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SADC GROUNDWATER MANAGEMENT INSTITUTE

Assessment and Mapping of Groundwater Resources in Lilongwe City

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IUCN · BRIDGE · International Association of Hydrogeologists, the World-wide Groundwater Organisation · IWMI International Water Management Institute · GRIPP Groundwater Solutions Initiative for Policy and Practice · igrac International Groundwater Resources Assessment Centre · BGS British Geological Survey · IGS Institute for Groundwater Studies · University of Botswana · The University of Zambia

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Presentation Outline

- Introduction
- Project Area
- Implementation
- Results
- Discussion and Conclusion

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Introduction

General Introduction

- The GW assessment was part of the World Bank/IDA funded Lilongwe Water and Sanitation Project
- Lilongwe City faces unique water security challenges
    - Existing system barely sustain the current demand during dry months – 130,000m^3/day
    - Demand projected to increase to 170,000m^3/day by 2025 and 255,000m^3/day

Project Objective

- to ascertain groundwater potential and vulnerability for conjunctive use, to provide basis for future investments in groundwater resource development

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Intro…cont

Project Justification

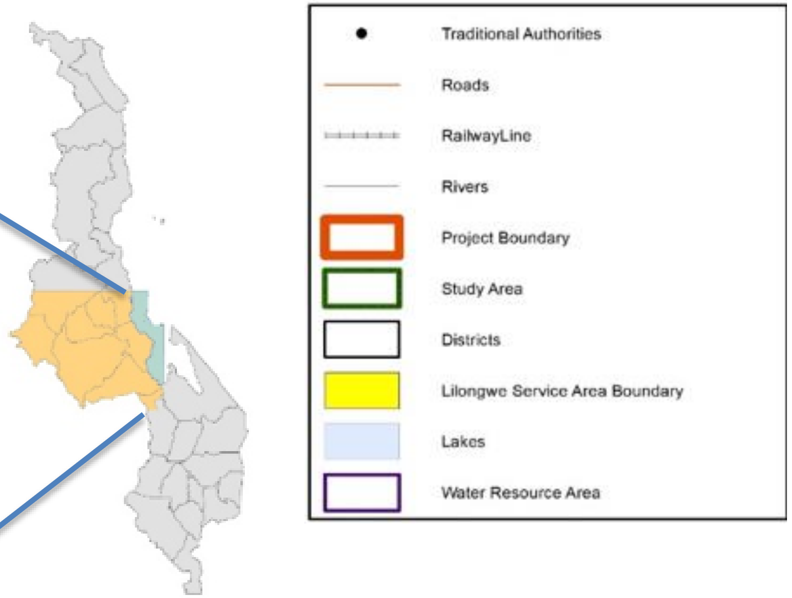
- Increase water security for the City to supplement the existing surface water sources
- Response to:
  - Limited information and understanding of groundwater occurrence in the project area
  - Effects of climate change – water shortages during drought periods

Specific Objectives

- Spatial mapping of occurrence of aquifers and their groundwater potential
- Determination of hydraulic characteristics for the identified and mapped aquifers
- Spatial mapping of groundwater quality and quantity and determination of potential limitations to its use
- Preparation of groundwater quantity and quality atlases that would guide groundwater exploration and development
- Preparation of groundwater vulnerability maps to inform on areas unsuitable for groundwater development and map aquifer protection zones

Study Area

- Project boundary – 50km radius of the city



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Implementation Approach

- Desk study
- Data Collection and Interpretation
    - Identification of potential aquifers
    - Geophysical surveys and hydrogeological investigations – three methods increase level of confidence in site selection
        - o HLEM – Horizontal Loop Electromagnetic Method
        - o MAG – Ground Magnetics
        - o AMT – Profiling using the Audio Magnetotelluric
    - Drilling and pumping test
- Preparation of Atlases and maps

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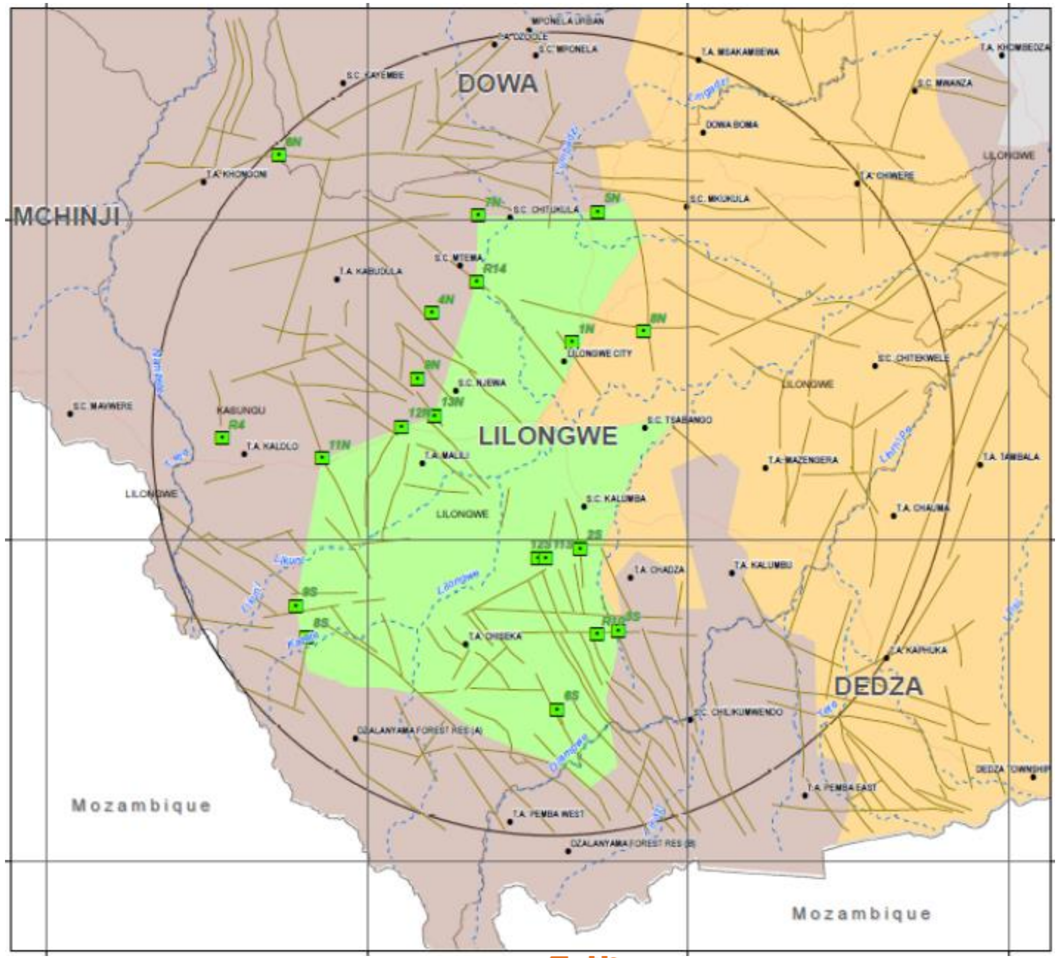
Geophysical surveys

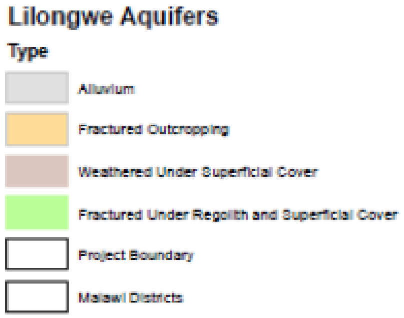
Results were plotted in excel and qualitatively interpreted

- High potential areas demarcated North, North West and South as results returned good anomalies
- East areas returned poor anomalies (vertical conductors) i.e. poor groundwater potential
- Most lineaments interpreted are vertical and could be identified on the ground
- HLEM was effective in identifying the vertical conductors
- 25 potential sites (13 North and 12 South) were selected for drilling the exploratory BHs from a target of 37

Aquifer Types and Distribution

- Weathered gneiss aquifer in the west
  - o Overburden/recent sediments
  - o Flatter terrain – better recharge
- Fractured gneiss aquifer in the west
  - o Superficial deposits and unsaturated weathered regolith
- Outcropping Fractured gneiss in the east
  - o Thin overburden or none at all
  - o Undulating terrain – high runoff





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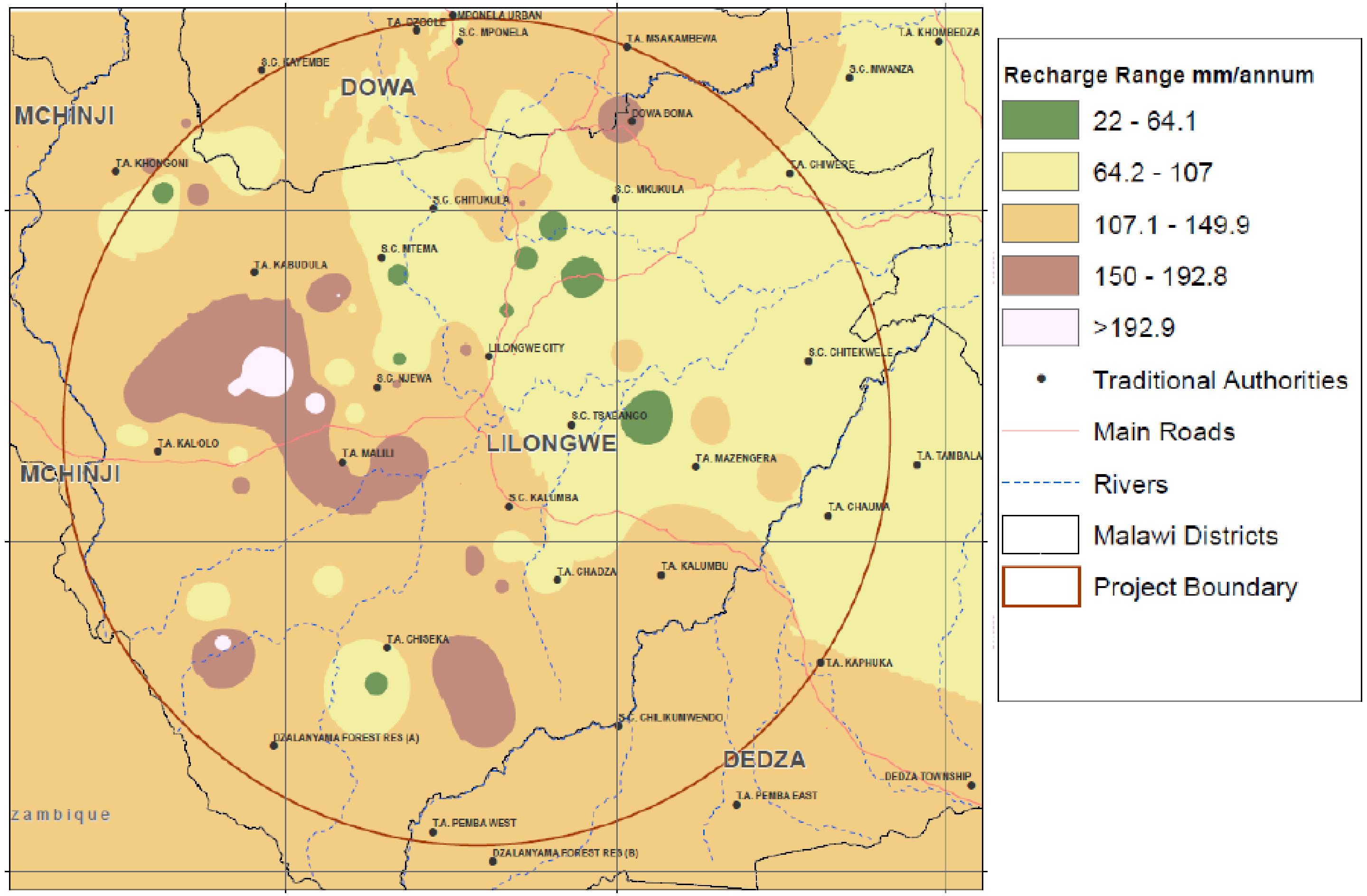
Groundwater Occurrence

- In both the Weathered and Fractured Aquifer
- High GW potential in the West (superficial cover), promotes recharge while low GW potential in the East
- Fractured basement aquifer has higher GW potential
    - 80% of successful boreholes intercepted water in fractured zones
- Water strikes were encountered between 3mbgl and 198mbgl
    - 85% of all water strikes encountered between 3mbgl and 50mbgl
- Borehole yields ranged from 0.01 l/s to 23 l/s
    - Yield of 23 l/s was recorded in weathered Biotite Gneiss
- Calculated long-term sustainable pumping rate ranged from 0.1 l/s to 9 l/s

Groundwater Recharge

- Estimated from water level hydrographs and chloride mass balance
- Recharge rates ranged from 20mm/yr to 120mm/yr, increasing from East to West



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Aquifer Transmissivity

- Highest transmissivity found within the fractured basement aquifer
  - Most of the flow during pumping came from the fractured bedrock
- Range from $1m^2/d$ to $58m^2/d$
  - 10 to $58m^2/d$ was from deeply seated fracturing along prominent regional faults
  - 4 to $9m^2/d$ from relatively thick weathered rock up to 40m, indicating moderate aquifer potential
  - Lowest values were from moderately fractured basement aquifer with range from $1\text{-}2m^2/d$
- High transmissivity values were also associated with lithological contacts of basement gneiss and granite

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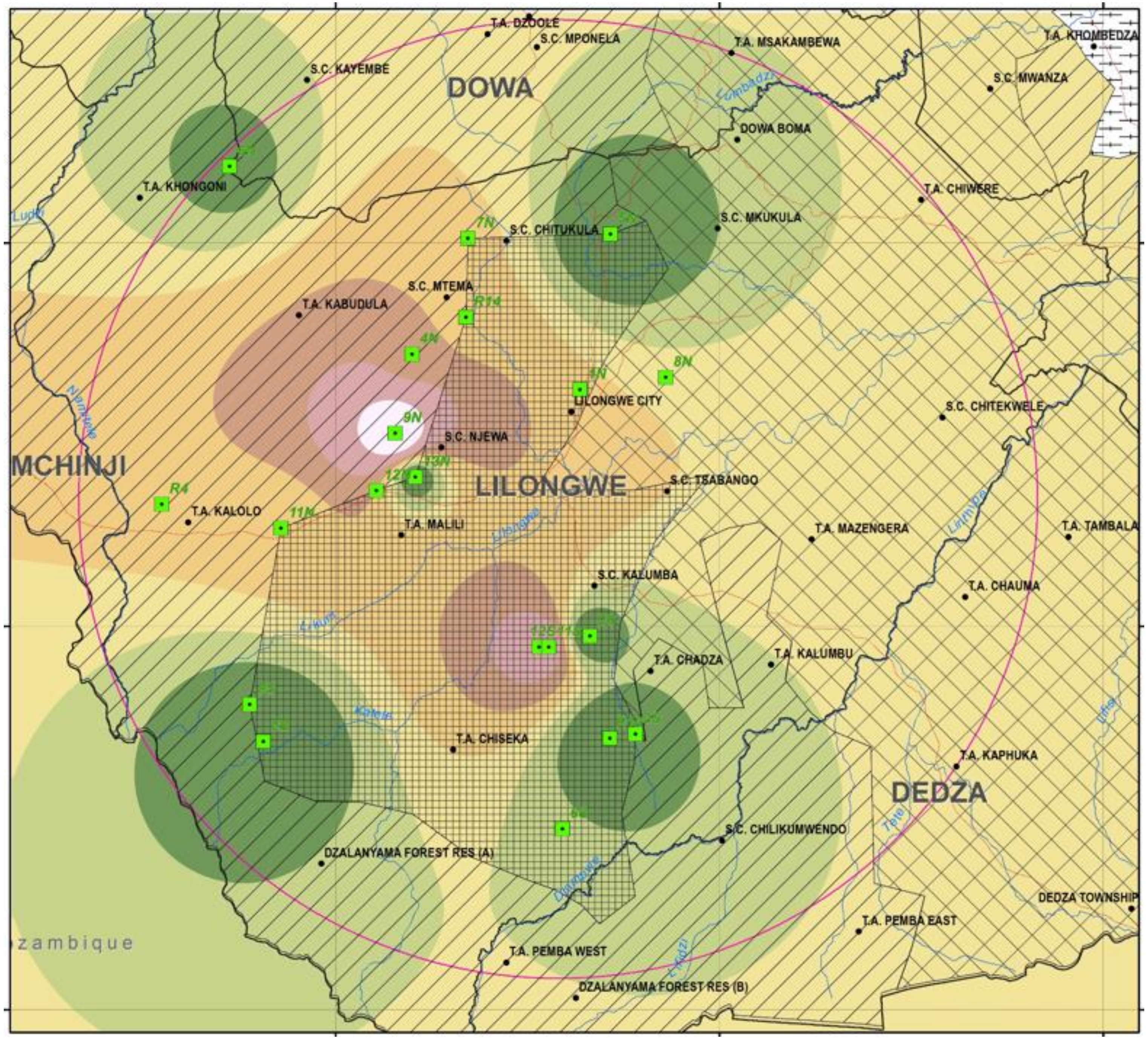
Groundwater Chemistry

- GW quality is good, all parameters within the recommended limits for Malawi drinking water standards for BHs and SW, MS733:2005
- No evidence of pollution from the data
- GW type showed dominance of $CaHCO_3$
  - Indicating fresh and recently recharged GW system, TDS < 1000mg/l and EC < 2000µS/cm
- Presence of Na^+ and SO_4^{2-} shows mixing of recently recharged GW with older GW associated with deep fractured aquifer while Ca^{2+}, Mg^{2+} and HCO_3^- water is associated with shallow GW flow within the weathered and shallower fractured aquifer.

Quantification of Groundwater Resources

- **Fractured Gneiss under weathered regolith and superficial cover** had the highest groundwater storage volume per square kilometer, at 18MCM/km^2
    - Prominent within 30km west of Lilongwe City
- The estimated volume in the **Weathered aquifer under superficial cover** was 8MCM/km^2
    - Storage volume is limited by aquifer thickness
    - Yields of 3.5 l/s to 23l/s were encountered where depth of weathering was ≥ 40m
- The **Outcropping Fractured Gneiss** to the east is characterized by low groundwater storage volume approximately 4MCM/km^2 due to limited weathering and lack of dense fracturing. Yields were generally less than 1 l/s
- Estimated available groundwater volume was **1818 MCM/yr**, reduced by 50% to cater for environmental flow requirements

Groundwater Potential Zones



Drilled Boreholes
Traditional Authorities
Main Roads
Rivers

Aquifer Type

Alluvium
Fractured Outcropping
Weathered Under Superficial Cover
Fractured Under Regolith and Superficial Cover
Project Boundary
Malawi Districts

GroundWater Potential Zones

Extremely Low
Low
Low to Medium
Medium
Medium to High
High
Very High

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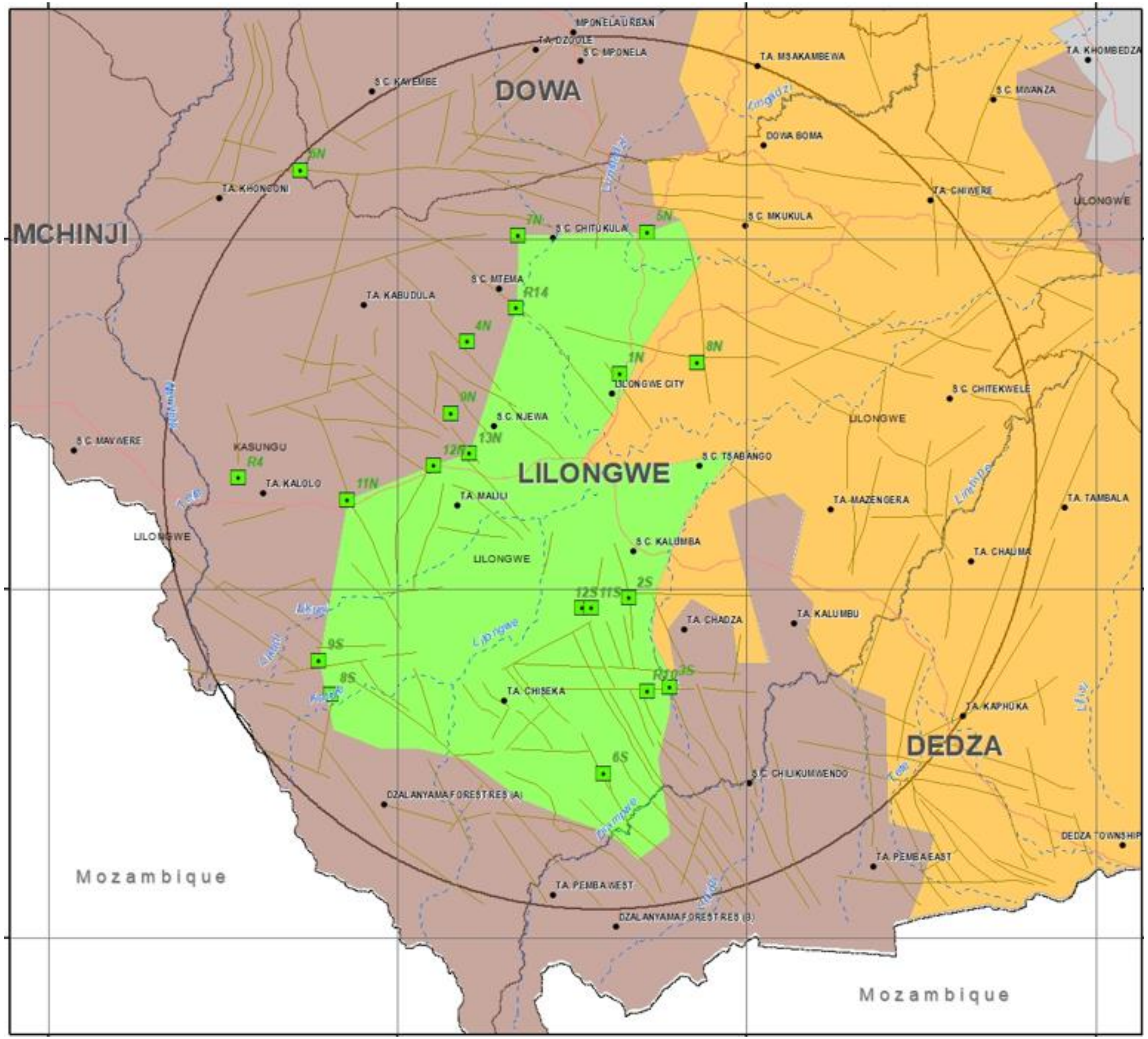
Groundwater Storage Map



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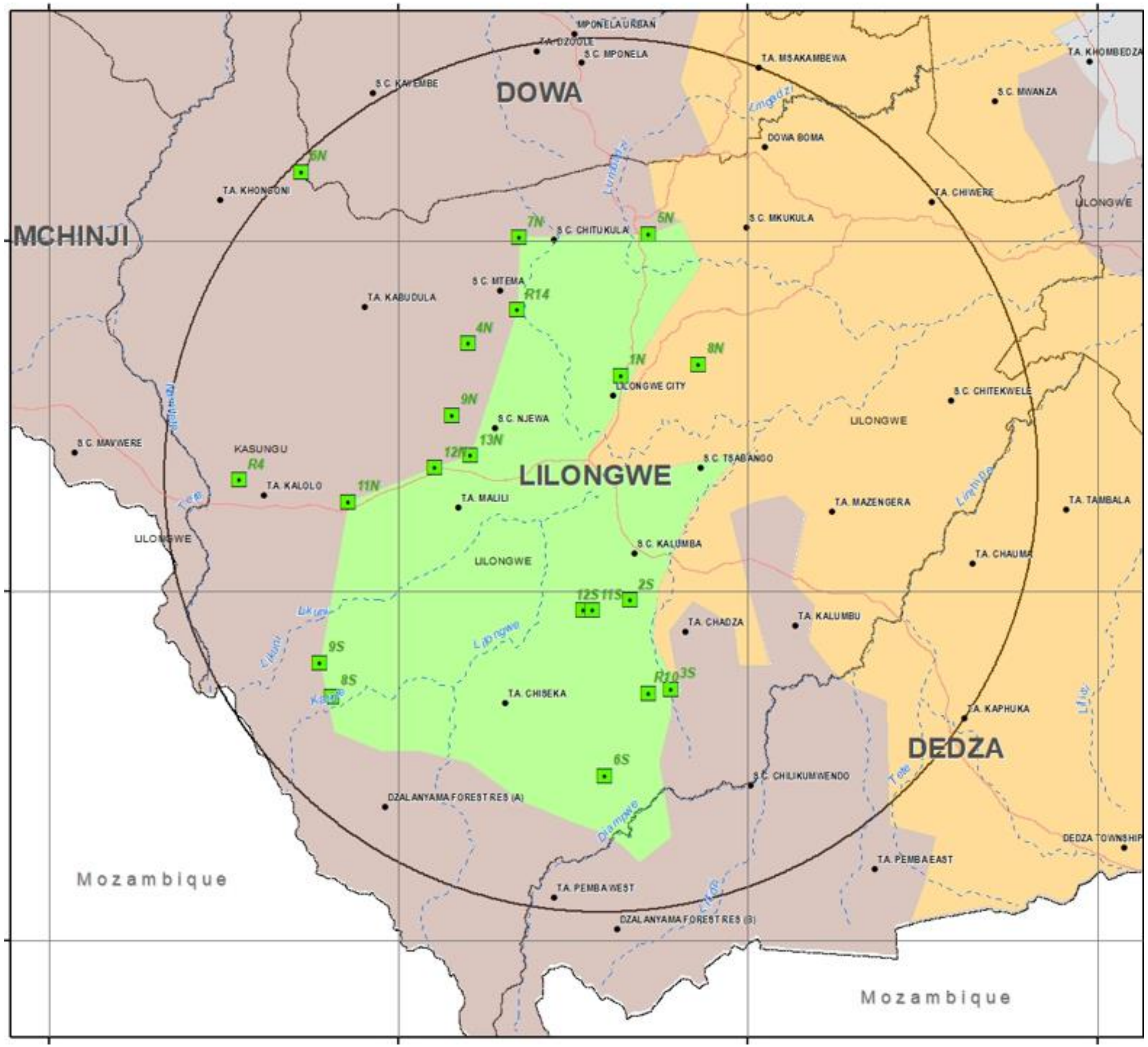
Annual Sustainable Groundwater Availability (ASGA)

Hydrogeological Unit	Area (km²)	Mean Recharge (mm/yr.)	ASGA (MCM/yr)	Net ASGA (MCM/yr) (50%)
Weathered Under Superficial Cover	3,549	129	458	229
Fractured Under Regolith and Superficial Cover	7,140	160	1,142	571
Fractured Outcropping	2,463	86	218	109
Total			**1,818**	**909**



Net ASGA (MCM) (50%)

Type

- Alluvium
- Fractured Outcropping (109)
- Weathered Under Superficial Cover (229)
- Fractured Under Regolith and Superficial Cover (571)
- Project Boundary
- Malawi Districts

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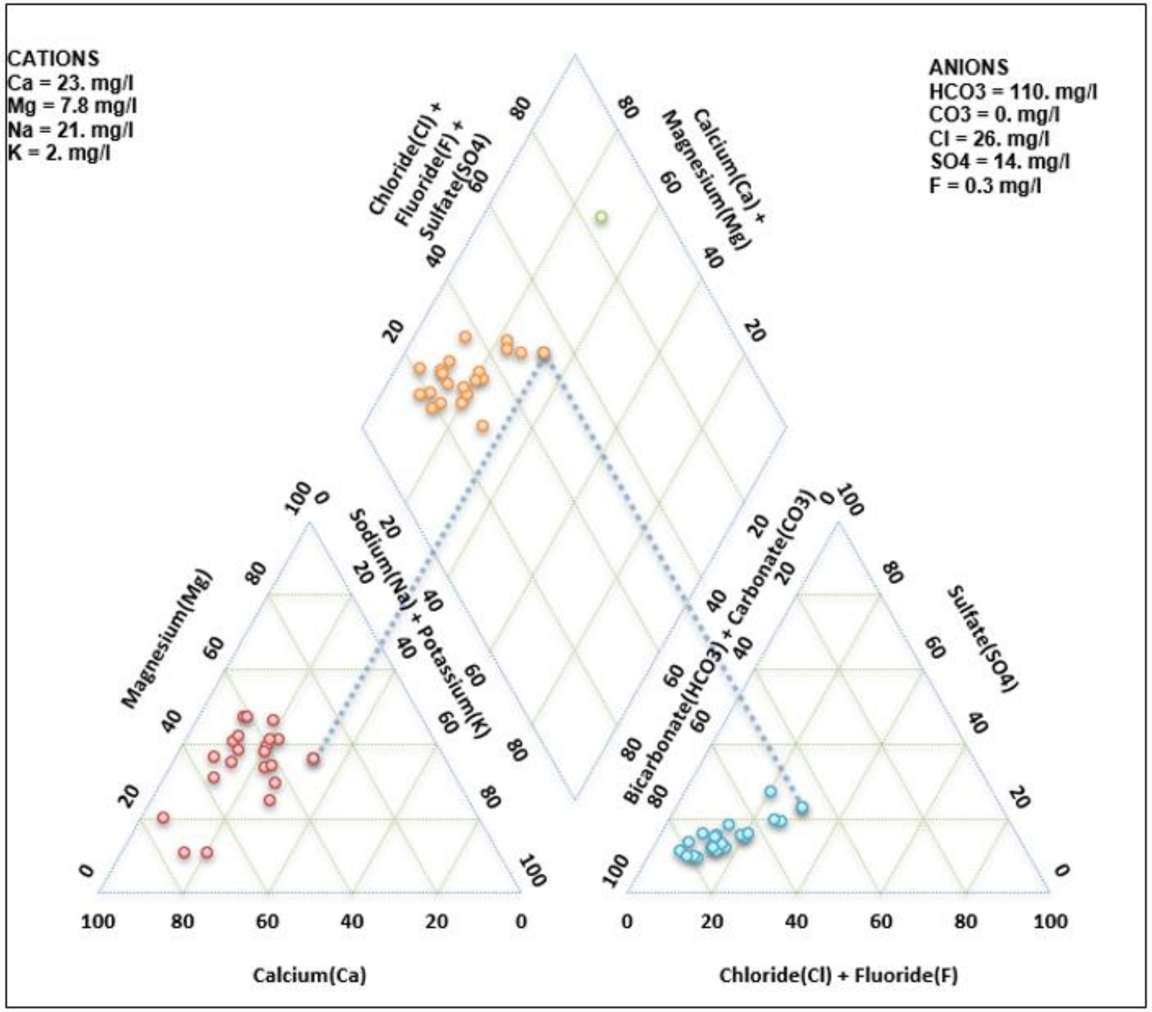
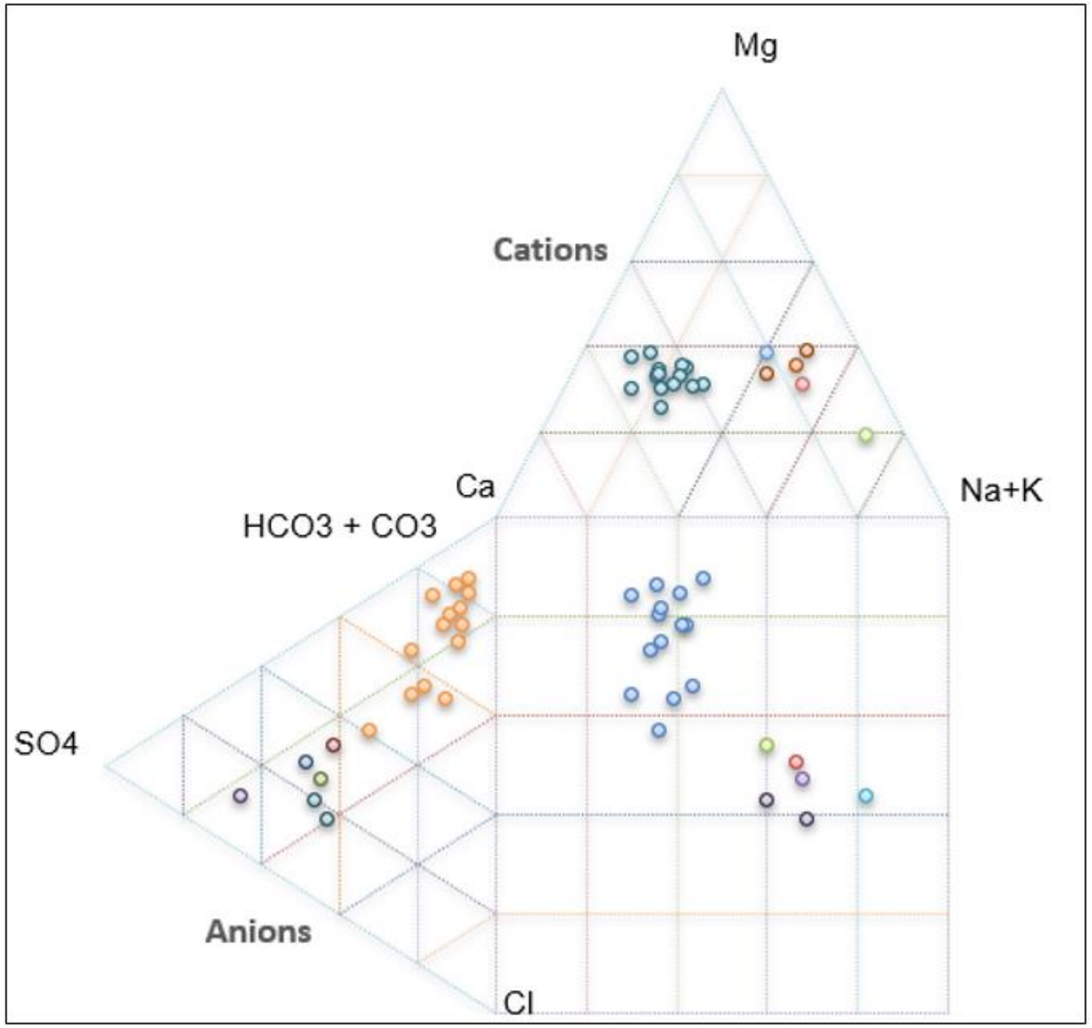
Limitations to Groundwater Development

- The ASGA of 909 MCM/yr is nearly 10 times the annual water demand for Lilongwe City approx. 129 MCM/yr by 2040
- However, the ASGA cannot be fully developed considering the median yield from the drilled exploratory boreholes is 2 l/s (7 m^3/hr), which would require about 2,100 BHs.
- The investment costs in boreholes and pipeline infrastructure prohibit such a water development strategy

Groundwater Quality Mapping

- Goal was to produce maps and charts detailing the quality of groundwater in the study area
- All information was interpreted and integrated to produce spatial maps, graphs and diagrams to characterize the groundwater chemistry and quality
- Parameters include: pH, EC, TDS, total hardness, total alkalinity, cations, anions, metals, heavy metals and bacteriological micro-organisms
- Water type was characterized using Piper, Durov and Stiff Diagrams
- Groundwater map of the project area produced at a scale of 1:130,000 which is valuable reference for stakeholders in water sector planning



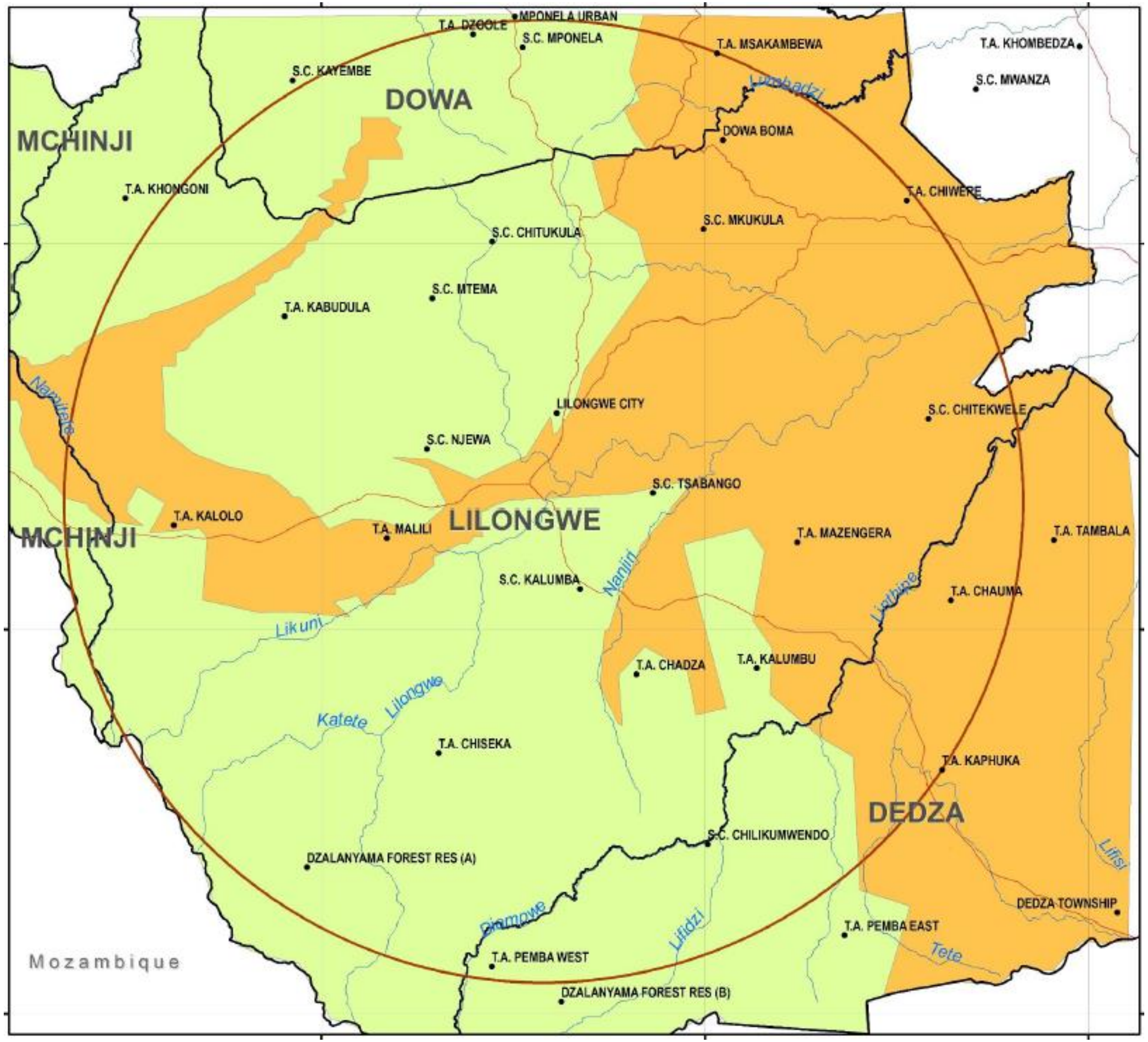


Hydrochemical facies plotted on Piper (left) and Durov (right) showing dominance of Ca-HCO_3

Groundwater Vulnerability Mapping

- GW vulnerability was assessed using the DRASTIC approach
- Main factors influencing groundwater vulnerability were assessed to generate classes which were weighted and given scores.
- The factors included: **D**epth to Water Table, Net **R**echarge, **A**quifer Type (Material), **S**oil Cover, **T**opography, **I**mpact of the Vadose Zone, and Hydraulic **C**onductivity
- Overall vulnerability was calculated by summing up the weights and scores using the index overlaying method in ArcGIS

Groundwater Vulnerability Map



- Traditional Authorities
- Main Roads
- Rivers
- Project Boundary
- Malawi Districts

Groundwater Vulnerability Zones

- High Risk
- Low Risk

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Conclusion

- The fractured aquifer under weathered regolith and superficial cover should be targeted for further groundwater investigation and development of groundwater monitoring system
- Groundwater quality in the project area is fresh with EC of <2,000 µS/cm. All chemical constituents were found to fall within the MS733:2005 drinking water standards for boreholes and shallow protected wells.
- A groundwater potential map has been produced showing high groundwater potential areas in the west for potential wellfield development
- Groundwater resources quantification estimate annual sustainable groundwater availability of 900 MCM/yr
- No significant areas regarded as having high groundwater vulnerability in the area

Thanks for your attention!!

Republic of Malawi

Lilongwe Water Board

GMS
GROUNDWATER & MINERAL SERVICES (PTY) Ltd

HydroConsult
Engineering and Management Consultants