Pathways to Water Resilient South African Cities (PaWS)

Transition to Novel Internet of Things Technology for Management of Groundwater Resources- Case of Cape Town, South Africa

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Contribution to PaWS

Research Question

“What is the potential for repurposing existing stormwater ponds to allow for the harvesting and treatment of contaminated surface runoff through MAR?”

WP1

Potential and suitability of ponds

Assess the use of IoT technologies to provide accurate and real-time data rather

Presentation Outline

Introduction and Background

Research Objectives

Study Area

Methodology

Results and Discussions

Conclusions and Recommendations

Introduction and Background

- **Semi-arid Region:** Unreliable water availability (Ebrahim et al., 2020)
- **Mean Annual Precipitation**: 450 mm/year, below the world average of 860 mm/year
- **Surface Water Resources:** Dominant but insufficient; need for diversification (Cobbing & Hiller, 2019)
- **Sustainable Practices:** Identification of recharge zones, protection, and monitoring (Keifer & Effenberger, 1967; DWA, 2010a)
- **Data Gaps:** Insufficient temporal data due to high costs of monitoring and limited infrastructure (Xu & Beekman, 2019)
- **Modern Technologies:** Use of IoT for data collection and model calibration (Gaffoor et al., 2020)

Research Objectives

Specific Objectives:

Identify Groundwater Potential Zones: Delineate specific areas with high potential for sustainable groundwater resource management

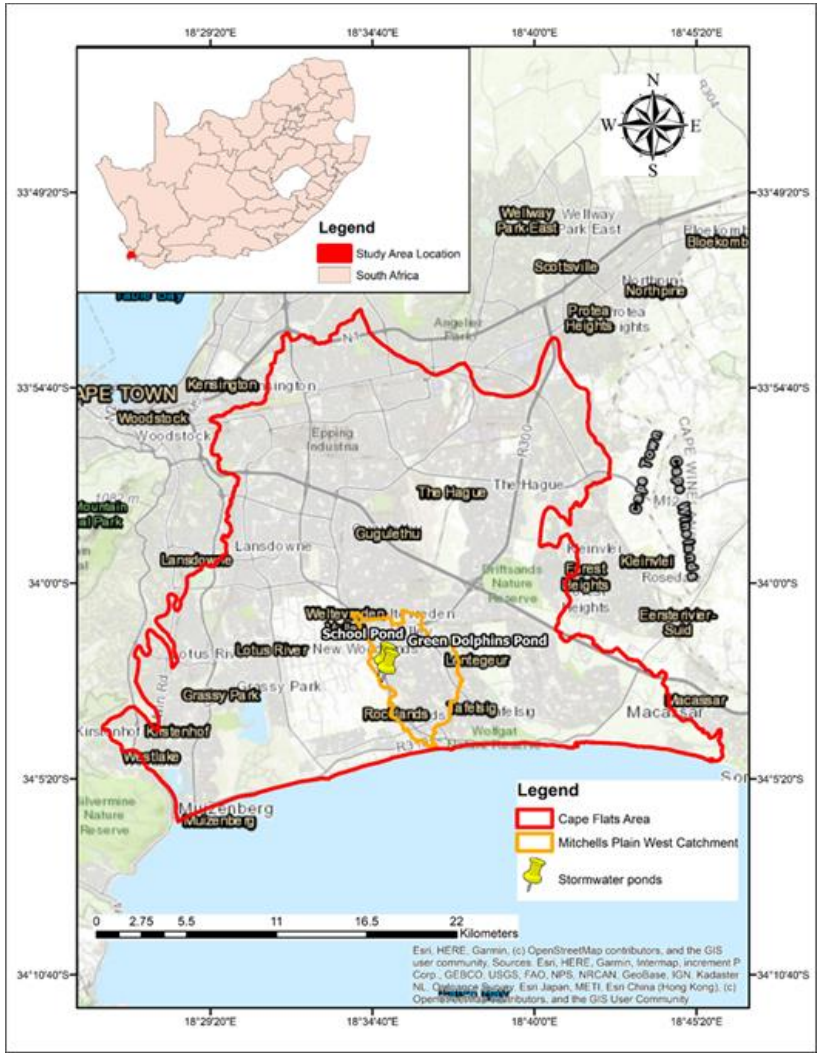
Data Collection: IoT system for real-time groundwater level monitoring

Stormwater Storage & Recharge Potential: Estimation using MODFLOW model

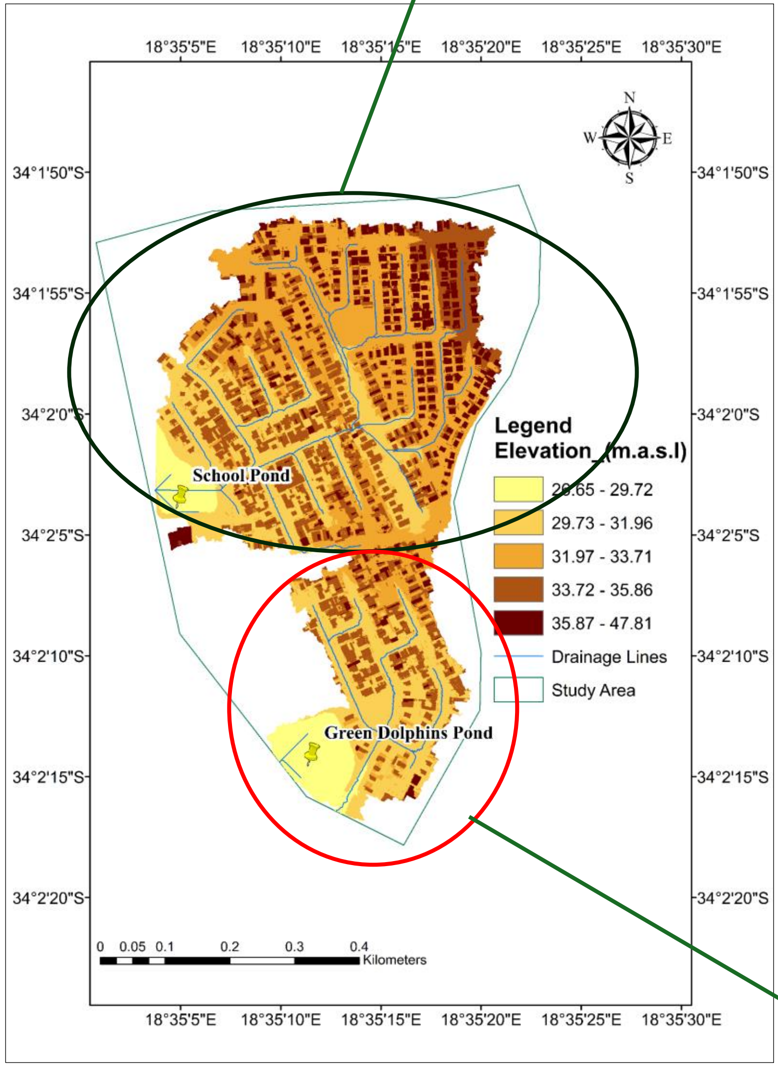
Recharge Rates & Processes: Assess through data analysis and modelling

Study Area

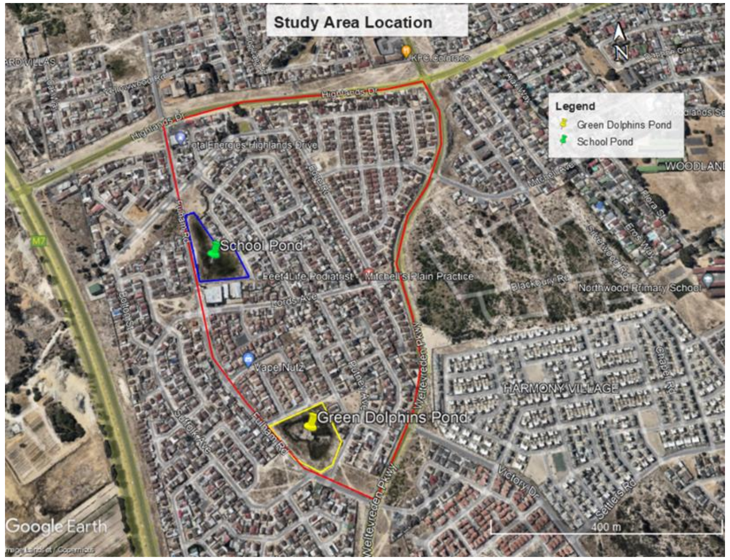
School pond catchment



Cape Flats Aquifer and Mitchells Plain West Catchment



Delineated Catchments of the Stormwater Ponds



Catchment Area: School Pond (0.155 km²),

Green Dolphins Pond (0.048 km²)

Catchment Area: 0.315 km²

Green Dolphins Pond Catchment

Methodology

Collection of Existing Hydrological, Geological and Hydrogeological Datasets

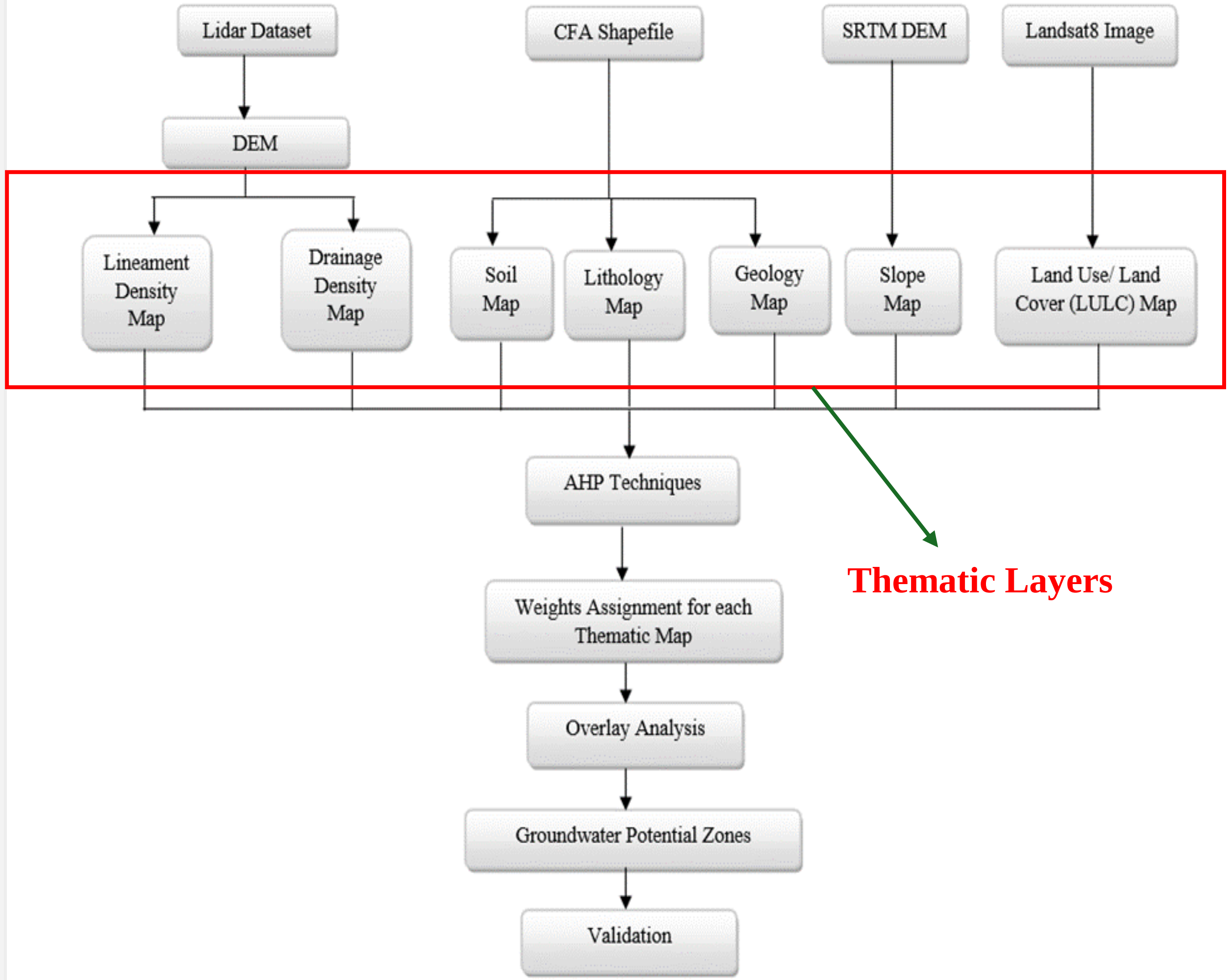
Groundwater Potential Zone Mapping using GIS and Analytical Hierarchical Process (AHP) Techniques

Collection of IoT-based Groundwater Level Data

Development of a Numerical MODFLOW Groundwater Flow Model

Mapping Groundwater Potential using

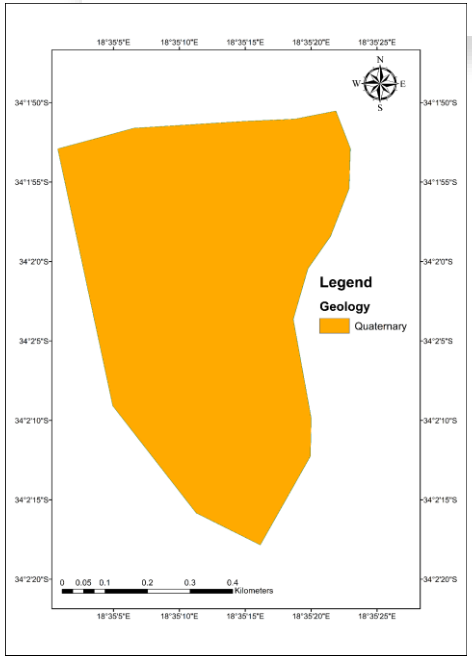
- A combination of GIS techniques and the Analytical Hierarchical Process (AHP)
- Seven (7) Thematic Layers Extraction
- Factors weighted based on groundwater occurrence, expert opinions, and insights from previous studies
- Groundwater Potential Zone Map was produced



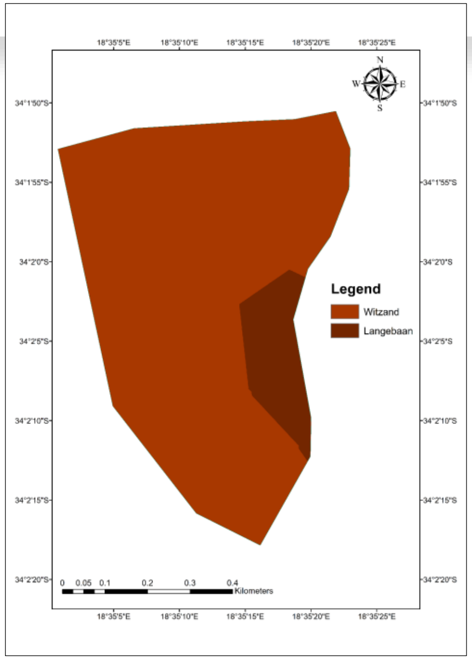
Flowchart used in Groundwater Potential Zone Mapping

Mapping Groundwater Potential

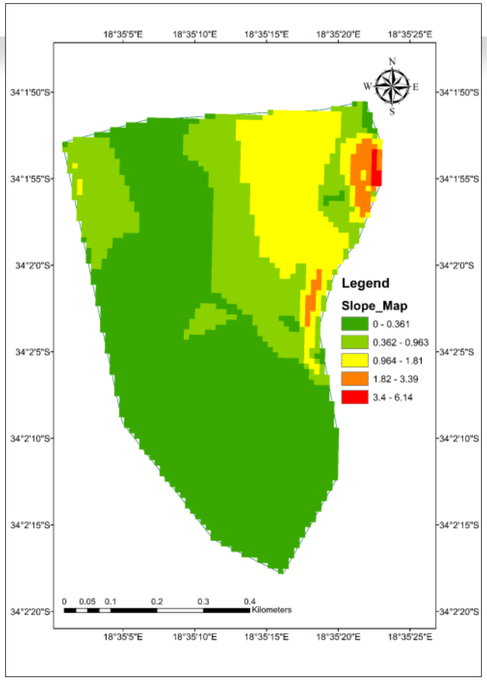
(Thematic layers)



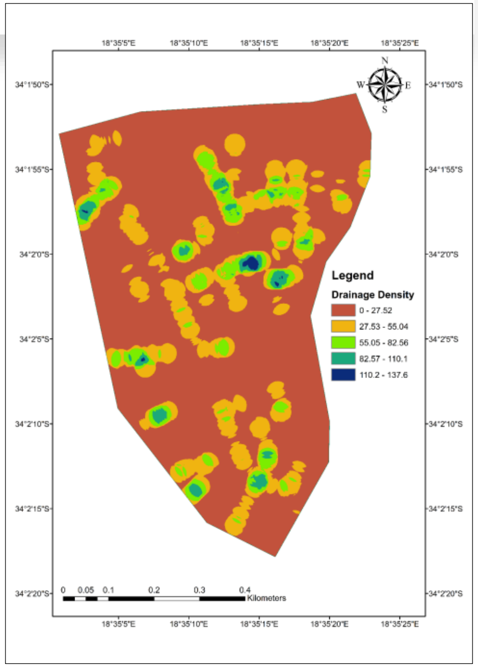
Geology



Lithology



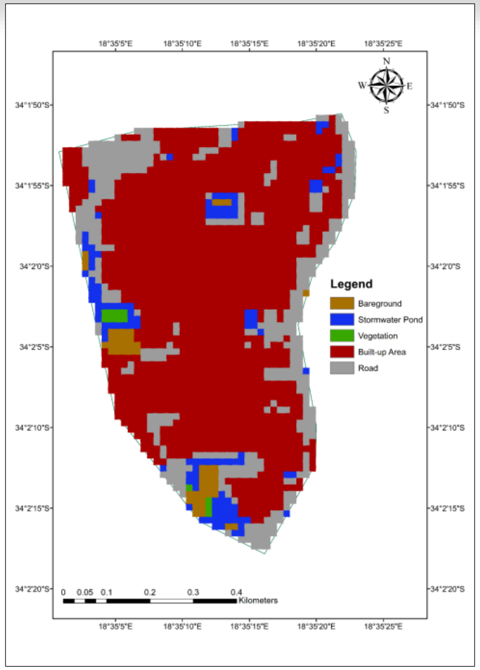
Slope



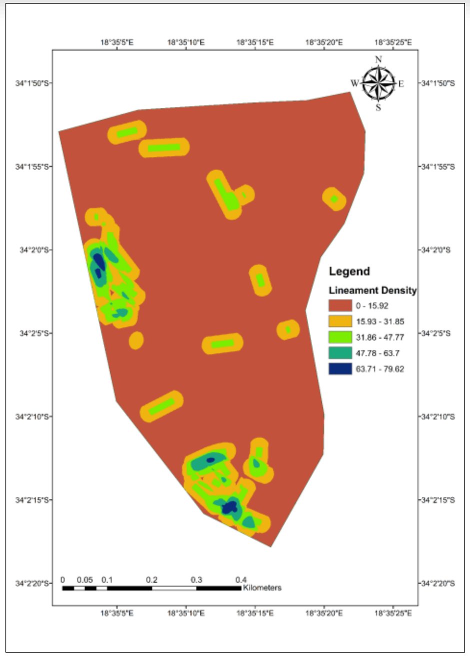
Drainage Density

Mapping Groundwater Potential

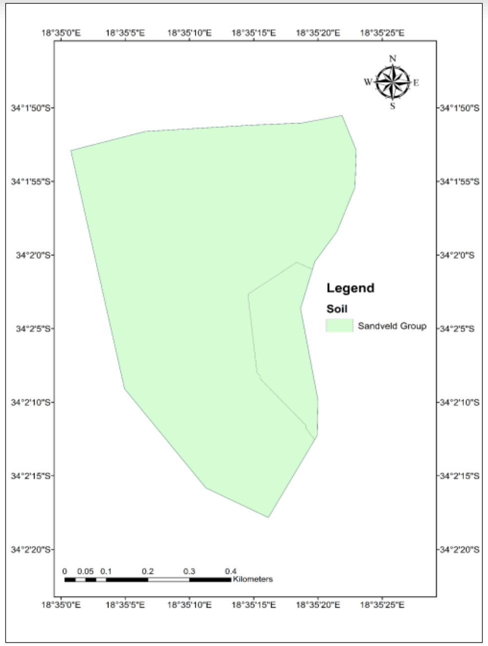
(Thematic layers)



LULC



Lineament



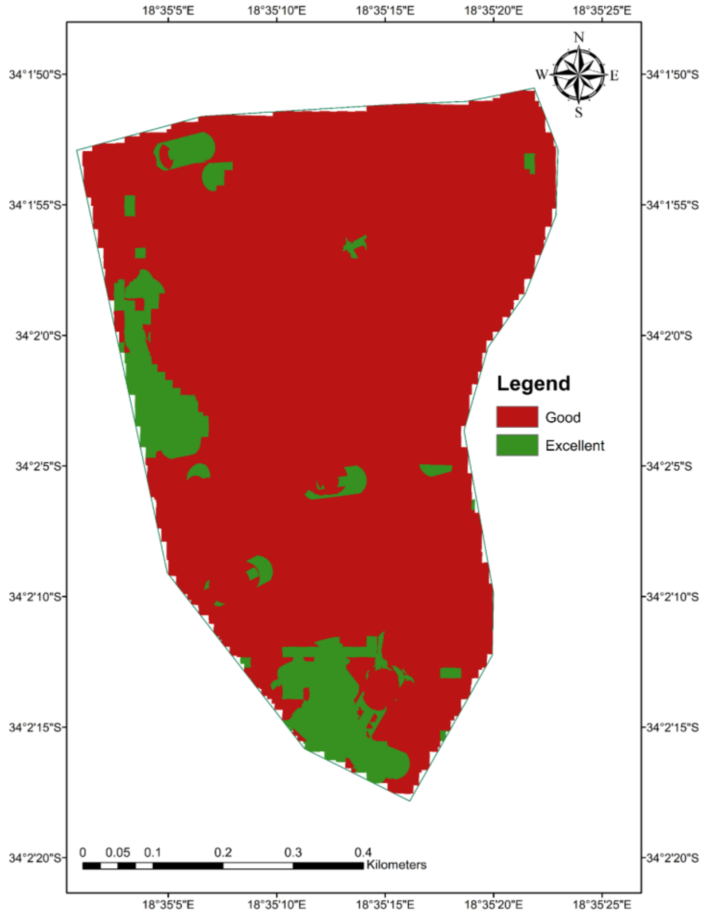
Soil

Mapping Groundwater Potential (Results)

Weight and Ranking of the Thematic layers

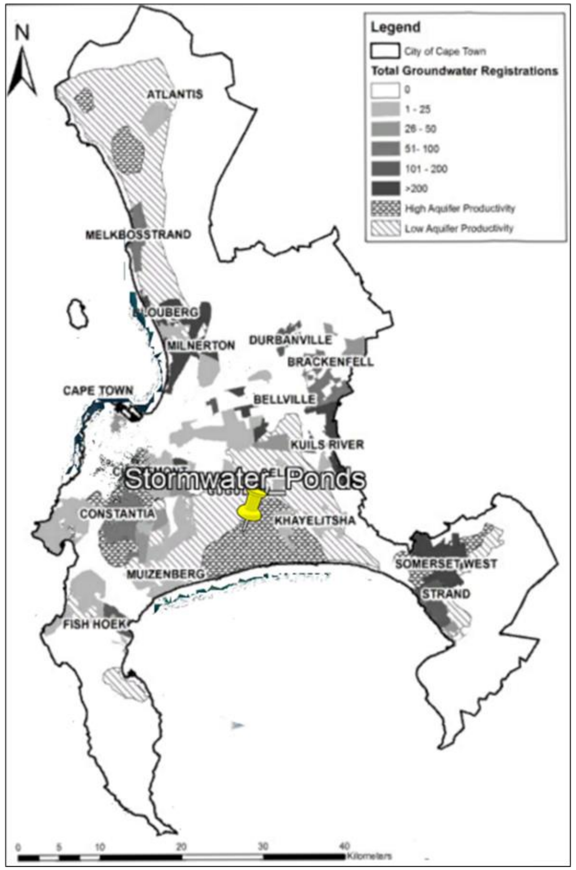
Parameter	Sub-Classes	Weight	Influence (%)	Rank	Area (km²)
Geology	Quaternary	0.30	30	5	0.315
Lithology	Sand	0.28	28	5	0.315
Slope (degrees)	0 - 0.15	0.14	14	5	0.161
	0.16 - 0.47			4	0.007
	0.48 - 0.82			3	0.078
	0.83- 1.2			2	0.048
	1.3 - 1.5			1	0.020
Drainage Density (km/km²)	0 – 27.52 (Low)	0.10	10	5	0.234
	27.53 – 55.04 (Very Low)			4	0.057
	55.05 – 82.56 (Moderate)			3	0.018
	82.57- 110.1 (High)			2	0.005
	110.2- 137.6 (Very High)			1	0.001
Land Use /Land Cover (LULC)	Bare Ground	0.07	7	1	0.008
	Stormwater Pond			5	0.019
	Vegetation			5	0.002
	Built-up Area			1	0.223
	Road			1	0.064
Lineament Density (km/km²)	0 – 15.92 (Low)	0.06	6	1	0.261
	15.93 – 31.85 (Very Low)			2	0.033
	31.86 – 47.77 (Moderate)			3	0.016
	47.78- 63.7 (High)			4	0.005
	63.71- 79.62(Very High)			5	0.001
Soil	Sandveld	0.05	5	5	0.315

- Overlaid weights of thematic layers:
- Highest weight assigned to Geology.



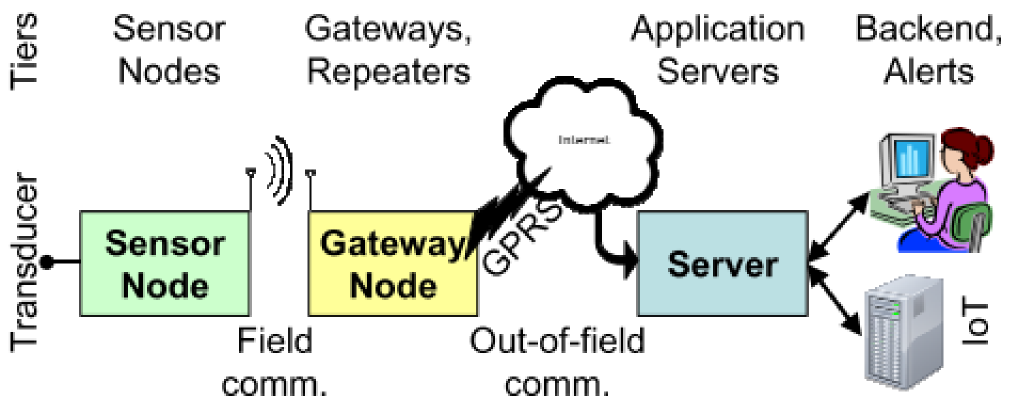
Groundwater Potential Zone map

- Classified into two classes: Good **(89%)** and Excellent **(10.6%)**



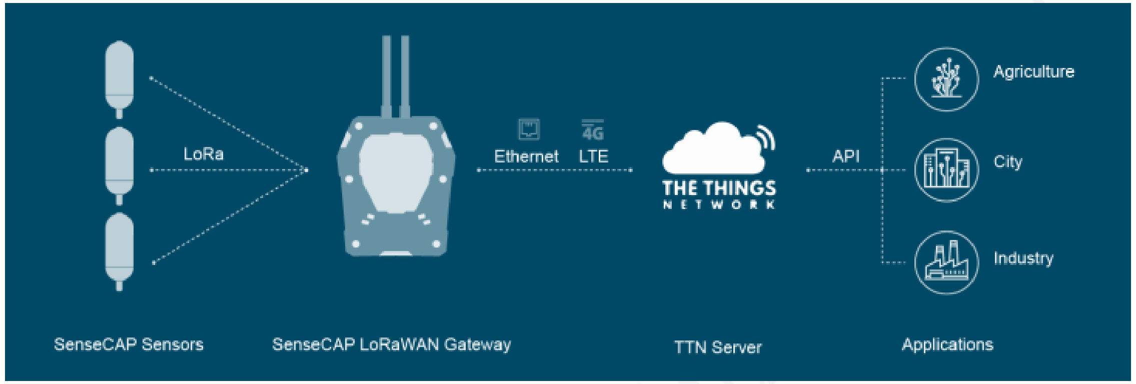
The Distribution of Groundwater Registration and Aquifers in the CCT from 2004 to 2012 (Mauck, 2017)

Internet of Things (IoT)



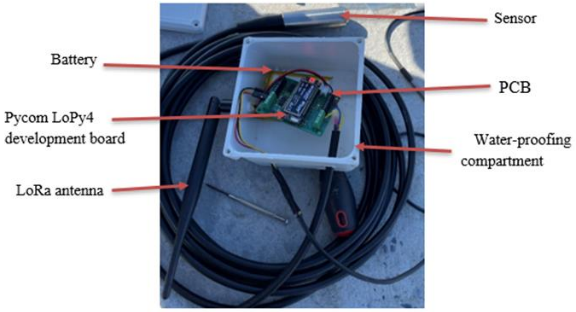
- Origin: Coined by Kevin Ashton in 1999.
- Defined as uniquely identifiable connected objects using RFID technology (Ashton, 2009).
- Expands the Internet by connecting physical "things" to collect and manage data

IoT-based Groundwater level Data



SenseCAP LoRaWAN Wireless Sensor Network

Location of Gateway and Water level sensor



Hefei WNK8010 submersible water level sensor and node

SenseCAP LoRaWAN Gateway

THE THINGS NETWORK

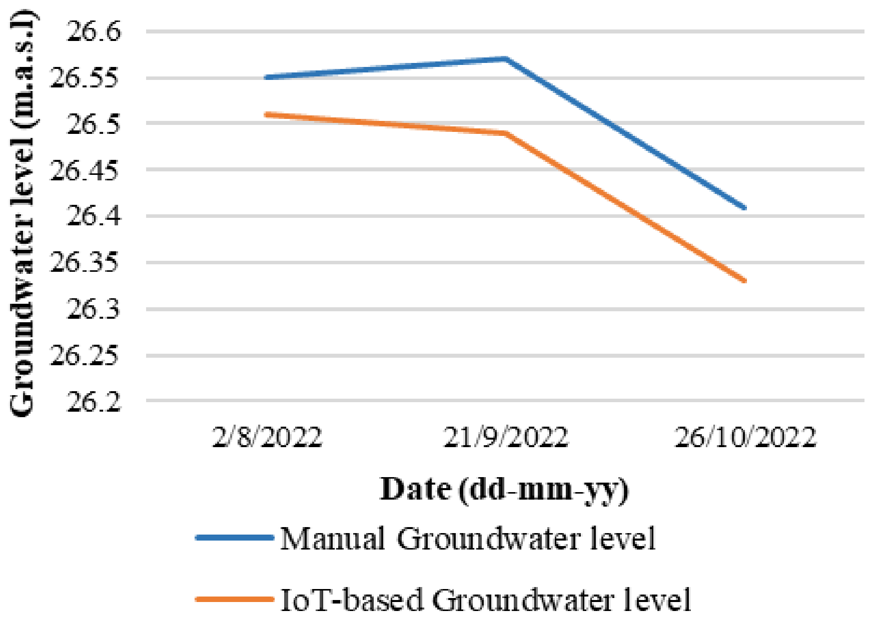
The Things Network (TTN)

IoT-based Water level data as seen on ThingSpeak

Validation of the IoT-based Groundwater level Data

Dipped and IoT-based Groundwater Level Comparison

Date	Manual (Dipped) Groundwater level (m.a.s.l)	IoT-based Groundwater level (m.a.s.l)	Difference (m)
2/8/2022	26.55	26.51	0.04
21/9/2022	26.57	26.49	0.08
26/10/2022	26.41	26.33	0.08



Comparison between Dipped and IoT-based Groundwater Levels

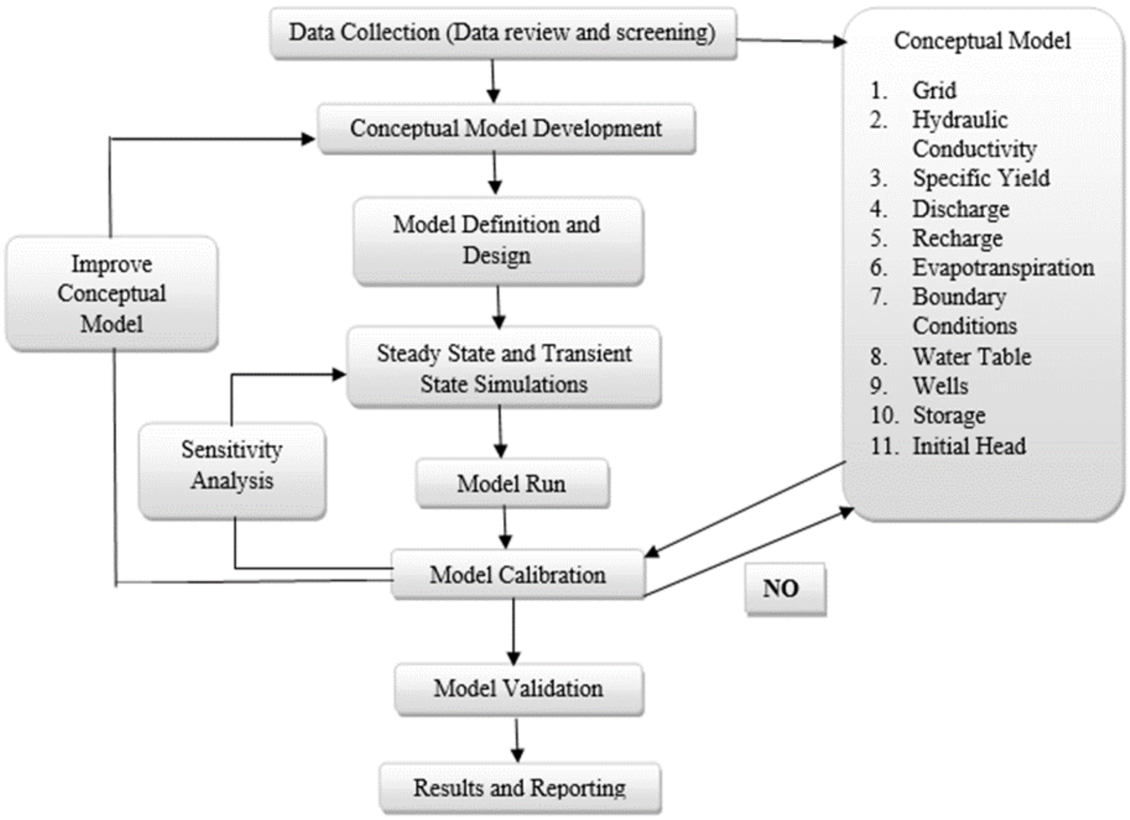
Groundwater Modeling with MODFLOW

Conceptual Model: Developed from secondary data

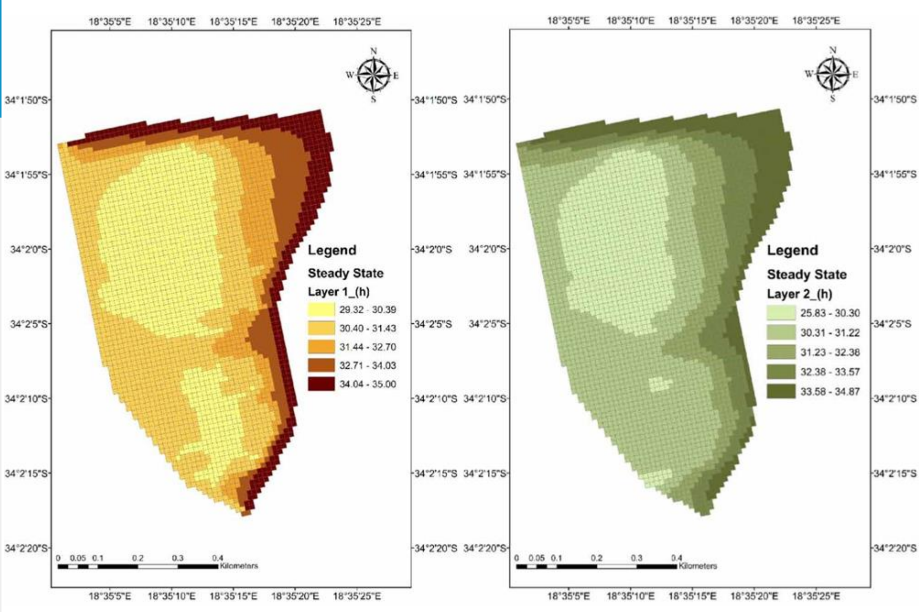
Numerical Model: Created using MODFLOW-NWT and ModelMuse

Calibration and Validation:

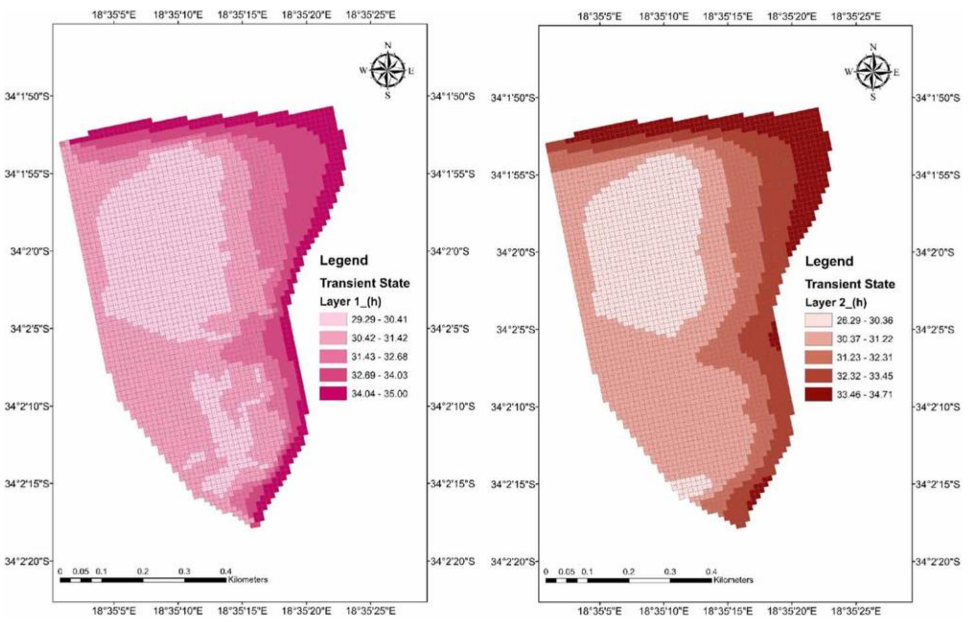
- Calibrated with IoT data
- Sensitivity analysis performed
- Model validated for accuracy



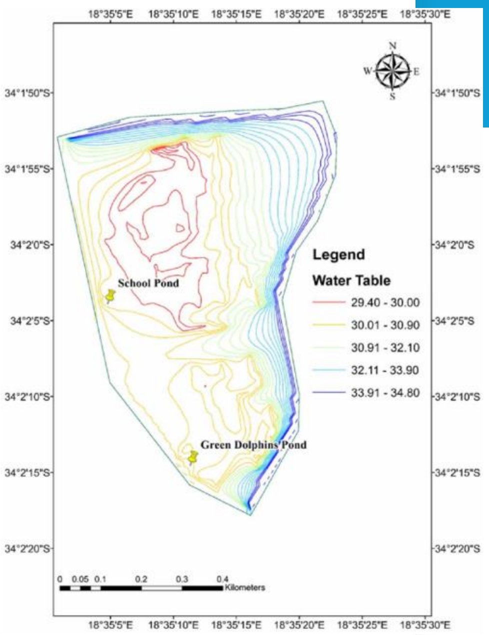
Groundwater Modelling Flowchart



Steady State Hydraulic head values



Transient State Hydraulic head values



Water Table Contours

Groundwater Modeling with MODFLOW

Model Structure:

- Aquifer Layers: Unconfined aquifer divided into two layers.
- Aquifer Parameters: Similar parameters with differing hydraulic conductivity.

Calibration Process:

- Steady state calibrated from RMSE of 4.50 to 0.65
- Transient state calibrated from RMSE of 4.51 to 0.86
- Recharge Rates: Adjusted based on Xu & Beekman (2019).
- Hydraulic Conductivity: Adjusted within CFA profile ranges.

Conclusions

- The results revealed that integrating GIS techniques and the AHP method provides a suitable tool for improved groundwater potential mapping
- IoT technologies are the solution to the lack of high-quality groundwater level data
- Stormwater ponds are a practical and effective means of replenishing the aquifer through infiltration. (Increase of 0.86 m at the MON71 borehole; confirmed Managed Aquifer Recharge)

Recommendations

- Use longer intervals for IoT data collection to conserve battery life.
- Provide alternative power sources to prevent data loss.
- Choose efficient and accurate water level sensors.
- Implement regular sensor calibration and validation checks.
- Register multiple boreholes for better model calibration.
- Develop a real-time modeling framework with IoT and web services for better monitoring and management.

Publication

Citation

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IoT-based data and analytic hierarchy process to map groundwater recharge with stormwater

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ABSTRACT

The sustainable management of groundwater resources in developing countries is often challenging due to limited measurement and monitoring infrastructure to collect data necessary for decision support. To make a contribution towards addressing these challenges, this study investigated the use of Internet of Things (IoT) technology and low-cost sensors to collect the required groundwater-level data and develop a model to map the recharge potential with stormwater. The study focused on two stormwater ponds located in a highly urbanised area in Cape Town, South Africa. A combination of Geographic Information System and analytic hierarchy process was integrated to generate a groundwater recharge potential zone map of the study area. The IoT-based data were used to develop and calibrate a numerical groundwater model in MODFLOW. The study determined that retrofitted stormwater ponds are potential groundwater augmentation zones and can provide opportunity for stormwater recharge in urban areas. Overall, this study highlights the potential of IoT to collect hydrogeological data with low-cost sensors. Data can be collected at high temporal resolution, and the spatial scale can be increased due to availability of low-cost sensors.

Key words: analytic hierarchy process, Cape Town, groundwater recharge, IoT-based data, MODFLOW, stormwater

HIGHLIGHTS

- Internet of Things (IoT)-based data were leveraged to address challenges in groundwater management.
- Rapid battery drain powering the IoT system was mitigated by reducing the data collection frequency and dead sleep mechanisms.
- Geographic Information System–based analysis and analytic hierarchy process were employed to map the recharge potential in a highly urbanised area in Cape Town.

THANK YOU

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Pathways to water resilient South African cities

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