VS30 MAPPING BASED ON EFFECTIVE STRESS AND VOID RATIO: USING NEW TRANSFORMATION FUNCTIONS AND ADDING DATA FROM BOREHOLES LESS THAN 30 METERS

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INTRODUCTION

Site effect plays an important role in issues of strong ground motion studies. Site effect is caused by soft deposits overlaying hard rock, causing seismic ground motions to be amplified and increasing damage during large earthquake. The time-averaged shear-wave velocity in the upper 30 meters, i.e. VS30, is the most popular and widely be used site parameters representing the site effect in engineering seismology. In this case, VS30 can be estimated based on void ratio and effective vertical stress by transformation functions with data within 30 meters. An extrapolation method: Conditional Independent Property (CIP) model by (Dai et al., 2013) is applied when available data is less than 30 meters. The data of soil physical property data and wave velocity measurements from the Engineering Geological Database for TSMIP (EGDT) were collected and checked, we then proposed transformation functions to predict the shear-wave velocity (VS) using void ratio and effective vertical stress based on the database from 2000 to 2008. Using both transformation functions and extrapolation method, the VS at each depth from numerous drilling boreholes from Central Geological Survey (CGS) has been estimated to obtain VS30 for each borehole. Finally, Kinging with varying local means is used to create a distribution map of VS30 in the Taipei Basin.

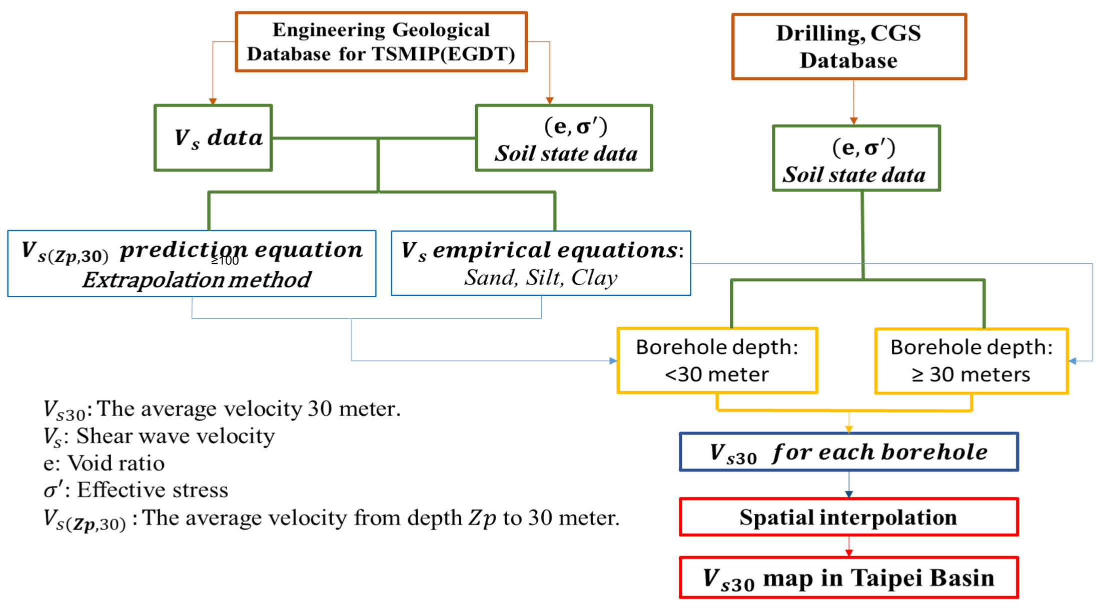


Figure 1: The workflow of this study

DATA

A. Engineering Geological Database for TSMIP (EGDT)

41 boreholes

- Soil profile characteristics are determined by subsurface investigation and field/lab testing program.

➡ Soil State Data (e, σ')

- Suspension PS logging method ➡ Vs data (Vs-profile)

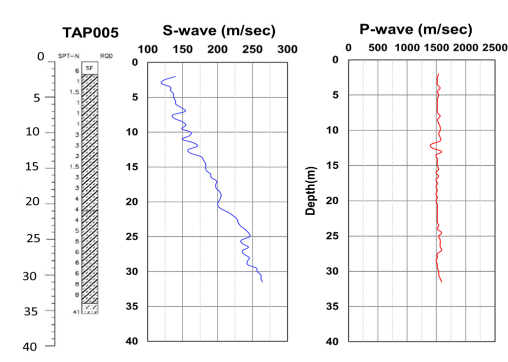


Figure 2: Example of drilling log and PS logging at Station TAP005 in Taipei.

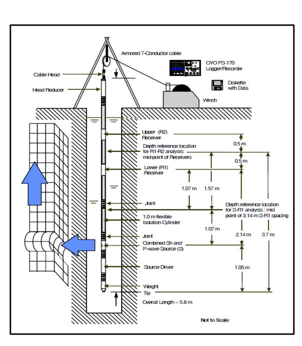


Figure 3: Sketch map of PS suspension logger (Diehl, J. 2001)

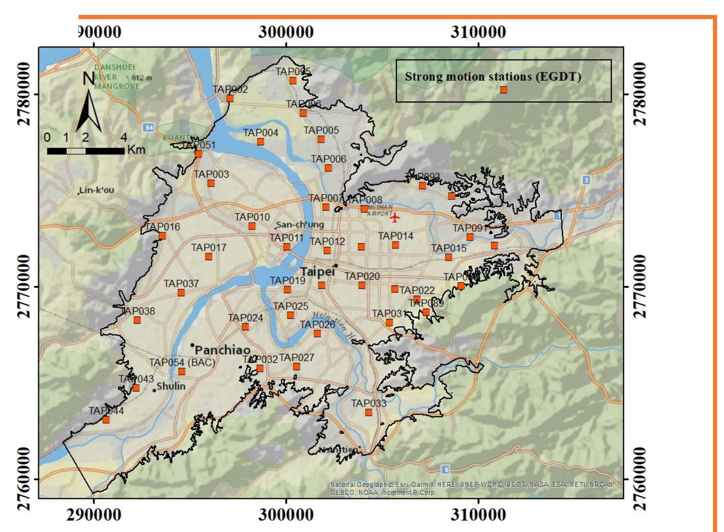


Figure 4: The map show distribution of 42 boreholes from EGDT in the Taipei Basin(2000-2008)

Using for	Boreholes
Vs Transformation functions	27
Extrapolation methods	29
Interpolation Vs30 map	41

Table 1: Three purposes used EGDT data

B. CGS, drilling Database

Total: 10768 boreholes

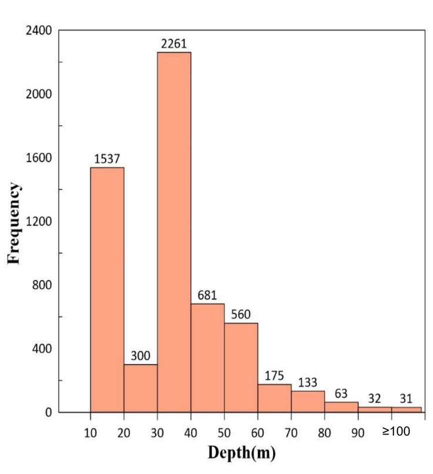


Figure 5: Histogram show depth distribution of 5773 boreholes in Taipei Basin.

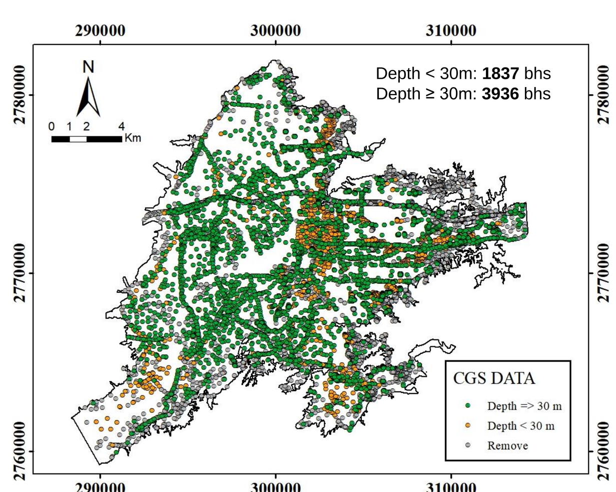
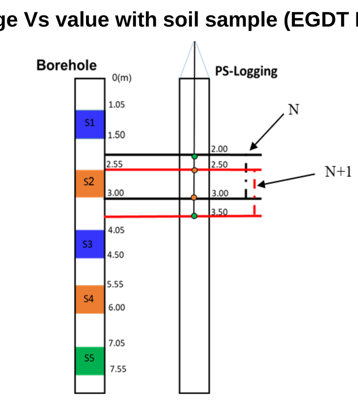


Figure 6: Distribution of 1837 boreholes less than 30m and 3936 boreholes equal or greater than 30m

- Merge Vs value with soil sample (EGDT Data)



Removed boreholes reason:

- *Lack of void ratio (e) , moisture water content (w), Specific gravity (Gs), unit weight(γ_t)*

METHODOLOGY

1. Correlation between Vs (Shear wave velocity), e (void ratio) and σ_v' (effective stress)

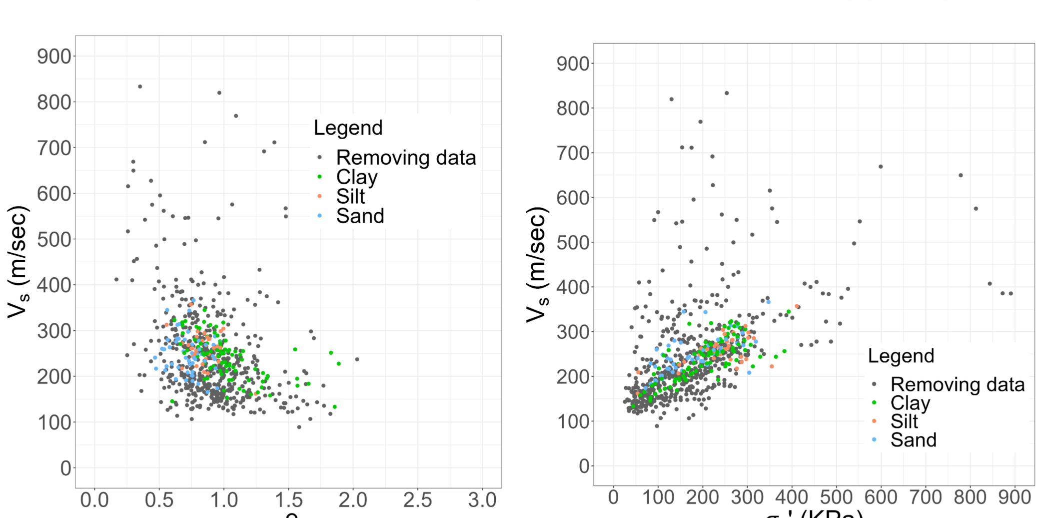


Figure 7: Distribution of data: Clay, Silt, Sand. After checking the quality of Shear wave velocity, Gravel is bad quality, so this study did not consider Gravel for regression.

Sand | Silt | Clay

$$V_s = (m_1 - m_2 e)\left(\frac{\sigma_v'}{100}\right)^{n_a}$$

Robertson et al. (1995)

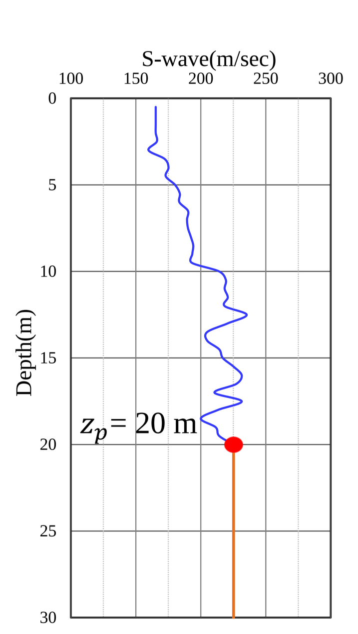
2. Extrapolation methods

2.1. Bottom constant velocity (BCV) model (Kuo et al., 2011,2012)

- The assumption of model that V_s is constant from z_p to 30m

$$V_{s30} = \frac{30}{\Delta t_z + \frac{30 - z_p}{V_{s(z_p)}}} \quad (1)$$

Δt_z the shear wave travel time from z_p to the surface



$V_{s\ at\ 20\ m}$= 225.5 m/sec

2.2. Conditional independence property model (CIP) (Dai et al.,2013)

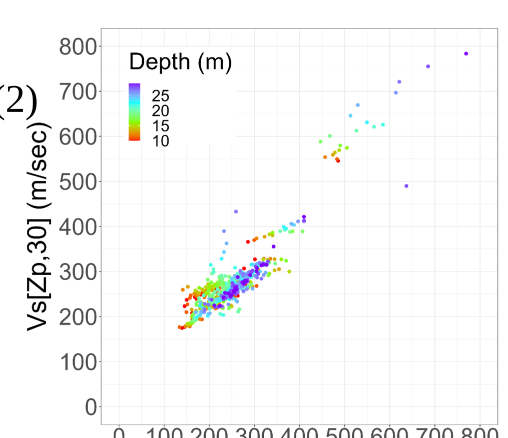
- The assumption that the V_s profile is a Markov process staring from z = 0
- The instantaneous velocity at depth Zp, the average velocity from surface to the depth Zp (V_{SZ}) cannot be effectively in estimating the average velocity from depth Zp to 30 m $V_{s[z_p,30]}$

$$\log(V_{s[z_p,30]}) = c_0 + c_1 \log(V_{S\ at\ z_p}) \quad (2)$$

c_0, c_1, : regression coefficients

- Using the average velocity from z to 30 m to estimate V_{s30}

$$V_{s30} = \frac{30}{\Delta t_z + \frac{30 - z_p}{V_{s(z_p,30)}}} \quad (3)$$



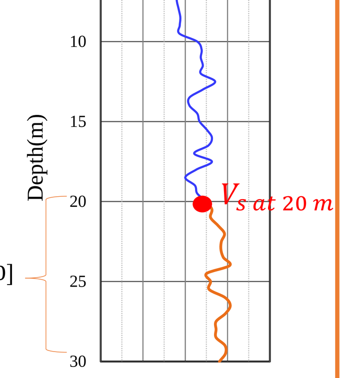


Figure 8: Correlation of The instantaneous velocity at depth Zp ($V_{S\ at\ z_p}$) and the average velocity from depth Zp to 30 m ($V_{s[z_p,30]}$)

RESULTS AND DISCUSSION

1. Correlation between V_S , e and σ_v' and comparing results of (Kuo,2021)

Table 2: Results of transformation function and Comparing the result of transformation functions with (Kuo, 2021)

Author		Functions	RMSE	R^2	Samples	Data
This study	Sand	$V_s = (240.5 - 35.9e)(\frac{\sigma_v'}{100})^{0.28}$	30.8	0.48	51	Taipei Basin (2000-2008)
	Silt	$V_s = (230.2 - 21.1e)(\frac{\sigma_v'}{100})^{0.23}$	26.5	0.46	34	
	Clay	$V_s = (213.1 - 21.3e)(\frac{\sigma_v'}{100})^{0.33}$	29.9	0.60	88	
	Silt and clay	$V_s = (220.4 - 24.5e)(\frac{\sigma'}{100})^{0.30}$	29.2	0.58	122	
(Kuo, 2021)	Sand	$V_s = (241-39.9e)(\frac{\sigma'}{100})^{0.30}$	45.8	0.51	672	Whole of Taiwan (2000-2004)
	Silt and clay	$V_s = (199.2- 2.9e)(\frac{\sigma'}{100})^{0.31}$	47.9	0.50	617	

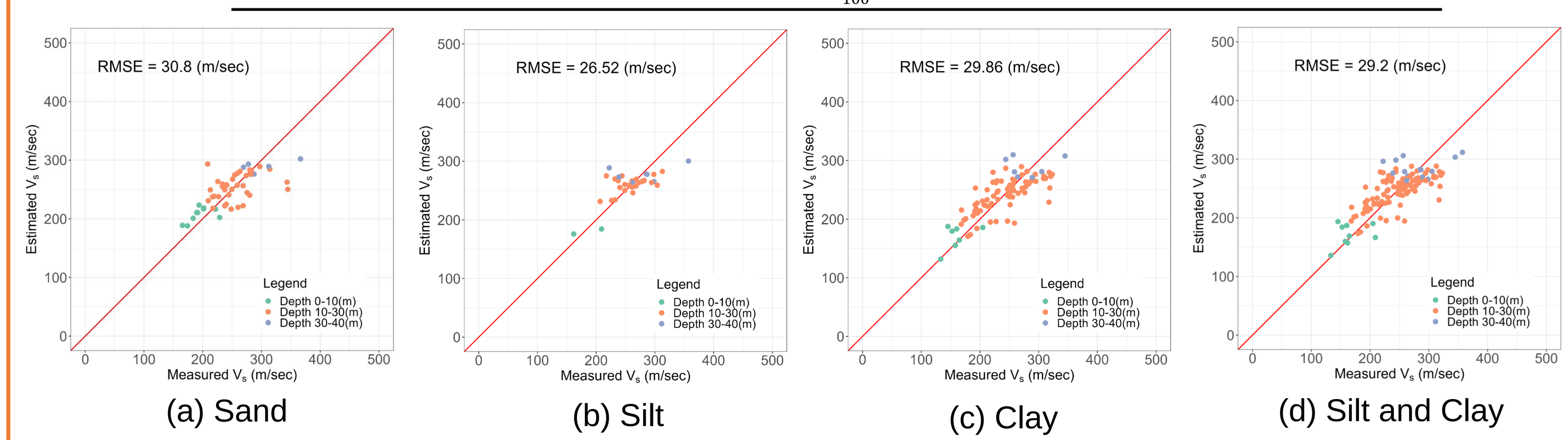


Figure 9: These figures compare the estimated V_S and measures V_S by transform equations of (a) Sand, (b) Silt, (c) Clay , (d) Silt and Clay in this study

2. Extrapolation methods

Depth (m)	c_1	c_2	R^2	Standard Deviation ($\sigma_{residual}$)
10	0.74	0.71	0.79	0.044
11	0.91	0.64	0.70	0.052
12	0.84	0.67	0.66	0.055
13	0.91	0.64	0.67	0.055
14	0.74	0.71	0.74	0.048
15	0.76	0.70	0.76	0.046
16	0.70	0.73	0.77	0.045
17	0.63	0.76	0.82	0.040
18	0.53	0.80	0.79	0.043
19	0.45	0.83	0.78	0.044
20	0.44	0.83	0.78	0.044
21	0.49	0.81	0.79	0.043
22	0.33	0.88	0.82	0.040
23	0.19	0.93	0.87	0.035
24	0.21	0.92	0.80	0.043
25	0.23	0.92	0.77	0.047
26	0.25	0.90	0.78	0.047
27	0.17	0.94	0.79	0.048
28	0.27	0.89	0.95	0.026
29	0.06	0.98	0.99	0.012

Table 3: Summary of Regression Results for the Linear Model of CIP model used 29 boreholes in Taipei Basin

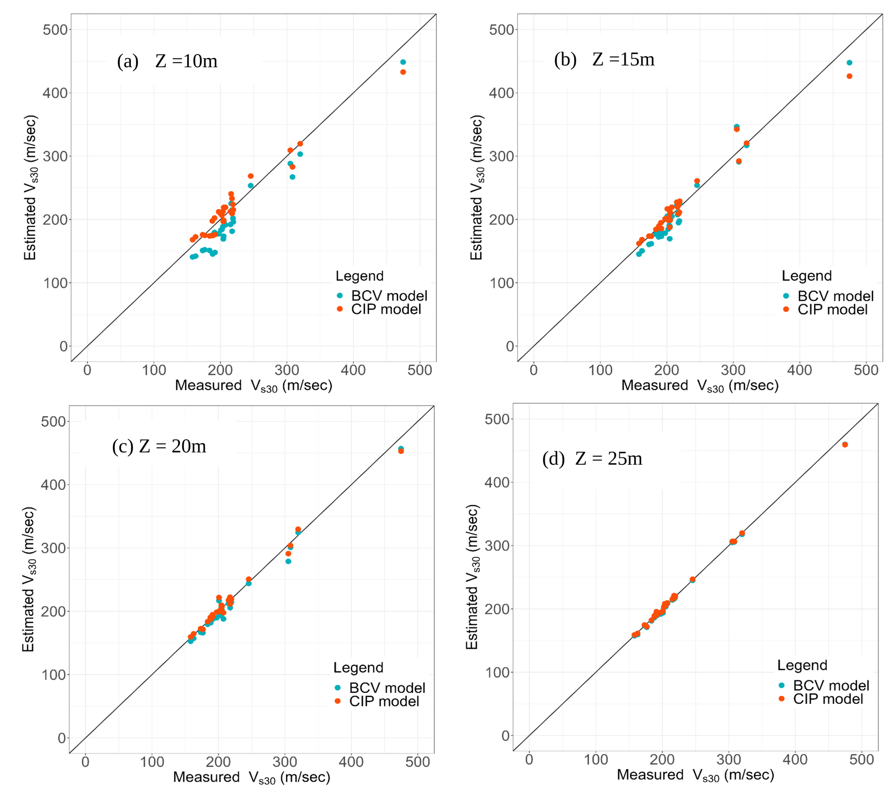


Figure 10: Comparing BCV and CIP model at depth 10m,15m, 20m, 25m meters (V_{S30} by model and V_{S30} by measurement)

Note: the point in these figure is each strong motion station in Taipei Basin.

- The equation to estimate the total error of the average velocity from depth Zp to 30 m $V_{s[z_p,30]}$:

$$\sigma_{residual} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\log(V_{s[z_p,30]}.est) - \log(\overline{V_{s[z_p,30]}}))_i^2} \quad (4)$$

3. Vs30 map with Kriging varying local mean

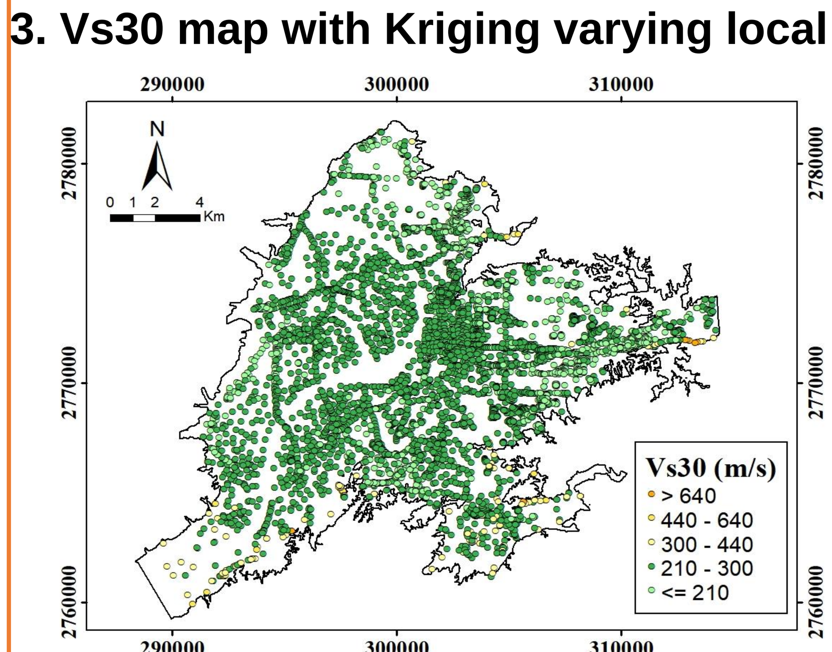


Figure 11: VS30 of 5773 boreholes from CGS

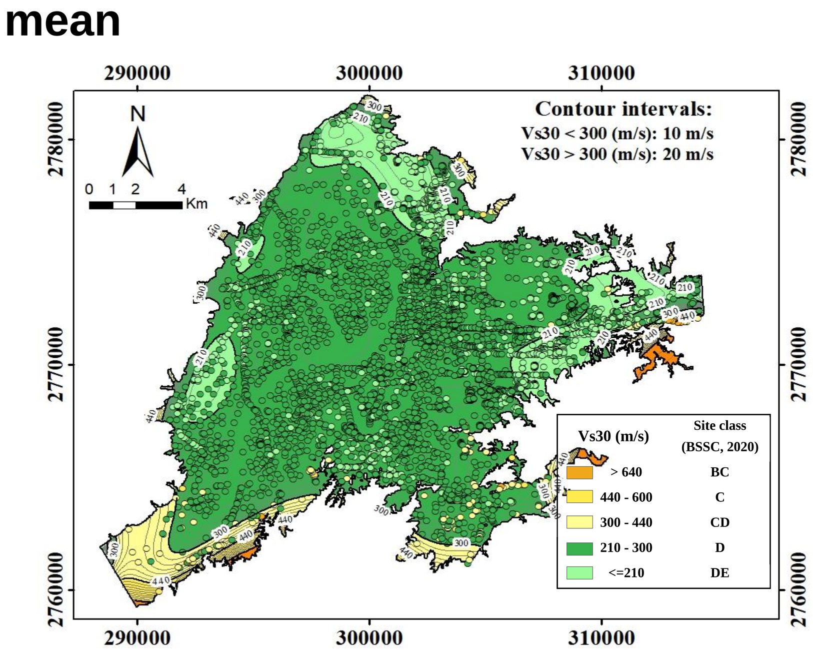


Figure 12: The final result VS30 map by Kriging with varying local means

In the Taipei Basin, the values range from 157 m/s to 640 m/s.
1. The study identifies four specific areas with relatively low VS30 values, specifically less than 210 m/s: North area, Northeast area and Western of Taipei Basin.
2. In the central area of the Taipei Basin, the VS30 values range from approximately 210 m/s to 300 m/s.
3. Near the margins of the western and southern regions, as well as the eastern southern region, the VS30 values tend to be higher, ranging from 300 m/s to greater than 640 m/s. In these areas, the presence of gravel or rock layers at depths less than 30 meters can significantly influence the VS30 values, as the properties of these layers contribute to higher shear wave velocities.

Conclusions

1. Based on regression analysis for sand, silt and clay in the Taipei Basin with EGDT data from 2000 to 2008, resulting in improved RMSE values compared with (Kuo, 2021) have results such as Transformation function for Sand: RMSE from 45.8 m/s decrease of 30.8 m/s and transformation function for Silt and Clay: RMSE from 47.9 m/s decrease to 29.2 m/s. In addition, by separating clay and silt, we have two transformation function better than combined with RMSE 26.52 m/s and 29.86 m/s, So three transformation functions estimate VS30 for CGS boreholes: Sand, Silt, Clay.
2. Comparing extrapolation methods: BCV model and CIP model at the depth 10,15, 20 and 25 meters. VS30 estimate for boreholes less than 30 meters from CIP model is better than the BCV model. The CIP model has shown a good fit with the data for the top 30 meters of soil in the Taipei Basin.
3. Vs30 map in the center of the Taipei basin has VS30 from 210 to 300 m/s. Some areas update VS30 value from this study, such as areas have VS30 equal to or less than 210m/s: North, Northeast, two small areas in West of Taipei Basin: areas have VS30 value equal or larger than 300 m/s margin South, East, and Southwest.

References

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