Spatial Inequalities in Educational Infrastructure: Bayesian Hierarchical Modelling of School Availability Across North Borneo

Alvin Bong

Understanding the spatial distribution of educational infrastructure is essential for ensuring equitable access to schooling. This study examines regional disparities in school availability across Brunei and the neighboring Malaysian states of Sarawak and Sabah, with a focus on identifying potential underserved areas. First, exploratory data analysis (EDA) was conducted to compare school counts and student-teacher ratios at the district level across the three regions. The core analysis employs Standardized Incidence Ratio (SIR) and Bayesian spatial Poisson model using Integrated Nested Laplace Approximation (INLA) to estimate the relative abundance of schools across Brunei's districts, adjusting for expected counts based on population, region size and socioeconomic indicator (house price + partially simulated). Spatially structured and unstructured random effects were incorporated to account for latent spatial processes. Posterior estimates identified districts with significantly lower school availability than the national baseline, supporting future policy planning and school placement.

Introduction

Education is a foundational pillar of national development and its people, influencing social well-being, economic growth, and long-term sustainability. The global significance of education is recognized in Sustainable Development Goal 4, which promotes inclusive and equitable quality education for all [1]. Nationally, Brunei Darussalam's national vision, Wawasan Brunei 2035, positions education as a cornerstone of the country's long-term development goals. Ensuring equitable access to education through sufficient infrastructure, fair resource distribution, and balanced student–teacher ratios is critical to delivering quality learning experiences.

While several studies have examined general aspects of education in Brunei, there have been limited studies based on quantitative spatial methods, with only one examining the spatial

distribution and hotspots of schools. This project aims to addresses that gap by first conducting a comparative analysis of school availability and student–teacher ratios across Brunei's districts, with additional context from neighboring Malaysian states, Sarawak and Sabah.

Next, Standardized Incidence Ratios (SIR) and Bayesian hierarchical models are used to identify adminstrative regions in Brunei where school availability falls significantly below the national baseline, supporting future policy planning and school placements.

Data

This study focuses exclusively on government primary and secondary schools, as these institutions serve as the main access points to education for most youth. The school dataset from 2018 was used as it is the most recent year for which disaggregated school-level data is available in Brunei. Although more recent statistics exist, they are published only in summary form.

Population data is drawn from the 2021 national census, the most recent census available in Brunei, despite the mismatch in years with the school dataset. Brunei conducts its national census every ten years, making the 2021 data the best option for population estimates.

The following key data variables were used: school counts, administrative boundary data, population, student–teacher ratios, and house prices. These datasets were cleaned, wrangled, and merged primarily using left_join() and rbind(), with further details provided below.

Brunei

Data on school locations, student–teacher ratios, administrative boundaries, and population were sourced from the `bruneimap` R package. The school dataset `sch_sf` includes georeferenced point data for each institution. For our areal analysis, schools were aggregated by district and mukim (finer administrative level). Despite composing of only four districts, district-level aggregation was used for broader comparisons (student–teacher ratios and school counts) to match the size of available administrative resolution in Malaysian data. Mukims ($N = 39$), which provide finer geographic resolution, were instead used for the Bayesian spatial analysis of school availability in Brunei.

To incorporate a socioeconomic indicator, we used median house prices derived from approximately 30,000 property listings spanning 1993–2025. These were calculated at the mukim level and included as a covariate in the Bayesian model. In cases where house price data were missing, values were imputed using predictions from an INLA-based Gaussian model. Manual imputations based on local knowledge were initially tested, but the INLA-predicted values were ultimately adopted, as both methods produced similar model outcomes. Given the nature of the data, house prices were treated as partially simulated estimates and may not fully reflect actual market values.

Malaysia

Malaysian data variables were sourced from the national open data portal [data.gov.my], and include district-level school counts and population estimates for the states of Sarawak and Sabah. Administrative boundary (districts) were obtained via the `geomdata` R package, as OpenStreetMap (`osmdata`) does not provide required administrative divisions level.

Some inconsistencies were found between school data and adminstrative boundaries, particularly in areas where older districts had been subdivided into newer ones. In these cases, school counts were available only for the original (larger) districts. To ensure consistency, we excluded the newer subdivisions and manually reassigned schools in the affected areas to the nearest valid district.

Method

Exploratory data anlysis using Clorepath maps for schools count, by area (usingst_area) studnet teacher ratio

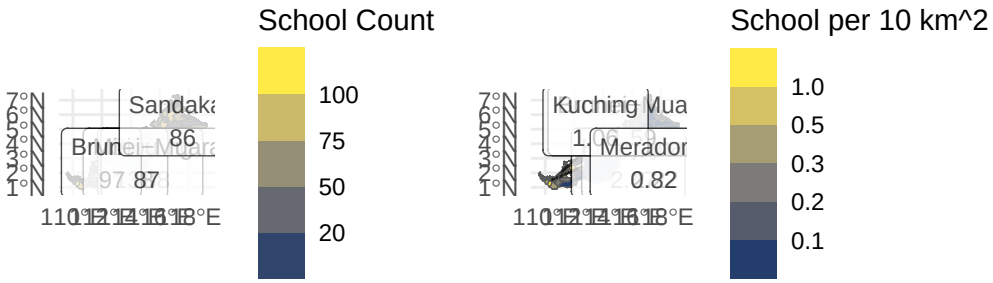
Neighbour type

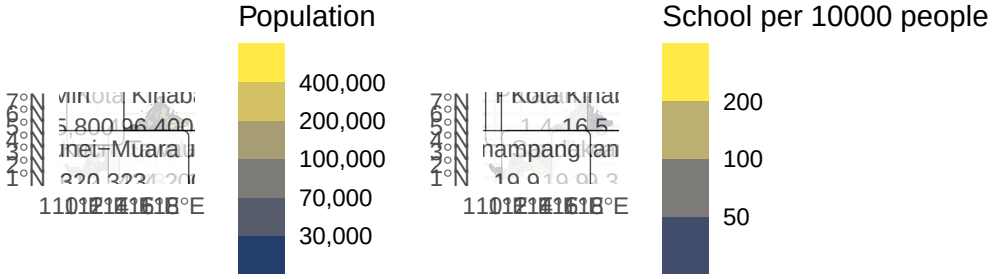
POisson INLA hierarchical model

covariates: house price as socio economic index

Spatial Poisson model Justify offset (population) Explain fixed and random effects Introduce INLA + BYM

Results





- School count quite similar, more in main city

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character(0)
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[1] "Matu"     "Pakan"    "Selangau"
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[1] "Matu"     "Pakan"    "Selangau"
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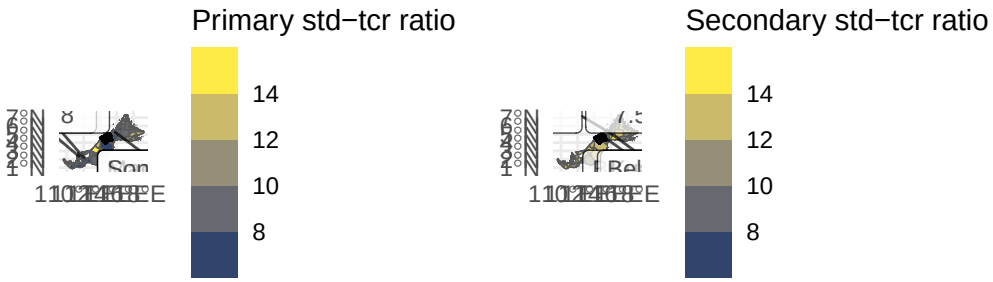
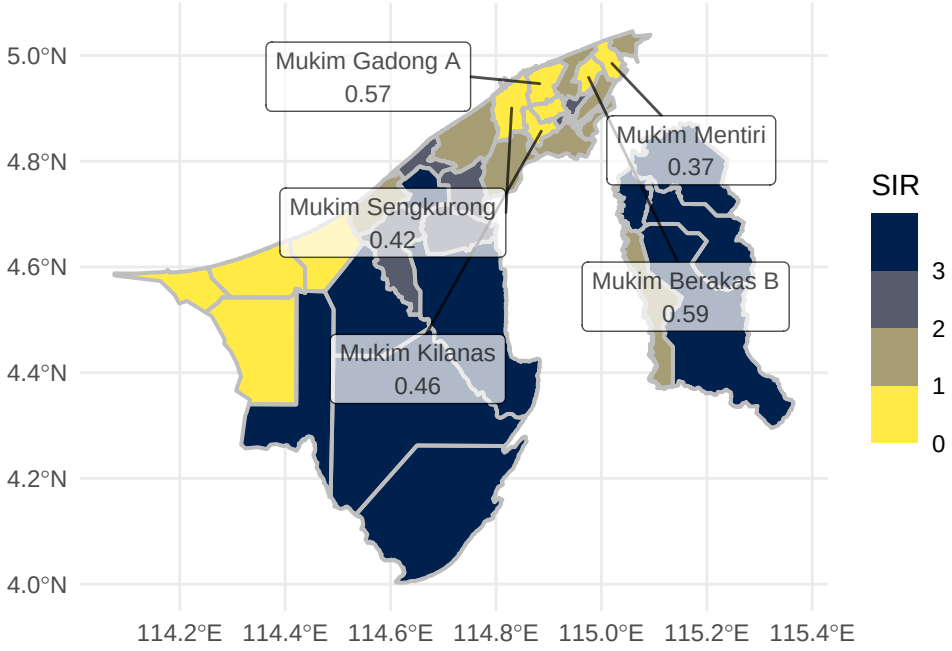
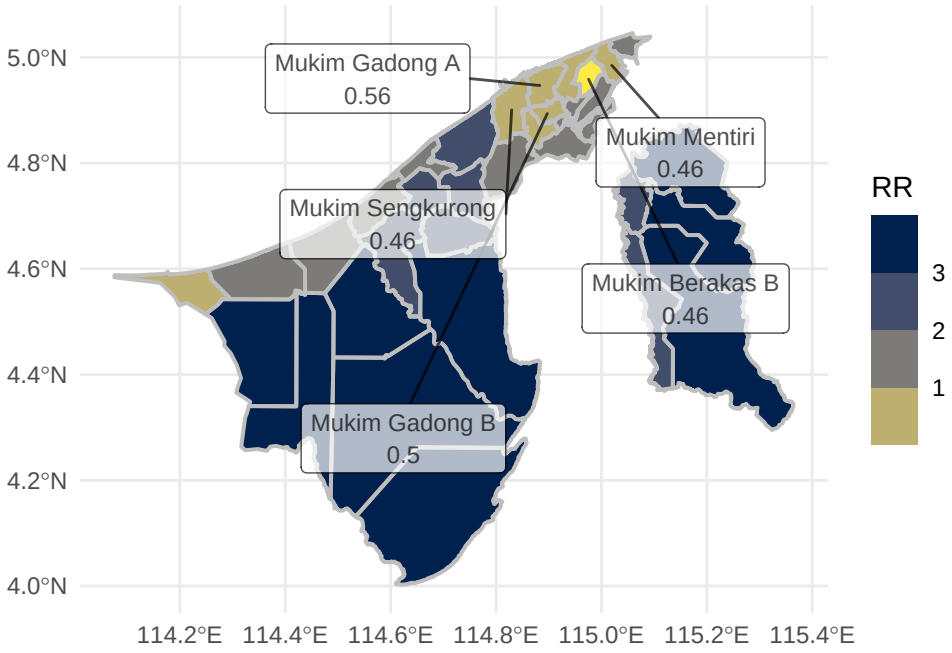


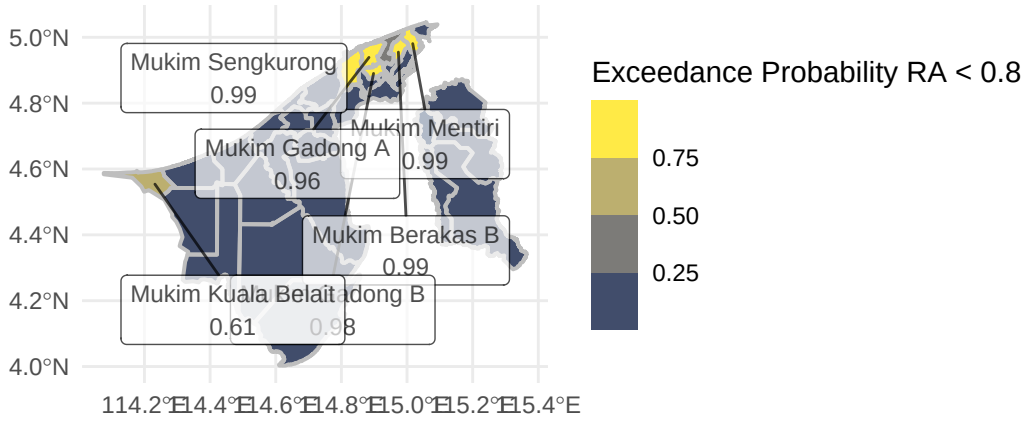
- studnet teacher ratio, primary simiilar other than dense city (miri, kuching, kota kinabalu), but brunei has lesser secondary std-tcr]

Model



- There are significantly fewer schools in Mukim xxx





- Coefficient , sginificance

Discussion & Limitation

There are significantly fewer schools in Mukim xxx, when explored, its not forested area. Housing region, some may be newer nieghbourhood so.. good idea for mroe schools there, nearer from home, less transportation cost, environmental, time.

Given that Brunei has higher PISA scores than Malaysia, it would be interesting to explore whether accessibility may be a potential factor. / Malaysia has more population than Brunei, how does the school compare

Limitation: only public schools, to consider private schools age groups, 2018 data, school types, some simulation in housing price, house price is listing price (only a proxy for market values), may deviate from actual sales price due to negotian dynamics and other factors ## Conclusions {#sec-conc}

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References