

**GROUNDWATER MODELLING USING WETSPASS-M AND
MODFLOW**

By

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CHAPTER 5

SUMMARY AND CONCLUSION

Groundwater has risen as one of the most important natural resources sustaining human life particularly in regions where surface water resources are limited. In humid tropical regions such as Kerala, groundwater plays a main role not only in meeting domestic and agricultural needs but also in supporting coastal life. Over the past few years, people have been using groundwater without control, and the landuse has been changing very quickly. Also, the Malappuram district's coastline areas have a high population density and a decadal growth rate.

One of the main rivers in the Malappuram district, the Bharathapuzha, flows through the districts of Palakkad, Malappuram, and Trichur before draining into the Arabian Sea near the Ponnani. The main challenge faced in the area near the downstream section of the river where it flows into the sea is the saltwater intrusion into the coastal aquifers during the dry summer months. In this study, an area from coastal stretch of Ponnani to Tavanur region was selected as the study area for observing the changes in groundwater levels over a period of 11 years utilizing WetSpss-M and MODFLOW models.

The land use and land cover changes of the study area were analysed using multi-temporal Landsat satellite imagery for the years 2014, 2017, 2021, and 2025. The supervised classification results showed a clear change in landuse over the eleven-year period. Areas that were predominantly vegetated in the earlier years were progressively converted into built-up and fallow lands. In 2014, vegetation formed 64.2% of the total area, providing favourable conditions for groundwater recharge and soil moisture retention. In 2025, this value had decreased sharply to 49.8%, indicating that nearly one fourth of the vegetation area had been converted into other land use classes. Also, built-up areas increased from 4.4% to 13.82%, representing more than a threefold rise in eleven years. Such rapid urban expansion caused a fundamental shift in land surface characteristics,

replacing permeable soils and vegetated surfaces with paved and impervious structures. Therefore, the recharging ability of the land surface got reduced eventually.

Also, two spectral indices namely Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI) were analyzed for the same period. NDVI indicated a significant and consistent drop, reducing from 0.218 in 2014 to 0.19 in 2025, showing deterioration in vegetation cover. Vegetation plays a crucial role in groundwater recharge by improving infiltration, lowering runoff, and assisting subsurface water movement through its roots. Its disappearance indicates a declining capability for groundwater recharge as well as an ecological imbalance. In contrast, the NDBI values rose from 0.117 to 0.17, indicating a rise in impermeable surfaces and rapid growth in urbanization. These areas restrict infiltration, disrupt the natural water balance, and increase surface runoff. The opposing trends of NDVI and NDBI consequently serve as quantitative indicator of landuse change driven mostly by human activities.

Groundwater depletion, however, does not occur instantaneously in response to land use changes in turn it exhibits a delayed but cumulative response. To understand this response, groundwater level trends were analyzed using monthly measurements from eighteen observation wells present throughout the study area. The Mann–Kendall trend test and Sen’s slope estimator which are robust and widely accepted non-parametric statistical tools, were applied to the groundwater depth data. The results clearly revealed a statistically significant rise in groundwater depth, confirming a continuous decline in groundwater levels over the study period. However, since the analysis was based on monthly data, seasonal effects may influence the results. Future studies may apply the seasonal Mann–Kendall test to better account for seasonality.

The maximum observed decline of 3.38 m during pre-monsoon months in well number 1 and 2.50 m during post-monsoon months in well number 2 with both wells situated in northern part of the study area. These results signify that recharge processes are severely constrained, while extraction and water demand continue to increase. The spatial patterns of groundwater depletion further supported the direct influence of land use changes. Wells located in densely urban zones exhibited the steepest declines, whereas

wells situated in relatively vegetated regions showed comparatively lower reductions. This spatial variability confirms that the extent of groundwater depletion is strongly influenced by land use patterns and is severe in zones where recharge capacity has been reduced. Moreover, the coastal characteristics of the aquifer intensify the problem: declining groundwater levels reduce hydraulic head, thereby increasing the likelihood of saline intrusion from adjoining coastal zones, which poses a severe threat to freshwater security.

The WetSpaas-M model was employed to simulate annual groundwater recharge under different land use scenarios. The model results indicated a significant decline in recharge from 277 mm in 2014 to 220 mm in 2025, signifying a loss of more than 20% of the basin's recharge capacity. Areas that previously exhibited high recharge potential, particularly floodplains and agricultural lands, have been reduced in extent and efficiency, while recharge deficient zones expanded over newly urbanised areas. These findings confirm that the reduction in groundwater recharge is a direct result of extensive land conversion and the consequent decrease in the land's ability to absorb water due to increase in impervious surfaces.

Visual MODFLOW was utilised to simulate groundwater flow using WetSpaas-derived recharge as an input parameter to integrate recharge behaviour with subsurface flow. The calibrated groundwater flow model showed satisfactory performance, achieving a correlation coefficient of 0.95 and an NRMSE of 7.16%, thereby indicating a high level of reliability and accuracy in the model outputs. The simulated water table elevation maps revealed a consistent lowering of groundwater levels, particularly in urbanized coastal built-up, and a hydraulic gradient sloping towards the Arabian Sea. These conditions suggest that the aquifer is becoming increasingly susceptible to seawater intrusion, which, if not controlled, may lead to permanent degradation of water quality.

In order to understand the influence of the increase in pumping rates on the groundwater availability of the area, the pumping rates were systematically increased by 5%, 10%, and 20% above the calibrated values. The simulation results showed that higher pumping levels caused a noticeable and immediate drop in water table elevations throughout the study area.

Therefore, the findings of this study clearly show that the groundwater of the area is experiencing stress as a result of continuous land use changes and excess pumping. The reduction in vegetation and expansion of built-up areas have disturbed the natural recharging capacity of the land. The results obtained from NDVI and NDBI analyses, groundwater level trend analysis, spatial estimation of recharge, and groundwater flow modelling clearly show that groundwater reduction in the region is not a short term but a long-term process primarily caused by human by changing the land use. If timely informed measures such as controlled groundwater pumping, protecting and restoring natural recharge areas, encouraging artificial recharge techniques, and increasing vegetative cover are not adopted, the aquifer system may suffer permanent damage. Therefore, sustainable land management methods and integrated watershed planning are needed to maintain long-term groundwater security and to protect the ecological and socio-economic resilience of the area.