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Hypothetical Numerical Evaluation of 10-Year Household Pumping-Induced Settlement Across Representative Soils in Cabanatuan City

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Abstract- This study presents a comparative numerical evaluation of hypothetical household pumping-induced settlement across eleven representative soil profiles in Cabanatuan City, Philippines. Using PLAXIS 3D (2025.1), three household-demand scenarios of 600, 800, and 1000 L/day were represented through proportional phreatic-level reductions over a modeled 10-year period. The scenarios were imposed as relative groundwater-stress conditions only and were not derived from hydrogeologically calibrated field drawdown. Default Mohr-Coulomb material parameters were applied uniformly to isolate comparative soil-response trends. Results showed a consistent increase in modeled settlement with stronger imposed groundwater-stress scenarios across all soil profiles. Brown Sandy Silt exhibited the highest settlement, increasing from 29.50 mm at 600 L/day to 57.18 mm at 1000 L/day, while Hard Brown Clayey Silt showed the lowest response, ranging from 0.6024 mm to 1.093 mm. The findings indicate that silty and sandy soils generally experienced greater relative deformation than denser or more cohesive profiles under the adopted assumptions. The study provides a preliminary comparative framework for geotechnical screening, while emphasizing that the results are not site-specific field predictions.

Index Terms- comparative modeling, groundwater extraction, land subsidence, PLAXIS 3D, settlement

I. INTRODUCTION

Groundwater extraction remains a critical water source for domestic, agricultural, and industrial activities in the Philippines. In Nueva Ecija, groundwater is widely used to support irrigation, especially during dry periods [1]. However, excessive and sustained abstraction can lower groundwater levels, reduce pore water pressure, and increase the effective stress carried by the soil skeleton [2], [4]. Over time, this mechanism can trigger consolidation and land subsidence, particularly where soil compressibility is high.

In Cabanatuan City, some households continue to rely on shallow wells or "poso" systems for daily domestic needs. These systems fall under the Level I water-supply category, which consists of protected wells or handpumps without piped distribution [3]. Although large-scale subsidence related to aquifer overdraft has been widely documented in metropolitan and agricultural regions [5]-[10], the comparative response of representative local soils to sustained household-scale pumping remains less explored.

This study addresses that gap through a scenario-based numerical framework rather than a predictive hydrogeologic model. Eleven representative soil profiles from Cabanatuan City were evaluated in PLAXIS 3D under three hypothetical household-demand scenarios. The objective was to compare long-term settlement behavior across soil types and to identify which profiles are more susceptible to modeled deformation under stronger groundwater-stress conditions. The manuscript explicitly treats the 600, 800, and 1000 L/day cases as relative stress scenarios only, not as direct or linearly computed field drawdown values.

II. METHODOLOGY

The study used PLAXIS 3D (2025.1) to simulate long-term settlement response under household groundwater extraction scenarios. Eleven representative soil profiles were selected from an

LGU-provided compilation of geotechnical investigation reports, boring logs, and soil test records for selected sites in Cabanatuan City [22]. Soil descriptions from these records were retained, but the numerical models used standardized default Mohr-Coulomb parameters rather than laboratory-calibrated site-specific values.

Groundwater extraction was simulated through staged phreatic-level reductions over a modeled 10-year period. The 600, 800, and 1000 L/day scenarios were converted into a proportional 6:8:10 ratio to impose low, moderate, and high relative groundwater-stress conditions. These reductions were introduced for comparative scenario analysis only and were not obtained from drawdown equations or field hydrogeologic calibration. Actual drawdown behavior depends on transmissivity, storage coefficient, recharge, pumping duration, well geometry, hydraulic conductivity, anisotropy, and interference from neighboring wells [11], [12].

A drained condition was assumed to represent long-term response, with a simplified 20 m x 20 m x 60 m soil domain, fully fixed base boundary, roller side boundaries, and auto-generated fine mesh. These controls were applied uniformly to isolate relative changes in settlement response across soil types.

Table 1. Numerical model setup and groundwater conditions used in PLAXIS 3D.

Parameter	Description
Model dimensions	20 m x 20 m x 60 m
Model geometry	Simplified soil domain representing a localized soil profile
Initial groundwater elevation	Phreatic level initially set at the ground surface (0.0 m datum)
Drainage assumption	Drained condition assumed for long-term staged response
Base boundary	Fully fixed (no displacement)
Side boundaries	Roller boundaries (horizontal movement restricted)
Mesh type	Auto-generated fine mesh
Groundwater condition	Controlled phreatic-level reduction representing relative stress-loading only
Simulation duration	Equivalent to a 10-year modeled period

Representative soil profiles were derived from the LGU source records and used as comparative numerical categories only. Because the analysis was not calibrated with site-specific laboratory and pumping-test data, the modeled response should be interpreted as a controlled comparison of relative settlement trends rather than a forecast of field settlement in Cabanatuan City.

III. RESULTS AND DISCUSSION

The simulations showed a consistent increase in settlement across all soil profiles as the imposed groundwater-stress scenario increased from 600 to 1000 L/day. Brown Sandy Silt exhibited the highest settlement response, increasing from 29.50 mm to 57.18 mm, while Brown Silty Sand increased from 24.60 mm to 47.69 mm. At the lower end of the range, Hard Brown Clayey Silt increased from 0.6024 mm to 1.093 mm and Silty Sandy Gravelly Clay Loam increased from 1.018 mm to 1.845 mm. These trends indicate that, under the selected default parameters, silty and sandy materials were more susceptible to modeled compression than denser or more cohesive profiles.

A descriptive statistical reading of the 600 and 1000 L/day cases further highlights this pattern. Percentage increases ranged from 81.24% to 94.94% across the eleven soil types. Brown Sandy Silt ranked first at 1000 L/day, followed by Brown Silty Sand and Silty Sand with fine to coarse grains. In contrast, Hard Brown Clayey Silt and Silty Sandy Gravelly Clay Loam showed the lowest absolute settlements. The uniform upward trend across all profiles suggests that stronger imposed groundwater-stress scenarios consistently generated larger modeled settlements, even though the magnitude of the response depended strongly on soil type.

These results align with the principle of effective stress and with prior numerical and field-based studies indicating that reductions in pore water pressure can increase compression and settlement [4], [7], [11], [12], [16]. At the same time, the study should not be interpreted as demonstrating a direct

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linear relationship between household pumping volume and field drawdown. The scenarios were simplified relative stress-loading conditions, and the model did not include calibrated groundwater flow, recharge, or aquifer interaction processes.

From an engineering perspective, the maximum modeled settlement of 57.18 mm over 10 years should be interpreted as a potential serviceability concern rather than a direct indicator of structural failure. For lightly loaded residential slabs and shallow foundations, settlement of this magnitude may become problematic if differential movement occurs. However, the present model evaluated total vertical ground response only and did not simulate foundation stiffness, structural redistribution, or site-specific damage thresholds. The results are therefore best treated as a screening-level comparative assessment for future geotechnical and hydrogeologic investigation.

Table 2. Modeled settlement of representative soil profiles under hypothetical household-demand scenarios.

Soil profile	600 L/day (mm)	800 L/day (mm)	1000 L/day (mm)
Brown Sandy Silt	29.50	48.41	57.18
Brown Silty Sand	24.60	40.38	47.69
Silty Sand (fine to coarse grained)	19.59	32.33	38.19
Clayey Sand (medium plasticity)	18.53	30.41	35.93
Brown Silty Sand (fine-coarse and gravel)	14.77	24.26	28.66
Dense Silty Sand (with gravel)	9.857	16.19	19.13
Silty Sand	6.92	11.37	13.43
Sandy Gravel	5.191	8.529	10.08
Silty Clay	1.538	2.513	2.796
Silty Sandy Gravelly Clay Loam	1.018	1.648	1.845
Hard Brown Clayey Silt	0.6024	0.9726	1.093

IV. CONCLUSION

The study demonstrated that higher hypothetical groundwater-stress scenarios produced larger modeled settlements across all eleven representative soil profiles in Cabanatuan City. Under the selected default PLAXIS parameters, silty and sandy soils generally exhibited the highest relative deformation, while denser or more cohesive profiles exhibited lower settlement. Brown Sandy Silt produced the maximum modeled settlement, whereas Hard Brown Clayey Silt produced the minimum response.

These findings are limited to a comparative numerical framework. Because the model relied on default material parameters and proportional phreatic-level reductions rather than hydrogeologically calibrated drawdown, the results should not be interpreted as site-specific field predictions. Even so, the manuscript provides a useful screening-level reference for identifying soil types that may warrant closer attention in future groundwater-management, geotechnical investigation, and shallow-foundation assessment in Cabanatuan City.

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