

**GROUNDWATER ASSESSMENT AND WATER RESOURCE
DEVELOPMENT OF CHITTUR BLOCK OF PALAKKAD
DISTRICT**

by

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CHAPTER V

SUMMARY AND CONCLUSIONS

Groundwater is an essential natural resource that sustains human life, agriculture, industries, and ecosystems, particularly in regions where surface water resources are limited. In India, where nearly 85% of rural and 50% of urban water supplies depend on groundwater, its sustainable management has become increasingly critical. The present study, entitled “Groundwater Assessment and Water Resource Development of Chittur Block, Palakkad District,” was undertaken to evaluate the spatio-temporal variation of groundwater levels, assess groundwater potential zones and recharge zones, and to formulate an effective groundwater resource development plan for the region through integrated GIS and numerical groundwater flow modelling techniques using visual MODFLOW.

The Chittur block, located in the south-eastern part of Palakkad District, Kerala, is characterized by semi-arid climatic conditions and recurrent droughts. Owing to its declining groundwater levels and high extraction rates, the block has been categorized as an over-exploited region by the Central Ground Water Board (CGWB). Hence, this study made an attempt to scientifically assess groundwater availability, recharge characteristics, and flow dynamics to support sustainable water resource development and planning.

Long-term groundwater level data from nine observation wells (1994–2022) were analyzed to assess temporal trends using the Mann–Kendall test and Sen’s slope estimator. Spatial datasets including geology, geomorphology, slope, drainage density, land use/land cover, and lineament characteristics were integrated in ArcGIS to prepare thematic maps and delineated groundwater potential zones through the Weighted Index Overlay Analysis (WIOA) method. Additionally, a three-dimensional transient numerical groundwater flow model was developed for the study area using Visual MODFLOW 2.8.1 to simulate groundwater behaviour under different recharge and abstraction conditions.

The model was calibrated using 20 years of observed data (1998–2017) and validated with five years of data from 2018–2022, ensuring high model accuracy and reliability. The validated model was then used to predict the groundwater level variations and water table contour maps for the forthcoming decade (2022–2032), assuming hypothetical increases in recharge rates of 5%, 10%, and 15%.

The long-term analysis of groundwater level dynamics revealed substantial spatial and temporal variations in groundwater levels across the study area. Deep water levels exceeding 20 m bgl were observed in wells such as PKD S-7 and Well No. 141, indicating severe depletion, whereas wells 126, 139, 149, 150, 151, PKD S-6, and PKD S-8 showed relatively shallower levels (<10 m bgl). The Mann–Kendall trend analysis indicated a statistically significant decline in groundwater levels during both pre-monsoon and post-monsoon seasons, particularly in wells 141, 149, PKD S-6, and PKD S-8, confirming the continuous lowering of the water table due to excessive abstraction and inadequate recharge. The Sen’s slope estimator revealed that the same wells showed a significant falling trend and the remaining wells showed a rising trend.

The Dynamic Groundwater Reserve (DGWR) analysis, based on 29 years of records, demonstrated a fluctuating pattern, with mostly positive values below 0.2 m, signifying modest recharge rates. However, in later years, notably around 2020, several wells (139, 149, 150, 151, PKD S-6, PKD S-7, PKD S-8) exhibited negative DGWR values (below –0.20 m), indicating that groundwater withdrawal exceeded recharge, leading to a net decline in aquifer storage and emphasising the unsustainable nature of current groundwater use.

The hydrogeomorphological mapping revealed that the Chittur block comprises predominantly pediment (63.34%), valley floor (24.28%), floodplain (6.48%), riverine landforms (4.52%), and waterbody masks (1.38%), collectively influencing infiltration and storage capacity. The valley floors, floodplains, and lineament intersections emerged as favourable zones for groundwater occurrence due to high infiltration rates and aquifer

thickness, whereas pediment zones, though less productive, offer potential for artificial recharge interventions.

The Weighted Index Overlay Analysis (WIOA) based, groundwater potential zonation map classified the area into excellent, good, moderate, and poor potential zones. Most of the area falls under good (116.26 km²) and moderate (95.82 km²) categories, with excellent zones concentrated in Vadakarapathy, Nallepilly, and Chittur Municipality, and poor zones in Eruthampathy, Kozhinjampara, and Perumatty. Recharge zonation indicated similar spatial patterns, identifying Vadakarapathy, Nallepilly, and parts of Pattecherry as optimal for artificial recharge development.

The study also identified potential sites and structures for artificial recharge by integrating thematic layers (geology, geomorphology, slope, drainage density, land use/land cover, lineament and lineament density) with guidelines from the Integrated Mission for Sustainable Development (IMSD) and the Central Ground Water Board (CGWB). The most suitable areas for artificial recharge sites and different structures viz. percolation pond (10 No.), Checkdam (5 No.), Recharge wells (30 No.) and sub-surface dyke (4 No.) were proposed for the area.

The Visual MODFLOW simulation provided valuable insights into groundwater flow behaviour under varying conditions, with performance indicators as follows. Steady-state calibration (1998): RMSE = 4.68%, R² = 0.986, NSE = 0.978. Transient calibration (1998–2017): RMSE = 3.76%, R² = 0.983, NSE = 0.976. Validation (2018–2022): RMSE = 2.77%, R² = 0.997, NSE = 0.997. These performance metrics confirmed excellent model reliability and predictive accuracy. The velocity vector map indicated groundwater flow predominantly towards river channels, with high flow magnitudes in the eastern and northern regions, suggesting zones of enhanced recharge and transmissivity. The validated model predicted groundwater level the next 10 years (2022–2032) by increasing recharge by 5%, 10%, and 15% showed that an increase in recharge resulted in corresponding groundwater table rises of 1–2 m, 1–3 m, and 2–5 m, respectively, with increase in water

table in the southern and western parts of the block, while minimal changes in Eruthampathy and Vadakarapathy panchayats.

Sensitivity analysis revealed that recharge and pumping rates were the most influential parameters, while hydraulic conductivity and storage properties exerted minimal effects. A 25% reduction in recharge caused a decline of 1.59 m in groundwater levels, while a 25% increase in pumping reduced groundwater levels by 2.22 m. Conversely, a 25% rise in recharge raised groundwater by 1.47 m while 25% decrease in pumping raised groundwater level by 1.56 m. A 50% reduction in recharge caused a decline of 3.33 m in groundwater levels, while a 50% increase in pumping reduced groundwater levels by 4.01 m. Conversely, a 50% rise in recharge raised groundwater by 3.31 m and 50% decrease in pumping rate raised groundwater level by 3.59 m.

The differences in the water table contour map during pre-monsoon and post-monsoon during the years 2000, 2010, and 2018 were generated by visual MODFLOW modelling and validated with available data to study the changes in the groundwater level behaviour. The year 2018 showed great changes in the post-monsoon season, exhibiting a remarkable recovery, with the water table rising by approximately 4 to 15 m across large portions of the block due to the extreme monsoon event, whereas the year 2000 showed a rise of 2 to 7 m, and 2010 showed a rise of 1 to 5 m during its post-monsoon season.

A comparative assessment of WIOA and MODFLOW outputs showed a strong spatial correlation, indicating that both methods identified similar groundwater potential zones. This correlation confirmed the reliability of both empirical and process-based approaches for delineating groundwater potential zones. It also suggested that WIOA can serve as a simple and effective alternative in regions where detailed data for MODFLOW simulations are limited.

Five management scenarios were simulated using the Zone Water Budget (ZWB) module: Scenario 1 (10% ↑ pumping)- unsustainable, high mass balance error (7.86%), Scenario 2 (20% ↑ recharge)- sustainable, excellent balance (0.02% error), Scenario 3 (10%

↓ recharge, 10% ↑ pumping)- severe stress (7.44% discrepancy), Scenario 4 (10% ↑ recharge, 10% ↓ pumping)- optimal balance (0.03% error), Scenario 5 (10% ↑ recharge and pumping)- unstable (9.08% error). Scenarios 2 and 4 were identified as sustainable scenarios, demonstrating that artificial recharge enhancement coupled with regulated pumping can effectively stabilize the groundwater system.

The findings of the groundwater flow modelling and multi-criteria weighted overlay analysis formed the basis for the preparation of a comprehensive groundwater resource development and management plan for the Chittur block. The key recommendations include 1. change in cropping patterns 2. adoption of water conservation practices 3. augmentation of groundwater through artificial recharge 4. implementation of incentive programs and continuous monitoring of groundwater level.

The integrated GIS-based hydrogeomorphological analysis and Visual MODFLOW modelling provided a comprehensive understanding of groundwater dynamics in the Chittur block. The study confirmed that unsustainable extraction, coupled with limited natural recharge, has resulted in a long-term decline in groundwater levels. However, the region possesses considerable potential for recovery through scientifically planned artificial recharge interventions and regulated groundwater abstraction.

Key conclusions of the study include:

- Groundwater levels across the block showed a consistent declining trend, particularly in the northern and northeastern regions.
- Recharge augmentation through artificial structures such as percolation ponds, recharge wells, and check dams can significantly improve groundwater availability.
- The integrated use of WIOA and MODFLOW enhances spatial and temporal understanding, offering a robust framework for sustainable groundwater development and management.

- Scenario analysis highlighted that enhancing recharge by at least 10% and reducing pumping by 10% could lead to a stable and sustainable groundwater regime in the study area.
- Implementation of the proposed groundwater recharge structures is expected to contribute approximately 0.815 MCM of additional recharge annually, aiding the gradual transition from the over-exploited to the critical category and then gradually to a safe condition.

Suggestions and recommendations

- Immediate regulation of groundwater abstraction in over-exploited zones of the Chittur block.
- Implementation of artificial recharge structures (recharge wells, percolation ponds, check dams, subsurface dykes) in high-priority recharge zones.
- Strengthening groundwater monitoring networks and expanding data collection for improved model calibration.
- Integrated surface-groundwater modelling to capture holistic hydrological interactions.
- Advanced numerical and machine learning approaches should be adopted for groundwater level prediction and drought forecasting.
- Promotion of sustainable agricultural practices, including crop diversification and water-efficient irrigation methods.
- Community participation in water conservation and decentralised groundwater management initiatives.