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From space to place: mapping poverty in Turkish regions with NASA's global gridded relative deprivation index

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Abstract
This study examines the spatial distribution of poverty in Turkish states using zonal statistics techniques. The recently released Global Gridded Relative Deprivation Index (GRDIv1) dataset by NASA has been utilized. The GRDIv1 index contains six pivotal components: Child Dependency Ratio, Subnational Development Index, Infant Mortality Rate, Built-Up to Non-Built-Up Ratios, VIIRS nighttime lights, and VIIRS Nighttime Lights (VNL) Slope Component. All the components capture various aspects of regional poverty differences. The results show the eastern regions have significantly higher levels of deprivation than the western regions. This disparity is attributed to conflicts, unemployment, and illiteracy in the East, while the West benefits from higher development. The analysis of the ratio of Built-Up Areas to Non-Built-Up Areas reveals a complex distribution of urbanization and industrialization, with the western Marmara region emerging as a center of development and industrial activity. Moreover, the analysis of Nocturnal Illumination Patterns, based on VIIRS nighttime light data, further confirms the higher levels of development in the west and the deprivation in the east. This study objectively proves that the Eastern region of Turkiye contains areas with much higher deprivation than does central and western regions.

Keywords Spatial distribution · Geospatial analysis · Poverty · GRDIv1 · Turkish states

1 Introduction

The challenge of accurately identifying impoverished individuals and the subsequent quantification of poverty has been a persistent issue in academic discourse. Scholars and policymakers have acquired insight into poverty measurement by examining monetary and non-monetary ways. One frequently employed strategy in the literature is to measure poverty using money-related factors such as income or consumption expenditures. An alternate method of measuring poverty is to examine the level of deprivation experienced by individuals using a variety of non-monetary measures [1]. The work of two economists has greatly aided the multidimensional measurement of poverty [2, 3]. They created methods of measuring poverty considering various factors, including living conditions, health, and education levels.

Poverty is a multidimensional issue, and measuring it is still a topic of continuing research and debate. One of the most contentious issues in this argument is the distinction between monetary and multidimensional poverty metrics [4]. Although the fact that poverty has many different dimensions is generally accepted, it is still unclear to what degree monetary metrics can be used as a substitute for non-monetary ones. Long-established conceptual objections have been raised against the idea that monetary metrics can reflect non-monetary consequences [5]. According to mounting evidence, estimates of poverty based on monetary measurements and non-monetary multidimensional dimensions are frequently not related to one another. One measure cannot be used as a replacement for the other. The way poverty is measured has changed, even though monetary measures have remained common in academic discourses and development bureaucracies into the twenty-first century, as highlighted by [6].

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Studies conducted on poverty issues in Turkiye primarily utilize national-level surveys. These studies reveal the dual nature of Turkey, characterized by a developed western region contrasted with a less developed eastern region [7]. This has created a longstanding disparity in poverty levels among the regions [8]. This study seeks to assess the extent to which the dualistic character of the Turkish economy is reflected in the Global Gridded Relative Deprivation Index. The "Global Gridded Relative Deprivation Index" is a comprehensive statistic for determining relative deprivation on a worldwide scale. This index gives a spatial perspective of economic inequities and exposes regional variations in resource availability, opportunity, and quality of life.

Moreover, previous studies on Turkiye focused on monetary and multidimensional aspects of poverty, but both approaches have limitations. Monetary indicators overlook non-financial forms of poverty, and existing multidimensional indexes lack comprehensive coverage, especially in areas like light density. The present study, utilizing a novel NASA dataset (GRDIv1), aims to enhance the understanding of Turkey's poverty by employing zonal statistics and geospatial visualizations. The study assesses deprivation across regions using indicators such as Child Dependency Ratio, Subnational Development Index, Infant Mortality Rate, Built-Up to Non-Built-Up Ratios, and Visible Infrared Imaging Radiometer Suite (VIIRS) nighttime lights. By addressing previous research limitations, this study offers valuable insights into effective poverty alleviation strategies in Turkiye.

2 Literature review

This literature review discusses poverty indexes and the state of poverty in Turkiye. Poverty, defined as a state where individuals lack resources to meet basic needs, can lead to health issues, low education, and social exclusion [9]. Various indicators are used to measure poverty, including monetary measures like the national poverty line [10, 11], multidimensional poverty measures assessing deprivation in areas like education, health, and living standards [12], and relative poverty measures comparing the poor's living standards to societal averages.

2.1 Monetary poverty index

Drawing from Multiple Indicator Cluster Surveys (MICS), and Demographic and Health Surveys (DHS) of six developing countries [13] introduced a trial of the Moderate Multidimensional Poverty Index (MMPI). Similarly, another study reviewed the debates on absolute and relative approaches and combined arguments of both approaches to create a single general monetary poverty measurement [14]. These studies defined poverty as falling below a predetermined income or consumption threshold. Two major methods for calculating financial poverty are absolute and relative. Absolute poverty defines poverty in terms of the minimal resources necessary to meet fundamental necessities (e.g., the World Bank's $2.15 per day international poverty threshold). Relative poverty defines poverty as the average standard of living in each society. Both methods have drawbacks, leading to the proposal of hybrid poverty alines that integrate both approaches. The underlying logic of monetary poverty presupposes that all characteristics necessary for satisfying essential needs can be purchased in markets and expressed in monetary terms, but in many cases, such markets may not function properly [2]. Additionally, just because people have enough money to buy a basic basket of commodities does not necessarily mean that they will spend it on that basket of products [15]. Additionally, most measurements of income or consumption are made at the household level surveys, which ignores intra-household dispersion, and forces one to employ equivalence scale approaches to draw inferences about specific household members including children [16]. Hence, some scholars argue that financial indicators are a poor representation of children's living conditions since children are dependent on others for income generation [17].

2.2 Multidimensional poverty index

Monetary poverty measures have limitations as they focus solely on one aspect. However, assessing poverty from various perspectives provides valuable information for targeted interventions addressing specific aspects of poverty [18]. This highlights the necessity for multidimensional poverty indices (MPI). The paper is authored by [19] introducing a fresh Multidimensional Poverty Index (MPI) designed for 104 developing countries. Notably, it pioneers the use of micro datasets (household surveys) across a substantial number of nations, encompassing around 78% of the world's population. This MPI, sharing a mathematical structure with one of the Alkire and Foster poverty measures, comprises ten indicators aligning with the three dimensions of the Human Development Index: Education, Health, and Standard of Living. The MPI serves to capture a simultaneous set of direct deprivations that individuals face. This tool holds promise for targeting the most impoverished, monitoring progress toward the Millennium Development Goals, and shaping policies that directly address the interconnected hardships experienced by those living in poverty.

As a comprehensive indicator of poverty beyond income-based metrics, the Multidimensional Poverty Index (MPI) has attracted much attention from academia and

policymakers. However, there are several shortcomings and restrictions with the MPI that must be considered. One of the main weaknesses of the MPI is the difficulty in obtaining and confirming the quality of data. This has a significant impact on the accuracy of poverty estimates and can result in restrictions on the index's scope and representativeness [20]. Another drawback of the MPI is the choice and weighting of indicators. The indicators included and their relative importance can have a significant impact on the index's outcome [12]. Moreover, the Multidimensional Poverty Index (MPI) has been criticized for not adequately reflecting changes in poverty levels or not accounting for the intensity or severity of poverty over time [21]. However, the MPI serves as a crucial instrument in comprehending and combating poverty by furnishing policymakers and academia with a more comprehensive and nuanced understanding of this socio-economic phenomenon [22].

2.3 Relative poverty index

The Relative Poverty Index (RPI) quantifies economic disadvantage by comparing individual or household income to the median income of the population. A pre-defined threshold, often set at 50% or 60% of the median, determines who falls into the "relatively poor" category (UK statistic). In other words, The Relative Poverty Index shines a light on how poverty affects different groups within a population, revealing more than just simple headcount numbers. It shows where individuals stand to the average, offering a deeper understanding of economic inequality. Several research endeavors have investigated the formulation and implementation of Relative Poverty Indices (RPIs). For instance [23], examined income poverty indices within a structured framework that incorporated two distinct delineations: an absolute poverty line encompassing subsistence and a relative poverty line addressing social exclusion. The findings highlighted these indices as a subset of additive measures, where an individual's poverty status depends on both their income and the prevailing income norm within their societal context. Crucially, these indices consistently assert that an individual in absolute poverty experiences greater economic hardship compared to someone solely experiencing relative poverty, regardless of the income standards prevailing in their respective societies [24]. utilized a methodology that entailed establishing the societal poverty line through the amalgamation of 699 standardized national poverty thresholds. This societal poverty line is anchored at an intercept of $1 per day and exhibits a relative gradient equivalent to 50% of the median national income or consumption. Their findings underscore the significance of societal poverty as a relative gauge, highlighting the crucial role of a distinctly relative poverty threshold within specific contexts. These results support Madden's (2000) assertion that emphasizing purely relative poverty lines is crucial in gauging poverty levels.

The researchers in [25] examined the relationship between urban built-up areas and poverty transformation in Tibet over time and space. The study utilized a multidimensional relative poverty model to compute the relative poverty index and categorized the degree of poverty into five levels: non-poverty, slight poverty, mild poverty, moderate poverty, and severe poverty. Similarly, the researchers in [25] investigated the variations and determinants of relative poverty among Chinese urban and rural residents. The study used the social poverty index to determine separate relative poverty thresholds for urban and rural areas. According to their findings, rural areas experience relative poverty that is more severe than urban areas. Additionally, the researchers in [26] investigated the spatial distribution of poverty in areas affected by protected areas in China. They created a multidimensional poverty index that considered environmental, economic, and social factors. Their study revealed how poverty has evolved in different regions and identified the factors that contribute to it.

2.4 The state of poverty in Turkiye: brief review of prior studies

The researcher in [27] explored the various lay explanations for poverty in Turkiye, as well as the elements that contribute to these explanations using an explanatory survey. The study offers useful insights regarding poverty perceptions and interpretations, as well as how these perceptions are influenced by the sociocultural setting. The researchers in [28] contributed to this discussion by looking at the medical and healthcare aspects of poverty in Turkiye. Their study takes a unique approach to poverty by examining its impact on health and well-being. Poverty is a major cause of illness and a barrier to receiving medical care when needed. This is a financial relationship: the poor cannot afford to buy the things necessary for optimum health, such as adequate quantities of high-quality food and medical care.

In [29] the researchers conducted a rigorous analysis of the discourse surrounding poverty in Turkey, focusing on the nuanced evolution of the country's welfare regime. The study involved face-to-face interviews with a substantive sample size of 150 participants across seven districts in Istanbul. The research critically elucidates the dynamic interplay between poverty and welfare, emphasizing the intricacies of policy frameworks and societal transformations that influence individuals' encounters with poverty. The scholarly endeavor underscores the imperative of nuanced empirical investigations to inform the development of effective, contextually relevant poverty-related policies

within the evolving socio-economic milieu of Turkey. The researcher in [30] extended this investigation by focusing on the role of gender, rural-urban differences, and social networks in poverty. These studies highlight the complex interplay of many factors that contribute to the persistence of poverty in varied contexts.

The authors in [31] presented an innovative methodology for evaluating poverty and inequality in Turkey. This methodology incorporates multidimensional and fuzzy metrics, addressing the prevalent concerns about poverty measurement techniques. The study further explains how to construct fuzzy measures of both non-monetary deprivation and monetary poverty using survey data, such as those collected by the European Union. This method considers factors other than income to give a more complex view of poverty. Furthermore, the author in [32] examined the evolving dynamics of multidimensional poverty in Turkey. The study has a dual focus: first, to identify the "poor" in Turkey using a multidimensional poverty measure that accounts for factors like labor market, housing, health, and living standards; second, to assess how the new measure differs from established poverty metrics (income poverty and EU material deprivation) through a random effect probit model. The study discovered that multidimensional poverty has been mounting in Turkiye in recent years, with women and children bearing the brunt of the burden. The researchers in [33] explored the contrast between material deprivation and income poverty in Turkey. The study highlights a notable divergence between these two metrics, particularly evident within rural households. The investigation relied on cross-sectional data extracted from the Survey of Income and Living Conditions spanning from 2007 to 2011. Notably, the study employed an analytical approach to address the identification challenges related to poverty, incorporating both monetary and non-monetary measures for a comprehensive understanding of the disparities observed.

Researchers in [7] using survey data from provinces of Turkey explored the topography and geographic distribution of multidimensional poverty in Turkiye. The study's findings indicate that the regional distribution of non-monetary characteristics of poverty in Turkey differs significantly from that of relative monetary poverty. Multidimensional poverty assessment, as opposed to the relative monetary poverty rate, illustrates Turkey's regional underdevelopment problem. Moreover, the study by [34] assessed the present and future of urban poverty programs within Turkiy's state administration. The study aimed to shed light on the nature of developments and modifications made to public administration policies intended to aid Turkey's urban poor, considering pertinent legal frameworks, relevant stakeholders, and future policy outlooks. It concluded that to lower Turkey's rate of urban poverty, rural development should be offered. Beyond the economic implications of poverty, the researchers in [35] using Survey on Domestic Violence explored the link between poverty and partner violence against women and shed light on the social implications. The overall findings revealed significant variations in the sorts of physical and sexual violence experienced by women based on their financial status and the effects of their location. Only physical violence is positively impacted by poverty; sexual violence is not affected in the same way. In addition, all regions play a significant effect in physical violence, while only less developed areas have a significant influence on sexual violence.

After an extensive review of the pertinent literature on poverty in Turkey conducted over the past decade, it is evident that previous studies have predominantly employed national surveys, emphasizing both multidimensional and monetary approaches. This study enhances existing knowledge by integrating NASA's Global Gridded Relative Deprivation Index Version 1 (GRDIv1). Unlike traditional indices, the GRDI takes a comprehensive approach by considering various factors beyond traditional multidimensional and monetary dimensions.

The GRDI comprises crucial elements, including the Child Dependency Ratio, Infant Mortality Rate (IMR), Subnational Human Development Index, Built-up Areas, Visible Infrared Imaging Radiometer Suite (VIIRS), VIIRS Nighttime Lights Intensity, and Nighttime Lights Slope (VIIRS2). By utilizing the GRDI, our study assesses the average deprivation level across Turkey and each specific region, mapping the distribution of deprivation. This approach not only expands upon the findings of prior research that relied on conventional poverty indexes but also provides a more nuanced and inclusive understanding of the poverty landscape in Turkey.

The analysis offers a comprehensive insight into the current state of poverty in Turkey, utilizing various metrics. It effectively highlights and substantiates the dual nature of the Turkish economy from different perspectives. This nuanced understanding will empower policymakers to discern the disparities in deprivation across different regions, enabling them to formulate targeted policies and interventions.

3 Materials and methodology

3.1 Methodology

This study utilizes geospatial data analysis techniques to examine the spatial distribution of poverty across Turkish states using the Global Gridded Relative Deprivation Index (GRDIv1) [36] dataset from NASA. The rgeoBoundaries R package developed by Bjorn Sandvik was used to access

shapefiles outlining the administrative boundaries of Turkish states (rgeoboundaries::gb_adm1("TUR")). The GRDIv1 raster dataset, which quantifies relative deprivation based on six components, was downloaded and unzipped into GeoTIFF format (unzip("povmap-grdi-v1-geotiff.zip")).

To enable localized analysis, the GRDIv1 raster was cropped to the extent of the Turkish state boundaries layer using the terra package (terra::crop()). Before cropping, the state boundaries shapefile was transformed into the WGS84 coordinate reference system for compatibility using the sf package (sf::st_transform(4326)) [37, 38]. This is crucial to ensure that both datasets (GRDIv1 raster and state boundaries) are in the same coordinate system, facilitating accurate analysis.

The cropped GRDIv1raster and state boundaries shapefile were then combined into a spatial dataset using zonal statistics (terra::extract()) [37] to calculate the mean and the maximum GRDIv1 value within each state. This integration is necessary to associate the GRDIv1 mean and maximum values with specific corresponding administrative units. In other words, as a measure of central tendency, the mean gives a single value that can describe the distribution of the data in each administrative unit. Also, the maximum GRDIv1 for each administrative unit has been calculated to identify the states or cities that have the highest depreciation level. Zonal statistics play a crucial role in offering two key advantages. Firstly, they enable the aggregation of data at a pertinent geographic level, such as administrative units. This facilitates a more meaningful analysis of poverty distribution across different regions and cities of the country. Secondly, zonal statistics simplify the intricate nature of data, condensing it into interpretable and comparable values for various geographic zones. These dual advantages enhance the clarity and utility of the mapped results, making them more accessible and informative for both analytical insights and effective communication for policy purposes.

The resulting spatial dataset integrates the GRDIv1 relative deprivation index values with the state boundary geometries in a terra-compatible format. This enables subsequent geospatial analysis like mapping to visually examine and interpret the spatial pattern of poverty across Turkiye. Mapping was conducted using ggplot2 [39] to visualize variation in GRDIv1 values between states. The state-level analysis of poverty data helps decision-makers to develop targeted, effective, and customized strategies to alleviate poverty. It provides a nuanced understanding of regional disparities and enables informed, evidence-based decision-making for sustainable development.

In the recent past, the application of 3D visual methodologies for geospatial and spatial analysis has risen sharply [40]. Therefore, the Rayshader package [41] was leveraged to create high-quality 3D surface maps and interactive visualizations of the results. The 3-D map allows us to convert the 2-D map into a three-dimensional space with depth, width, and height simulating the physical study area more realistically. In a nutshell, we integrate several R packages like terra, sf, Rayshader, and ggplot2 to conduct a geospatial analysis of poverty in Turkiye using the GRDIv1 dataset. It demonstrates a reproducible workflow to process geospatial data and generate meaningful visualizations using open-source tools. Figure 1 below shows the workflow and steps for data analysis.

3.2 Data

The data utilized in this study is the Global Gridded Relative Deprivation Index, Version 1 (GRDIv1), released by NASA on July 14, 2023. This comprehensive dataset is accessible through the NASA Earth Data Search portal as well as the Socioeconomic Data and Applications Center (SEDAC) website. The dataset characterizes the multidimensional deprivation and poverty levels for each 30 arc-second (~1 km) pixel in a raster image. GRDIv1 defines

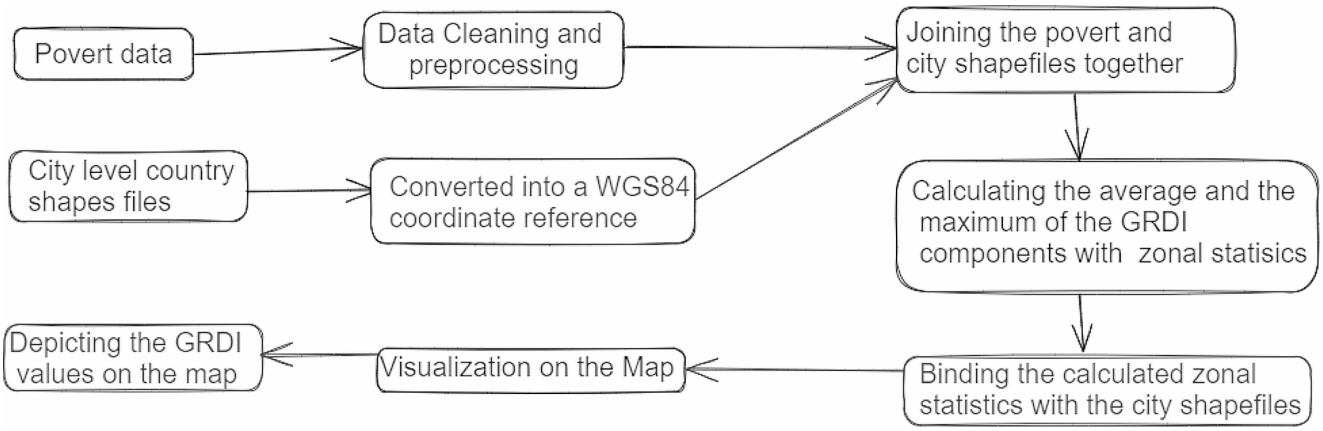

Fig. 1 Flow chart of data analysis

areas of relative deprivation using non-traditional inputs at a higher resolution than previously possible and for the entire world. The index comprises six insightful metrics that shed light on poverty levels:

The first metric is the Child Dependency Ratio (CDR), which captures the proportion of children ages 0–14 relative to the working-age population of 15–64. A higher ratio signals greater reliance on the labor force and accelerated population growth, both hallmarks of heightened deprivation. The second measure is the Infant Mortality Rate (IMR), which tallies the number of deaths among children under 1 year old per 1,000 live births annually. Given that infant mortality is a well-established gauge of population health [42] elevated rates denote greater deprivation. The third factor is the Subnational Human Development Index (SHDI), which evaluates human well-being across three pillars - education, health, and standard of living. More modest values on this composite index at subnational levels betray higher deprivation [43]. The fourth element is Built-up Areas (BUILT), which contrasts the extent of constructed versus non-constructed land areas. Globally, rural populations frequently grapple with higher multidimensional poverty compared to urban zones [44]. Therefore, smaller built area proportions signal greater deprivation, assuming all else is constant.

The fifth and sixth metrics center on Visible Infrared Imaging Radiometer Suite (VIIRS) Nighttime Lights. The fifth measure is VIIRS Nighttime light intensity (VIIRS), which harnesses satellite images of average light intensity in 2020 as an indicator of poverty, with weaker illumination denoting higher deprivation [45]. The sixth metric is the Nighttime Lights Slope (VIIRS2), which computes the linear regression slope across annual VIIRS data from 2012 to 2020. Ascending brightness over time (steeper slope) reflects decreasing deprivation while descending brightness (flatter slope) indicates escalating deprivation [45]. By combining these six metrics, the GRDIv1 dataset delivers valuable insights into relative deprivation levels in a gridded format. This granular geospatial perspective on poverty measures enables meticulous analysis. Table 1 below shows the description of the data used in the study.

4 Results and discussion

In our mapping endeavors, we employed the plasma color palette from the colorspace package in R to represent the scale colors on the maps. The plasma palette is a sequential multi-hue palette based on the HCL color model, which is designed to produce perceptually uniform colors. The scale colors range from light green to yellow to dark blue, where the lighter colors indicate lower levels of deprivation, and the darker colors indicate higher levels of deprivation for the main GRDIv1, IMR, and CDR, which the VIIRS, VIIRS2, and SHE is the opposite. Also, the maps of the average and the maximum zonal statistics were reported for each GRID V1 component.

Figure 2a and b delineates the general components of the Relative Deprivation Index (GRDI) across Turkiye, serving as an indicative gauge of poverty and deprivation within the region. Computation of the GRDI considers a diverse array of variables encompassing factors such as Child Dependency Ratio (CDR), Infant Mortality Rate (IMR), Subnational Human Development Index (SHDI), the proportion of Built-Up to Non-Built-Up areas (BUILT), and nocturnal luminosity or the Visible Infrared Imaging Radiometer Suite (VIIRS and VIIRS2). A progressive deepening of color on the map corresponds to an elevated GRDI value.

The geographic depiction reveals a discernible pattern wherein the eastern segment of Turkiye exhibits a notably higher GRDI when compared to its western counterpart. Of note is the province of Şırnak, demonstrating the highest GRDI at 70.6. Adjacent provinces like Siirt, Hakkâri, Mardin, Van, and Diyarbakir follow suit with GRID values

Table 1 Descriptions of GRDI data components

Dataset	Format	Resolution	Index Range	Index Direction
Global Gridded Relative Deprivation Index (GRDI)	GeoTIFF format	30 arc-second (~1 km)		0 indicating the lowest deprivation level while 100 representing the highest
BUILT Component	GeoTIFF format	30 arc-second (~1 km)	0-100	0 indicating the highest deprivation level while 100 representing the lowest
Child Dependency Ratio (CDR) Component	GeoTIFF format	30 arc-second (~1 km)	0-100	higher dependency ratios, implying higher relative deprivation.
Infant Mortality Rates (IMR) Component	GeoTIFF format	30 arc-second (~1 km)	0-100	0 indicating lower deprivation while 100 representing higher poverty
Subnational Human Development Index (SHDI) Component,	GeoTIFF format	30 arc-second (~1 km)	0-100	0 indicating the highest deprivation level while 100 representing the lowest
VIIRS Nighttime Lights (VNL) 2020 Component	GeoTIFF format	30 arc-second (~1 km)	0-100	0 implying increasing deprivation and 100 indicating decreasing deprivation
VIIRS Nighttime Lights (VNL) Slope Component,	GeoTIFF format	30 arc-second (~1 km)	0-100	0 implying increasing deprivation and 100 indicating decreasing deprivation

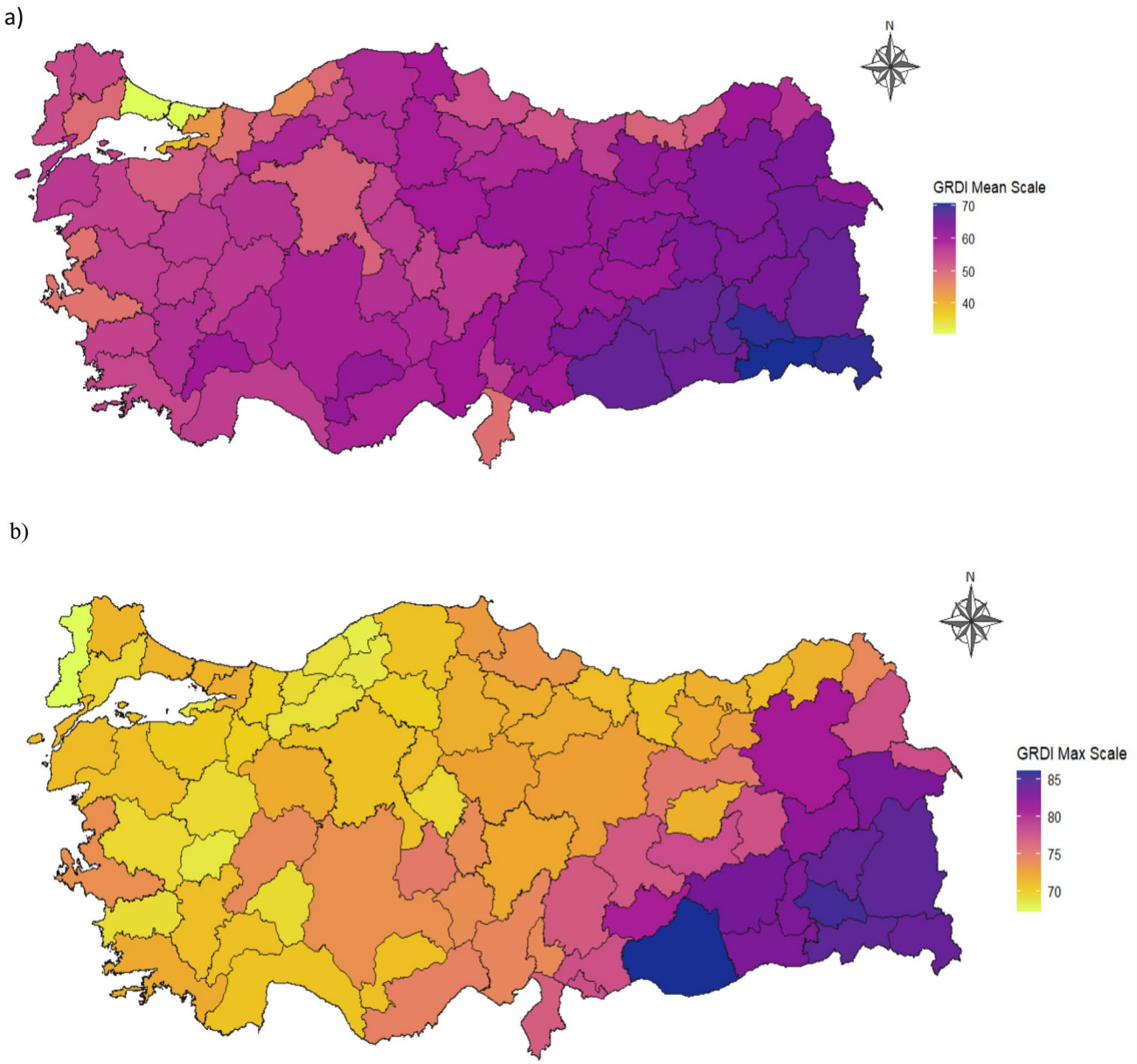

Fig. 2 Overall global gridded relative deprivation index (GRDI) of Turkiye **a**: mean **b**: maximum

of 70.5, 70.3, and 68.8, respectively. Conversely, Istanbul, Yalova, Kocaeli, Zonguldak, and Sakarya are characterized by the most subdued GRDI values at 30.7, 37.9, 43.7, 44.8, and 48.7, respectively. The 2021 regional results of the Income and living conditions survey conducted by the Turkish Statistical Institute also corroborate these findings, highlighting a consistent pattern of higher income levels in the western regions when contrasted with the eastern regions [46].

The higher GRDI observed in the eastern part of Turkiye can be attributed to a complex interplay of factors. Among these, the prolonged conflict between the Turkish government and the Kurdistan Workers' Party (PKK) emerges as a significant impediment to infrastructural advancement. Concurrently, the region contends with elevated levels of unemployment and illiteracy. In stark contrast, the western facet of Turkiye epitomizes a greater echelon of development and prosperity, bolstered by a diminished child dependency ratio, an elevated human development index, and a lower infant mortality rate.

Undoubtedly, the GRDI constitutes an invaluable analytical instrument for discerning the dimensions of destitution and privation within a nation. Furthermore, its utility extends to pinpointing locales necessitating targeted

interventions aimed at poverty alleviation. In the case of Turkiye, the conspicuous elevation of the RDI in the eastern territorial expanse underlines an exigent requirement for amplified investments in sectors such as education, healthcare, and infrastructural augmentation within this specific region.

4.1 Child dependency ratio

The following Fig. 3a and b presents an overview of the Child Dependency Ratio (CDR) across different regions of Turkiye. This metric serves as an indicator of the prevailing poverty levels. A higher CDR is indicative of a heightened state of deprivation or poverty, while the converse holds as well. As the map illustrates, the Eastern provinces of Turkiye exhibit a notably higher CDR when contrasted with their counterparts in the Western and Central regions of the country. Specifically, provinces such as Şırnak, Siirt, Hakkâri, Mardin, Van, Diyarbakir, Bitlis, and Agri stand out for their elevated CDR, as evidenced by the darker shading that signifies a higher degree of dependency.

Conversely, a significant portion of the Central regions is characterized by a relatively lighter shade of yellow, while the Western regions are more pronounced in their lighter yellow hues, indicative of a lower CDR. This CDR Ratio analysis aligns seamlessly with the overarching geographical context, corroborating findings from the broader analysis. It underscores the discernible developmental asymmetry between the Eastern and Western parts of Turkiye. It's important to note that this analysis is in harmony with the broader Geographical Information System (GIS) data, which consistently indicates a less developed Eastern region compared to the more developed Western segment of Turkiye.

4.2 Subnational human development index analysis

Figure 4 provides a comprehensive visualization of the Subnational Human Development Index (SHDI). The average zonal statistics of the SHDI were found to be meaningless and contradictory hence, the maximum zonal statistics have been used in this component. This index serves to validate the consistent pattern observed within the main constituents: the Global Gridded Relative Deprivation Index (GRDI), infant mortality rate, and child development index. The SHDI depicts the same trend as the components. Eastern and large parts of central regions of Turkiye are denoted by a light shade, symbolizing lower levels of SHDI —an indication of heightened poverty. On the contrary, the western, and peripheral coastal regions of the country are depicted in shades of dark blue or moderately light blue, reflecting higher levels of SHDI which indicates, less poverty. This congruence between the SHDI and the broader components underscores the reliability and robustness of the analysis. It reaffirms the marked disparity between the East and West of Turkiye, emphasizing the variance in development and poverty levels across the nation.

4.3 Infant mortality rate analysis

Infant Mortality Rate (IMR) analysis in concurrence with the previously examined factors, namely the main component, GRDI, CDR, and SHDI, the IMR reinforces a similar pattern evident in the poverty map of Turkiye. As illustrated in Fig. 5a and b the geographic depiction accentuates this correspondence. The eastern regions of Gaziantep, Van, Sanliurfa, Şırnak, and Hakkari are conspicuously highlighted as areas with elevated IMR. Conversely, the remaining regions of the country exhibit a lower incidence of IMR, predominantly observed in the western and central segments. This consistent alignment across multiple critical indicators reinforces the robustness of the analysis and underscores the pronounced disparity in poverty levels, particularly evident between the eastern and western or central regions of Turkiye.

4.4 Built-up to non-built-up ratios in context

Examining the Built-Up to Non-Built-Up Ratios (BUILT), a distinct and nuanced pattern emerges, differing somewhat from the trends identified in other pivotal indicators such as the CDR, IMR, and SHDI Index. Researchers worldwide have conducted regional and national studies utilizing exploratory spatial and various data analysis techniques to uncover intriguing insights into diverse environmental and socioeconomic concerns. Nevertheless, its applicability in rural development and planning remains largely unexplored [47]. As portrayed in Fig. 6, unlike the more concentrated alignments observed in the indicators, the BUILT metric presents a more diverse distribution across the landscape. While regions identified by other factors as less developed or indicative of higher poverty levels are consistently associated with fewer built-up areas, the landscape reveals an additional layer of complexity. Several other regions across the nation also exhibit a lower prevalence of built-up spaces.

However, the western Marmara region, home to Istanbul – the foremost metropolitan city and the financial epicenter of Turkiye – stands out with higher built-up ratios. Notably, provinces such as Kocaeli, Yalova, Sakarya, and Bursa, which collectively constitute an industrial hub characterized by concentrated industrial activities, exhibit a marked inclination toward more extensive built-up areas as compared to other regions in the country. This nuanced variation

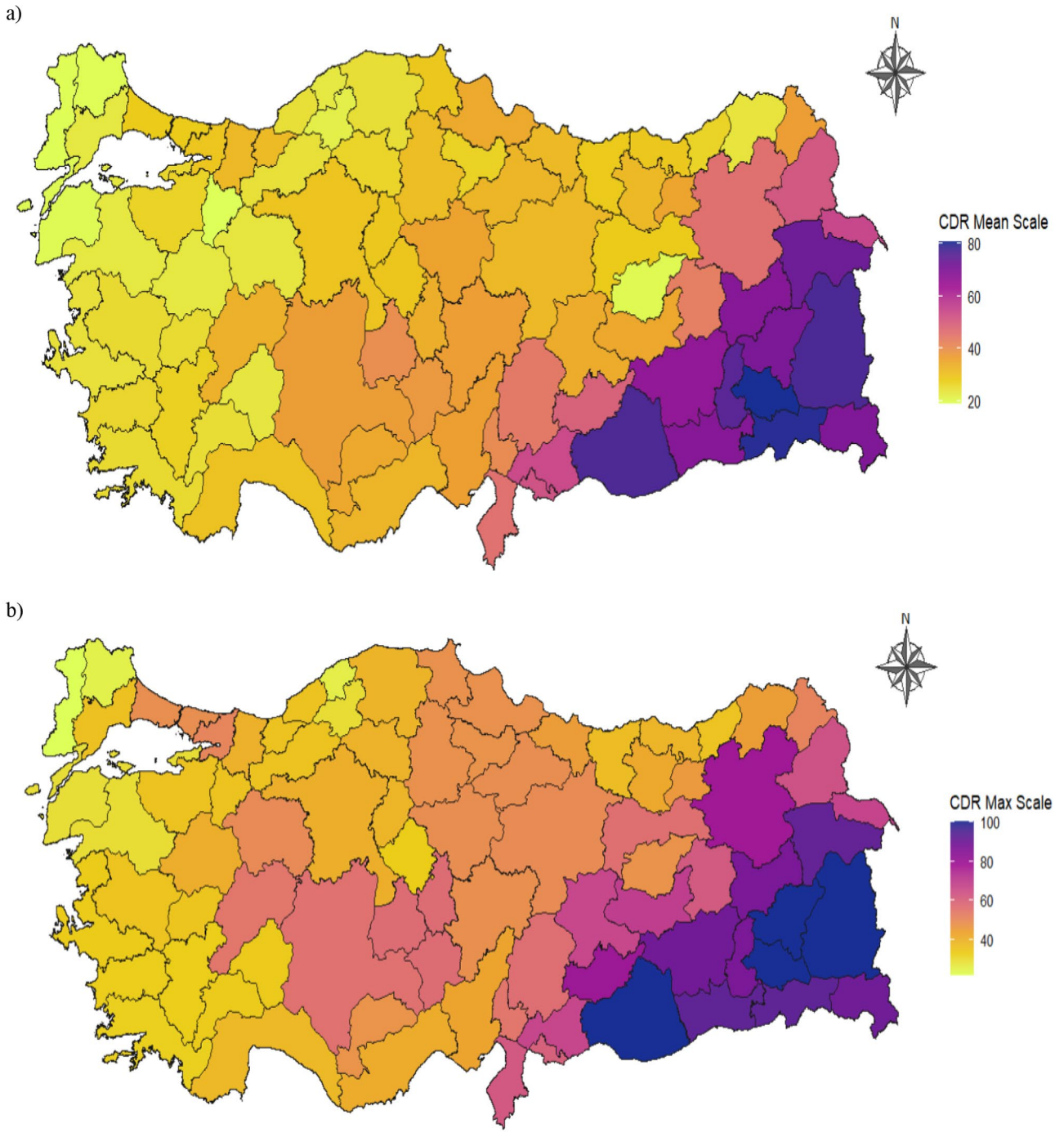

Fig. 3 Child dependency ratio index (CDR) across the regions of Turkiye **a**: mean **b**: maximum

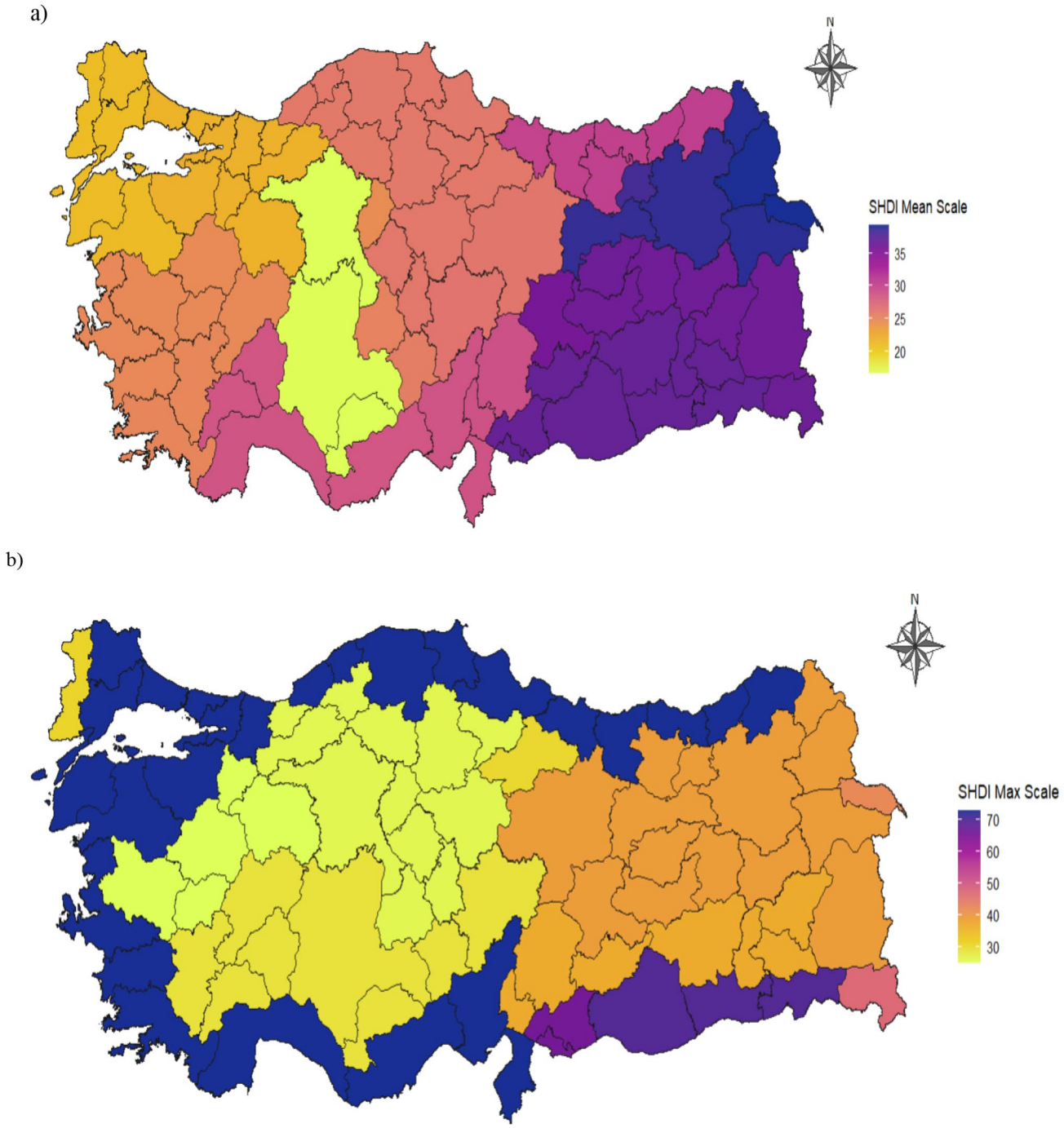

Fig. 4 Subnational human development index (SHDI) **a**: mean **b**: maximum

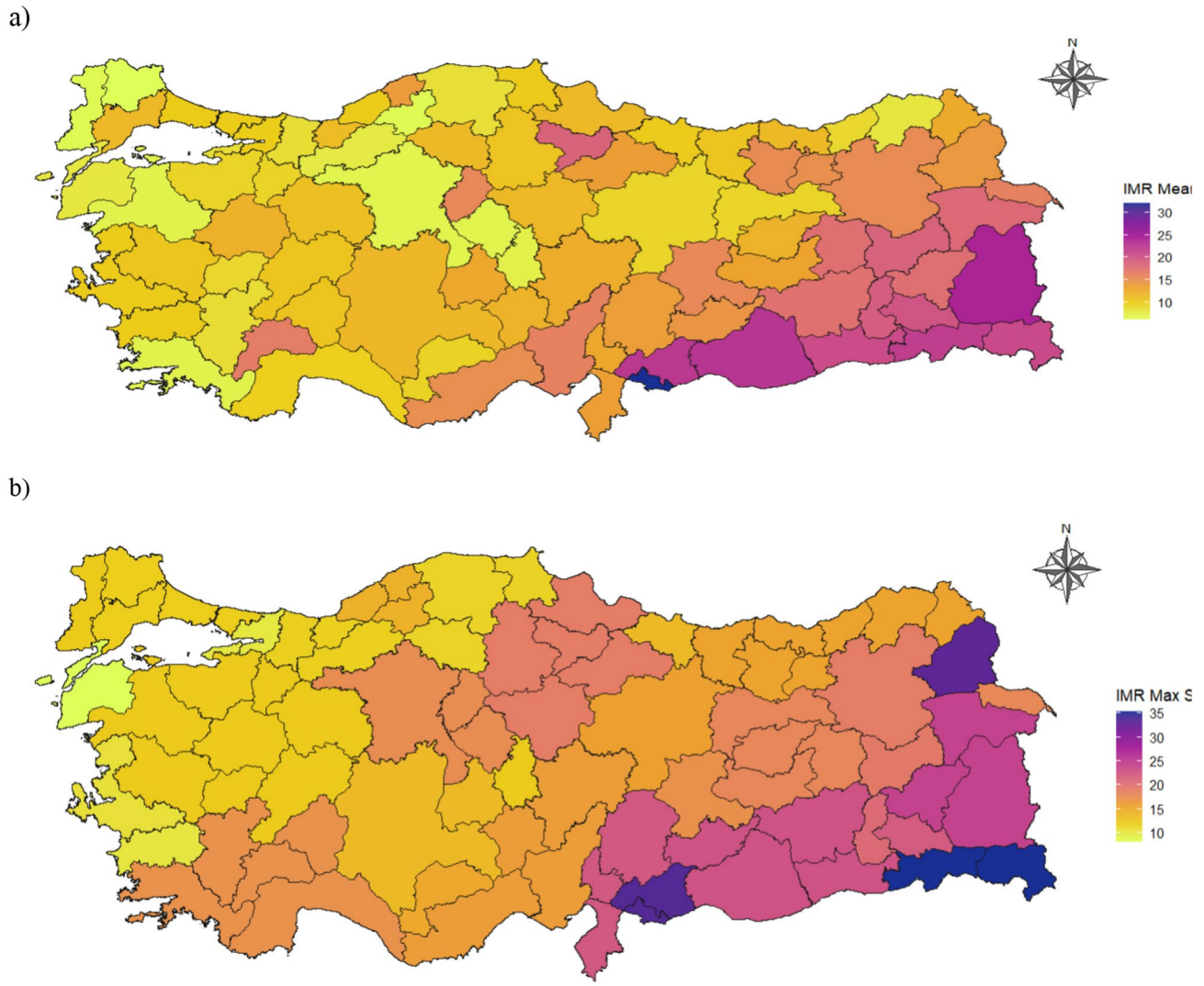

Fig. 5 Infant mortality rate (IMR) analysis across the regions of Turkiye **a**: mean **b**: maximum

underscores the intricate interplay between development, urbanization, and industrialization. The deviations in the built-up to non-built-up ratios from the more uniform trends in other indicators highlight the multidimensional nature of poverty and development dynamics within the distinct regions of Turkiye.

4.5 Nocturnal illumination patterns

The subsequent visual depictions in Fig. 7, present a comprehensive overview of the Visible Infrared Imaging Radiometer Suite (VIIRS) nighttime lights in 2020. The Nighttime Lights Slope (VIIRS2) data spanning from 2012 to 2020 (as displayed in Fig. 8). Major urban centers around the world have evolved into central command and control hubs for subordinate production centers, leading to a shift in the mega-metropolitan system's structure from a single dominant center to a multi-centered one [47]. Thus, in this paper, we employed night light density to visually analyze Turkish nocturnal illumination patterns.

Notably, the Marmara region in the western expanse of Turkiye emerges prominently on the map as an area characterized by the highest density of nocturnal illumination. This finding resonates harmoniously with the outcomes derived from other key indicators, such as BUILT, SHDI, IMR, and CDR. Collectively, these indicators consistently underscore the western region of Turkiye, including the Marmara region, as exhibiting elevated levels of development and a lower propensity for poverty. This congruence among diverse metrics solidifies the robustness of the analysis, consistently positioning the western territories of Turkiye as the focal point of enhanced development and lower susceptibility to poverty while the eastern region is generally revealed as less developed Light.

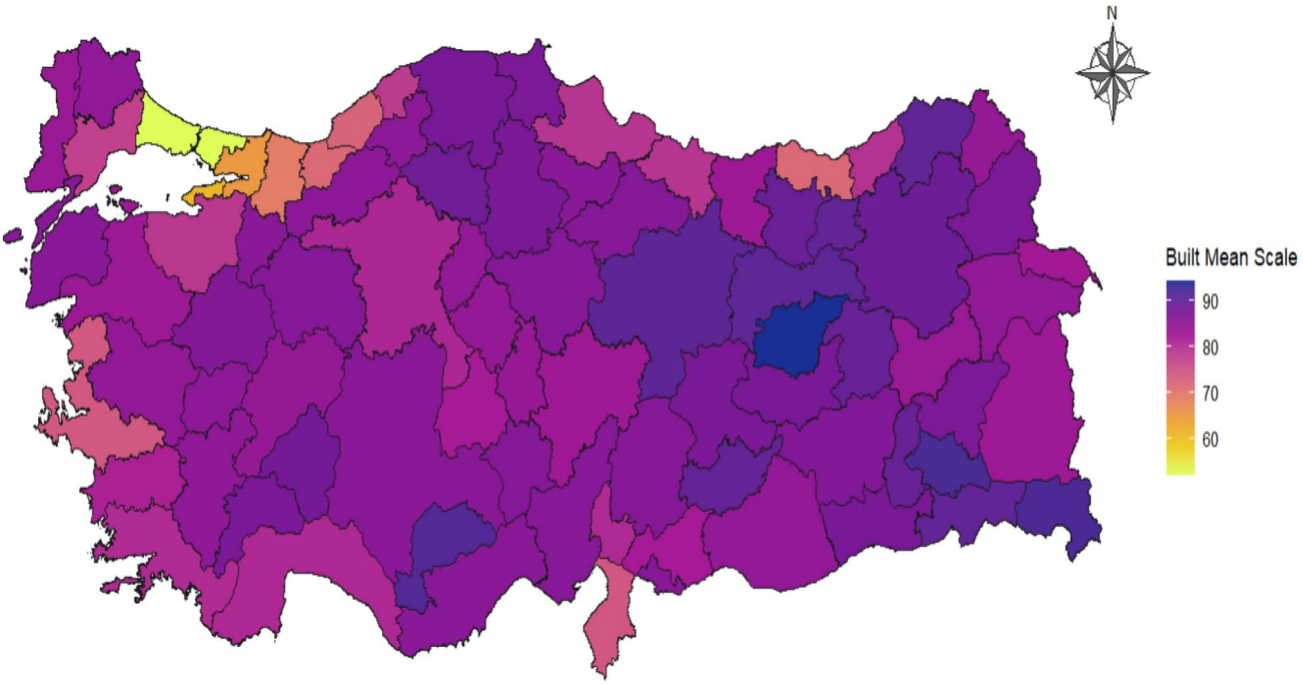

Fig. 6 Built-up mean ratio analysis across the regions of Turkiye

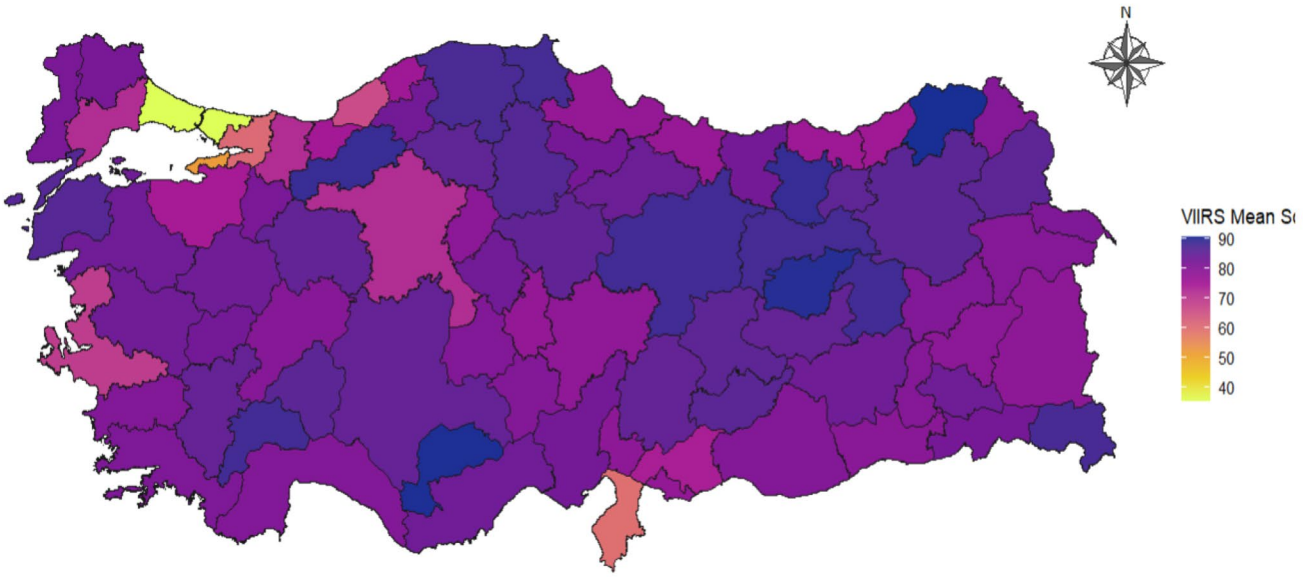

Fig. 7 Visible infrared imaging radiometer suite (VIIRS) nighttime lights in 2020

4.6 Discussion

This study used geospatial data analysis techniques and NASA's GRDIv1 dataset to examine the spatial distribution of poverty in Turkish 81 states. The results showed that the eastern regions of Turkiye have significantly higher levels of deprivation than the western regions. This evidence aligns with the findings presented by [33], who argued that a disparity exists between material deprivation and income poverty in Turkey. Their research indicates that the poverty levels are notably elevated in the regions of Central Eastern Anatolia and Southeastern Anatolia.

Furthermore, our study explored the regional differences in poverty in Turkiye by examining the specific components

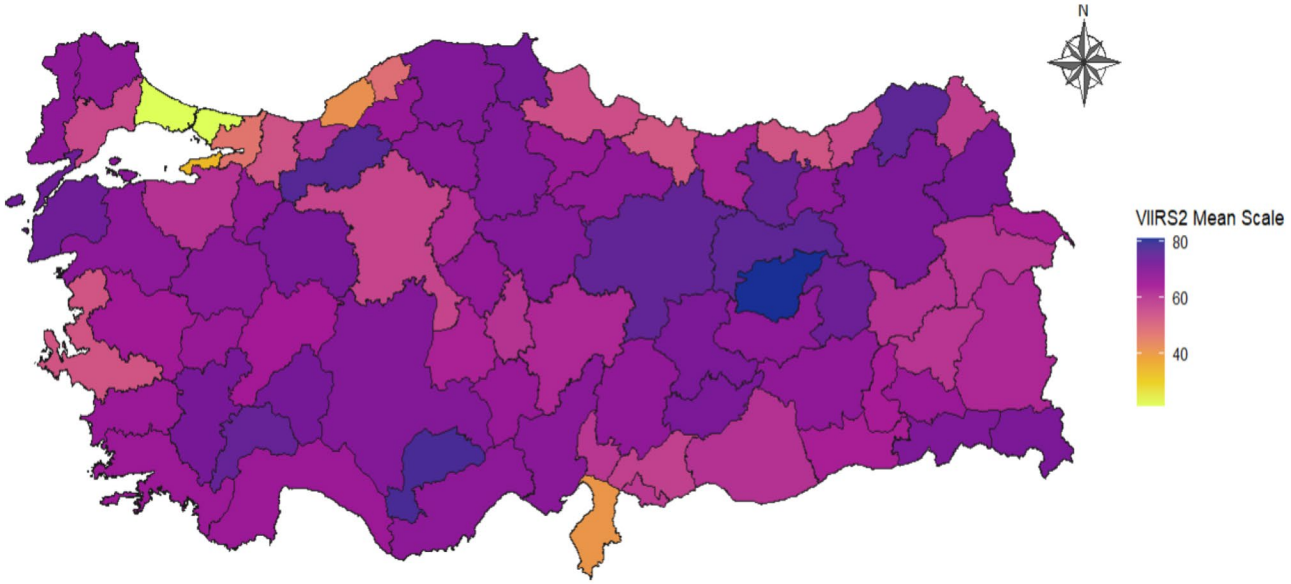

Fig. 8 Nighttime lights slope (VIIRS2) data spanning from (2012–2020)

of the GRDI (Global Gridded Relative Deprivation Index, Version 1), such as the Child Dependency Ratio CDR, Subnational Development Index (SHDI), and Infant Mortality Rate (IMR). The results indicate that each of these factors plays a role in the observed regional differences in poverty. This highlights that the western regions, as demonstrated by the maps, exhibit higher levels of development and prosperity compared to their eastern counterparts. These findings are consistent with the research conducted by experts in [7], who examined the distribution of multidimensional poverty across Turkey's regions. Their study underscored that access to education and health services is relatively diminished in the eastern regions as compared to the more affluent western regions of the country.

Therefore, our study contributes to the existing literature by measuring poverty by Visible Infrared Imaging Radiometer Suite (VIIRS 2020) nighttime lights as well as the Nighttime Lights Slope (VIIRS2) data spanning from 2012 to 2020. Furthermore, the analysis of Built-Up to Non-Built-Up Ratios revealed a complex distribution of urbanization and industrialization in Turkiye. The western Marmara region, which includes the cities of Istanbul, Bursa, and Kocaeli, emerged as a center of development and industrial activity. This is due to several factors, including the region's strategic location, stability, and proximity to European trade routes.

The analysis of nocturnal illumination patterns, based on VIIRS and VIIRS2 nighttime light data, further confirmed the higher levels of development in the west and the deprivation in the east. The western regions were much brighter than the eastern regions, indicating that they had a higher level of economic activity and population density.

The findings of this study have important implications for the design of policies to reduce poverty in Turkiye. The significant regional differences in poverty suggest that a one-size-fits-all approach will not be effective [7]. Instead, more targeted interventions are needed to address the specific needs of different regions.

For instance, the eastern regions of Turkiye are characterized by high levels of poverty, lower literacy rates, and higher unemployment. Also, some of these regions have a history of conflict and violence which led to the region's higher deprivation level and underdevelopment [8].

5 Conclusion

This research utilized geospatial data analysis methodologies and NASA's GRDIv1 dataset to scrutinize the spatial distribution of poverty across all 81 provinces in Turkey.

The study dissected the regional poverty differences in Turkey by scrutinizing specific components of the Global Gridded Relative Deprivation Index (GRDIv1). These components included the Child Dependency Ratio (CDR), Subnational Development Index (SHDI), Infant Mortality Rate (IMR), Visible Infrared Imaging Radiometer Suite (VIIRS 2020) nighttime lights, and Nighttime Lights Slope (VIIRS2) data spanning from 2012 to 2020.

The findings revealed a pronounced disparity, with the eastern regions of Turkey exhibiting significantly higher deprivation levels than the western regions. To address the

needs of the deprived regions, it is recommended that policymakers concentrate on enhancing education, healthcare, and infrastructure. Additionally, addressing the root causes of conflict, such as poverty, inequality, and stability, is crucial to fostering economic growth and improving the well-being of these regions.

Finally, this study has certain limitations due to its scope. It did not investigate external factors that could exacerbate deprivation, such as the impact of inflationary pressures and currency devaluation on poverty prevalence. Given these limitations, future research should focus on these factors and investigate how the seismic events of 2023, particularly the devastating earthquake, may have compounded the challenges faced by households in the Eastern regions already grappling with economic difficulties.

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Data availability Data will be prepared and accessible on request.

Declarations

Ethics approval The manuscript has been submitted only in this journal and not published in any other language before. All the data and results (image or graph) used here was not manipulated. The authors do not require approval for publication of this research.

Compliance with ethical standards This paper complies with the ethical standards of research and methodology.

Conflict of interest The authors declare no competing interests.

Informed consent Not applicable.

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