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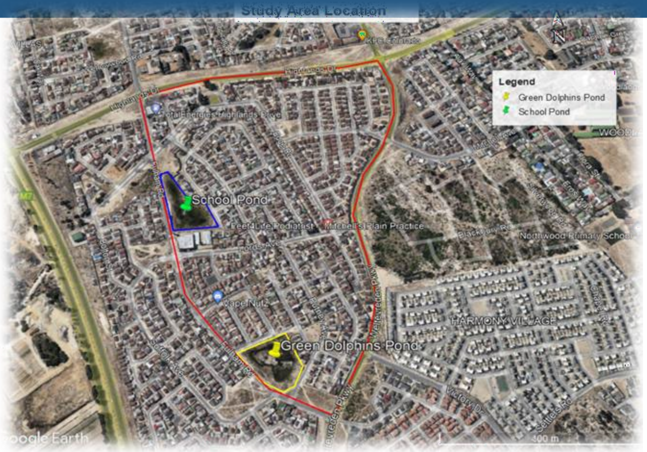
Newsletter

Pathways to water resilient South African cities project



TRANSITION TO NOVEL INTERNET OF THINGS (IoT) TECHNOLOGY FOR MANAGEMENT OF GROUNDWATER RESOURCES - CAPE TOWN, SOUTH AFRICA

Miriam Arinaitwe

The PaWS project aims to identify opportunities for integrating nature-based approaches into the urban landscape through collaborative retrofitting of an existing stormwater pond. The School Pond was selected to map, evaluate, and redesign it to create infiltration areas to improve MAR. Similarly, the project has modified the functions of the pond to improve the stormwater quality and enhance the amenity and biodiversity in the environment.

The contribution of this study to the PaWS project is to assess the use of IoT technologies to provide accurate and real-time data rather than only relying on conventional approaches to data collection.

This issue

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

About the project

The 'Pathways to water resilient South African cities (PaWS)' project is a collaboration between UCT's Future Water Institute, and the University of Copenhagen, funded by Danida MFA. Drawing on physical experiments and governance and social processes, it explores the potential for existing flood attenuation infrastructure to be adapted towards water resilient cities (read more here).

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Enhancing groundwater resource management in Cape Town – leveraging IoT and low cost sensors

Effective management of groundwater resources in developing nations faces challenges due to inadequate measurement and monitoring infrastructure for essential decision-making data. To address these issues, this research explored the utilization of Internet of Things (IoT) technology and affordable sensors. Their aim was to gather crucial groundwater level data and create a model for mapping recharge potential using stormwater.

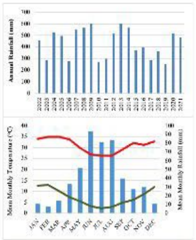
The study concentrated on two urban stormwater ponds in Cape Town, chosen based on available hydrological and hydrogeological data. By integrating Geographic Information System (GIS) and Analytic Hierarchy Process (AHP), a map depicting potential groundwater recharge zones was generated.

The IoT-based data facilitated the development and calibration of a numerical groundwater model within MODFLOW.

This study concluded that retrofitting stormwater ponds could serve as viable groundwater augmentation urban areas offering opportunities for stormwater recharge. Ultimately, the research underscores IoT's capacity to collect hydrogeological data at high temporal resolutions and emphasizes the expanded spatial scale achievable with low-cost sensors. The methods employed are depicted below.

The details of the two stormwater ponds are as follows:

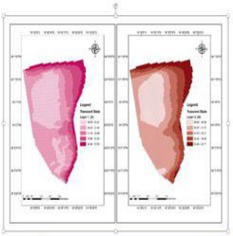
Name	Area (m²)	Latitude (°)	Longitude (°)
School Pond	8,744	34°2'3.0"S	18°35'4.7"E
Green Dolphins Pond	7,604	34°2'14.08"S	18°35'11.57"E



Data collection
- Study area
- hydrological
- hydrogeological
- climate

Recharge mapping
- GIS
- AHP

IoT data
- Groundwater levels



Groundwater model
- Modflow
- Calibration and validation with IoT data

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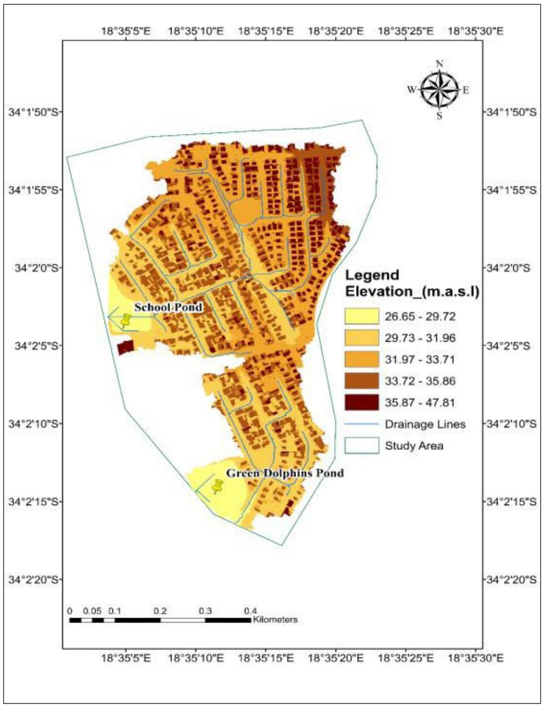
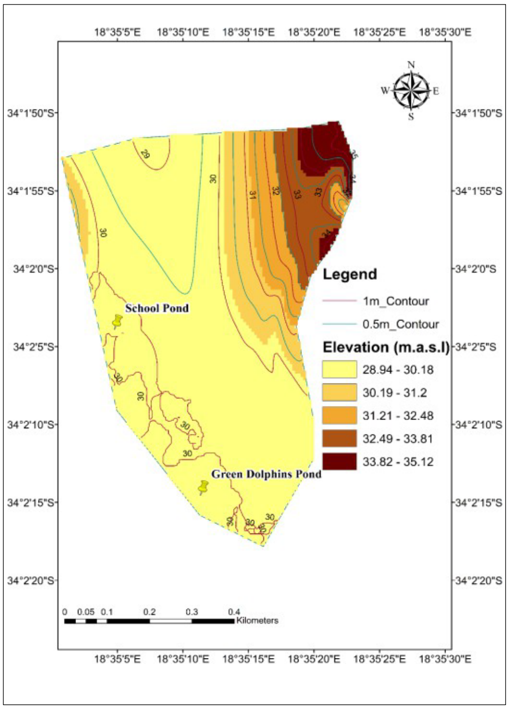
Hydrological studies of the Study area

The catchment area of the stormwater ponds was delineated using a 0.5 m high-resolution DEM created from a Lidar dataset. This analysis revealed that the ‘School Pond’ and ‘Green Dolphins Pond’ had catchment areas of 0.155 km^2 and 0.048 km^2 respectively.



The lidar dataset captured building tops, leading to a higher elevation of 47.81 m in the depicted figure. During modeling, adjustments were made to consider ground level measurements exclusively, with the maximum elevation in the study area being 35.12 m, as illustrated below.

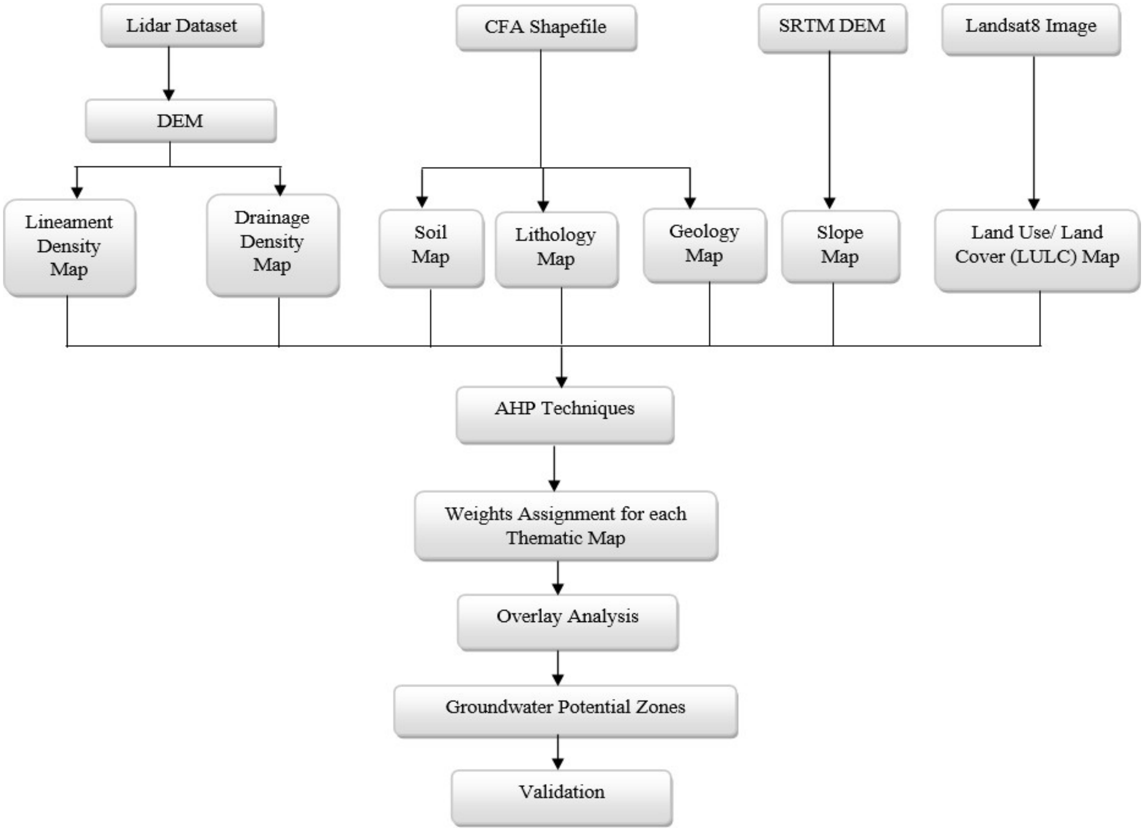


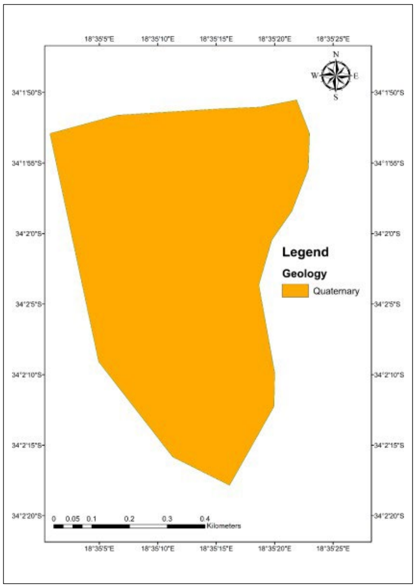
For simulating the study area's hydrology, daily rainfall and temperature data were gathered from the Cape Town Automatic Weather Station (CT-AWS) because of its proximity and ability to represent the local microclimate. An evaporation dataset obtained from the Phillipi weather station, using the evaporation pan method, was used To calculate evapotranspiration (ET$_o$).

Groundwater Potential Zones Mapping for MAR through GIS and AHP Techniques

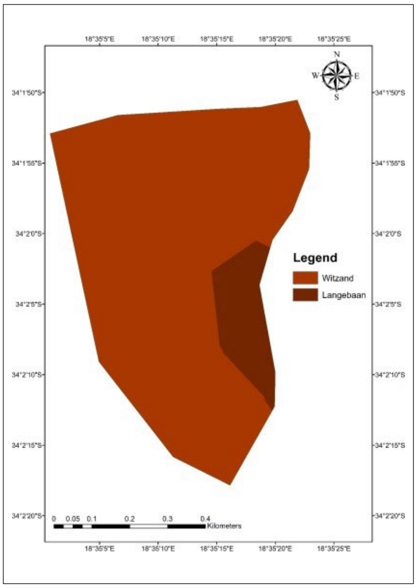
Geospatial techniques in ArcGIS software were employed to define groundwater potential zones within the catchment of the stormwater ponds. This process involved knowledge-based factor analysis of seven thematic layers, including geology, lineament density, lithology, slope, soil, land use/landcover (LULC), and drainage density. The flowchart below, outlines the process used for mapping groundwater potential zones.

The thematic maps were considered as the control factors of groundwater flow and storage. These influencing factors were assigned weights based on their reaction to groundwater occurrence, expert opinion, and consideration from the reviews from previous studies. Similarly, weights and ranks were assigned to each map according to its influence on the infiltration of groundwater into the aquifer. Consequently, a final groundwater potential map was developed, outlining prime locations for potential groundwater presence.

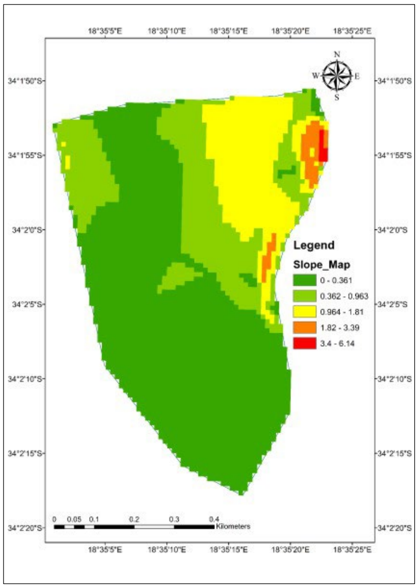




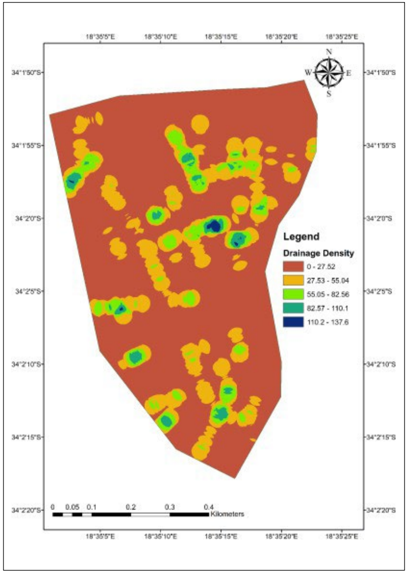
Geology



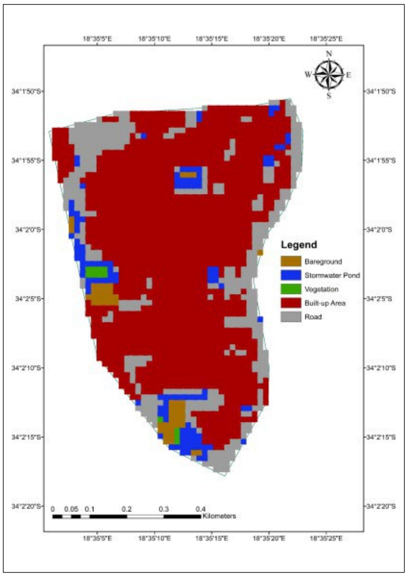
Lithology



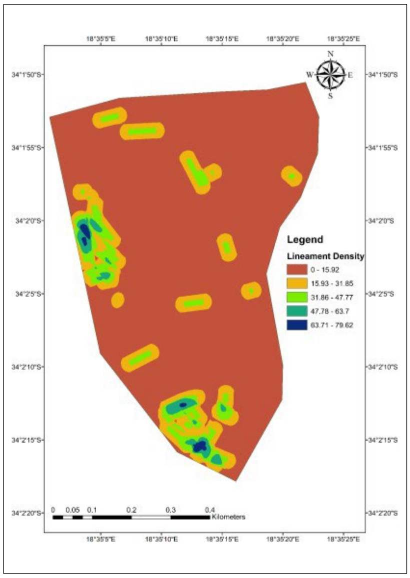
Slope



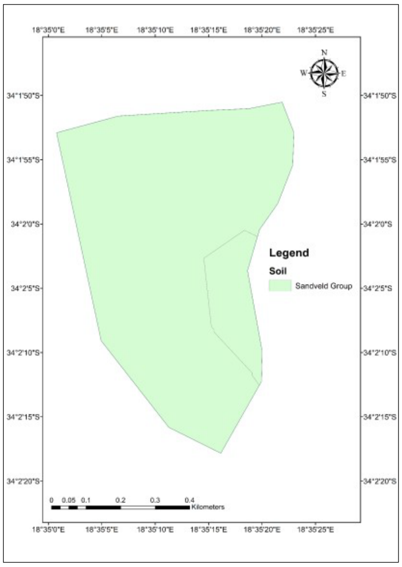
Drainage Density



Land use/Land Cover



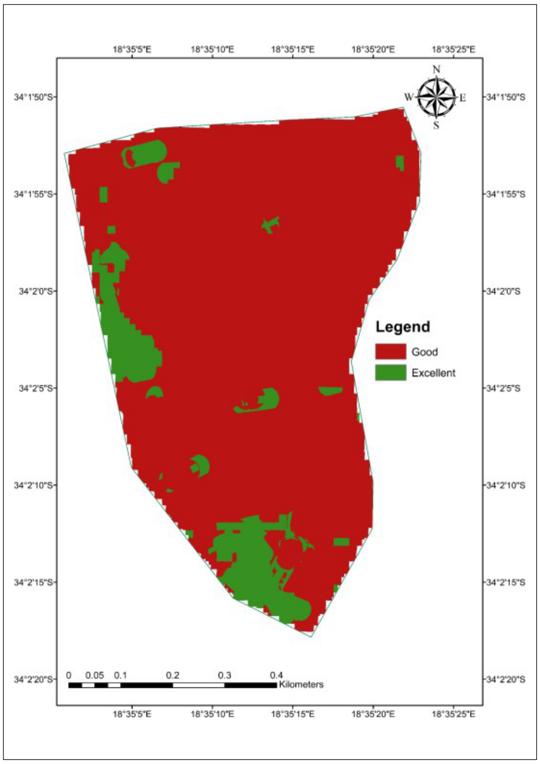
Lineament



Soil

The final groundwater potential zone (GWPZ) map was prepared by overlaying the cumulative weights of all seven thematic layers using the weighted overlay tool in ArcGIS. The highest weight was assigned to geology in the pairwise comparison results signifying its paramount influence on groundwater potential compared to other factors.

A consistency ratio (CR) of 0 was obtained in the comparison phase, indicating perfect consistency. The final GWPZ map obtained through the natural breaks classification method in ArcGIS categorized the area into two classes: Good (89%) and Excellent (10.6%) as shown below.



Groundwater Potential Zones Map

The GWPZ map was validated using a map showing the distribution of groundwater registration and aquifers in the CCT from 2004 to 2012 obtained from Mauck (2017). The location of the stormwater ponds catchment was in the high aquifer productivity area of CCT; thus, the area has a high groundwater potential, as clearly illustrated in the GWPZ map.

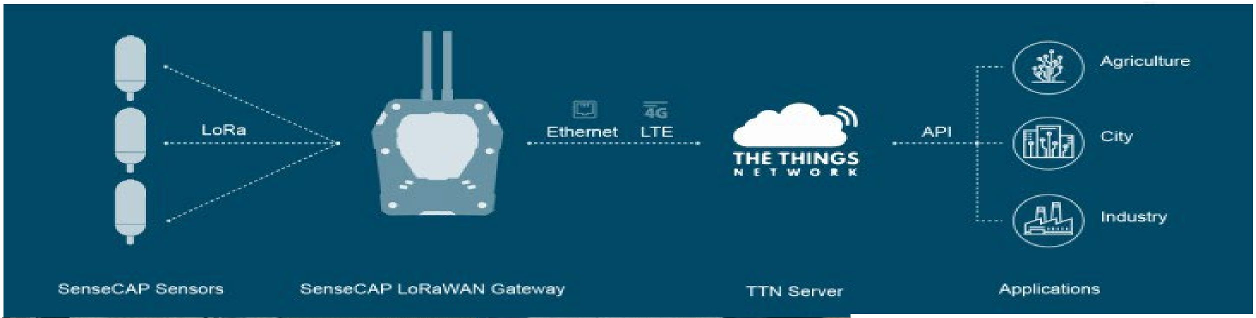
IoT-based Groundwater level Data

The study employed a SenseCAP Long Range Wide Area Network (LoRaWAN) Wireless Sensor Network (WSN) for monitoring groundwater levels. This setup included a water level sensor, node, gateway, and smartphone. For safety, the gateway was positioned at a nearby high school near the 'School pond'.

The Hefei WNK8010 submersible water level sensor was installed in the secure MON71 borehole close to the 'Green dolphins pond'. The gateway was connected to the internet through a 4G LTE micro-SIM card with a monthly subscription. An uninterruptible power supply (UPS) ensured uninterrupted communication between the sensor and gateway.

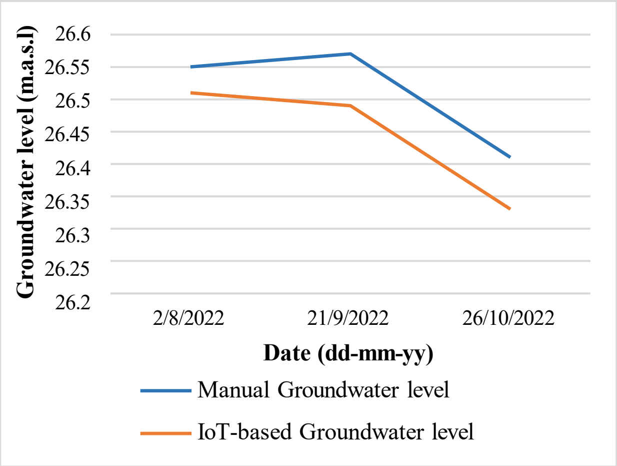
A micro python code was developed to process the data. The sensor featured an onboard voltage divider that converted electrical resistance into water level depth.

The voltage of the battery of the sensor dropped significantly in a month due to frequent data recording every 15 minutes which caused communication failure between the sensor and gateway. A new battery was installed, with data collection reduced to a 24-hour interval as the groundwater levels did not exhibit significant changes within a sub-daily time step. This replacement determined that reducing the temporal resolution and frequency of data collection prolongs the battery life.



Water level data on the Things Network (TTN) underwent analysis and visualization using MATLAB and the ThingSpeak application. This platform stored and displayed data through a LoRa application, offering real-time cloud-based tracking, analysis, and visualization. A ThingSpeak channel was created, generating a write API to link TTN and ThingSpeak. This facilitated in-depth data analysis, variable visualization, alerts, and data export to Microsoft Excel. IoT-based data validation occurred by comparing it to manually recorded water level data at the MON71 borehole.

When compared with the manually recorded groundwater levels from the MON71 borehole, the IoT-based data displayed an acceptable difference of under 0.1 m. This validation highlighted the reliability of IoT in gathering substantial data while maintaining desired accuracy levels. This suggests the viability of using IoT-based systems for collecting high-resolution data in groundwater studies and model development.



Groundwater Flow modelling

The collected datasets, including both existing and IoT-based data, were utilized to create and fine-tune a numerical groundwater model in MODFLOW. This model employed MODFLOW NWT and ModelMuse 4 as graphical interfaces to explore groundwater flow and water levels.

The conceptual model framework divided the unconfined aquifer into two layers based on subsurface geology, sharing similar aquifer parameters except for hydraulic conductivity differences. The model was run with estimated boundary conditions and initial conditions, and the IoT-based data collected over almost five months was adopted to calibrate the model.

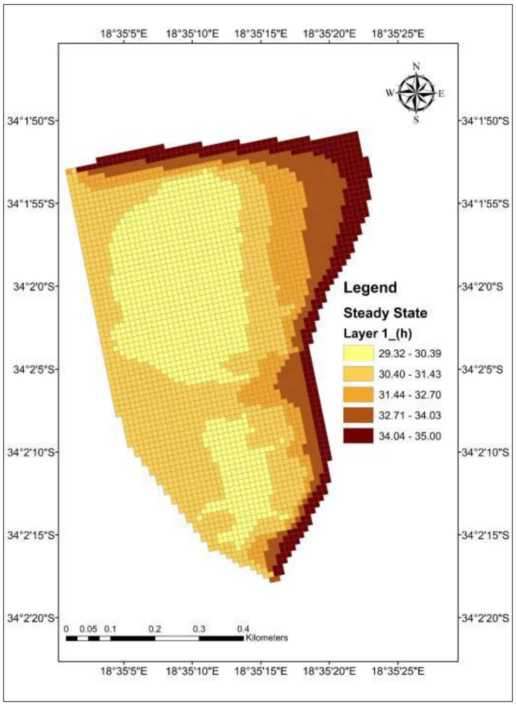
The recharge rates were adjusted according to the study by Xu & Beekman (2019). The values of the hydraulic conductivity in the x-direction (Kx) of the layers were adjusted within the allowable range as specified by the Cape Flats Aquifer (CFA) hydraulic conductivity profile.

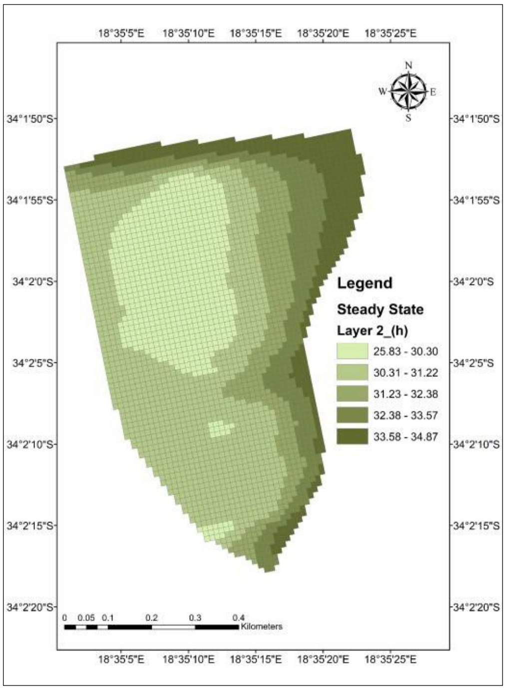
The evapotranspiration rates were calculated using the FAO Penman-Monteith equation and the aquifer thickness was adjusted with reference to the CFA thickness.

Effect of Stormwater Recharge on Groundwater levels

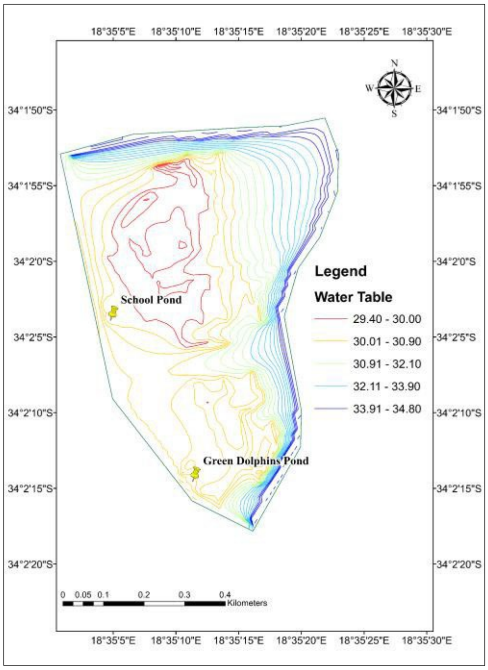
The steady state model was calibrated through iterative adjustments to achieve closely aligned simulated heads with field-measured values. This process employed a trial-and-error approach, considering IoT-based groundwater level data from September as observed head. Running the model yielded results that displayed a strong correspondence between simulated and observed heads at MON71, as indicated by a Root Mean Square Error (RMSE) value of 0.65.

The higher hydraulic head values in Layer 1 than Layer 2 were attributed to the lower hydraulic conductivity due to the presence of coarser sands. The higher heads were located along the northern and eastern boundaries with high elevations and flow towards the low-elevation areas that comprise the stormwater ponds.





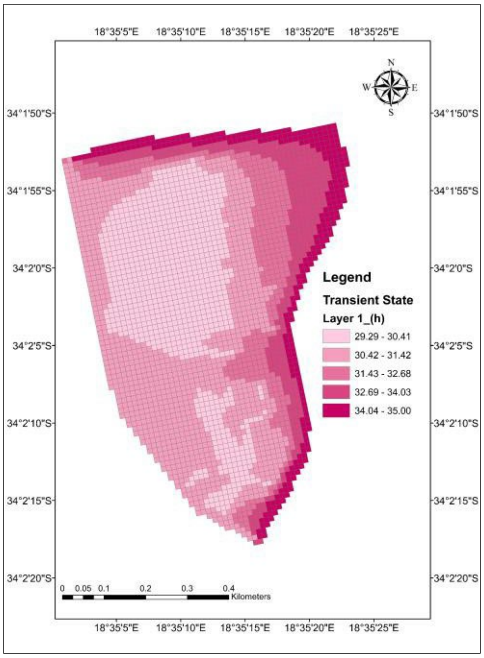
The water table is higher in areas of high elevation and lower in areas with low elevation, especially around the school pond catchment area, as it has the lowest elevation as shown below

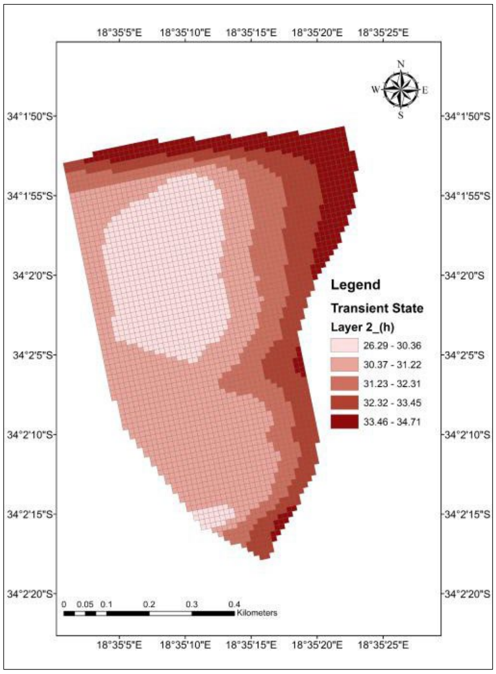


The transient state model encompassed variations in factors like recharge rates, hydraulic conductivity, aquifer thickness, and stormwater pond influence on the water table and outflows. Calibration of the model involved the utilization of IoT-based water level data collected during the wet months of July, August, and September 2022.

The steady state model, as the initial condition, was used to determine the reliability of the parameters described. The final calibrated model confirmed that the residual value between the observed and simulated heads had acceptable RMSE of 0.86. The hydraulic heads reduce towards the location of the stormwater ponds, i.e.,

from areas of high elevation to low elevation.





Key Findings

1) This study explored using IoT technology and low-cost sensors to manage groundwater challenges. IoT data effectively addressed data limitations and drainage concerns.
2) Adjusting data collection frequency helped extend sensor battery life, ensuring sustainable data collection.
3) The study employed Geographic Information System (GIS), Analytic Hierarchy Process (AHP), and MODFLOW software to map recharge potential of stormwater ponds.
4) Observed vs. simulated data confirmed stormwater ponds' efficacy for groundwater augmentation.
5) GIS and AHP are crucial for mapping recharge zones, revealing stormwater ponds' potential for groundwater replenishment.
6) IoT technology provided accurate hydrogeological data at high temporal resolution, overcoming cost and spatial limitations.
7) Stormwater ponds classified as excellent groundwater recharge zones, showcasing potential for replenishment through infiltration
8) Water table fluctuations and outflows were influenced by recharge rates, conductivity, and aquifer thickness, highlighting their interdependence.
9) Higher recharge rates lead to increased water table and outflow values, establishing a direct relationship between groundwater levels, recharge rates, and effective resource management.

Conclusion

The study showcases the potential of IoT in groundwater management, addressing challenges and offering insights into effective groundwater augmentation. The study paves the way for sustainable urban groundwater resource management by leveraging IoT, GIS, and modern modeling techniques.

Until the next edition……

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