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Climate Change and Educational Access in Somaliland: Assessing Enrollment and Dropout Trends

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ABSTRACT

This study investigates the relationship between drought conditions and educational access in Somaliland, utilizing spatial analysis to examine enrollment and dropout patterns. Results reveal significant regional disparities in educational infrastructure, with western urban areas having more schools than eastern regions. Despite having the highest density of educational facilities, the Maroodi Jeex region shows the highest dropout rate (45%), while remote regions like Saaxil and Sanaag maintain relatively low dropout rates (8%). Western districts demonstrate substantially higher kindergarten enrollment (14,827 students) compared to southeastern regions (549 students), indicating early vulnerability to climate-influenced disparities. Primary education dropout data shows higher rates for male students than females, particularly in western districts, likely reflecting household labor allocation during climate stress. Grade-level progression analysis revealed a systematic narrowing of the educational pipeline, with dramatic enrollment declines between Grades 3 and 4 and virtually zero enrollment in Grade 8 in several eastern districts. Temporal drought analysis (2020–2022) shows significant variability across regions, with northeastern coastal areas improving while southeastern districts worsened. The temporal consistency of recurrent drought impacts across the 2020–2022 period suggests that prolonged climate stress systematically reinforces educational disruption patterns rather than producing isolated short-term effects. Extreme weather events, particularly recurrent droughts, have directly shaped enrollment and dropout trends across climate-exposed districts. This research identifies climate-vulnerable educational zones and provides actionable recommendations for enhancing educational resilience through targeted interventions.

1. INTRODUCTION

Climate change represents one of the most pressing global challenges of the 21st century, with disproportionate impacts on vulnerable populations in developing regions [1]. While extensive research has documented climate change effects on agriculture, health, and migration, the relationship between climate variability and educational outcomes remains understudied, particularly in fragile contexts [2, 3]. Education serves as a critical pathway for sustainable development and climate resilience, yet climate-related disruptions increasingly threaten educational systems worldwide, with an estimated 40 million children annually experiencing educational disruptions due to environmental hazards [4].

In sub-Saharan Africa, where approximately 617 million children and adolescents lack minimum proficiency in reading and mathematics, climate change impacts introduce additional complexity to already-strained educational systems [5]. Recurring droughts, floods, and other extreme weather events disrupt school attendance, damage infrastructure, and exacerbate resource scarcity in educational institutions [6]. Recent evidence demonstrates that climate-induced economic

shocks frequently result in decreased school enrollment as households reallocate resources and labor in response to environmental stressors [3, 7]. Despite these documented relationships, significant knowledge gaps persist regarding the precise mechanisms through which climate variability affects educational access and retention in specific regional contexts.

The Horn of Africa represents a particularly vulnerable region to climate change impacts, experiencing increased frequency and intensity of droughts over the past three decades [8, 9]. Within this region, Somaliland, a self-declared state functioning with limited international recognition, faces compound challenges of climate vulnerability, fragile governance, and development constraints [10-12]. The predominantly pastoral and agropastoral livelihoods in Somaliland are highly sensitive to climate variability, with cascading effects on household resources and educational decision-making [13]. Despite substantial progress in expanding educational access since the early 2000s, Somaliland's education system remains characterized by significant regional disparities and vulnerability to external shocks [14, 15].

While previous studies have examined general educational challenges in Somaliland, including infrastructure limitations, teacher qualifications, and gender disparities [16], the specific relationship between climate variables and educational outcomes remains inadequately investigated. The few existing studies addressing this nexus in comparable contexts have typically relied on limited geographical scope, cross-sectional approaches, or qualitative methodologies [17, 18]. This study addresses these limitations by employing a comprehensive spatial analysis approach that integrates climate data, specifically drought indices, with educational enrollment and dropout statistics across Somaliland's diverse regions.

Similarly, in the education sector, the Somaliland Ministry of Education has been prioritizing access to education for the last 3 decades [19]. High student dropout rates are a critical issue in Somaliland, significantly impeding educational progress and socioeconomic development [20]. The available data revealed school dropout rate in Somaliland is 12.67%. Despite this, no study has investigated the link between climate change impacts and education accessibility in Somaliland.

The integration of geospatial analysis with educational data represents a methodological advancement in understanding climate-education relationships in resource-constrained environments. By combining remote sensing data with educational metrics, this study develops a spatially explicit framework for identifying educational vulnerability hotspots in relation to climate stressors [20, 21]. The spatial approach enables examination of how environmental conditions interact with pre-existing educational infrastructure, socioeconomic factors, and geographical accessibility to influence educational outcomes across Somaliland's heterogeneous landscape.

This study aims to assess the relationship between climate change impacts, specifically drought conditions, and educational access in Somaliland by analyzing enrollment and dropout trends across different administrative regions. The research examines how spatial variations in drought severity correlate with educational metrics, controlling for relevant socioeconomic and infrastructural factors. Through this analysis, the study seeks to identify climate-vulnerable educational zones and inform targeted interventions to enhance educational resilience in the face of increasing climate variability. The findings contribute to broader scholarship on climate-education relationships in fragile contexts while providing actionable insights for educational planning and climate adaptation strategies in Somaliland and similar environments.

2. STUDY AREA

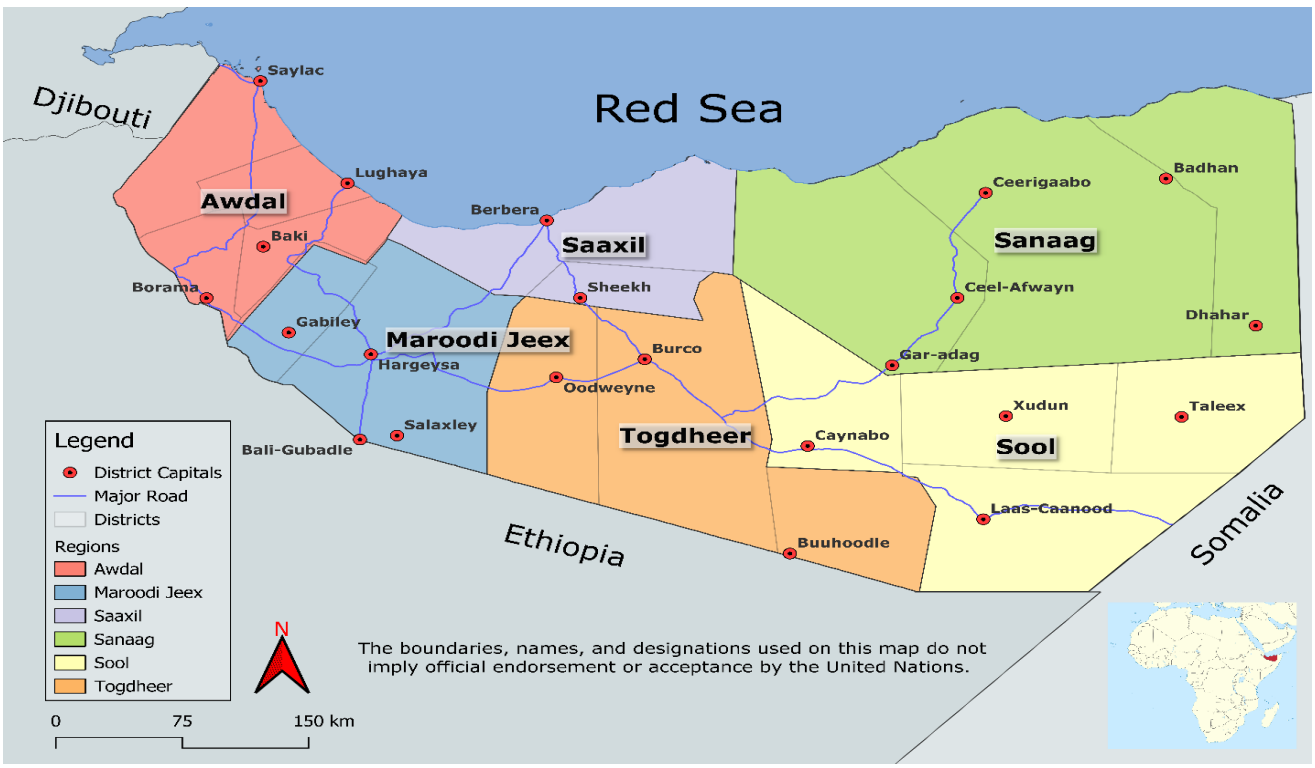

Figure 1. Study area map, Somaliland

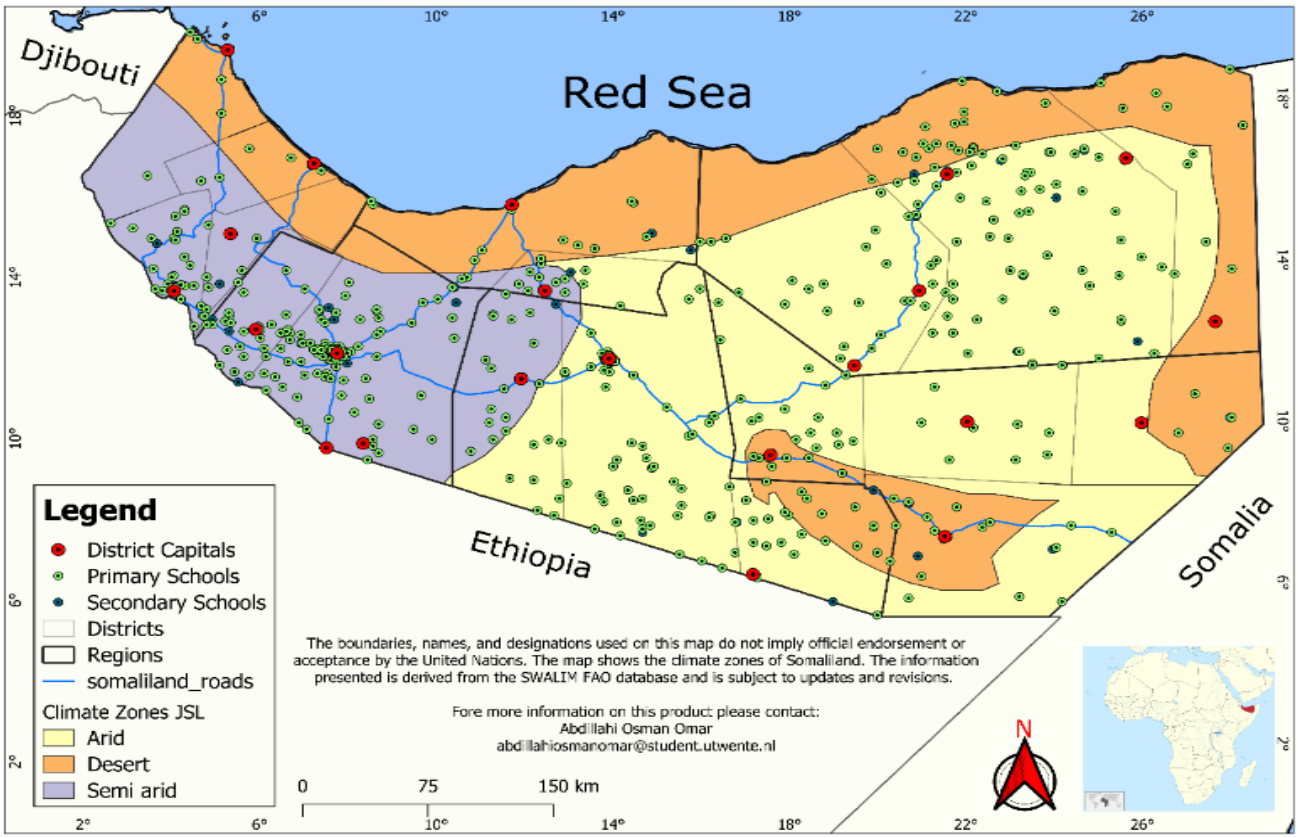

Figure 2. Climate zonation in Somaliland

Somaliland is a self-declared state located in the Horn of Africa (Figure 1), bounded by the Gulf of Aden to the north, Djibouti to the northwest, Ethiopia to the south and west, and Somalia to the east [12]. Despite declaring independence from Somalia in 1991, Somaliland remains internationally unrecognized, yet functions as a de facto independent state with its own government, currency, and public services [10]. The territory spans approximately 137,600 m^2 and is characterized by diverse topography ranging from coastal plains along the Gulf of Aden to the Golis Mountain range in the central regions, and semi-arid plateaus in the south. The climate is predominantly arid to semi-arid, with average annual rainfall between 100 and 500 mm varying by region, with the highest precipitation occurring in the mountainous areas [13].

Administratively, Somaliland is divided into six main regions: Awdal, Woqooyi Galbeed, Togdheer, Sahil, Sanaag, and Sool, which are further subdivided into districts. The total population is estimated at 4.5 million, with approximately 55% living in rural and nomadic settings [22]. The education system in Somaliland operates under the Ministry of Education and Science, featuring a structure of 8 years of primary education, 4 years of secondary education, and varying lengths of tertiary education [16]. The structure of the Ministry also features 2 years of early childhood education now as depicted in the National Early Childhood Education Policy (2020). Primary education enrollment has been steadily increasing since the early 2000s, though significant regional disparities persist.

The climate zonation of Somaliland (Figure 2) reveals critical intersections between environmental conditions and educational infrastructure across the territory. The semi-arid western regions, particularly around Hargeisa, display the highest concentration of both primary and secondary educational facilities, creating a relative educational advantage in these moderately dry areas. In stark contrast, the extensive arid zones that dominate central and eastern Somaliland show a more dispersed pattern of schools, primarily clustered along major transportation corridors that traverse these drier landscapes. Desert regions, predominantly located in the north and northeast along the Red Sea coast and in pockets of the eastern interior, exhibit the sparsest educational coverage, highlighting potential climate-related barriers to educational development. District capitals serve as educational nodes across all climate zones, though their educational gravitational pull appears strongest in semi-arid areas where population density is likely to support greater institutional investment. This climate-education interface suggests graduated vulnerability to climate disruptions, with desert and arid zone schools likely facing greater sustainability challenges during climatic extremes than their semi-arid counterparts. The spatial correspondence between climate zones and educational density indicates that environmental factors may function as determinants of educational accessibility in Somaliland, with implications for enrollment stability and dropout vulnerability as climate variability potentially intensifies in the region.

3. METHODOLOGY

3.1 Data collection and preparation

This study employed a systematic approach to investigate the relationship between climate change impacts, specifically drought conditions, and educational access in Somaliland. The investigation utilized data from the Education Management Information System (EMIS), the primary repository for

educational data [20]. The Ministry of Education and Science established EMIS as a centralized database accommodating over 600,000 students and 14,000 teachers across all education centers. EMIS tracks enrollment, transfers, dropouts, and academic progress from pre-primary to upper secondary levels, including vocational and adult education institutions. According to the National Education Strategic Plan (2022-2026), EMIS provides critical data for policy decisions, annual sector reviews, and evaluations, capturing key indicators aligned with Somaliland's National Education Policy (2015).

The study focused on Somaliland at the regional and district levels during 2022–2023 to ensure temporal relevance and geographical precision. Regional and district identifiers were verified to maintain data integrity, following best practices established by Dryden-Peterson and Mulimbi [17] for spatial data validation in fragile contexts. The educational dataset comprised three components: (1) geospatial data on school locations, distinguishing primary and secondary institutions; (2) enrollment statistics across administrative units; and (3) dropout figures for the specified timeframe. School location data was collected through EMIS records, while enrollment and dropout statistics were extracted from quarterly reports submitted by regional education officers.

Since spatial mapping of schools had not been previously conducted in Somaliland, coordinate data were extracted through geocoding based on available school addresses. However, due to the absence of a standardized national addressing system, geocoding alone was insufficient for accurately determining school locations in remote areas. Geocoding, the process of assigning coordinates to physical locations, has improved performance across various domains through spatial analysis. To address this limitation, manual verification and web scraping were employed to enrich the school location dataset. Data was supplemented from publicly available online sources, including social media platforms (Facebook, Twitter, TikTok) and educational directories, to gather valuable location information. School names were cross-referenced with the EMIS database, and location data were validated through manual checks using satellite images, Google Maps, and OpenStreetMap (OSM).

3.2 Climate data acquisition and processing

For climate impact assessment, we utilized a drought index as an indicator of slow-onset hazards affecting the region. To ensure temporal alignment with educational data, our primary analysis focuses on 2022 VCI data corresponding to the 2022–2023 academic year. VCI data from 2020 and 2021 are included to provide contextual understanding of drought progression and temporal variability across the region, rather than for direct correlation with the current educational outcomes. Climate data was derived from MODIS (Moderate Resolution Imaging Spectroradiometer) satellite imagery, which provided comprehensive coverage of the study area at 250-meter spatial resolution. This approach aligns with methodologies employed in the assessment of drought impacts on rural livelihoods in Eastern Africa. We specifically processed MODIS data to generate the Vegetation Condition Index (VCI) for 2022, which served as a proxy measure for drought severity. The VCI calculation followed the methodology, which compares current vegetation conditions to historical minima and maxima. VCI values were classified into five categories: no drought (> 40), light drought (30–40), moderate drought (20–30), severe drought (10–20), and extreme drought (< 10), consistent with the classification system employed by the Famine Early Warning Systems Network. Additionally, we incorporated drought index mapping from 2021–2022 to establish a temporal understanding of drought progression in the region. The temporal correspondence between 2022 VCI measurements and 2022–2023 educational statistics was maintained to ensure valid spatial correlation analysis, while historical drought data (2020–2021) illustrates the dynamic nature of drought conditions in Somaliland.

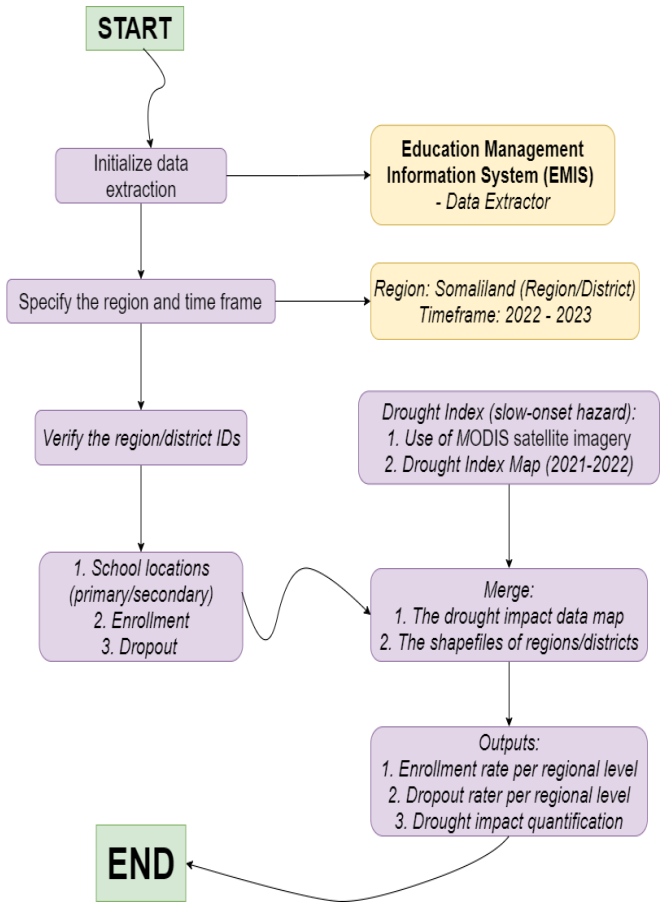

Figure 3. Methodology description

3.3 Data integration and spatial analysis

The methodological framework then proceeded to a data integration phase, where drought impact data were merged with geospatial information on regional and district boundaries. This integration utilized geographical information system (GIS) techniques to overlay drought severity indices with administrative boundaries. Spatial correlation analysis was conducted using temporally aligned 2022 data for both drought severity (VCI) and educational metrics (enrollment and dropout rates) to maintain analytical validity. The spatial analysis methodology builds on approaches developed by Opiyo et al. [23] for analyzing climate vulnerability in pastoralist communities of the Horn of Africa. The integration process involved raster-to-vector conversion of drought index data and spatial joining with administrative boundary polygons, following protocols established by De Longueville et al. [21] for climate impact assessment in data-scarce environments. Concurrently, school location data was integrated with drought severity zones to establish spatial relationships between educational infrastructure and climate

conditions. This spatial joining utilized a point-in-polygon operation to associate each school with the drought severity value of its containing administrative unit. Buffers of a 5-kilometer radius were created around schools to assess the immediate drought impact zone, consistent with the catchment area analysis methodology for educational accessibility in rural East Africa.

3.4 Analytical framework

The final analytical phase generated three primary outputs as shown in Figure 3: (1) enrollment rates calculated at regional levels; (2) dropout rates assessed across administrative units; and (3) quantification of drought impact on educational indicators. Enrollment rates were calculated as the ratio of enrolled students to the school-age population per district, utilizing demographic data from the Somaliland Population Estimation Survey. Dropout rates were computed as the percentage change in enrollment between academic terms, following the methodology established by UNESCO [24] for education indicators in crisis-affected regions. Statistical significance was established at $p < 0.05$, and spatial autocorrelation was assessed using Moran's I to account for potential clustering effects. This integrated analysis allowed for the examination of statistical relationships between drought severity and fluctuations in school enrollment and continuity. The methodological approach enabled a comprehensive assessment of how climate-induced stressors, particularly drought conditions, correlate with educational access and retention across Somaliland's diverse geographical contexts. This rigorous methodology provided the foundation for identifying spatial patterns in educational vulnerability to climate change impacts, particularly in a region characterized by fragile educational infrastructure and recurrent climate hazards.

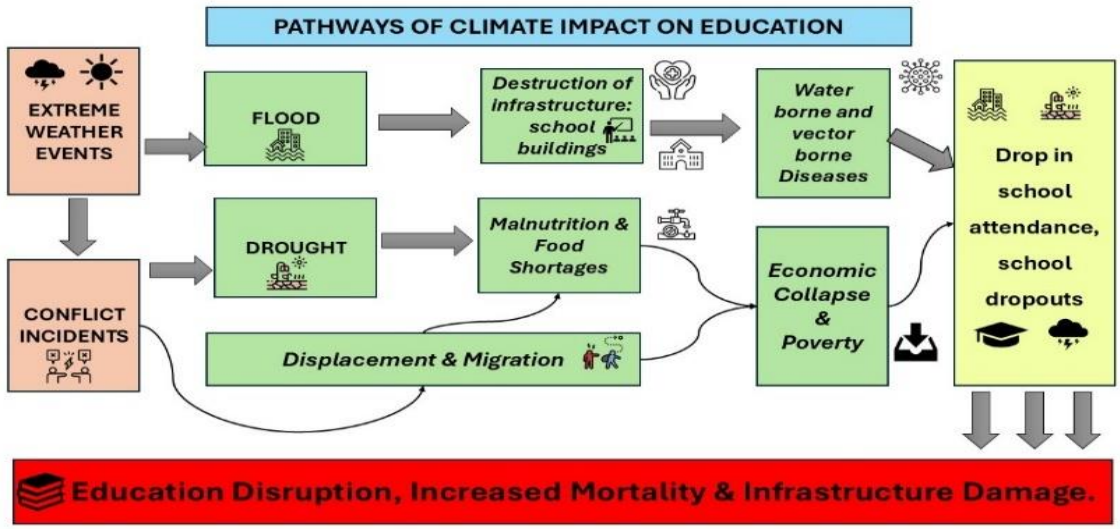

Figure 4. Pathways of climate impacts on education

The conceptual framework for this study identifies multiple interconnected pathways through which climate change affects educational access in Somaliland (Figure 4). The framework recognizes extreme weather events and conflict incidents as primary drivers that trigger cascading effects on education. We mapped how floods lead to infrastructure destruction and disease spread, while drought conditions result in food insecurity and malnutrition. The model captures how these climate-related challenges contribute to displacement and migration, which further compounds economic instability. All pathways ultimately converge on educational outcomes, specifically decreased attendance and increased dropout rates. This conceptual approach guided our data collection strategy and analytical methods, allowing us to examine the spatial and temporal relationships between climate variables and educational metrics across Somaliland's districts. By employing this framework, we were able to systematically investigate how differential exposure to climate stressors might explain the regional variation in enrollment patterns observed in our district-level analysis. The framework also informed our selection of control variables to account for confounding factors that might influence the climate-education relationship, such as pre-existing economic conditions and infrastructure development levels.

4. RESULT

Figure 5 illustrates that the educational landscape in Somaliland displays pronounced geographic disparities that are likely to influence access and enrollment patterns across the territory. Urban centers, particularly Hargeisa and surrounding areas, exhibit dense concentrations of educational facilities, creating privileged zones of educational opportunity. This centralization contrasts sharply with the sparse distribution observed in eastern and southern regions, where communities face significantly limited access to both primary and secondary education. Transportation networks appear to play a crucial role in determining school placement, with educational facilities predominantly clustering along major roads, thus creating corridors of accessibility that leave intervening areas underserved. This spatial arrangement suggests a structural vulnerability where climate-related disruptions would disproportionately impact already marginalized communities in remote areas, potentially intensifying enrollment fluctuations and dropout rates. The western region's educational advantage compared to eastern territories indicates entrenched regional inequalities that may be amplified during climate events such as droughts or flooding. Secondary education facilities appear particularly concentrated in urban centers, creating additional barriers for

rural students attempting to progress beyond primary education. This uneven distribution of educational resources across Somaliland likely creates zones of educational vulnerability that correlate with geographic remoteness, with climate change potentially serving as a multiplier effect on existing disparities in enrollment stability and educational continuity.

Figure 6 illustrates the analysis of dropout rates across Somaliland's regions, revealing striking disparities that challenge conventional assumptions about educational retention and regional development. Maroodi Jeex, despite hosting the highest concentration of educational facilities as seen in previous figures, paradoxically exhibits the most severe dropout challenge with rates exceeding 45%, suggesting that school density alone does not guarantee educational persistence. This counterintuitive finding indicates that urban educational environments may face unique retention challenges despite their infrastructural advantages. Togdheer follows as the region with the second-highest dropout rate at approximately 24%, occupying an intermediate climate zone with moderate school coverage, which points to potential climate-educational vulnerability intersections affecting student retention. Awdal demonstrates a moderate dropout rate of around 14%, despite its relatively substantial educational infrastructure in semi-arid conditions, hinting at relative resilience in educational persistence. Most notably, the Saaxil and Sanaag regions present the lowest dropout rates (approximately 8%) despite their more challenging climate conditions and less developed educational infrastructure, suggesting potential adaptive mechanisms or cultural factors that promote educational resilience in these areas. This regional dropout distribution appears to invert expected patterns based solely on school availability or climate conditions, pointing toward complex socio-economic, cultural, and potentially climate-adaptive factors that influence educational persistence beyond mere physical access to schools. These findings indicate that dropout vulnerability manifests unevenly across Somaliland's educational landscape, with high-resource regions unexpectedly demonstrating greater retention challenges than some areas with more limited educational infrastructure.

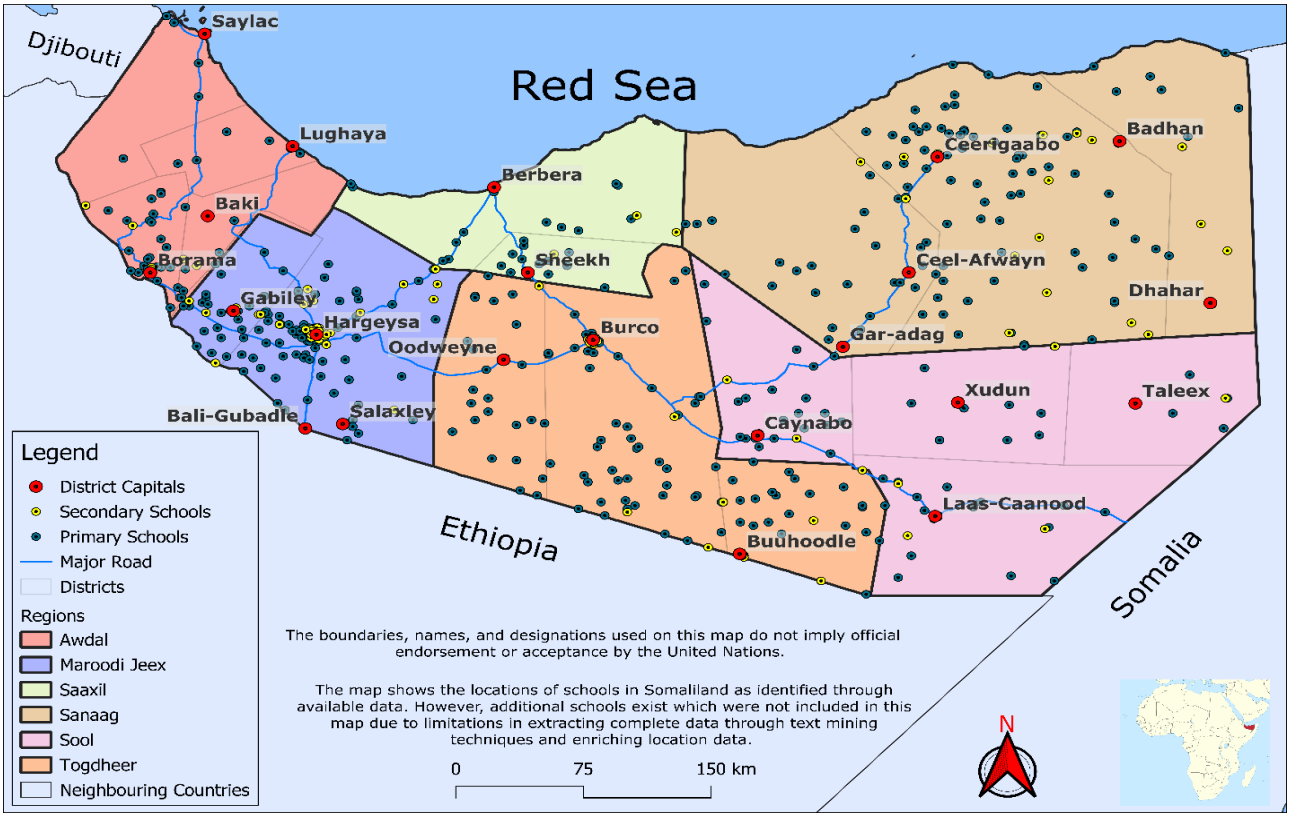

Figure 5. Educational landscape in Somaliland

Figure 7 provides the kindergarten enrollment distribution across Somaliland reveals profound spatial disparities in early childhood educational participation that may serve as precursors to later educational outcomes. The western region has extraordinary enrollment intensity, with 14,827 kindergarten students concentrated in a relatively compact area around Hargeisa, creating an epicenter of early childhood education that dramatically outpaces all other regions. This western educational nucleus transitions to moderately high enrollment zones (1,964 and 1,163 students) in adjacent central-western districts, establishing a gradient of diminishing early educational participation moving eastward. The northeastern coastal region maintains moderate kindergarten engagement with 1,147 students despite its desert climate classification, suggesting potential resilience factors mitigating environmental challenges to early education in this area. Most striking is the stark educational divide evident in the southeastern regions, where enrollment plummets to the lowest levels recorded (549 students), creating an early childhood education desert that aligns with previously identified patterns of limited school infrastructure. The north-central region demonstrates intermediate kindergarten participation (835 students), positioned between the high-enrollment western hub and low-engagement eastern periphery. This spatial patterning of kindergarten enrollment illuminates foundational disparities in educational

opportunities that emerge at the earliest stages of academic development, potentially foreshadowing the regional variations in dropout rates observed in later academic stages. The concentration of early childhood educational resources in the western region may establish educational trajectories that reverberate throughout Somaliland's educational ecosystem, with implications for how climate vulnerabilities might differentially impact regions already characterized by disparate educational foundations.

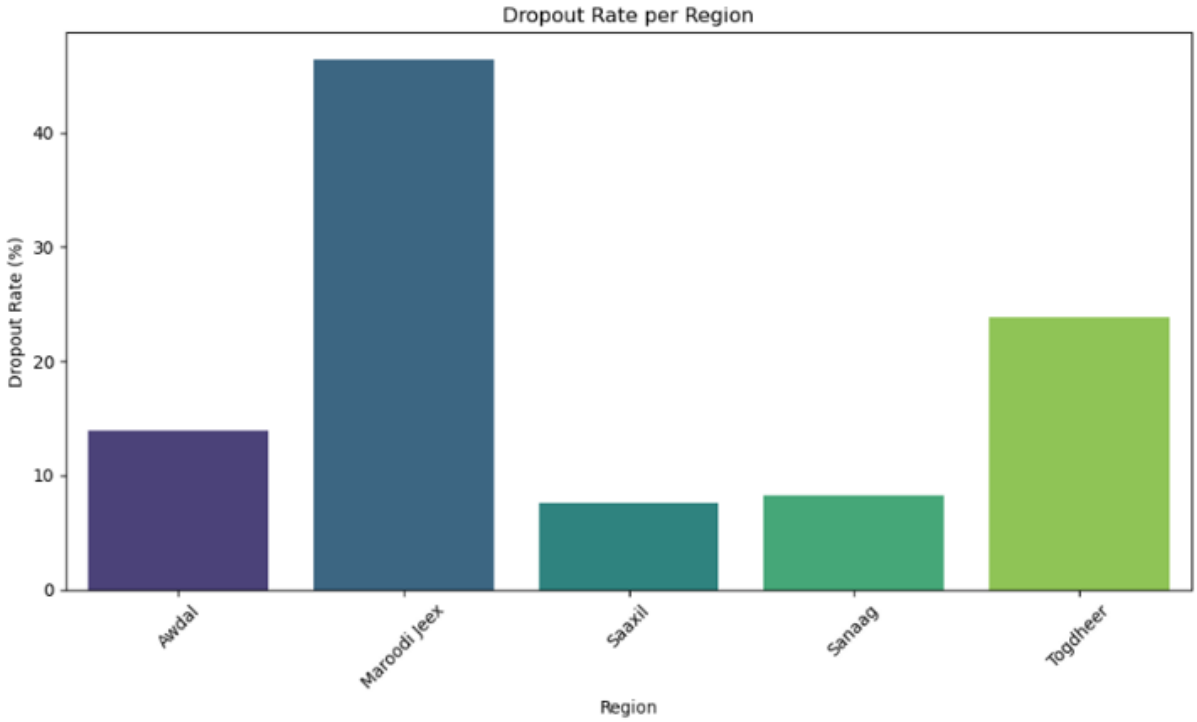

Figure 6. Dropout rates across Somaliland's regions

Figure 8 illustrates the geographical distribution of primary school enrollment across Districts in Somaliland, synthesizing education data obtained through the EMIS. Western districts display exceptionally high enrollment figures (191,242 students), represented by deep red coloration, indicating a significant concentration of educational participation in this region. Central districts demonstrate moderate enrollment numbers (50,008–66,176 students), while northeastern and southeastern regions show progressively lower primary education participation (24,617–44,577 students). This spatial synthesis effectively captures the uneven distribution of educational access across administrative boundaries, potentially reflecting variations in population density, infrastructure development, and resource allocation. The pattern suggests targeted educational policy interventions may be necessary to address these substantial regional imbalances. The synthesis acknowledges data collection limitations, noting that additional schools may exist beyond those captured through available information systems, which should be considered when interpreting these enrollment disparities in the context of broader educational planning efforts in Somaliland.

Figure 9 depicts the enrollment in secondary schools across different Districts in Somaliland, which borders the Red Sea to the north, Djibouti to the west, Ethiopia to the south, and Somalia to the east. The data is sourced from the EMIS of Somaliland, as noted in the legend. The districts are color-coded according to their Secondary school enrollment numbers, with darker shades of pink/magenta indicating higher enrollment figures. The highest enrollment (70,431 students) is found in the southwestern region bordering Ethiopia, represented in dark magenta. The second-highest enrollment (22,968) appears in the south-central region. Moving northward, enrollment figures decrease to 16,729 in the northwestern area near Djibouti. The eastern and southeastern districts show significantly lower enrollment figures (10,209 and 8,283 respectively), while the lowest enrollment (7,351) is observed in the north-central district along the Red Sea.

Figure 10 illustrates the comprehensive grade-level enrollment patterns across Districts in Somaliland, synthesizing education data from Grade 1 through Grade 8. This multi-panel visualization reveals both spatial disparities and enrollment trends across the educational progression in the northern regions. The maps demonstrate a consistent pattern of higher enrollment concentration in the western districts across all grade levels, with enrollment numbers systematically decreasing in eastern and southeastern regions. Most notably, there is a significant decline in overall enrollment figures as grade levels advance from lower to upper primary grades. The western districts maintain the highest enrollment figures throughout all grades, though the absolute numbers decrease substantially from Grade 1 (14,827 students in the highest-enrolled district) to Grade 8 (530 students in the comparable district). Grade 2 shows relatively strong retention from Grade 1, but a pronounced enrollment drop becomes evident between Grades 3 and 4, with further significant decreases through Grades 5 and 6. By Grade 8, several districts report zero enrollment, particularly in the eastern regions, indicating complete educational attrition in these areas by the upper primary level.

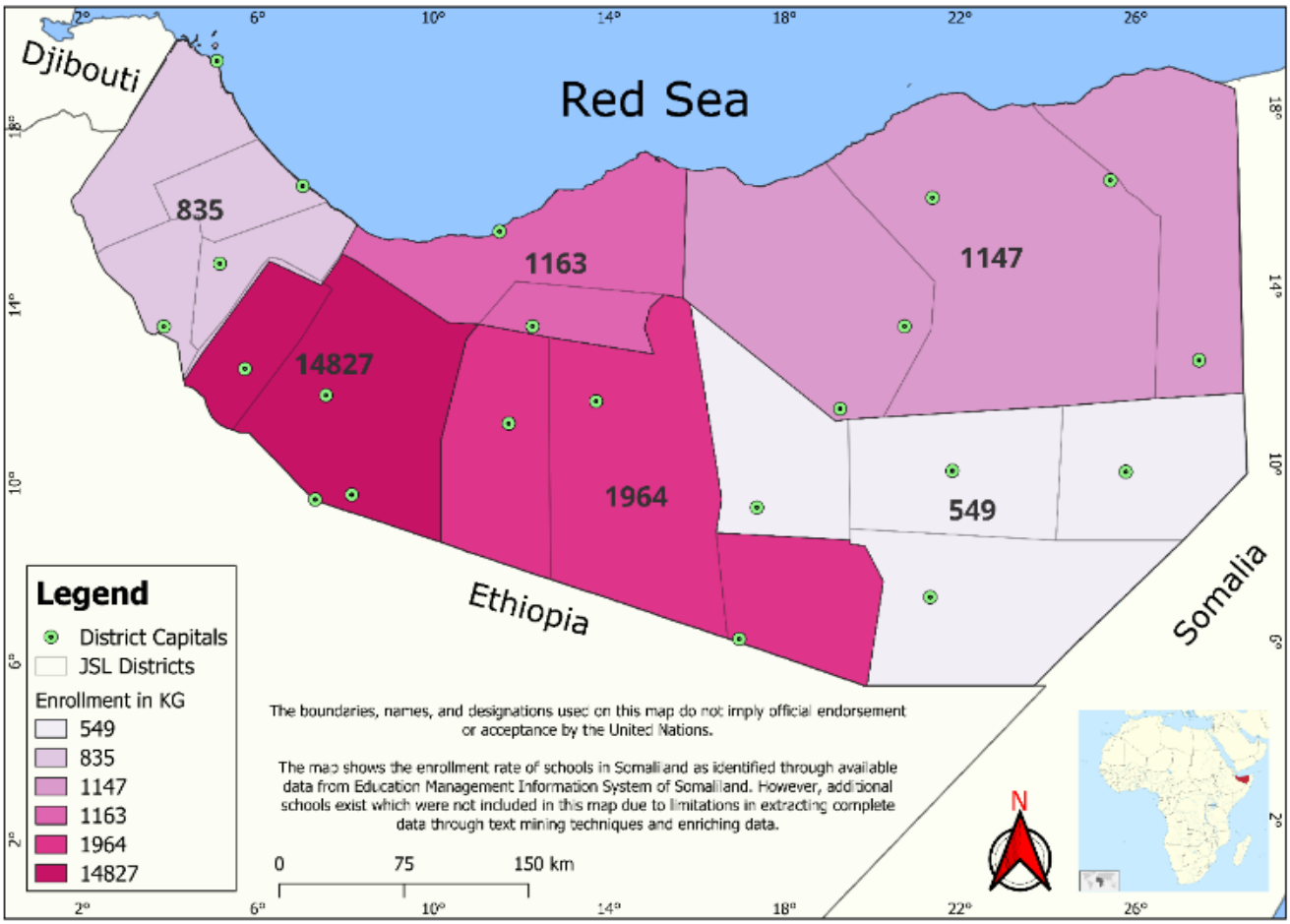

Figure 7. Kindergarten enrollment distribution across Somaliland

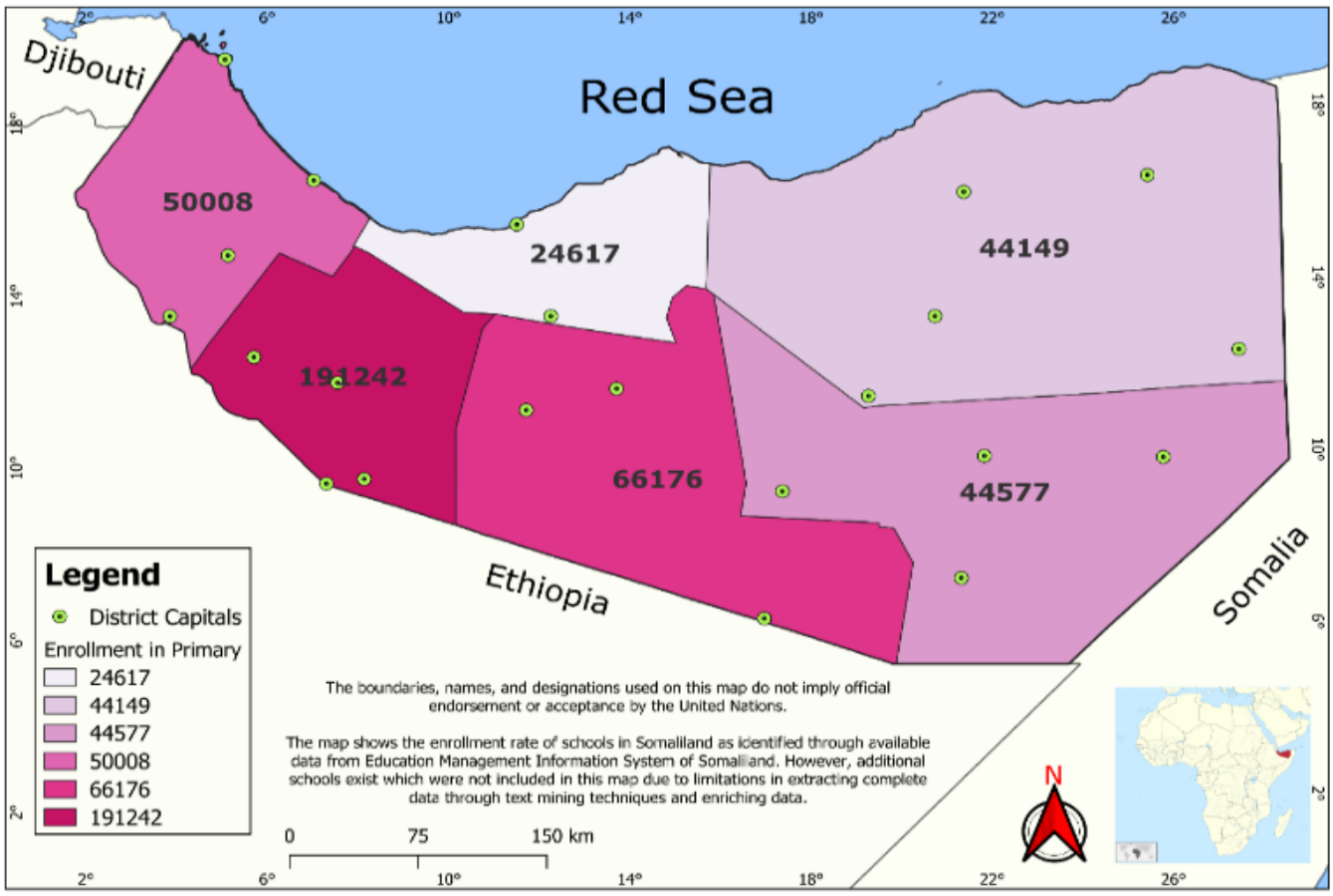

Figure 8. Geographical distribution of primary school enrollment across districts in Somaliland

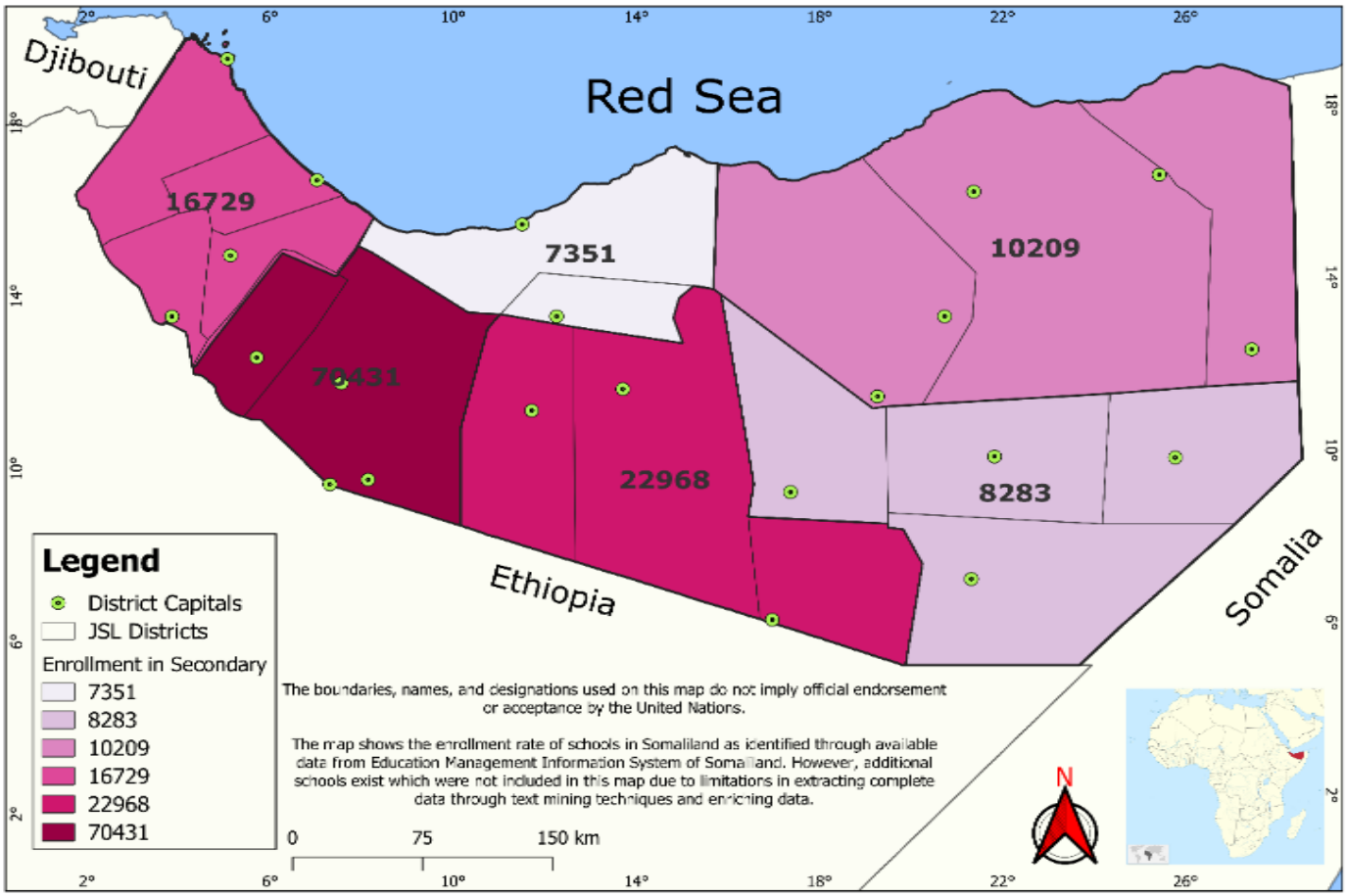

Figure 9. Geographical distribution of secondary school enrollment across Districts in Somaliland

Figure 11 illustrates the spatial distribution of school dropout patterns across Districts in Somaliland for 2023, offering a comprehensive gender-disaggregated analysis at both primary and secondary education levels. The visualization synthesizes dropout data through a six-panel comparative approach, revealing important spatial and gender-based disparities throughout the regions in the coastal areas. In primary education, western districts consistently demonstrate the highest dropout numbers across both genders, with male dropouts (2,799 in the highest district) exceeding female dropouts (1,947 in the corresponding district). The central districts maintain moderate dropout levels, while eastern and southeastern regions show lower absolute dropout figures, though this likely correlates with their generally lower enrollment rates, as shown in previous figures. The secondary education panels reveal a significant reduction in absolute dropout numbers compared to primary education, reflecting the lower overall secondary enrollment. However, the spatial pattern remains consistent, with western districts showing substantially higher dropout rates (511 males and 429 females in the highest districts) compared to eastern regions. Notably, the gender gap narrows at the secondary level in most districts, suggesting that while fewer students reach secondary education overall, those who do demonstrate more gender-balanced retention patterns. The combined total dropout visualizations effectively highlight the concentration of educational attrition in western districts, which paradoxically also maintained the highest enrollment figures in previous maps. This suggests that these regions face particular challenges in student retention despite their stronger initial participation rates. The pronounced difference between primary (4,746 maximum district total) and secondary (940 maximum district total) dropout numbers further emphasizes the substantial educational pipeline narrowing that occurs between these levels.

On the other hand, Figure 12 illustrates the spatial relationship between educational infrastructure and drought conditions across Districts in Somaliland for 2020, synthesizing environmental and educational data to provide insights into potential environmental influences on schooling access. The visualization overlays the geographic distribution of primary schools (blue dots), secondary schools (yellow dots), and district capitals (red dots) against a drought severity index derived from MODIS satellite data. Furthermore, the map reveals a complex interplay between drought conditions and school distribution patterns.

Therefore, areas experiencing extreme drought (depicted in red) are prevalent along the northern coastal regions near the Red Sea and in scattered patches throughout the western and eastern territories. Severe drought conditions (orange) dominate much of the territory, particularly in the northern and eastern regions. In contrast, central-southern areas display notably improved conditions, with some districts experiencing only light drought (light green) or no drought (dark green). School distribution appears denser in western regions, consistent with the higher enrollment figures observed in previous figures, despite these areas experiencing variable drought conditions ranging from severe to extreme. The central regions with more favorable drought conditions (light to no drought) demonstrate moderate school density, while eastern districts show sparser educational infrastructure despite varying drought severity.

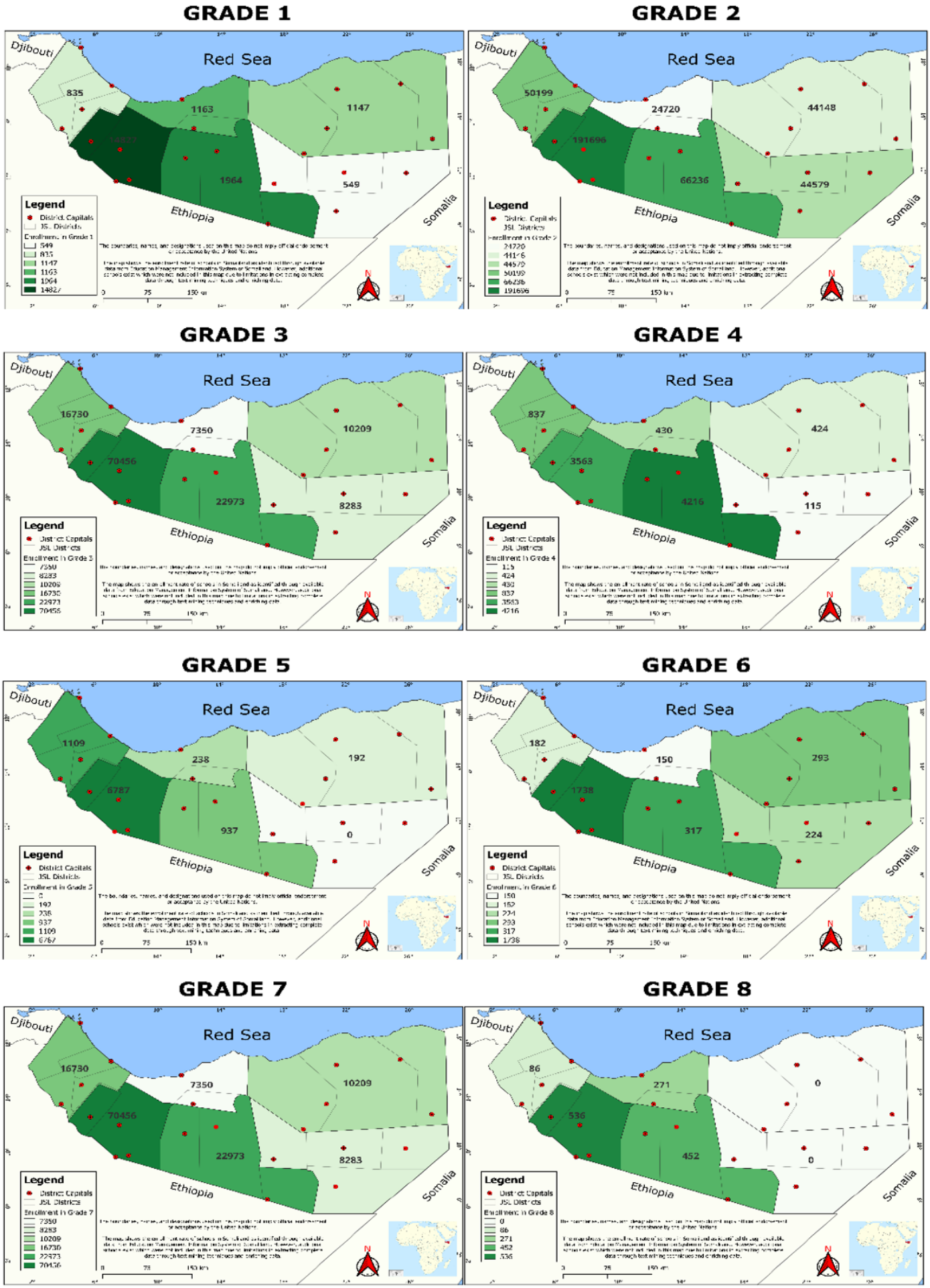

Figure 10. Grade-level enrollment patterns across JSL districts in Somaliland

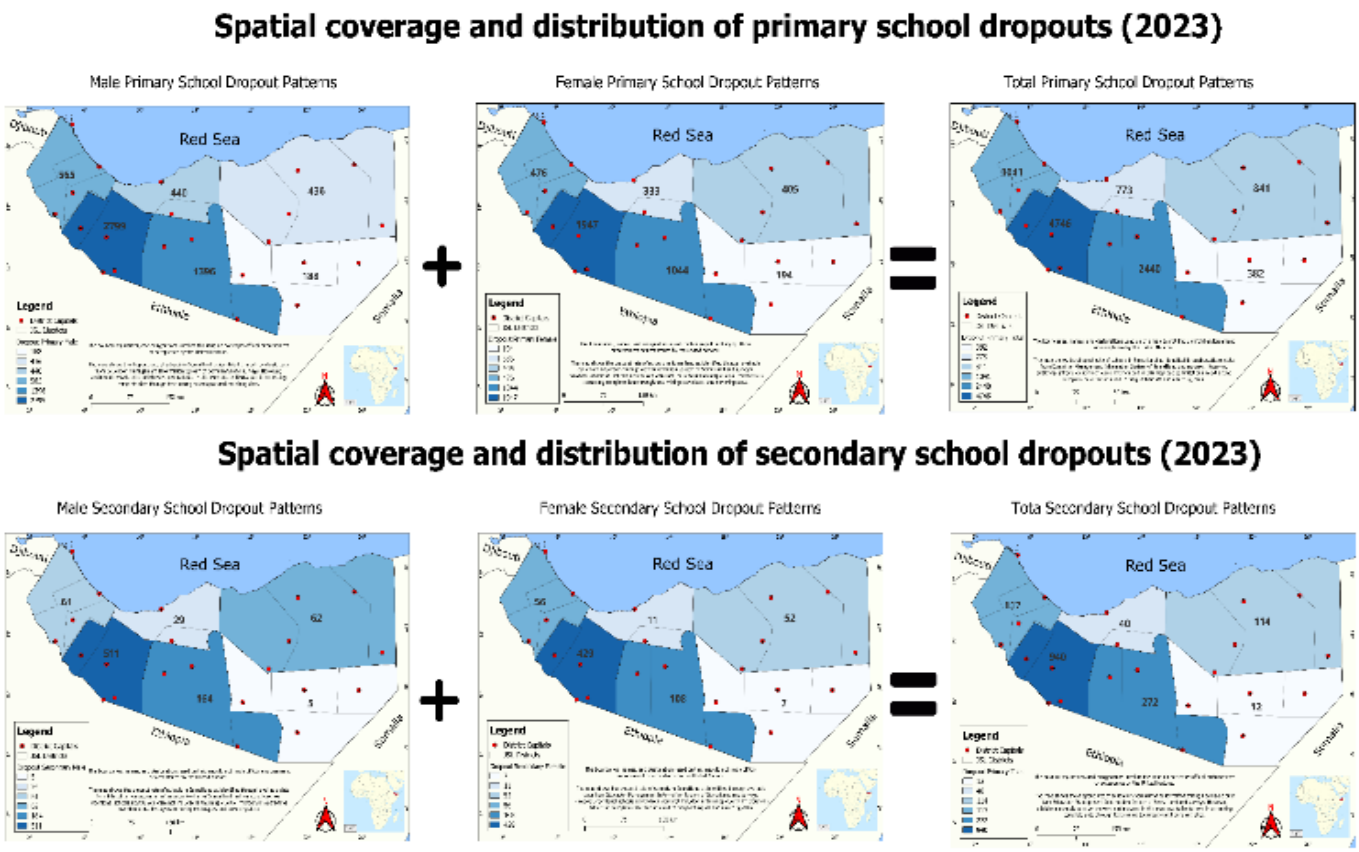

Figure 11. Spatial distribution of school dropout patterns across JSL districts in Somaliland for 2023

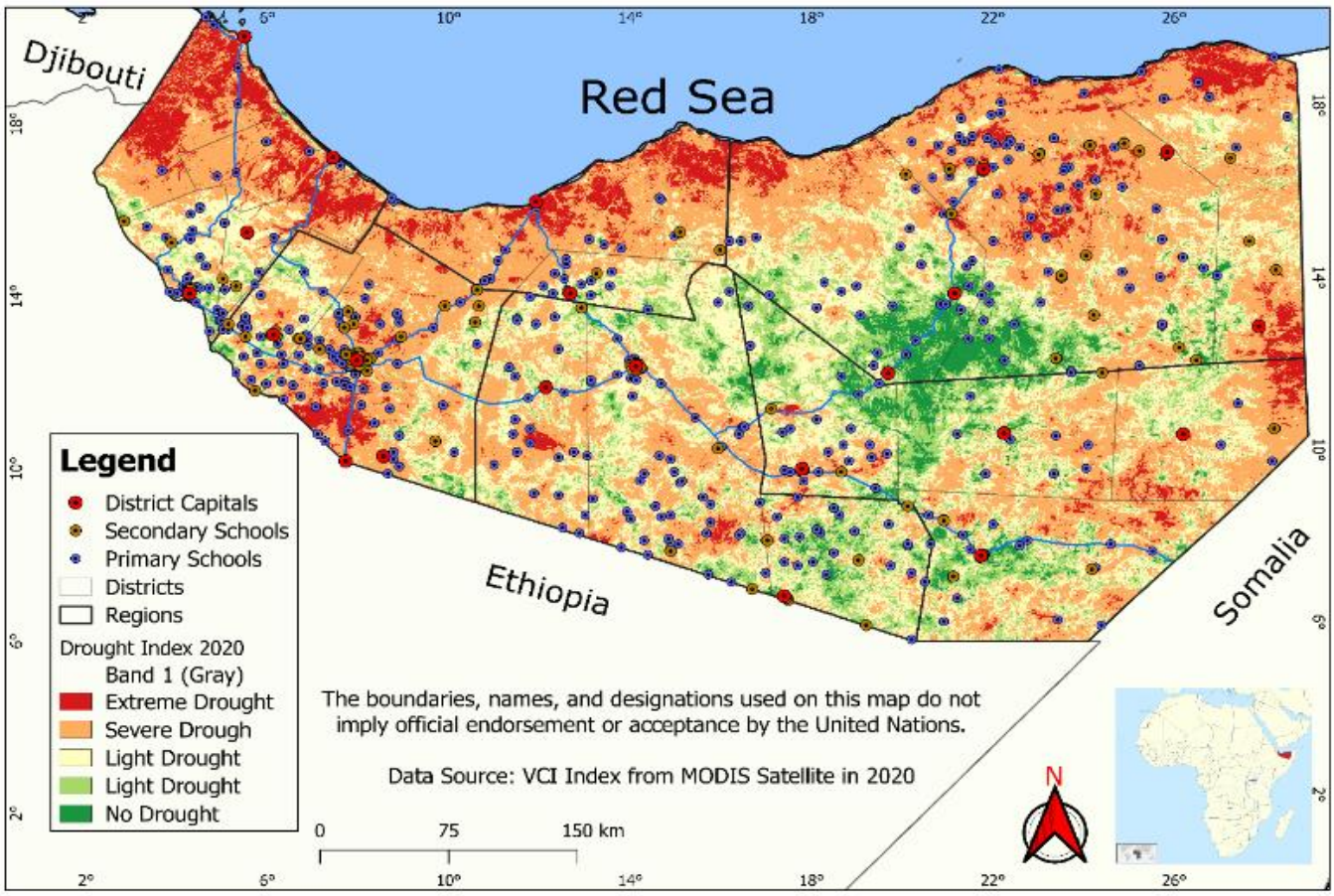

Figure 12. The spatial relationship between educational infrastructure and drought conditions across the districts in Somaliland for 2020

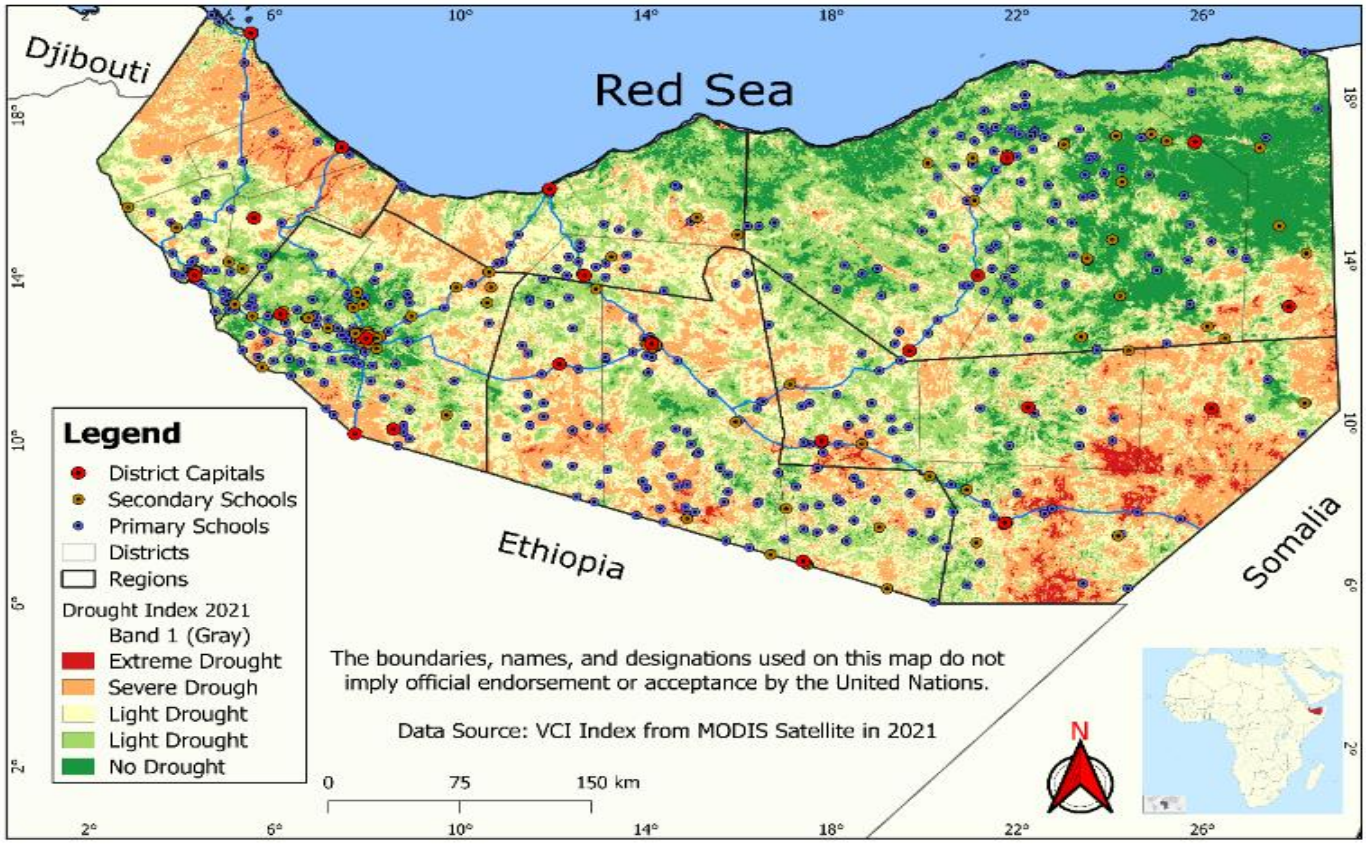

Figure 13. Spatial relationship between educational infrastructure and drought conditions across JSL districts in Somaliland for 2021

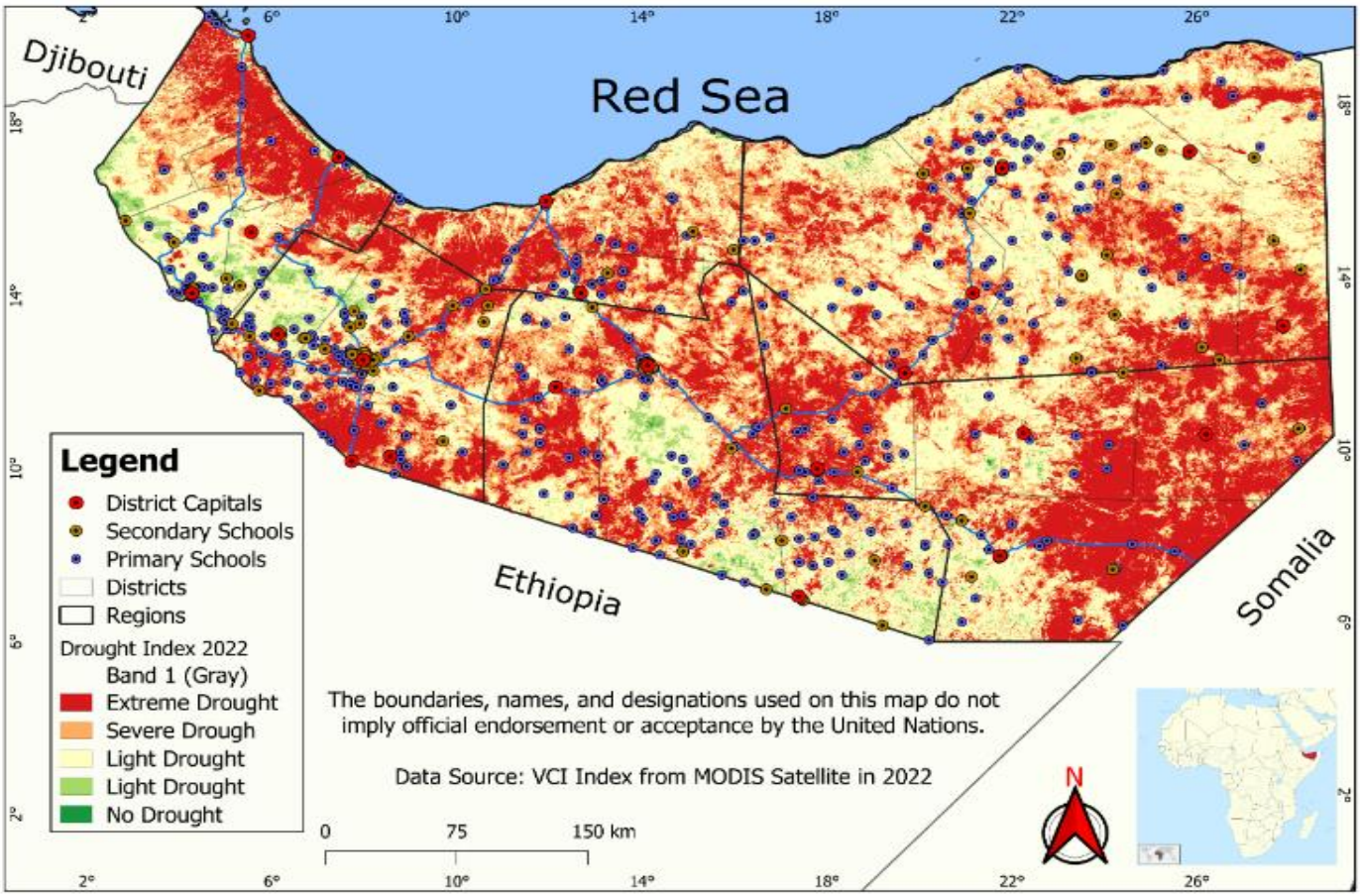

Figure 14. Spatial relationship between drought conditions and educational infrastructure across Somaliland in 2022

Figure 13 illustrates the spatial relationship between educational infrastructure and drought conditions across JSL Districts in Somaliland for 2021, synthesizing environmental and educational data to reveal year-over-year changes in environmental factors affecting education access. The visualization maps the distribution of primary schools (blue dots), secondary schools (yellow dots), and district capitals (red dots) against updated drought severity indices derived from MODIS satellite data. The 2021 drought pattern demonstrates notable shifts from the 2020 conditions depicted in Figure 11. Northeastern coastal regions along the Red Sea show significant improvement, transitioning from predominantly extreme drought conditions to areas with light drought or no drought (green areas). The western regions maintain a mixed pattern of drought severity, with pockets of extreme drought (red areas) persisting alongside improved conditions. Southeastern districts show a concerning expansion of extreme drought conditions compared to the previous year. School distribution remains consistent with earlier visualizations, with western districts maintaining the highest density of both primary and secondary schools despite variable drought conditions. The northeastern regions with improved environmental conditions in 2021 show moderate school distribution, suggesting potential opportunities for educational expansion in these increasingly hospitable areas.

Figure 14 illustrates the relationship between drought conditions and educational infrastructure across Somaliland in 2022, forming a critical component of research examining climate change impacts on educational access. Using the VCI derived from MODIS satellite imagery, the map reveals extensive drought conditions affecting much of the territory, with particularly severe conditions dominating the eastern regions and coastal areas. Educational facilities, including district capitals, secondary schools, and primary schools, appear distributed throughout the country, though their concentration varies regionally. Most notably, the western portions of Somaliland show both less intense drought conditions and higher densities of educational institutions. This spatial relationship suggests a potential correlation between climate conditions and educational access, with drought-stricken areas possibly facing greater challenges in maintaining educational infrastructure and enrollment. As Figure 12 within the broader study on climate change and educational access, this visualization likely supports analysis of how environmental stressors influence school enrollment patterns and dropout rates across Somaliland's diverse regions.

5. DISCUSSION

The spatial analysis of drought impacts on educational access in Somaliland reveals complex correlational relationships that challenge conventional assumptions about climate-education patterns. Western regions, particularly around Hargeisa, demonstrate the highest concentration of schools despite experiencing variable drought conditions, suggesting that urbanization and historical development patterns may provide buffering effects against climate-related disruptions [3]. The temporal alignment of 2022 drought severity data (VCI) with 2022–2023 educational outcomes strengthens the validity of observed spatial correlations, while historical drought patterns from 2020–2021 demonstrate significant regional variability in climate conditions over time.

The paradoxically high dropout rates in Maroodi Jeex (exceeding 45%) despite infrastructural advantages indicate that school density alone does not guarantee educational persistence. This counterintuitive finding suggests that urban educational environments may face unique retention challenges related to economic pressures, opportunity costs, and livelihood diversification strategies that are distinct from infrastructure availability [16]. In contrast, eastern and southeastern regions exhibit concerning patterns of educational vulnerability with sparse school distribution and lower enrollment coinciding with severe drought conditions, reflecting a potential climate-development trap where environmental stress may constrain educational investment and household resource allocation for schooling [25].

Grade-level progression analysis reveals systematic narrowing of the educational pipeline, with dramatic enrollment declines between Grades 3–4 and virtually no enrollment in Grade 8 in several eastern districts. This pattern suggests that the transition from lower to upper primary grades represents a critical vulnerability point where the combined effects of limited infrastructure, economic pressures, and potentially climate-related household stress may intensify educational attrition [16]. The spatial correspondence between areas experiencing persistent drought conditions and low upper-grade enrollment indicates that climate stressors may compound existing educational challenges during these critical transition points.

Unexpected gender patterns emerged in the data, with male students showing higher primary-level dropout rates than females, particularly in western districts, contrasting with traditional expectations of female educational disadvantage. In Somaliland's predominantly pastoral and agropastoral context, boys traditionally assume livestock herding and migration responsibilities from early ages, making them potentially more vulnerable to withdrawal during drought-induced household stress when families must mobilize labor for distant grazing areas or diversify income sources [13]. Similar gender-differentiated patterns have been documented in other East African pastoral societies where male children's economic contributions to household livelihoods take precedence over schooling during climate shocks and resource scarcity [21]. However, this interpretation requires further empirical verification through qualitative investigation. Future research should employ household surveys and in-depth interviews to understand the decision-making processes underlying gender-differentiated dropout patterns during periods of climate stress, as the mechanisms linking drought conditions to gendered educational outcomes remain inadequately documented in the Somaliland context.

The 2020–2022 drought analysis demonstrated significant spatial and temporal variability, with northeastern coastal regions improving from extreme drought to light conditions while southeastern districts experienced worsening situations. This dynamic pattern aligns with climate projections anticipating increased variability rather than uniform directional change [9, 26], highlighting the need for adaptive and regionally differentiated educational planning approaches. The persistent concentration of educational infrastructure in western regions despite climate variability suggests that historical development patterns and urbanization exert stronger influence on educational distribution than short-term climate fluctuations. However, the spatial correlation between drought severity zones and educational outcomes indicates that climate conditions may interact with existing socioeconomic and infrastructural factors to influence

enrollment stability and dropout vulnerability.

The relatively low dropout rates in remote regions like Saaxil and Sanaag (approximately 8%) despite challenging climate conditions and limited infrastructure suggest potential adaptive mechanisms or cultural factors that promote educational resilience in these areas. This finding warrants further investigation to identify protective factors that might inform retention strategies in other vulnerable regions. Possible explanations include stronger community commitment to education, different livelihood strategies that allow for educational continuity, or demographic factors such as smaller school-age populations that enable more targeted support. Understanding these mechanisms could inform policy interventions aimed at enhancing educational resilience across diverse contexts.

These findings necessitate targeted, context-specific interventions rather than universal approaches. Integrated climate-education resilience programs should focus on areas experiencing both persistent drought and limited infrastructure, potentially incorporating climate-responsive school calendars, mobile education units for pastoralist communities, and infrastructure investments in climate-vulnerable zones. Retention strategies must address factors beyond physical access through mechanisms such as conditional cash transfers, school feeding programs, and flexible attendance policies that accommodate seasonal livelihood patterns [7]. Equity-focused investment should prioritize underserved eastern regions through climate-smart education approaches that consider the interaction between environmental conditions and educational access.

The study's limitations must be acknowledged. First, the relatively short temporal window (2020–2022) limits our ability to assess longer-term climate-education relationships or capture multi-year drought cycles. While our primary analysis maintains temporal alignment between 2022 VCI data and 2022–2023 educational outcomes, drought impacts may manifest through lagged effects from prior years' conditions. Second, the cross-sectional spatial correlation approach, while revealing important patterns, cannot establish definitive causal relationships between drought severity and educational outcomes. Future research should employ longitudinal panel data methods with fixed-effects models or instrumental variable approaches to strengthen causal inference [3]. Third, our analysis examines drought as the primary climate indicator but does not incorporate other climate hazards such as flooding or temperature extremes that may also affect educational access in certain regions. Fourth, the inability to control for all potential confounding factors such as household-level socioeconomic status, educational quality metrics, teacher availability, and community-level characteristics, limits our ability to isolate drought effects from other determinants of educational outcomes.

Future research directions should include: (1) longitudinal studies tracking the same students and schools over multiple years to establish temporal relationships and potential lag effects between climate conditions and educational outcomes; (2) qualitative investigations of household decision-making processes during drought periods to understand the mechanisms linking climate stress to enrollment and dropout decisions; (3) incorporation of additional climate variables beyond drought, including rainfall variability, temperature extremes, and flood events; (4) analysis of educational quality metrics alongside access indicators to assess whether climate conditions affect not only enrollment but also learning outcomes; and (5) comparative studies across different livelihood zones (pastoral, agropastoral, urban) to understand how economic strategies mediate climate-education relationships.

Despite these limitations, this study contributes to the emerging understanding of climate-education relationships in fragile contexts by providing empirical evidence of spatial correlations between drought conditions and educational vulnerability. By identifying climate-vulnerable educational zones and elucidating patterns through which environmental conditions correlate with educational outcomes, this research offers actionable insights for enhancing educational resilience in the face of increasing climate variability in Somaliland and similar environments. The spatially explicit approach developed here can be adapted to other data-scarce contexts where understanding the geographic dimensions of climate-education interactions is essential for targeted policy interventions.

6. CONCLUSION

This study has examined the complex relationship between climate change, specifically drought conditions, and educational access in Somaliland through comprehensive spatial analysis. The findings reveal multifaceted interactions between climate variability, educational infrastructure, and enrollment patterns that extend beyond simplistic correlations. Pronounced spatial disparities in educational access persist across Somaliland, with western urban centers maintaining significantly higher concentrations of schools and enrollment compared to eastern and southeastern regions. This spatial inequality closely aligns with climate zonation patterns, suggesting that environmental factors function as determinants of educational accessibility, where semi-arid western regions demonstrate relative educational advantages while arid and desert zones show progressively sparser coverage.

The relationship between drought severity and educational outcomes reveals counterintuitive patterns challenging conventional assumptions. Notably, the Maroodi Jeex region demonstrates paradoxically high dropout rates (exceeding 45%) despite infrastructural advantages, while remote regions like Saaxil and Sanaag maintain relatively low dropout rates (approximately 8%) despite challenging conditions. These findings suggest that school density alone does not guarantee educational persistence, and community-level resilience factors may mitigate climate-related disruptions. The systematic narrowing of the educational pipeline through primary grades, with virtually no enrollment in Grade 8 in several eastern districts, indicates that climate stressors exacerbate educational attrition at key transition points. Gender-disaggregated patterns reveal higher male dropout rates at the primary level, particularly in western districts, likely reflecting household labor allocation strategies during climate stress where boys support pastoral livelihoods or migration.

These findings have important implications for educational policy and climate adaptation strategies in Somaliland. Future interventions should adopt targeted, context-specific approaches with integrated climate-education resilience initiatives focusing on areas experiencing both persistent drought and limited infrastructure. Retention strategies must address factors beyond physical access, including quality, relevance, and household decision-making during climate

stress periods. This research contributes to the emerging understanding of climate-education relationships in fragile contexts by providing empirical evidence of spatial patterns in educational vulnerability. By identifying climate-vulnerable educational zones and elucidating mechanisms through which environmental conditions interact with educational outcomes, this study offers actionable insights for enhancing educational resilience in the face of increasing climate variability in Somaliland and similar environments.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Gulled Yasin: Conceptualization, Writing – original draft preparation, Writing – review & editing, Data curation, Investigation, Writing – original draft preparation, Writing – review & editing, **Abdillahi Osman Omar:** Conceptualization, Data curation, Visualization, Software, Formal analysis, Methodology. **Ahmed Abdiaziz Alasow:** Writing – original draft preparation, Writing – review & editing, Supervision. **Yasmin Abdullahi Mohamoud**: Writing-original draft preparation, Writing – review & editing. All authors have read and approved the final manuscript.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

Data will be made available on request.

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APPENDIX

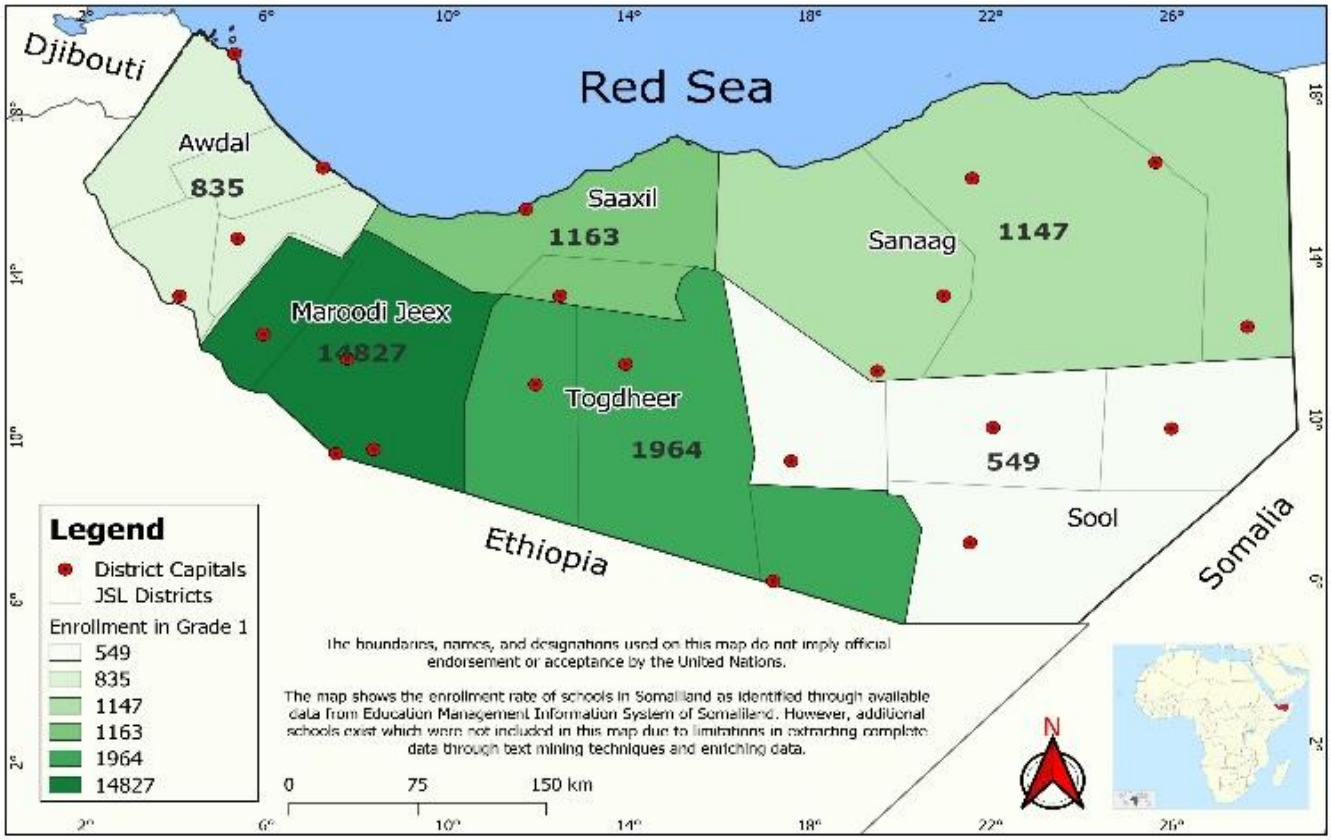

Figure S1. Grade 1 enrollment distribution across Somaliland districts, 2022−2023 academic year

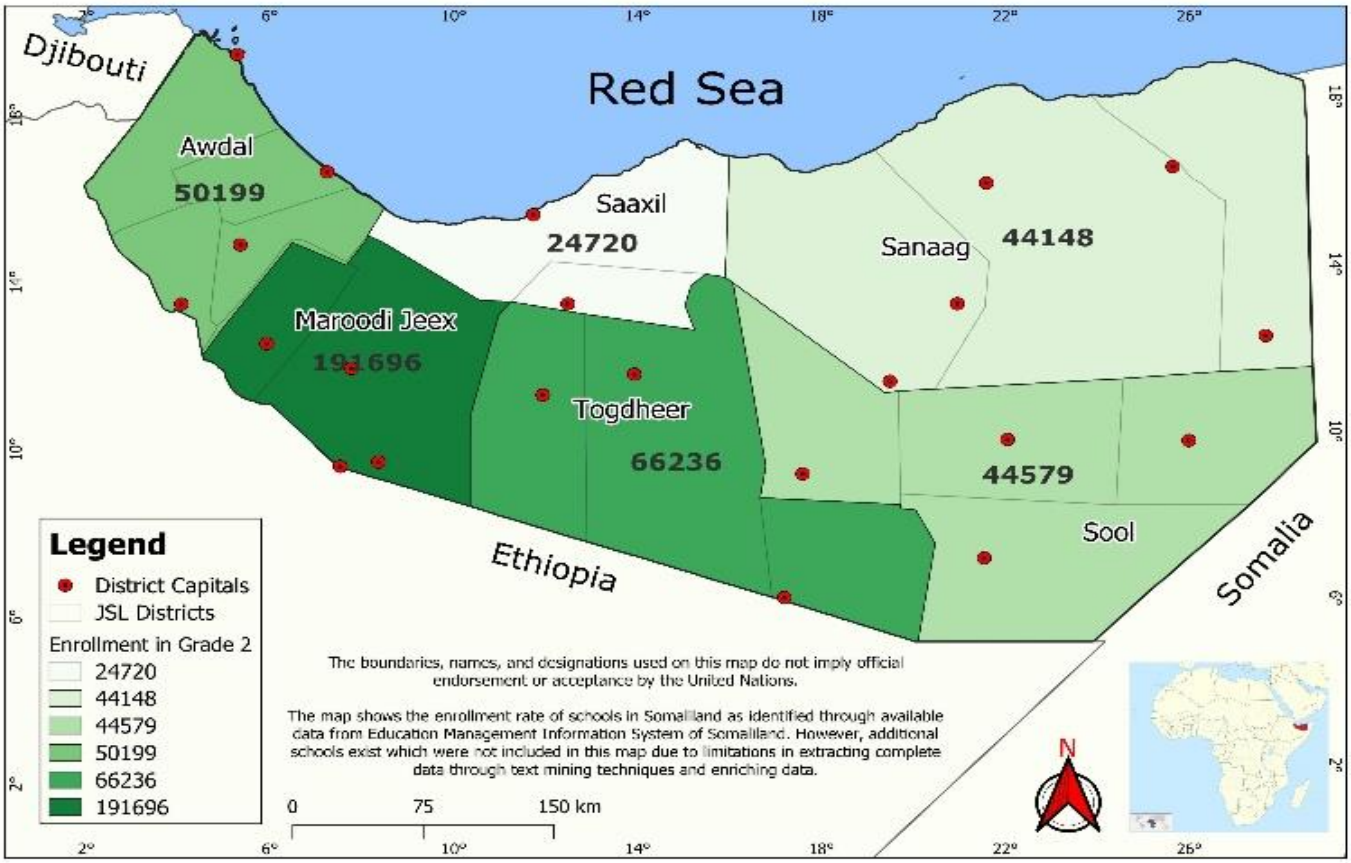

Figure S2. Grade 2 enrollment distribution across Somaliland districts, 2022−2023 academic year

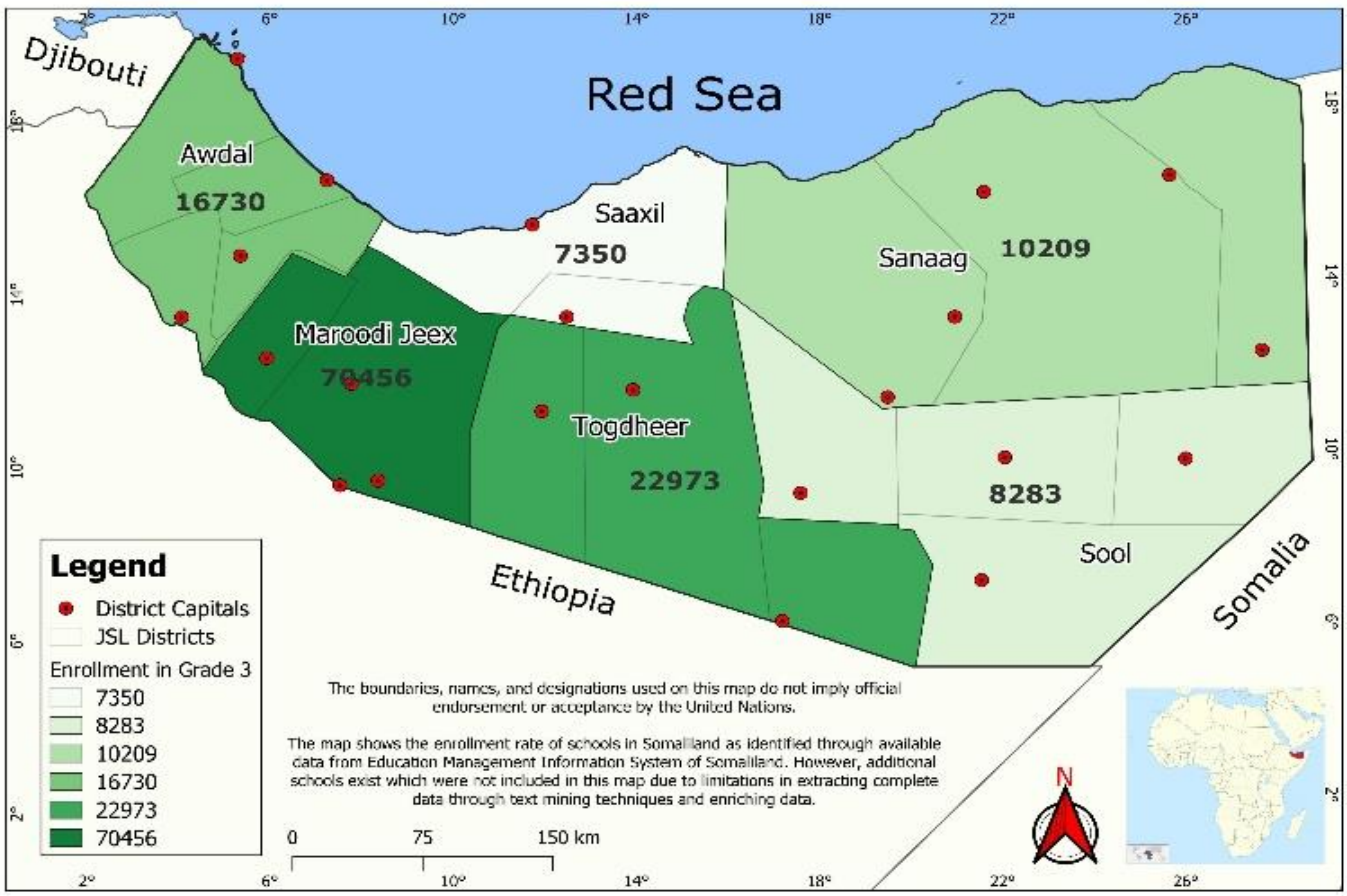

Figure S3. Grade 3 enrollment distribution across Somaliland districts, 2022−2023 academic year

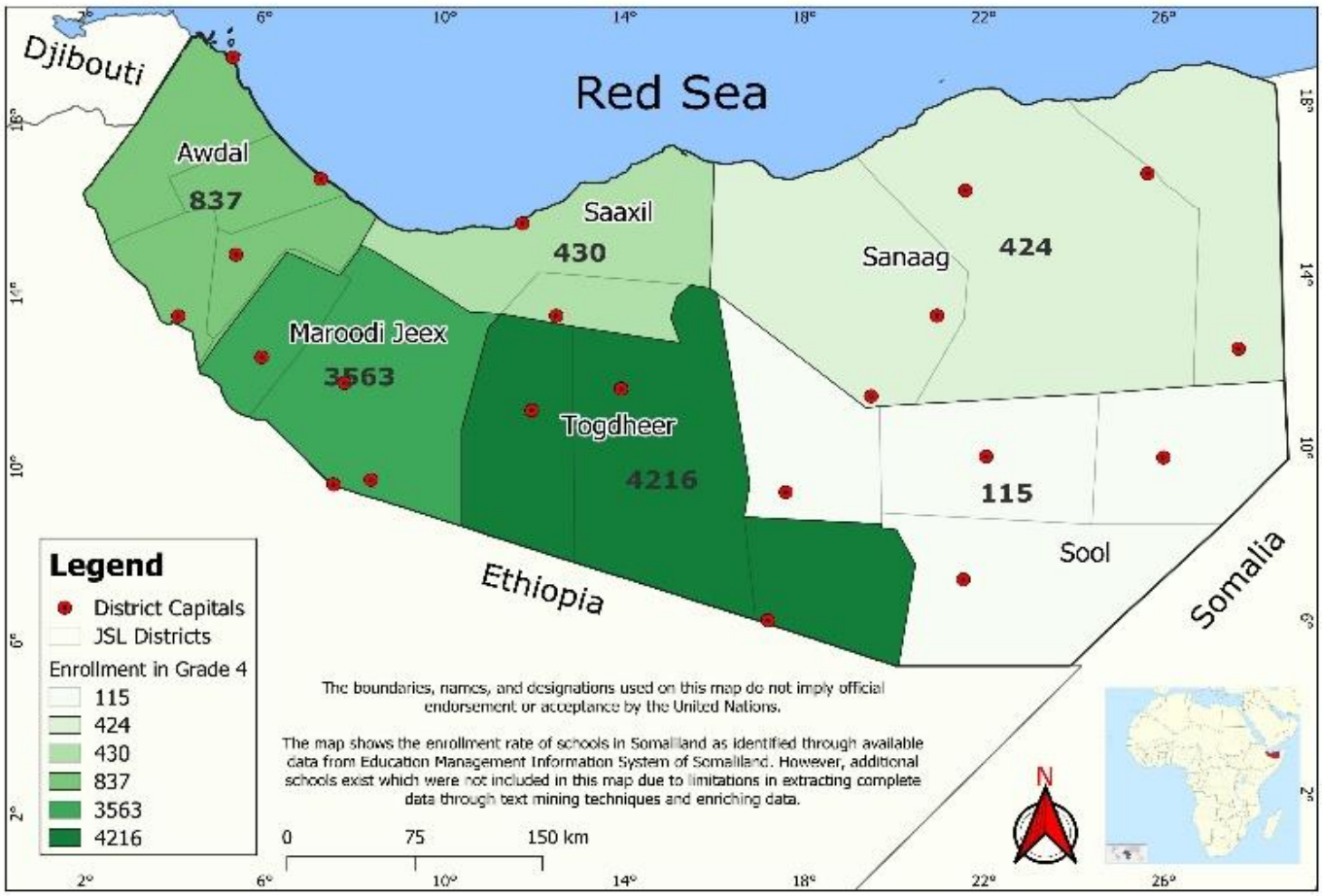

Figure S4. Grade 4 enrollment distribution across Somaliland districts, 2022−2023 academic year

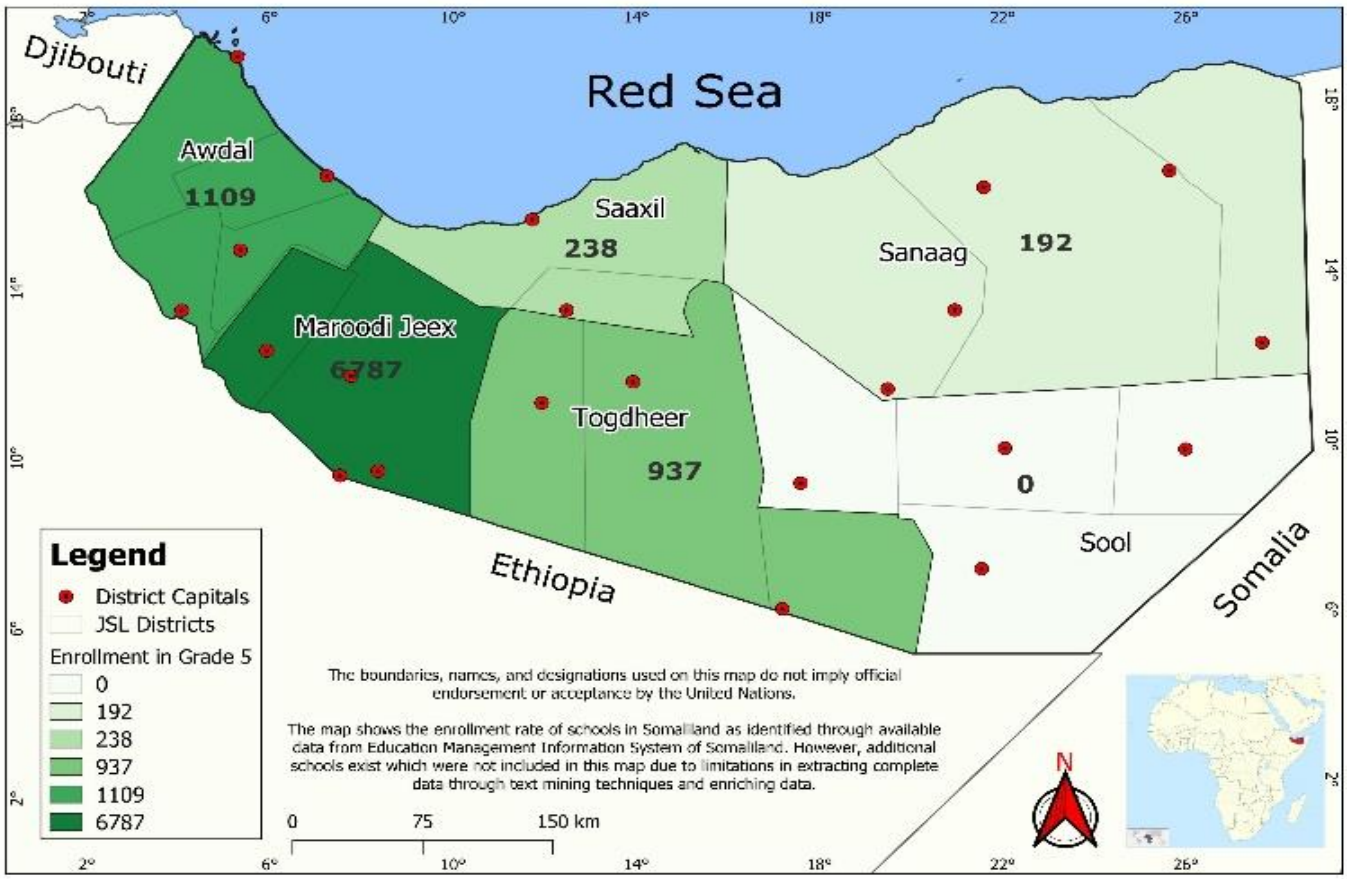

Figure S5. Grade 5 enrollment distribution across Somaliland districts, 2022−2023 academic year

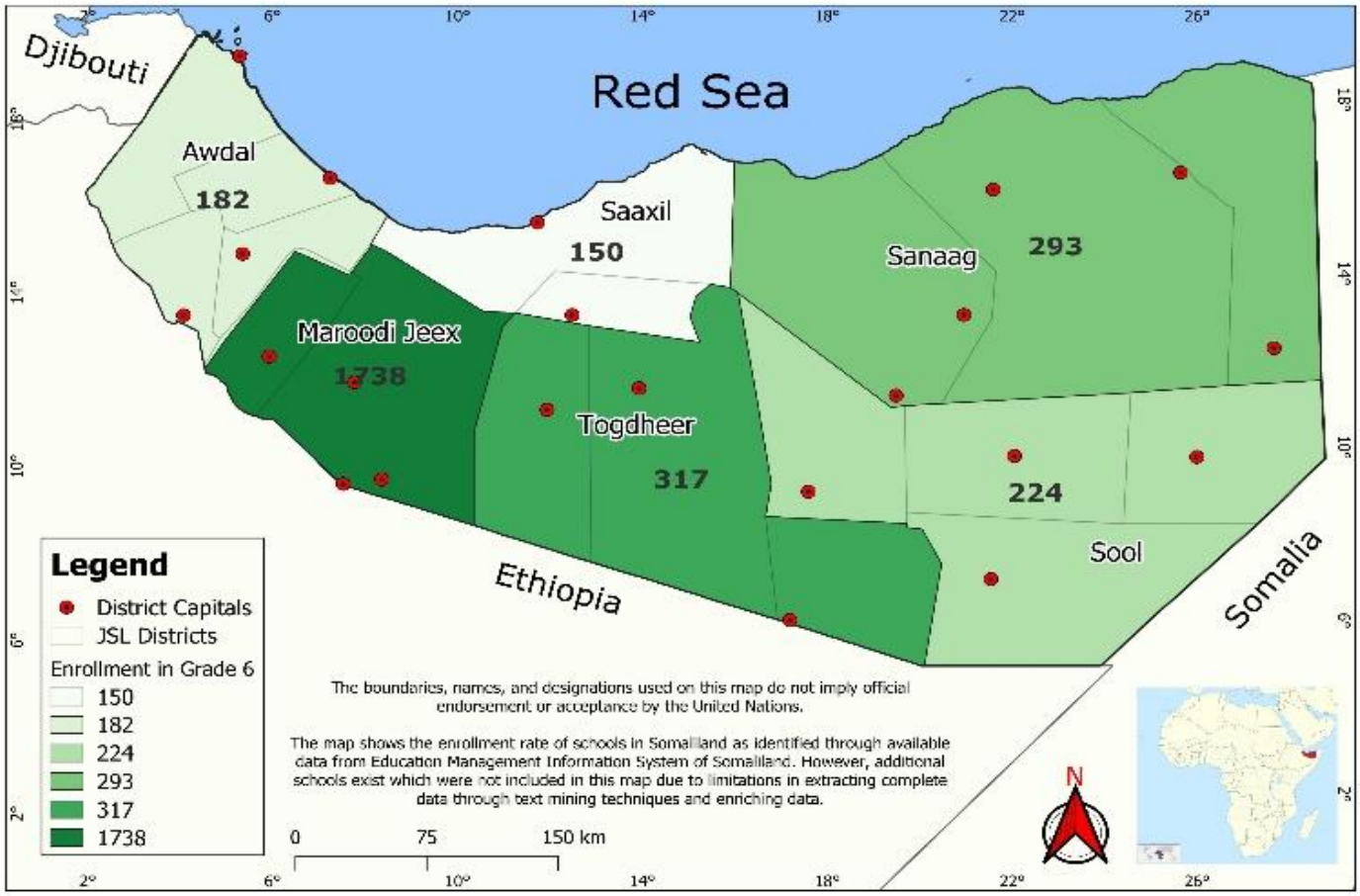

Figure S6. Grade 6 enrollment distribution across Somaliland districts, 2022−2023 academic year

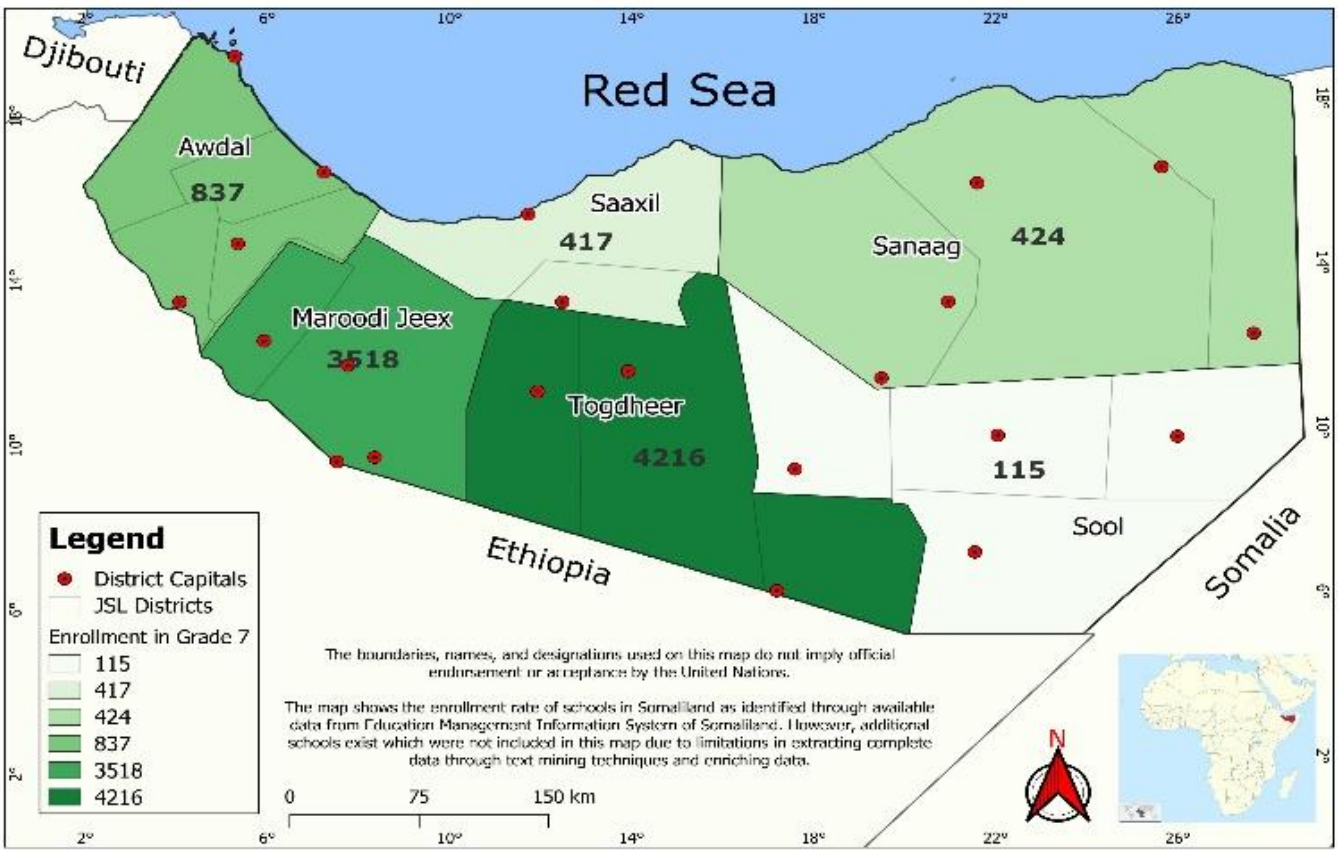

Figure S7. Grade 7 enrollment distribution across Somaliland districts, 2022−2023 academic year

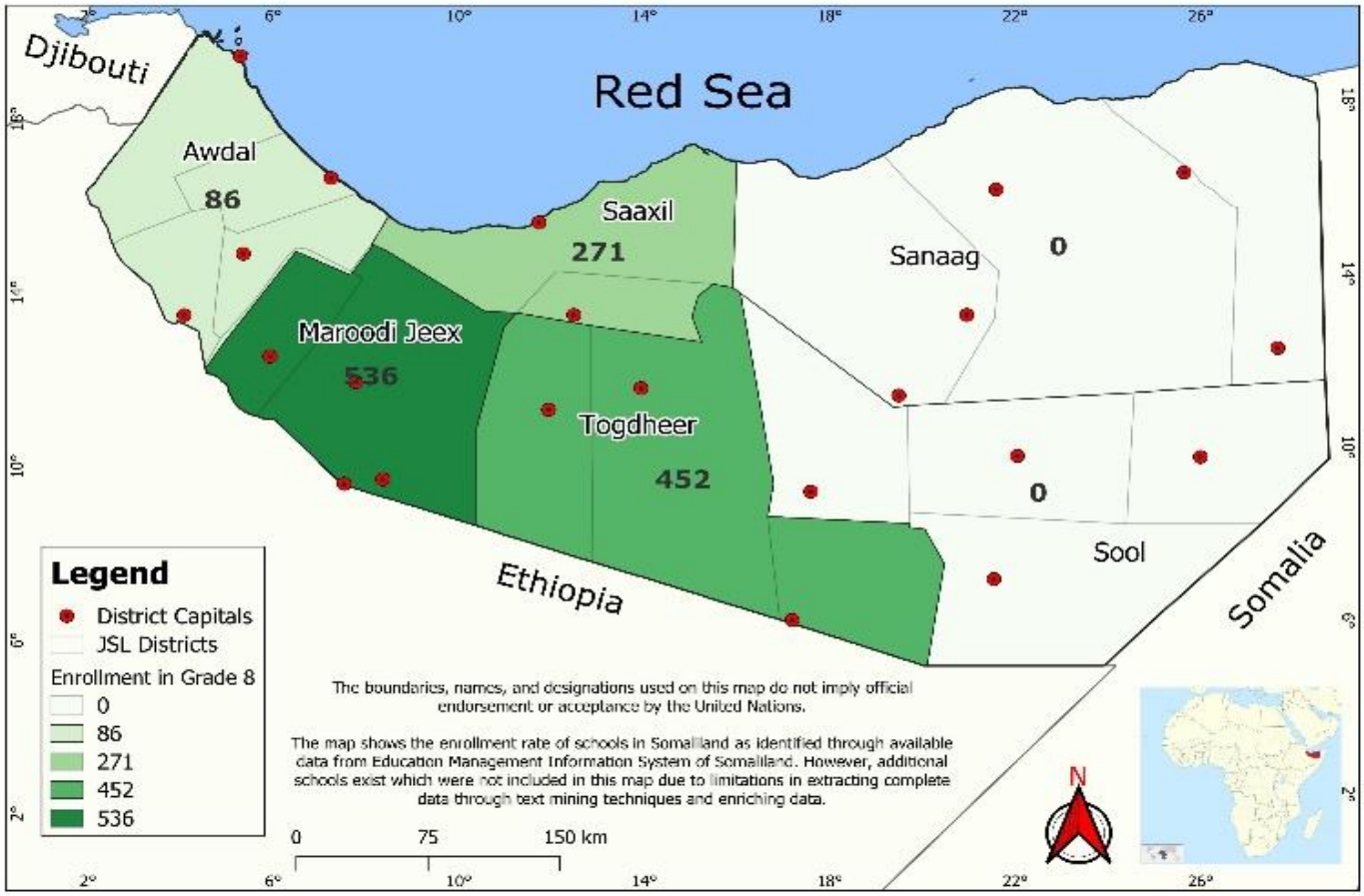

Figure S8. Grade 8 enrollment distribution across Somaliland districts, 2022−2023 academic year