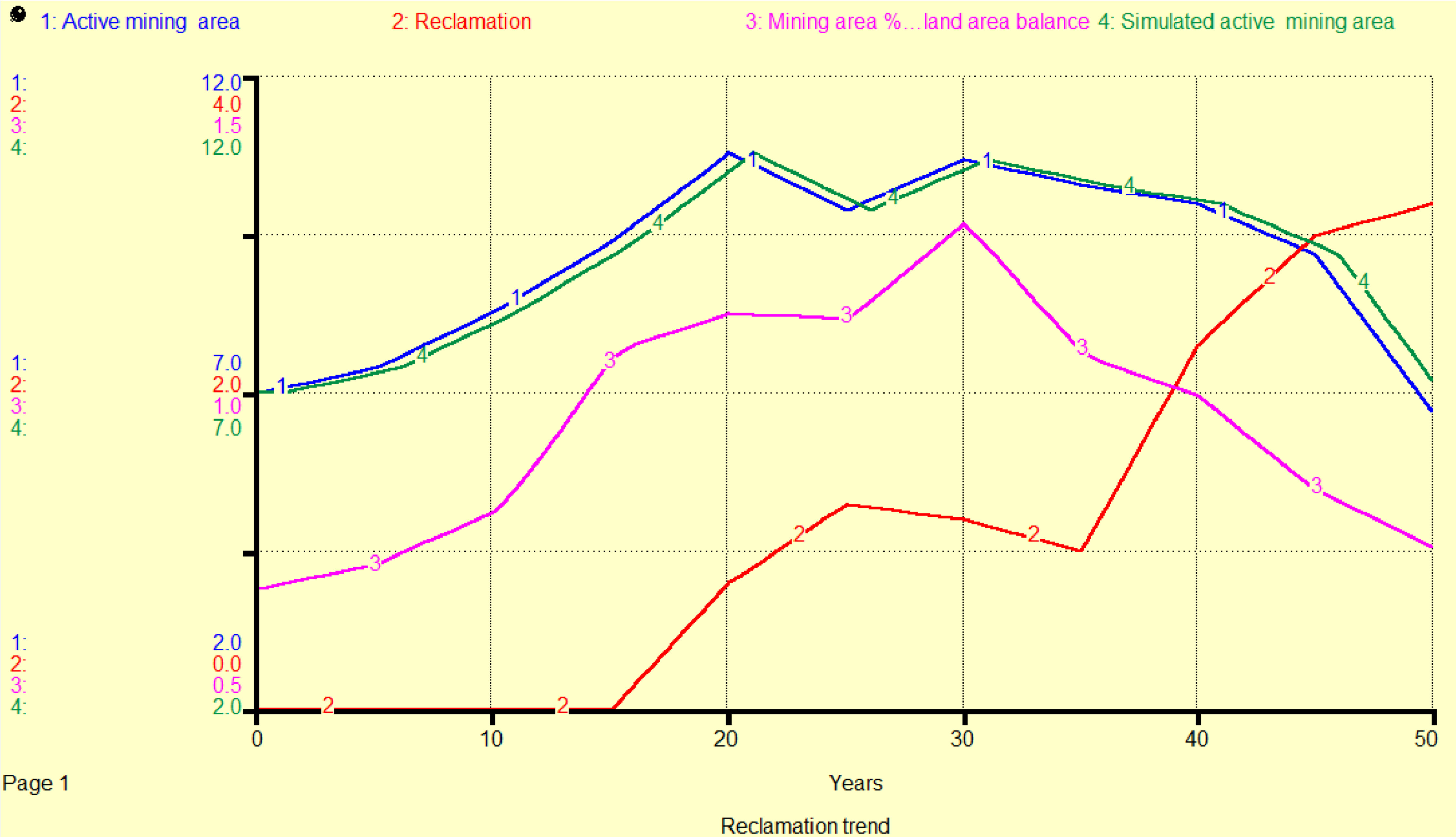
Projected population:

355,798 persons by 2019

(Census **340,671, -4.4%**)

420,000 persons by 2029

- **Annual water demand:**
- **26** million cubic metres by 2019;
- **31** million cubic metres by 2029


1: Active mining area
2: Reclamation
3: Mining area %…land area balance
4: Simulated active mining area
1: 12.0
2: 4.0
3: 1.5
4: 12.0
1: 7.0
2: 2.0
3: 1.0
4: 7.0
1: 2.0
2: 0.0
3: 0.5
4: 2.0
0
10
20
30
40
50
Page 1
Years
Reclamation trend

Summary and outlook

Model integrates spatial metrics for precision of indicators at scale

Technology: Satellite image, GNSS, optical surveys, dynamic models

Application: Compliance monitoring, transparency, inclusivity

Actionable visual intelligence – ML in image classification, DEA

Mini satellites, UAS – automated update of land use/cover metrics

Conclusion 1

A **generic** dynamic systems model has been developed to demonstrate the **novelty of integrating spatial modelling into a systems approach.**

This systems approach facilitates a **shared visual understanding** of the **interconnectedness** between mining activities, protected areas, demographic drivers of change, and other competing **spatial and temporal** land-use interests.

Conclusion 2

Large-scale impacts of interventions can be tested, hence scenario simulations to **inform policy and strategic planning**.

The model will facilitate consistent mining policy implementation and monitoring of compliance **to scale** in a **visual** and **transparent** manner.

Conclusion 3

Spatial models are critical to mine planning and resource management amidst the **increasingly complex web of competing, and at times conflicting**, space-use and socio-economic dynamics of the 21st century.

Way Forward: Policy Perspectives

Ensure a **participatory model** for awareness raising, ownership, active stakeholder engagement for ***collective environmental responsibility***

Political goodwill/regulations and policy-relevant research that provides objective, transparent and ***actionable visual intelligence***

Sustainable partnerships in sector development strategies needed for inclusive and win-win development

Quality research, education and training policy – for progressive, strategic and long-term societal transformation in all the sectors

Way Forward: Technological Perspectives

Blockchain technology to be considered as a way of facilitating traceability of origin and safety in the **mineral**, food safety, and water security value chain

Green technologies, circular economy – environmentally friendly technologies for efficient development, production, water harvesting, irrigation, aquifer recharge

Drones, sensors and **mapping** technologies – to help minimise wastage, collect and map data for scalability towards **AI & *Mining 4.0***

Digitalisation, GIS – digital spatial data & geocoded crowdsourcing by public ***mobile*** alerts to generate citizen science and map ***leakages***, ***illegal*** activities in water/ resource supply cycle

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