

Using GIS To Identify Hotspot and Land Management In and Around The Rail Reserve

Vhonani Samphenyane

Gautrain Management Agency (GMA), South Africa

Key words: GIS, Hotspot, Land Management, Power BI, Dashboard GTIA Rail Reserve Events

Abbreviations

AI	Artificial Intelligence
DEM	Digital Elevation Model
GIS	Geographic Information System
GMA	Gautrain Management Agency
GCRO	Gauteng City Region Observatory
GTIA	Gauteng Transport Infrastructure Act
OHTE	Overhead Traction Equipment
RREs	Rail Reserve Events
SAICE	South African Institute of Civil Engineering

1. EXECUTIVE SUMMARY

Gautrain system is one of Africa's most advanced Public Private Partnership (PPP) infrastructure initiatives, designed to provide a modern, reliable, and efficient rapid rail system across Gauteng South Africa. Since its inception, the network has connected 3 major metropolitan centres—City of Johannesburg, City of Tshwane, and City of Ekurhuleni—while also providing a crucial rail link to OR Tambo International Airport. There were two phases between 2010 and 2012, the Gautrain system represents South Africa's first major PPP rail project, and it has been rated *Grade A* by the South African Institute of Civil Engineering (SAICE) for its exceptional infrastructure performance.

Geographic Information Systems (GIS) have played a strategic role in strengthening Gautrain's operational efficiency, security, asset maintenance and protection, and long-term planning. Officially established as a functional unit within the Gautrain Management Agency (GMA) in 2013/14, the GIS expertise has become fundamental to security operations, land management, environmental compliance, incident tracking, and decision-making support.

Some of the GIS application within the rail environment is the monitoring and analysis of Rail Reserve Events (RREs)—including crime and non-criminal vandalism, accidents, trespassing, encroachments, and damage to palisade fence and infrastructure. By capturing incidents at precise (accurate) absolute and relative locations, GIS enables the detection of spatial patterns, trends and high-risk hotspots. The persistent cable theft at Salvokop showing cable theft spike, while busy highway-adjacent reserves frequently experience motor vehicle-related fence damages. Through hotspot and heatmap analysis, GIS has shown targeted interventions that have led to notable improvements in security and operational resilience between 2011 and 2026. The GIS framework supports the administration of Gauteng Transport Infrastructure Act (GTIA) applications, making sure that all construction or operational activities adjacent to, above, or below the rail reserve comply with safety and regulatory requirements. This is important in protecting the legally demarcated rail reserve, preventing unauthorized works, and reducing risks to passengers, infrastructure, and communities.

~~GMA's GIS system integrates multiple data sources—including cadastral records, environmental layers, rail infrastructure datasets, incident reports, mobile survey data, and Silesca outputs—to generate analytical products, dashboards, and spatial decision-support~~
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tools. These include hotspot maps, land-use impact maps, flood and erosion risk models, encroachment detection outputs, and priority maintenance rankings.

Overall, GIS has significantly enhanced operational efficiency, improved safety and security, supported regulatory compliance, optimized maintenance planning, and strengthened environmental management across the Gautrain system. As the rail network continues to change, expanding GIS capabilities and integrating emerging technologies will remain essential in enabling the GMA to deliver world-class rail services and ensure the long-term protection of the Gautrain asset.

2. BACKGROUND

The Gautrain Rapid Rail Network, a Public Private Partnership (PPP) project, was initiated to construct a modern rapid rail system in South Africa's Gauteng Province. The first and largest project of its kind in Africa, the

Gautrain rail system today links three metropolitan areas (Johannesburg, Tshwane and Ekurhuleni) and the OR Tambo International Airport (ORTIA). situated in Ekurhuleni. The Gautrain network consists of 10 stations, 80 kilometers of railway lines, a train depot and a bus depot, constructed

for the Dedicated Feeder and Distribution Services at all stations except for ORTIA. The first phase of this greenfield project – the first Public Private Partnership rail project in South Africa – was completed shortly before the

2010 FIFA World Cup, and involved linking Sandton to ORTIA as well as

constructing the train depot. The second phase, completed in June 2012, expanded the rail network to include Hatfield and Park stations. The Gautrain project involved several key public and private partner role players. The key public partner is the Gauteng Provincial Government, administered by the Gautrain Management Agency (GMA). Other key public partner role players

include the Gauteng Provincial Treasury and the National Treasury through Its PPP Unit.

3. INTRODUCTION

The Gautrain Project has been rated first grade by (South African Institute of Civil Engineering) in terms of infrastructure in South Africa by SAICE. In their infrastructure report card for 2022, SAICE had listed Gautrain grade A based on their grading framework.

It is important to have a robust strategy to secure the asset hence GIS is strategic tool decision making system useful in this regard.

This paper outlines how the GMA invested and used GIS tool to assist in securing the Gautrain assets.

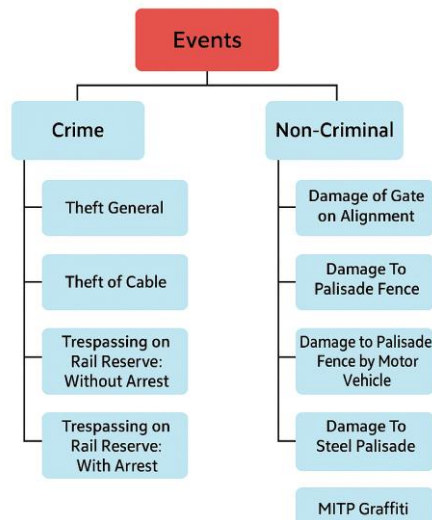
4. GIS IN GAUTRAIN OPERATIONS

Railway Reserve means an area of the land and associated vertical clearance along a railway line between the proclaimed boundaries on which the railway is found. Rail Reserve events are the occurrence of crime or non-criminal activities within the rail reserve. The Rail Reserve Events (RREs) statistics are extracted from the Monthly Security Report and captured by ArcGIS software.

The Rail reserve events are captured in a point format on the relative Overhead Traction Equipment (OHE) mast pole number (relative location), Patrol gates and Coordinates system (absolute location).

Using GIS to identify hotspots and concentrations of incidents, and the Rail Reserve (RREs). This helps the organization with deploying interventions to address the risks and reduce reoccurrence.

- Provide insight into the spatial distribution of Rail Reserve Events (RRE) across the Gautrain system.
- Identify geographical areas with high concentrations of events between January 2025 and February 2026.
- Compare RRE patterns and trends across different years.
- Present spatial analyses that support improved operational and security decision-making.



The areas prone to this is reserve along the busy highway is experiencing high volume of Motor Vehicle accident-causing damage to palisade fence.

The Salvokop area experienced numerous attempted cable theft and cable theft, becoming high concentrated areas of cable theft. This was because the area was isolated and dark during the night. GIS was used to highlight hotspots and heatmap outputs to pinpoint this area that requiring targeted intervention.

The Trespassing mostly occurs in the commercial and construction areas where most people frequent looking for opportunities.

Damage to palisade fence occurs due to natural courses heat and floods. And sometimes palisades are damaged by trespassers looking for a short cut to cross to the other side of the rail reserve.

MITP graffiti has been noted in mostly viaducts and concrete areas. It has shown a rise in the previous few years.

A truck fell onto track and caused train derailment, 50 passengers dead in the accident at Hualien Taiwan in Apr 2021(Hong Kong Safety regulator presentation at UITP Conference)

5. APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEMS (GIS) IN GAUTRAIN OPERATIONS

5.1 HISTORY OF THE USE OF GIS BY THE GAUTRAIN PROJECT

- The first GIS enabled website was developed in 2007 to keep stakeholders up to date with the latest project developments.

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- The growth of the GMA saw a large increase in human resources.

- GIS capacity was earmarked to support transport planning and integration programs.

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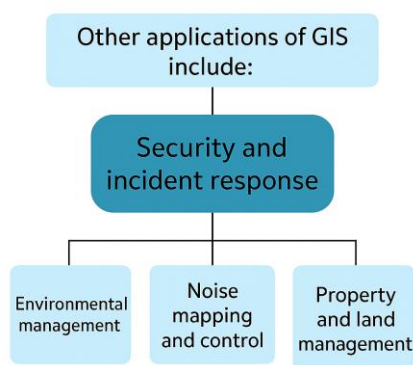
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- As a result, GIS was formally introduced as a functional project area in the 2013/14 financial year.
- Using GIS to support decision making, planning and operations is one of the key success factors of the Gautrain System.

5.2 GIS TECHNOLOGY

- Transport systems like Gautrain rely on making continuous improvements in engineering and technology to keep the system efficient.
- Rail organizations around the world have pioneered the use of geospatial technology like Intergraph and ArcGIS.
- These Geographic Information Systems (GIS) can be integrated with other systems to gain clear insight into asset performance.

5.2.1 Other applications of GIS include:



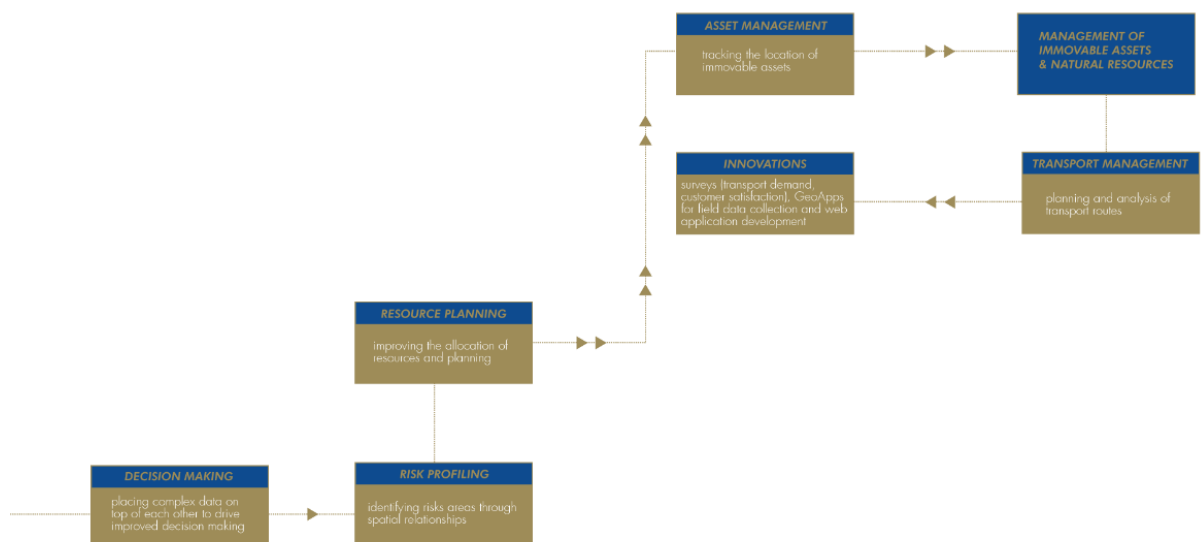
5.2.2 There are interesting parallels between the main components of a GIS and the requirements of an efficient rail system. These are detailed in the table below:

COMPONENT	GIS	RAIL
 PEOPLE	Highly skilled and knowledgeable personnel.	Highly skilled and knowledgeable personnel in the different facets of rail.
 HARDWARE	Equipment required to perform the task i.e. GIS server, desktop computers and mobile gadgets.	Machinery: engineering required for the manufacture of such equipment.
 SOFTWARE	Technology Tools, Graphic User Interface (GUI), Database Management Systems etc.	Rail technology for various components such as signalling, communications etc.
 PROCESSES	Well-designed plan and business rules, which are the models and operating practices.	Strategies, plans, tools and techniques applied in rail.
 DATA	Spatial and attribute data.	Transport and Asset Data.

5.2.3 Implementing the GIS was done using a project approach and completed in four phases: Using GIS To Identify, Adopt and Land Management using ArcGIS in the Randburg (1) Vhokhosi (South Africa)



5.3 KEY BENEFITS OF A GIS SYSTEM



5.4 HOW GIS SUPPORTS GMA OPERATIONS

- Land management
- System security
- Route planning and analysis
- Asset management
- Environmental management and planning
- Marketing
- GTIA applications: capturing GTIA application location and attributes, plus assessing applications to determine spatial relationships.

5.4.1 GTIA (Gautrain Transport Infrastructure Act)

- GIS Team of Transport Integration and Planning at Gautrain Management Agency (GMA) receive and processes incoming Applications from third parties. A third party can be an entity, organization, or any individual who has interest in conducting any activities above, below or adjacent to the rail reserve. The

Using GIS To Identify Applications and Manage them to get permission to perform operations that may affect Vhonani Samphenyanti (South Africa). The GMA specialist assesses the Application and together with

relevant affected parties make decisions whether to approve, approve conditionally or disapprove the Applications.

- The Gautrain system is governed by the GTIA, and that act seeks to protect and manage the need to work in adjacent, below or above the railway. Anyone who seeks to conduct any works with the rail reserve must apply to Gautrain Management Agency (GMA) using the GTIA. GMA will therefore look in the application, approve the application with conditions or not approve the application due to risks associated with the application. In case of the of unauthorised works in adjacent, below or above the railway reserve, actions may be taken to the perpetrators

5.5 Rail Reserve

A Railway Reserve (RR) is a legally demarcated, restricted strip of land adjacent to and including railway tracks, stations, and infrastructure, designed to ensure safe rail operations. A rail reserve must be fenced for protection. Railway reserve acts as a safety buffer zone, often extending beyond the tracks, and is protected against unauthorized, encroachment, construction, or excavation. It therefore has restrictions of the unauthorised activities such as crossing the tracks, building structures, drilling boreholes, removing fences and illegal dumping. The safety zone is crucial for managing risks related to train speed, noise and potential accidents.

5.6 GIS Software

GMA uses the GIS software to capture the Rail reserve events, crime or non-crime from monthly security report. Wherein all rail reserve events are captured on GIS System. The captured incidents are therefore analysed and determine hotspots. The hotspot report is shared with management for decision making

6. Key GIS Applications in Rail Reserve Management

6.1 Hotspot Identification

GIS can detect spatial concentrations of risks or incidents, also known as *hotspots*. This helps prioritize interventions.

Common Hotspots along Rail Corridors

- Wayleave application (Constructions areas) hotspots
- Rail Reserve events
- Vegetation overgrown areas
- Encroachments
- Drainage and erosion-prone areas
- Illegal crossing hotspots
- Illegal dumping areas

Category	Description
Wayleave application (Construction areas) hotspots	Areas where construction activity requires permission and poses operational or safety risks
Rail Reserve events	Incidents occurring within the designated rail reserve boundary

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Category	Description
Vegetation overgrown areas	Sections where vegetation growth obstructs visibility, signage, or safe train operations
Encroachments	Unauthorized use or occupation of railway land or servitudes
Drainage and erosion-prone areas	Locations vulnerable to flooding, poor drainage, wash-aways, or erosion affecting track integrity
Illegal crossing hotspots	Informal footpaths or vehicle crossings posing serious safety hazards
Illegal dumping areas	Places where waste is regularly dumped, affecting safety, drainage, and environmental compliance

On their presentation, Hong Kong safety regulator shared how AI Plus Big Data Technology Driven Culture Change on Railway Safety and Security play an important role in early detections.

GIS Tools for Hotspot Mapping

- Kernel Density Estimation (KDE) for accident on crime and none-crime
- The proposed possible intervention outlined below as per Gauteng City Region Observatory GCRO Report. GCRO conducted research for Gautrain system security, had some of the recommendations, Strengthening the GMA's knowledge base by utilising the platform and methodology provided. The identification and analysis of hotspots, when combined with the in-loco 2investigation, can be used to develop security and operational interventions that can help prevent future events.
- To enhance the security of the rail infrastructure, additional protective buffer zones can be developed by creating partnerships with adjacent residential and business communities. This means fostering partnerships with these neighbours and neighbouring structures (such as community policing forums or youth desks) through regular engagements and providing them with infrastructure or service support, which must be needs-based as identified during engagements. This may take the form of sponsoring community patrols on the parameter of the rail reserve. These partnerships, if sustained, may enable greater protection and resilience over the longer term.

7. Data Sources for Rail Reserve Analysis

Using rail centrelines assist in supporting connectivity, determining the shortest paths calculations and accessibility. It allows the rail and road to be referenced by use of chainages in kilometres. Land Cover assist in detecting the changes over time (i.e. deforestation). The environmental impact assessment, water corridor management and suitability analysis studies used to identify suitable locations for railway, pipelines or housing projects, The Digital

Elevation model assist in determining slopes, floods lines, hazard assessment, drainage models and infrastructure design,

7.1 Spatial Data Base layer (Source)

GMA GIS has four licenses for users, allowing them to access and maintain GIS datasets. These datasets are:

DATA TYPE	DESCRIPTION	DETAIL
POLYGON	Land parcels	Contains Land Information Register (LIR)
LINE	- Rail Route - Rail Reserve - Bus Routes - Midibus Routes	- Contains rail track position within the reserve - Contains the boundary of the rail reserve, as per proclamation notice - Contains bus/midibus network and route information data
POINTS	- Bus Stops - Train Stations - GTIA Applications - Rail reserve incidents - Rail immovable assets i.e. mastpoles, CCTV cameras etc.	

- Rail centerlines, buffers, and servitude boundaries
- Infrastructure shapefiles (bridges, culverts, stations, signals)
- Municipal zoning
- Cadastral data
- Environmental sensitivity layers (protected areas, wetlands)

7.2 Field & Operational Data (Incident Data Layer) Input

- Incident/accident logs (Monthly Security Reports)
- System inspections
- Photographs and mobile data collection (Collector/Survey123)
- Sitescan data

7.3 Analysis Layer (Output)

- Land cover/land use
- Digital Elevation Model (DEM)
- Map book
- Impact Maps
- Infrastructure shapefiles (bridges, culverts, stations, signals)

8. GIS Workflow for Hotspot and Land Management Analysis

Step 1: Define the Rail Reserve Area

- Buffer the rail centerline (Between 20 – 40m on rail reserve and varies per station)

Step 2: Integrate Incident & Maintenance Data

- Geocode accident/incident reports
- Map vandalism/theft locations
- Vegetation overgrown points from inspections

Step 3: Perform Hotspot Analysis

- Use KDE to visualize concentrations

Step 4: Conduct Environmental Risk Mapping

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- Vegetation risk: NDVI, land cover classification
- Fire risk: fuel load + proximity to communities + slope
- Flood/erosion risk: DEM, flow accumulation, soil types
- Encroachment risk: overlay land use & cadastral parcels

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Step 5: Develop a Rail Reserve Management Map

- Identify High-risk hotspots
- Prioritise maintenance zones
- Encroached land parcels

Step 6: Produce Dashboards & Reports

Use ArcGIS Dashboard and Power BI

Monitor incidents

- Track vegetation maintenance cycles
- Visualize work orders spatially

Step	Category	Process	Key Activities
1. Define the Rail Reserve Area	 <i>Data Preparation</i>	Create Rail Reserve Boundary	• Buffer rail centerline (20–40m, varies per station) • Generate continuous rail reserve polygon
2. Integrate Incident & Maintenance Data	 <i>Data Preparation</i>	Import & Geocode Data	• Geocode accident/incident reports • Map vandalism/theft locations • Add vegetation overgrown inspection points
3. Perform Hotspot Analysis	 <i>Analysis</i>	KDE Density Modelling	• Run KDE for incidents, theft, vegetation issues • Identify spatial clusters & severity zones
4. Conduct Environmental Risk Mapping	 <i>Risk Assessment</i>	Multi-Risk Environmental Analysis	Vegetation Risk: NDVI, land cover Fire Risk: fuel load, slope, proximity to communities Flood/Erosion: DEM, flow accumulation, soil type Encroachment: cadastral + land use overlay
5. Develop Rail Reserve Management Map	 <i>Decision Support</i>	Generate Prioritized Risk Map	• Hotspot identification • Maintenance priority zoning • Sensitive ecological areas • Encroached land parcels
6. Produce Dashboards & Reports	 <i>Decision Support</i>	Reporting & Monitoring	Tools: ArcGIS Dashboard, Power BI • Monitor incidents • Track vegetation maintenance cycles • Visualize work orders spatially

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. Outputs and Products

9.1 Maps

- Hotspot maps
- Encroachment detection maps
- Rail corridor land-use planning maps

9.2 Analytical Reports

- Priority maintenance zone ranking (Highest to Lowest)
- Early-warning alerts and predictive models

9.3 Dashboards (Management)

- Incident trends and patterns
- Maintenance backlogs
- Heatmaps of high-risk locations

10. Benefits of Using GIS in the Gautrain System

GIS enables the following.

10.1 Operational Efficiency

- Targeted maintenance reduces cost and improves response times

10.2 Safety and security Enhancements

- Early detection of risks reduces derailments and accidents

10.3 Compliance Management

- Ensures rail operations adhere to environmental and land-use regulations

10.4 Strategic and long-term Planning

- Long-term investment decisions supported by spatial evidence

10.5 Environmental and Quality Management

- Sustainable vegetation management, erosion, and drainage management

11. Conclusion

GIS has been used effectively within the GMA in the planning of Dedicated Feeder and Distribution Services (DFDS) and Midibus Feeder and Distribution service (MFDS) routes,

assessment of GTIA applications, Gautrain System Security and representation of development or transport plans to support decision making. GIS team to be exposed to latest technologies that can assist the GMA in its assurance role and to enhance its business operations.

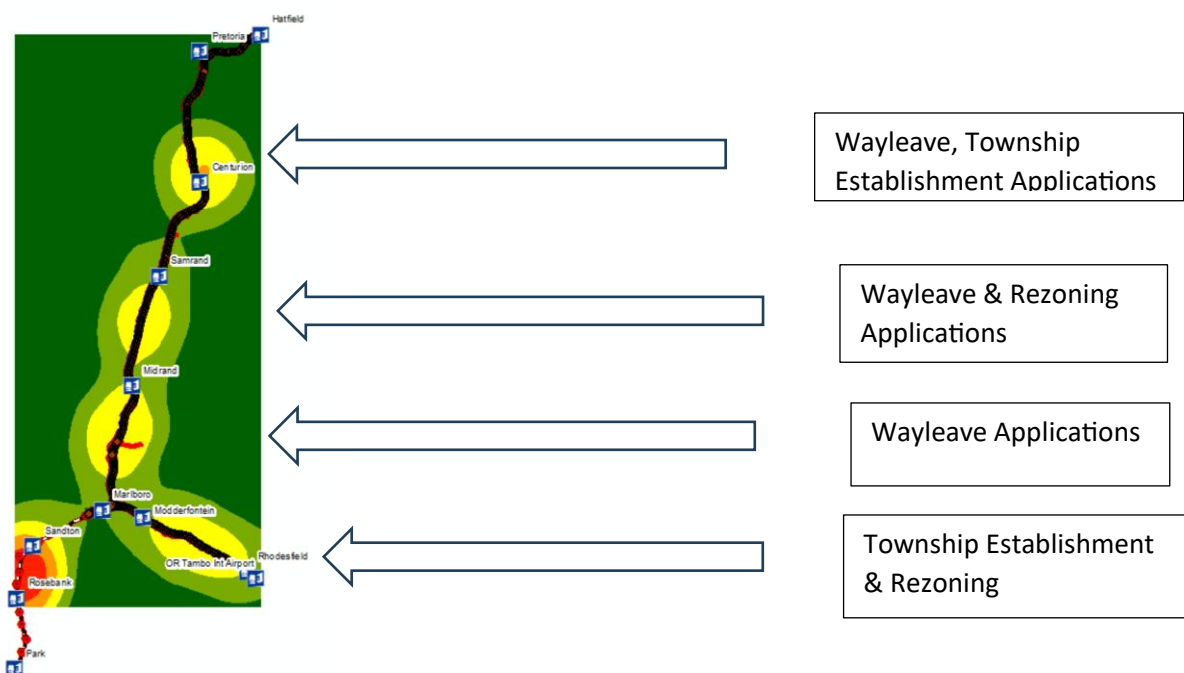
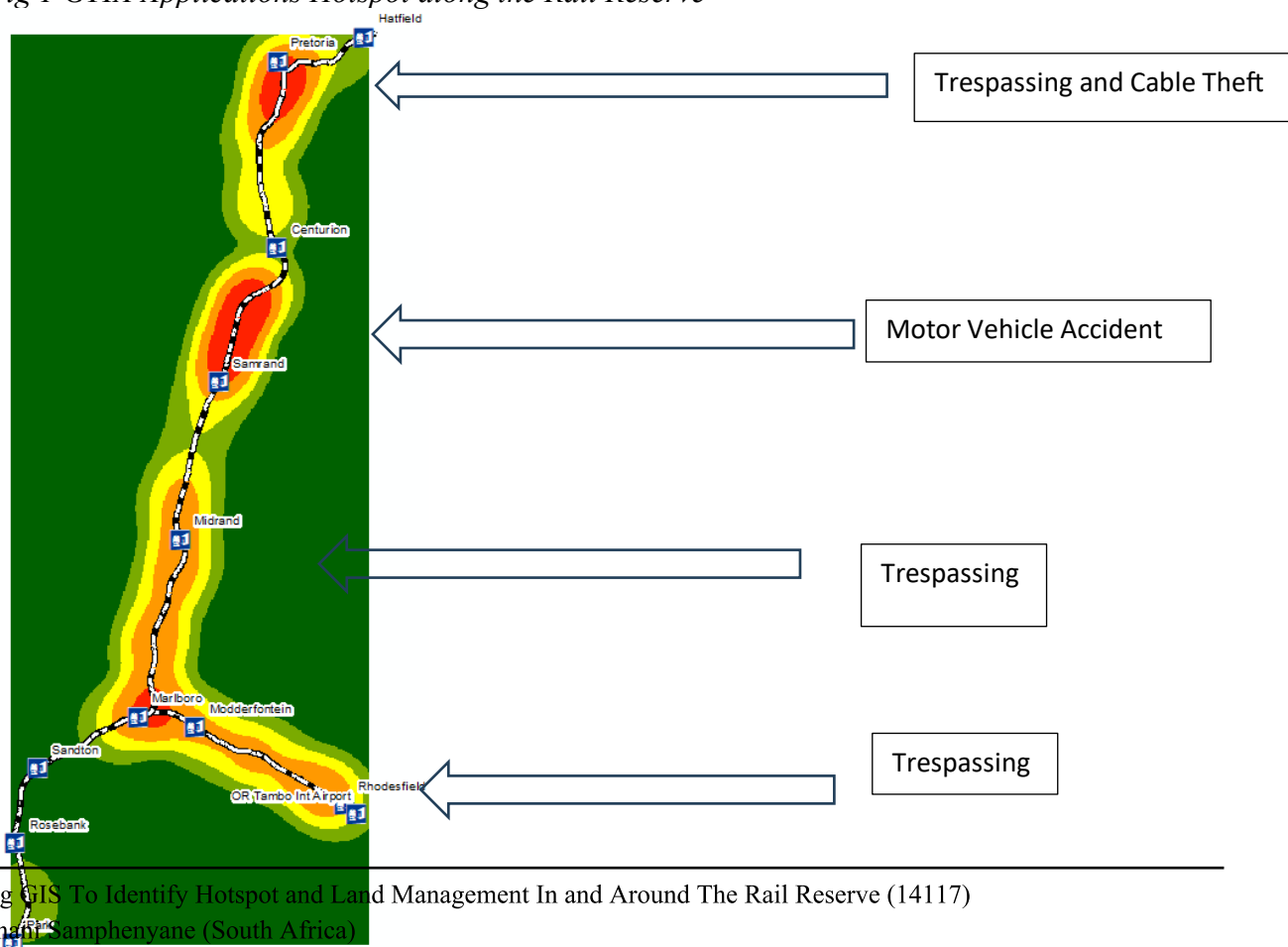


Fig 1 GTIA Applications Hotspot along the Rail Reserve



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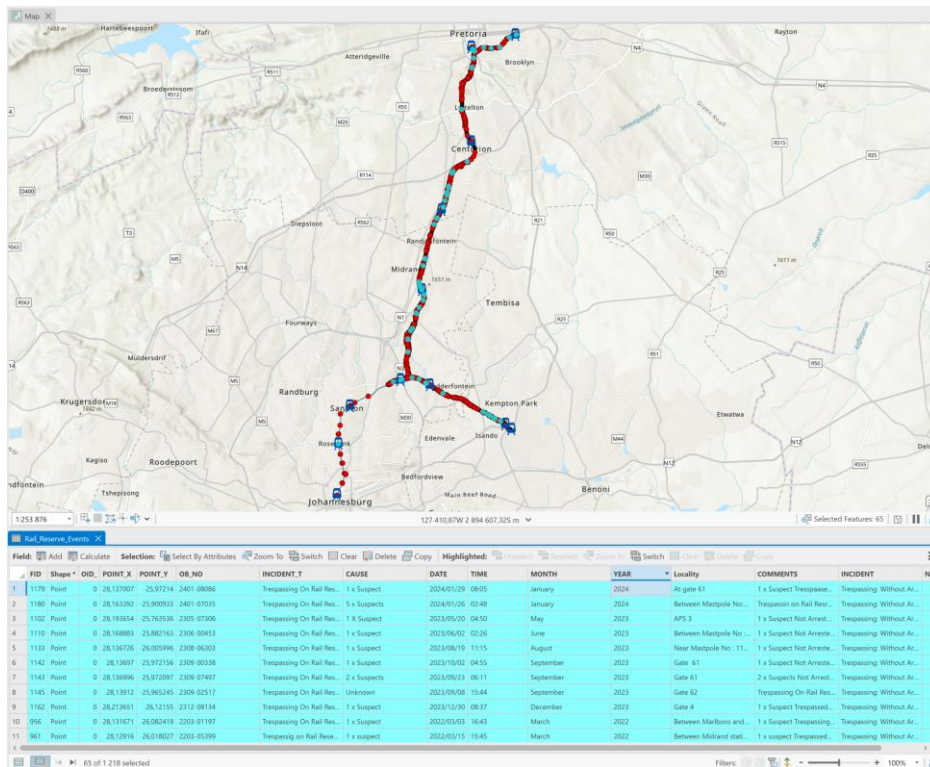


Fig 3 Gautrain RREs

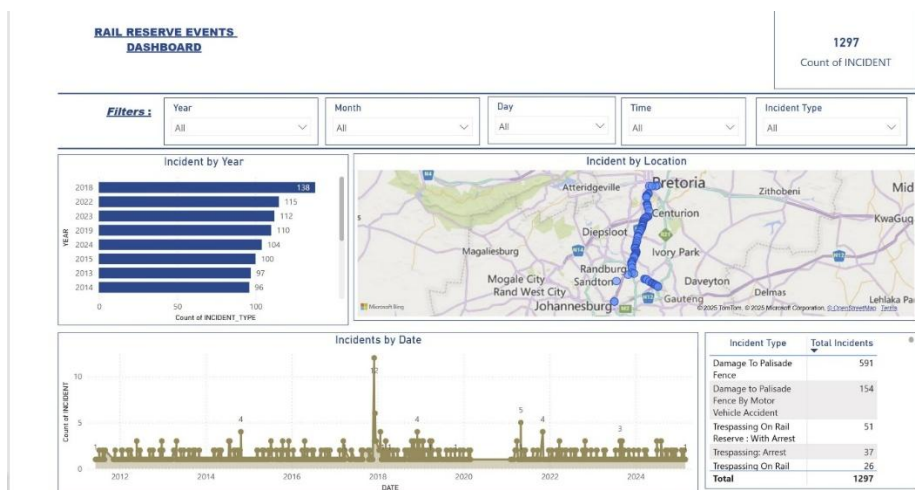


Fig 4 Gautrain RREs Powerbi Dashboard

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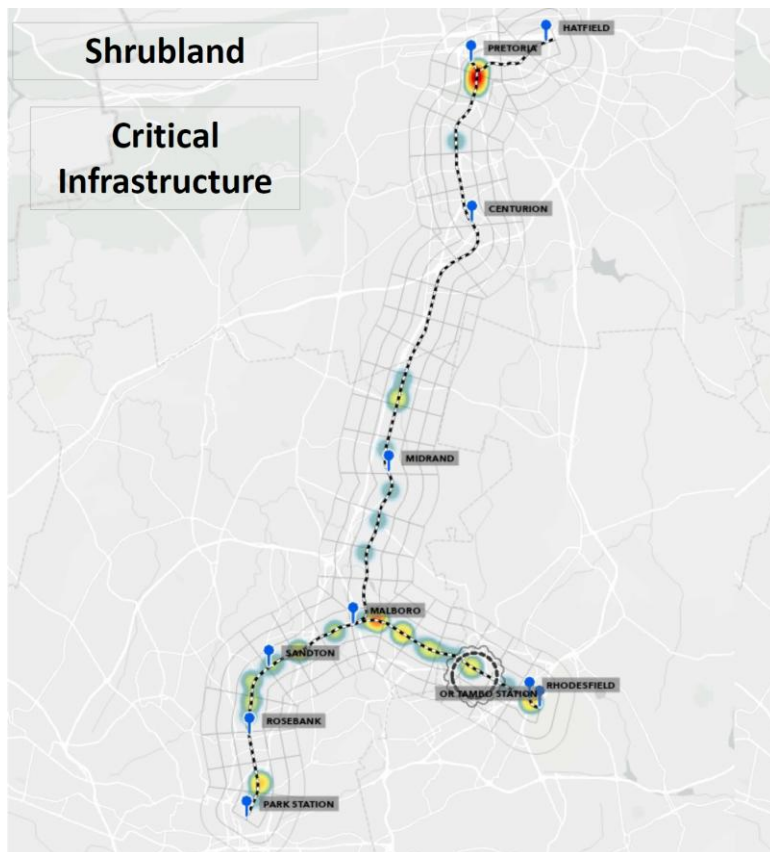


Fig 5 Shrubland along the Rail Reserve

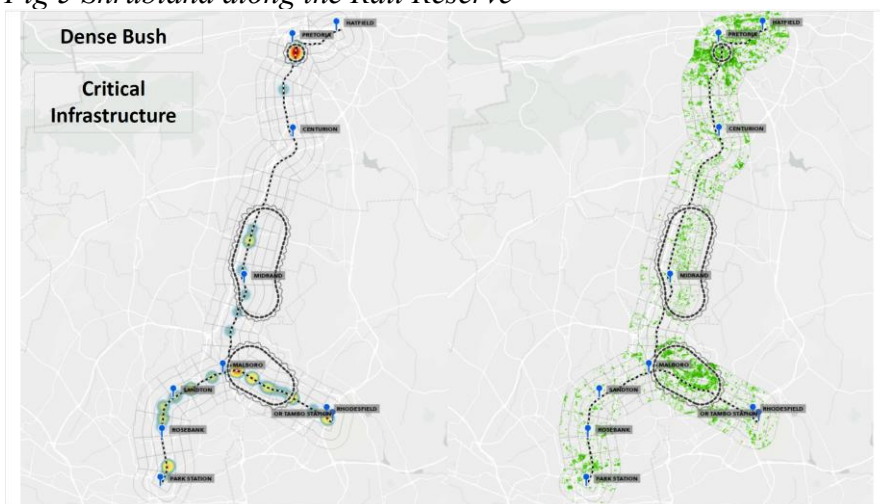
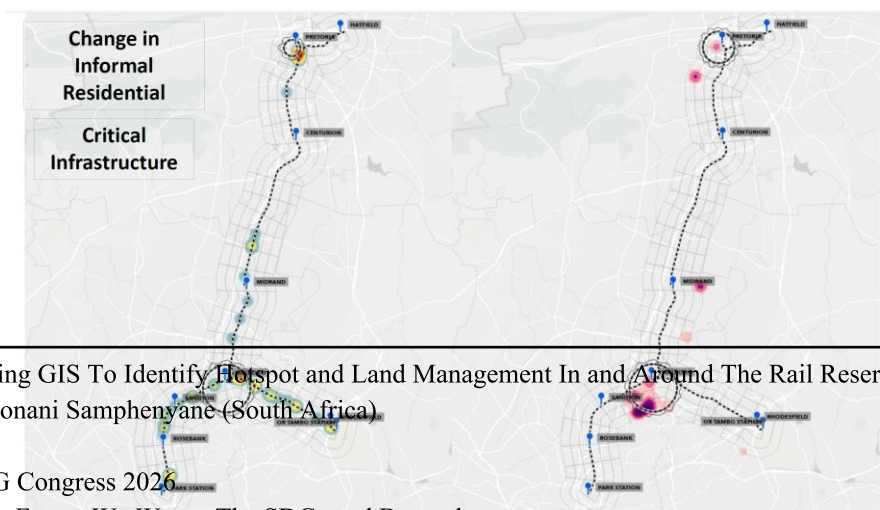


Fig 6 Dense Bush along the Rail Reserve



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Fig 7 Change in Informal Residential

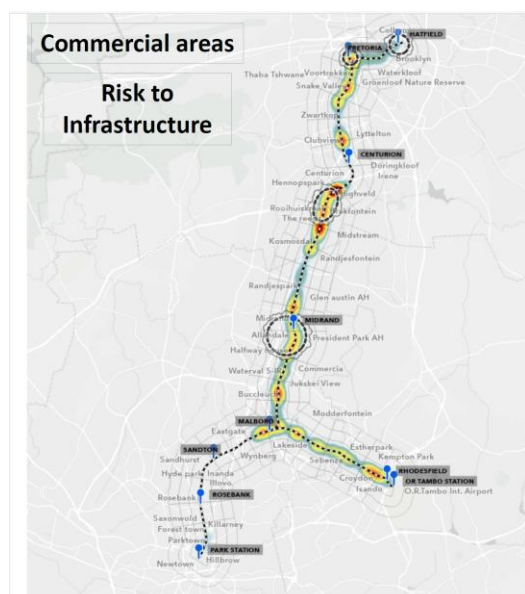


Fig 8 Commercial area along Rail Reserve

Based on the above studies and presentations, we can conclude that there are similar incidents at Gautrain, Prasa and what Hong Kong Railway Safety Regulator shared on their presentation.

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