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Intermittent Development of Central Place Systems: The Dynamics of Unification and Breakup

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ABSTRACT
Relevance. The development of central place theory has been hindered by its static nature, as it fails to capture transitions between equilibrium states in central place systems. This long-standing problem remains unsolved since the theory's inception 90 years ago. This article presents a solution by examining the cases of system unification and system breakup, where previously independent systems merge or split.
Research objective: The study aims to identify the conditions under which central place systems resume continual development following revolutionary transformations in their structure.
Data and methods: The research analyzes census data from India (1941–2011) and Yemen (1973–2004) using equations based on the axioms of central place theory. The study also considers isostatic equilibrium as the foundation of central place system structures.
Results: The effect of intermittence on the steady evolution of a central place system diminishes rapidly after the unification of two independent systems. In contrast, the adaptation of elements from a previously unified system to new conditions, including reinstating the former hierarchy and spatial structure, takes significantly longer after a system breakup. The study introduces a novel perspective, highlighting that the unification of central place systems tends to lead to progress, whereas the breakup of a unified system results in degradation.
Conclusions: The true benefit to a central place system lies not solely in achieving isostatic equilibrium but in maintaining a secure and optimal structure. While these concepts share similarities, they may appear more distinct when examining the central place system as a whole. Equilibrium represents an optimal state for individual hierarchy levels rather than the entire system.

KEYWORDS
central place theory, spatial structure, hierarchical structure, evolution, revolutionary change

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Дискретное развитие систем центральных мест: объединение и распад

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АННОТАЦИЯ
Актуальность. Главная проблема теории центральных мест, которая не была решена за 90 лет, прошедших с момента ее возникновения – статический характер, не позволяющий описать переходы между равновесными состояниями систем центральных мест. В статье предлагается вариант решения этой проблемы на примере системы, образовавшейся в результате объединения самостоятельных систем, и систем, образовавшихся после распада целостной системы.
Цель исследования. Исследование направлено на выявление условий возобновления континуального развития систем центральных мест после революционных преобразований их структуры.
Данные и методы. Исследование примеров Йемена и Индии базируется на уравнениях, вытекающих из аксиоматического фундамента теории центральных мест, а также на представлении об изостатическом равновесии

КЛЮЧЕВЫЕ СЛОВА
теория центральных мест, пространственная структура, иерархическая структура, эволюция, революционные изменения

структуры соответствующих систем. Статистическую базу исследования составляют данные переписей населения Индии (1941–2011 гг.) и Йемена (1973–2004 гг.).
Результаты. Влияние дискретизирующего поступательную эволюцию объединения двух систем центральных мест достаточно быстро сходит на нет. В случае распада адаптация части ранее единой системы к изменившимся условиям в виде восстановления прежних иерархии и пространственной структуры происходит дольше. Новизна исследования заключается в доказательстве авторской гипотезы о том, что объединение нескольких систем центральных мест определяет прогрессивную направленность эволюции, в то время как разделение единой системы на изолированные части ведет к регрессу.
Выводы. Выгодным для системы оказывается не столько пребывание в состоянии изостатического равновесия, сколько закрепление оптимальной структуры. Эти понятия достаточно близки по своей сути, однако при рассмотрении системы в целом могут отличаться: оптимальным является равновесное состояние не всей системы, а отдельных уровней иерархии.

БЛАГОДАРНОСТИ
Статья опубликована в рамках проекта «Посткризисное мироустройство: вызовы и технологии, конкуренция и сотрудничество» по гранту Министерства науки и высшего образования РФ на проведение крупных научных проектов по приоритетным направлениям научно-технологического развития (Соглашение № 075-15-2020-783).

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中心地理论系统的离散发展：统一与瓦解

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摘要
现实性：中心地理论自提出以来的90年里仍未得到完全解决。理论的静态性不能详尽描述中心地理系统平衡状态之间的转变。本文以独立系统合并后形成的系统和整体系统崩溃后形成的系统为例，提出了解决这一问题的变通方案。
研究目标： 该研究试图确定中央地方系统在其结构发生革命性转变后重新持续发展的条件。
数据与方法：也门和印度的案例研究是基于方程（从中心地理论的公理基础中得出）以及系统的等高线平衡结构概念。该研究的统计基础是印度（1941-2011）和也门（1973-2004）的人口普查数据。
研究结果：两个中心地点系统合并后逐步演变的离散化效果很快消失。系统一旦崩溃，以前统一的部分系统为恢复到以前的等级和空间结构形式，需要更长的时间来适应条件变化。本研究的新颖之处在于证明了作者的假设，即几个中心系统的统一决定了进化的前进方向，而单个系统的分裂导致了回归。
研究结论：系统处于均衡平衡状态并不那么有利，保持一个最佳结构是最有利的。这些概念本质上非常接近，但是，当将系统视为一个整体时，它们可能会有所不同。最佳状态不是整个系统的平衡状态，而是层次结构中的各个层次的平衡状态。

关键词
中心地理论、空间结构、等级结构、演化、革命性变化

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Introduction

This year commemorates the 90th anniversary of the publication of W. Christaller's book on the Central Place Theory (CPT) in 1933. This influential theory delineates the spatial hierarchy of urban settlements and experienced active development during the 1960s and 1970s. Subsequently, the interest in the theory resurged in the 1990s and has remained strong ever since. Although the term "place" in the classical version of central place theory traditionally referred to settlements, Christaller himself argued that it encompassed more than just settlements, political communities, or economic units (Christaller, 1966, p. 17). Instead, Christaller conceived centrality as a relative concept, relating to dispersed settlements within a region (Ibidem, p. 16). He emphasized that all regions have centers, with closer centers of lower order located in smaller towns, while centers of higher order are found in larger towns that fulfill the demands of both the country and smaller towns (Ibid., p. 16). Importantly, Christaller introduced the notion of order, which establishes a hierarchy within the central place system. This hierarchy forms nested hexagonal lattices of three types in an infinite homogeneous plane, with central places located at the vertices, in the middle of the edges, or inside the hexagons themselves.

Economists and geographers evaluated the classical version of central place theory (CPT) as having limited explanatory power (Parr & Denike, 1970; Sjøholt, 1984; Meijers, 2007). The main reason for this assessment is the discrepancy between the regular arrangement of central places (CPs) described in theory and the actual irregularity observed in reality. Even in Southern Germany, which served as a testing ground for Christaller's theory, settlements with similar population sizes or functional characteristics did not align in neat hexagonal patterns. To address this issue, the relativistic version of CPT (Shuper, 1995) was developed. In this framework, the emphasis shifted from the regularity of CP arrangement to the proportions governing their overall arrangement within the lattice. The focus extended beyond a specific level of the hierarchy to consider the combination of CPs as a whole.

Thus, within the framework of the complementarity principle (Shuper, 1996), which allows the CP hierarchy to be determined by a single attribute, we can expand the scope of CPT beyond settlements alone. Various attributes such as population size, the extent of consumer services, educational functions, and more can each have their own hierarchy within the CP system. Here, the CP system refers to the interconnected set of CPs fulfilling their respective central functions, with the volume of these functions being calculated directly or indirectly (e.g., using population indicators).

The relativistic version of central place theory (CPT), incorporating the isostatic equilibrium index (see below), introduces the concept of attractors as local and global goals that shape the evolutionary stability of systems. However, both the classical and relativistic versions of CPT have been criticized for their static nature (Preston, 1983), as they do not provide a clear understanding of how the evolution of central place systems unfolds. Specifically, it remains unclear in what order central places of different hierarchy levels emerge and occupy positions within the hexagonal lattice.

Addressing the issue of the static nature of CPT proved challenging, and researchers predominantly focused on other aspects until the late 1970s. In the 1990s, the question resurfaced, with "classic" (Vazhenin, 1997) and "new" (Fujita et al., 1999) economic geographers putting forth two hypotheses regarding the evolution of central place systems, considering population and economic components of the hierarchy. These hypotheses, however, suffer from the limitation of defining CP hierarchy based on pre-existing classifications or researcher-proposed classifications, such as population size (e.g., million-plus cities, large cities) or the number of key functions (e.g., long-distance calls, businesses) (Krugman, 1996). The evolution of CP systems is influenced by the number and volume of hierarchical subsets established within these classification frameworks. Despite these efforts, international experts have not fully addressed the problem of the static nature of CPT, and instead, turned to alternative methodological frameworks, such as the "new" economic geography. Pioneering articles by P. Krugman and his co-authors made significant contributions in this regard.

However, in the early 2020s Russian specialists demonstrated a solution to the problem of the static nature of CPT within the framework of CPT itself, without relying on other areas of economic geography or economics. Notably, it has been shown in (Dmitriev, 2021a) that instead of establishing hierarchy from above, a bottom-up approach can be employed to distribute CPs across different levels within the system. By identifying the hierarchy in this manner, it becomes possible to define, albeit with some imprecision, the succession and mechanisms of CP emergence, shedding light on the system's evolution. The continual development of CP systems has been substantiated based on (Dmitriev & Gorokhov, 2022) and alternative (Vazhenin, 2020) approaches.

The significance of our study lies in the fact that, for the first time, the problem of CP system evolution is addressed directly within the framework of CPT itself rather than relying on alternative methodological constructs. This research tackles the cases of unified systems that previously developed relatively independently, as well as systems formed after the breakup of a previously unified system. The study aims to identify the conditions under which CP systems can resume continual development following revolutionary transformations in their structure. It will enable us to do the following: 1) determine the speed at which a new system restores continual development after the unification of two CP systems;

2) identify the characteristic features of systems formed after the breakup of a previously unified system; and 3) validate the theoretical proposition that the change of CPs at the first level of the hierarchy mainly occurs during the early stages of development.

Theoretical Framework, Method and Data

We define the evolution, or continual development, of a CP system as the gradual changes in urbanization levels accompanied by minimal accretion (Dmitriev & Gorokhov, 2022). This process corresponds to a logical succession whereby new CPs emerge or disappear within the system.:

$$\varphi = 1 - (1-k) \times \left(\frac{K^r_{n-2} \times (1-k)}{K^r_{n-2} - k} \right)^{n-2}, \quad (1)$$

where φ is a share of urban population in the system's general population,

k is the CP's share in the population of the zone it serves,

K^r represents the maximum population size relative to a single CP at the *nth* level of the hierarchy. It accounts for the dual functions of the CP, namely, "serving" an urban center by catering to its own population and "forming" an urban center by incorporating the populations of all lower-level CPs that are "attached" to it[1],

n is the number of hierarchy levels in the system, including the 1st level (consisting of one CP) and the last one (in this case, consisting of rural communities).

In the tables provided below (Tables 1–5), the settlements of the actual systems are listed in descending order of their population size (column 2). Columns 3 and 4 display the calculated values of the absolute and relative size of the urban population accumulated for each settlement, respectively. According to the principles of the CPT, the value of k (column 5) remains consistent across all levels of the hierarchy, except for the final level, which is not included in the tables.

We obtain the calculated values of K (columns 6–8)[2] for each CP of each level of the hierarchy from equation (1). Ideally, the population of each level's CPs should be uniform, and when calculating, it should yield the value of K corresponding to their number plus one. However, in real settlement systems, having the same population for all settlements is a rare occurrence. Therefore, the value of K does not apply to each individual CP separately but rather to the accumulated population that can be served by a CP at a higher level. The calculation of K (moving down the column) is performed until this parameter reaches the value of 7. While it may be lower than this threshold, it must not exceed it in any circumstances according to the principles of CPT. Once the maximum value is reached, the calculation is concluded, and all the counted settlements are attributed to one level of the hierarchy. Taking into account the derived expressions for the previous levels, the calculations then proceed for the next level. This process continues until all CPs are appropriately assigned to their respective levels.

Next, it is necessary to determine the spatial structure of this system, specifically its lattice. One main challenge with isolated lattices having different K values is the inability to visually and conceptually transition between them during the system's evolution. To address this issue, we propose assigning a consistent K value of 7 to each level, which will serve as the definitive graphic representation of the structure. Consequently, systems corresponding to different K values will be depicted as sections of a structure that represents the final stage of evolution—a stencil of sorts—where each CP occupies its designated location as it emerges[3].

At any stage of its evolution, a CP system strives to reach an attractor—a state of the system's hierarchical and spatial structure that sufficiently supports overall stability and equilibrium[4]. We view structure as an invariant aspect of the system (Ovchinnikov, 2019) and understand absolute stability as equipoising of gravitational effects related to differences in population size and distances between communities and CPs in the real system and in corresponding ideal Christaller's grid (Shuper, 1995). Stability of a CP system has a quantitative index such as isostatic equilibrium, proposed in (Shuper, 1989): $\sum_{i=2}^{n} \frac{R_i^t}{R_i^e}$, which is an integral characteristic showing the combined dif-

[1] The relativistic CP theory has a host of values of $K^r \in (1; 7]$; in the classic CP theory K^r is transformed into K^C, which is the number of CPs of the next, lower hierarchy level served by one higher-level CP (the levels are numbered from the top down) plus 1, and it has three possible values: 3, 4 or 7 (Hudiaev, 2008).

[2] The corresponding formulae for the first seven levels of the hierarchy are presented in (Dmitriev, 2021a).

[3] See (Dmitriev, 2021a) for more detail on the method of distribution of the CPs over the loci of the hexagonal lattice.

[4] Dmitriev, R. V. Evolutionary processes in central place systems. Dissertation for the Degree of Doctor of Geographical Sciences. Moscow, 2022. URL: http://igras.ru/sites/default/files/announcements/Диссертация-Дмитриев.pdf (Accessed: 25.11.2022).

ference in population size (theoretical radius R_i^t) and in the distance between CPs at different hierarchy levels (empirical radius R_i^e) in the real system and the ideal isolated system. The closer its estimated value to (n – 2), the closer the real system's structure to the ideal version and, ultimately, the more immune to changes in its structure.

After distributing all the CPs by hierarchy levels and grid loci, we calculate the total ideal population size for each level using equation (2) introduced by Beckmann (1958) and further developed by Parr (1969):

$$\frac{p_i}{p_{i+1}} = \frac{K-k}{1-k} \quad (2)$$

Dividing the actual population (tables below) by the calculated ideal, we get R_i^t for each of the n levels of the hierarchy. Based on the established spatial structure of the CP system, we calculate[5] the empirical average distances in a straight line from the CP of the 1st level to the CP of each of the other hierarchy levels present in the system. Dividing the empirical average distances by the ideal ones, we obtain R_i^e for the corresponding levels. Further, by dividing the values of R_i^t by R_i^e for the corresponding levels and summing up the results, we obtain the value of the isostatic equilibrium index.

We examine intermittent development solely in relation to the system's return to the logical sequence of continual development after unpredictable structural changes (Sonis, 2005), as described in detail in (Dmitriev, 2021b). Envisioning all possible conditions of a CP system during intermittent development (Vazhenin, 1999; 2006) can be quite challenging. In the following text, we focus on discussing two specific scenarios.

One possible scenario of intermittent evolution involves the unification of CP systems that previously developed independently from each other. The selection criterion for the objects of this research is the availability of a statistical database. Therefore, we are faced with the choice between two options: the development of the systems in the German Democratic Republic and the Federal Republic of Germany, or the Yemen Arab Republic (YAR, or North Yemen) and the People's Democratic Republic of Yemen (PDRY, or South Yemen)[6]. Considering that the first case involves the unification of two relatively well-developed systems, our focus is on the second case: the previously independent CP systems of North Yemen and South Yemen, which have merged into a single system.

Population censuses were taken in North Yemen in 1975 and 1986, and in South Yemen, in 1973 and 1988 (although only data of the 1970s' censuses are available to us), and after the two states' unification, censuses were conducted in 1994 and 2004[7]; in 2014, the census-taking was disrupted by the armed conflict between the government and the Houthi rebels (Savateev & Bokov, 2017).

Another scenario of intermittent development within a CP system involves its breakup. A breakup can result in the emergence of two or more independent systems. However, we are specifically interested in exploring how the breakup affects a particular element within the new system. In this case, we examine the settlement system of a historical region within a country, rather than the entire country itself. A noteworthy example in this regard is Northeast India, often referred to as the "Seven Sisters" - the seven states in present-day India that were geographically separated from the rest of the country in 1947 during the division of British India into the Union of India and the Dominion of Pakistan. The only transportation route connecting these regions with the rest of India is Siliguri, which bypasses Bangladesh (formerly East Pakistan, which gained independence in 1971) and connects the mainland of India to the northern section of the state of West Bengal, Sikkim, and the Seven Sisters States - Assam, Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Mizoram, and Tripura.

Similar to many former British colonies, population statistics in India are meticulously collected (Gorokhov, 2011). The first relatively comprehensive census in India took place in 1881, preceded by the 1871 census, which, according to official assumptions, was conducted between 1867 and 1876. Subsequently, population censuses have been carried out every 10 years without fail[8]. The relevant data for our study is derived from the last census conducted in 1941, prior to the partition of British India, as well as from all subsequent censuses conducted in India, starting

[5] In fractional units of distance from the CP of the 1st level to the CP of the 2nd level.

[6] North Vietnam and South Vietnam too would be an interesting case to consider, but when these states existed, no population census was conducted in them (Banens, 1999).

[7] Farhan, H. T. (2014). *Presentation of the Republic of Yemen on census 2014 plan of population, housing and establishments.* Retrieved from: https://www.sesric.org/imgs/news/image/831-s2-yemen-en.pdf (Accessed: 25.11.2022).

[8] The sole exception to this rule was the 2021 census – on occasion of COVID-19, it was postponed and is now tentatively scheduled for 2024.

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from the first census after independence in 1951 and concluding with the latest one in 2011. Before the 1941 census, the areas under examination were part of two provinces of British India: Bengal and Assam. Comparing data across historical periods presents some challenges due to the fact that the border between India and Pakistan in this region, after gaining independence, did not precisely align with the borders of the colonial provinces. In other words, certain parts of Bengal Province became incorporated into Northeast India, while some areas of Assam Province became part of East Pakistan. To address this, we deemed it necessary to "standardize" the border and utilize data from 1941 only for those communities that officially formed part of Northeast India's territory since 1951. Consequently, the main adjustment involved including data for a larger portion of Tripura in the 1941 Assam census, despite it being part of Bengal Province at that time. Conversely, a significant section of the Sylhet district, which was part of Assam in 1941, was excluded due to its incorporation into East Pakistan after the Partition of India.

Results

Following the Ottoman Empire's defeat in World War I, North Yemen underwent a period of significant independent development. Initially, it functioned as the Mutawakkilite Kingdom of Yemen (1918-1962) and later transformed into the Yemen Arab Republic (1962-1990). On the other hand, South Yemen was a British protectorate and did not exist as a cohesive political entity until it gained independence in 1967. These historical circumstances greatly influenced the development of the two systems.

By 1975, the first CP system comprised 17 central places distributed across four levels of hierarchy. In contrast, the second system, as of

Table 1

Central Place Systems in South (1973) and North (1975) Yemen

South Yemen							
Population of the system (persons), including:	**1 590 275**	**Accumulated population of the system (persons)**	**φ**	**k**	**K^r_1**	**K^r_2**	**K^r_3**
Aden	240 400						
Mukalla	45 000	285 400	0.179	0.151	1.240	–	–
Seiyun	20 000	305 400	0.192	0.151	1.397	–	–
North Yemen							
Population of the system (persons), including:	**6 471 893**	**Accumulated population of the system (persons)**	**φ**	**k**	**K^r_1**	K^r_2	K^r_3
Sanaa	134 600						
Al-Hudaydah	88 700	223 300	0.035	0.021	3.015	–	–
Taiz	86 900	310 200	0.048	0.021	–	2.976	–
Dhamar	21 000	331 200	0.051	0.021	–	5.790	–
Ibb	20 600	351 800	0.054	0.021	–	–	1.188
Beit al-Faqih	13 300	365 100	0.056	0.021	–	–	1.354
Yarim	8 000	373 100	0.058	0.021	–	–	1.478
Zabid	7 600	380 700	0.059	0.021	–	–	1.620
Bajil	7 300	388 000	0.060	0.021	–	–	1.784
Radaa	6 900	394 900	0.061	0.021	–	–	1.974
al-Marawi'a	6 800	401 700	0.062	0.021	–	–	2.207
Al Bayda	6 500	408 200	0.063	0.021	–	–	2.487
Hajjah	6 300	414 500	0.064	0.021	–	–	2.837
Amran	5 400	419 900	0.065	0.021	–	–	3.226
Az Zaydiyah	5 300	425 200	0.066	0.021	–	–	3.730
Saada	4 600	429 800	0.066	0.021	–	–	4.316
Al Mahwit	2 600	432 400	0.067	0.021	–	–	4.738

Source: the authors' calculations are based on statistical data: Brinkhoff, T. City Population. URL: https://www.citypopulation.de/Yemen.html *(Accessed: 14.03.2022).*

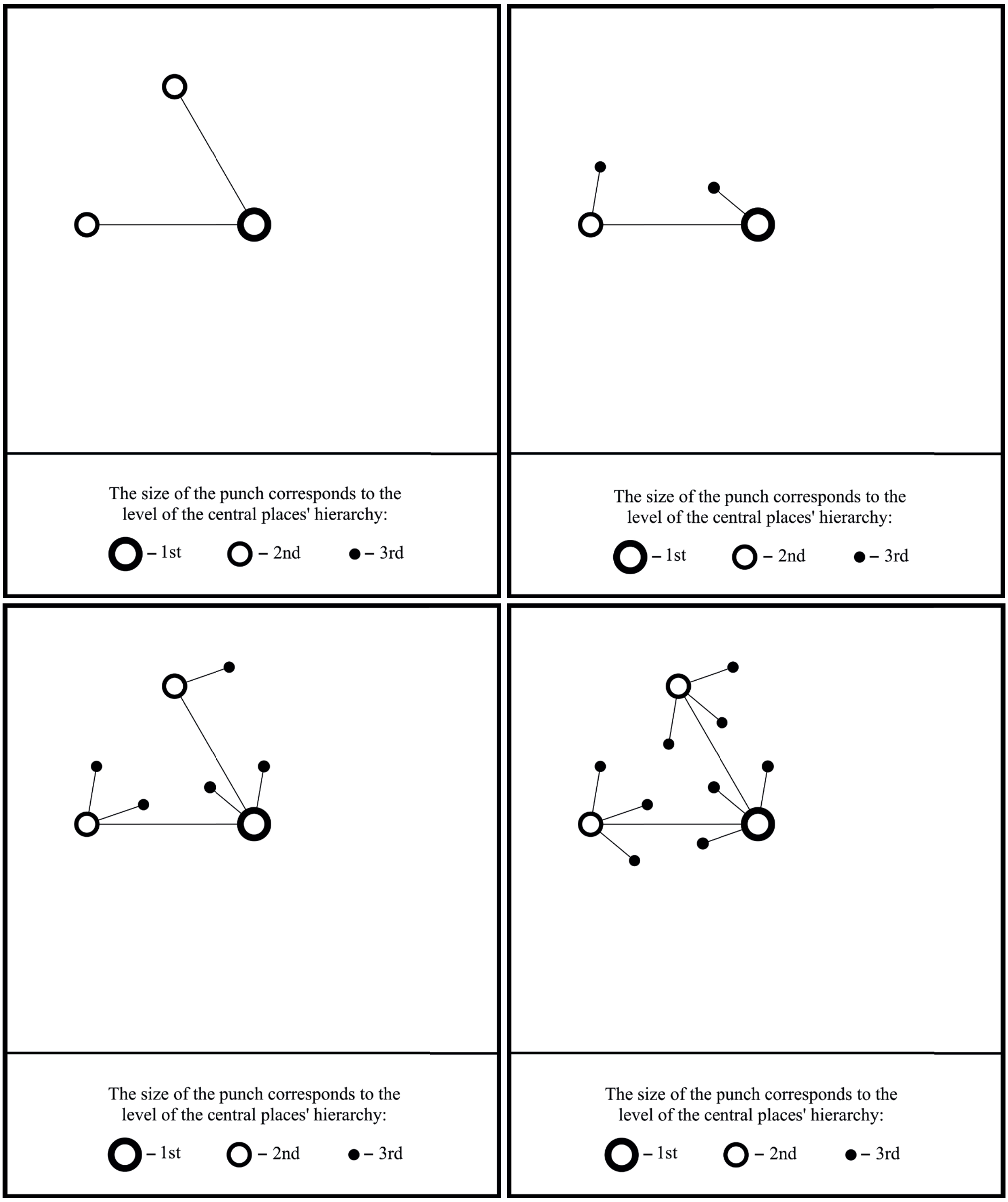

Figure 1. *The ideal grid structure corresponding to the central place system of South Yemen in 1973 (top left), North Yemen in 1975 (top right), Yemen in 1994 (bottom left), and 2004 (bottom right)*
Source: Compiled by the authors.

1973, consisted of only three central places and two hierarchy levels (see Table 1). At the same time, in South Yemen the share of urban population was 19.2% with $K^c_1 = 3$, and in North Yemen, only 6.7%, with $K^c_1 = K^c_2 = 2$: this shows that a large share of South Yemen's population was concentrated in a handful of cities.

One of the prominent cities, Aden, held significant importance in both systems. It not only served as a major harbor but also had a distinct administrative status as a separate colonial entity and governed for an extended period of time from India. The spatial structure of an ideal model representing both systems is depicted in Figure 1.

Table 2

Central Place Systems of Yemen in 1994 and 2004

1994						
Population of the system (persons), including:	**14 587 807**	**Accumulated population of the system (persons)**	φ	k	K^r_1	K^r_2
Sanaa	954 448					
Aden	398 294	1 352 742	0.093	0.065	1.754	–
Taiz	317 571	1 670 313	0.115	0.065	4.798	–
Al-Hudaydah	298 452	1 968 765	0.135	0.065	–	1.510
Mukalla	122 359	2 091 124	0.143	0.065	–	1.927
Seiyun	111 728	2 202 852	0.151	0.065	–	2.592
Ibb	103 312	2 306 164	0.158	0.065	–	3.839
Dhamar	82 920	2 389 084	0.164	0.065	–	6.315
2004						
Population of the system (persons), including:	**19 685 161**	**Accumulated population of the system (persons)**	φ	k	K^r_1	K^r_2
Sanaa	1 707 531					
Aden	588 938	2 296 469	0.117	0.087	1.554	–
Taiz	466 968	2 763 437	0.140	0.087	2.915	–
Al-Hudaydah	409 994	3 173 431	0.161	0.087	–	1.354
Ibb	212 992	3 386 423	0.172	0.087	–	1.673
Mukalla	182 478	3 568 901	0.181	0.087	–	2.111
Dhamar	146 346	3 715 247	0.189	0.087	–	2.685
Amran	77 825	3 793 072	0.193	0.087	–	3.146
Bajil	55 760	3 848 832	0.196	0.087	–	3.592
Saada	51 870	3 900 702	0.198	0.087	–	4.142
Rada'a	51 087	3 951 789	0.201	0.087	–	4.883
Seiyun	49 083	4 000 872	0.203	0.087	–	5.905

Source: the authors' calculations are based on statistical data: Brinkhoff, T. City Population. URL: https://www.citypopulation.de/Yemen.html (Accessed: 14.03.2022).; Yemen Central Statistical Organisation. URL: https://www.cso-yemen.com/ (Accessed: 14.03.2022).

In the case of South Yemen's central place (CP) system, it exhibited considerable instability. The isostatic equilibrium value stood at a mere 0.454, significantly below the ideal value of 1.000. The second hierarchy level either remained partially unfilled or had CPs with a population size less than 50% of the projected estimate.

Conversely, North Yemen's CP system demonstrated greater stability. It achieved an isostatic equilibrium of 3.173, close to the ideal value of 3.000. The population size of the 2nd, 3rd, and 4th levels exceeded the theoretical forecast. However, CPs at the 3rd and 4th levels were situated farther away from the 1st-level CP than anticipated.

Upon reviewing the suggestion proposed by Shuper and Valesyan (1999) that hierarchy levels alternate in terms of population size, referred to as "light - heavy," we find no substantial evidence to support this claim as a general rule.

In 1990, the Republic of Yemen was formed through the unification of South Yemen and North Yemen. The spatial structure of the ideal grids corresponding to the real settlement systems of both regions suggested that the optimal outcome of this unification would involve one 1st-level central place, three 2nd-level central places, and two 3rd-level central places. However, as depicted in Table 2 and Figure 1, the desired scenario did not materialize.

Upon reviewing the spatial structure of the newly formed unified system, it becomes apparent that the central place system of North Yemen was integrated into that of South Yemen, resulting in the replacement of the 1st-level central place. Following the unification, the newly formed CP system demonstrated remarkable stability, surpassing the stability of each of the two original systems. The isostatic equilibrium, with central places distributed across 4 hierarchy levels, reached a value of 2.959, which was close to the ideal value of 3.000. Subsequently, by 2004, the structure of Yemen's CP system underwent minimal changes, remaining relatively consistent. By 2004 the structure of Yemen's CP system did not change much: the value of K^c_1 remained the same (3) while K^c_2 grew to 4. The stability of the system, however, experienced a decline, with the isostatic equilibrium decreasing to 2.492. From this observation, the first conclusion that can be drawn is that a state of equilibrium, characterized by an index close to the ideal, does not always persist for an extended period. Instead, it is influenced by the unique characteristics of the system. Furthermore, this decline in stability indicates that the system is undergoing a process of transformation. Quite possibly, at the next stage it will change from $K^c_1 = 3$ to $K^c_1 = 4$.

In 1941, the CP system of Northeast India, despite its quite low urbanization level (less than 5%), had $K^c_1 = 4$ (see Table 3, Figure 2). All the identified subordinate hierarchy levels, ranging from the 2nd to the 4th, exhibited a "heavy" characteristic, indicating that their actual population size exceeded the theoretical forecast. In 1941, and in all subsequent years, the majority of the central places were situated within the present-day boundaries of the State of Assam, while the other states primarily housed their administrative centers at the 2nd to 4th hierarchy levels.

Table 3

Central Place System of Northeast India in 1941

Population of the system (persons), including:	8 858 624	Accumulated population of the system (persons)	φ	k	K^r_1	K^r_2	K^r_3
Imphal	99 716						
Shillong	30 734	130 450	0.015	0.011	1.448	–	–
Guwahati	29 598	160 048	0.018	0.011	2.559	–	–
Dibrugarh	23 191	183 239	0.021	0.011	6.480	–	–
Barpeta	18 466	201 705	0.023	0.011	–	1.231	–
Agartala	17 693	219 398	0.025	0.011	–	1.581	–
Silchar	16 601	235 999	0.027	0.011	–	2.162	–
Nagaon	12 972	248 971	0.028	0.011	–	3.036	–
Dhubri	12 699	261 670	0.030	0.011	–	5.034	–
Tezpur	11 879	273 549	0.031	0.011	–	–	1.138
Jorhat	11 664	285 213	0.032	0.011	–	–	1.318
Tinsukia	8 338	293 551	0.033	0.011	–	–	1.486
Karimganj	7 813	301 364	0.034	0.011	–	–	1.688
Goalpara	7 793	309 157	0.035	0.011	–	–	1.953
Sivasagar	7 559	316 716	0.036	0.011	–	–	2.304
Gauripur	5 783	322 499	0.036	0.011	–	–	2.673
Golaghat	5 470	327 969	0.037	0.011	–	–	3.151
Lumding	3 864	331 833	0.037	0.011	–	–	3.607
Palasbari	3 692	335 525	0.038	0.011	–	–	4.187
Nalbari	3 578	339 103	0.038	0.011	–	–	4.959
Kohima	3 507	342 610	0.039	0.011	–	–	6.055

Source: the authors' calculations are based on statistical data: (Dutch, 1942; Marar, 1942).

The 1st hierarchy level, however, was different: in 1941, it was occupied by Imphal, the administrative center of what is now the State of Manipur. Imphal played a significant role as an outpost of British presence in Northeast India, with a large number of British troops stationed there. It gained historical importance during World War II when, in the Battle of Imphal, the previously undefeated Japanese army suffered its first major defeat.

However, after India gained independence, all British soldiers left Imphal, resulting in a significant decline in its population. By the time the census was conducted in 1951, its population had decreased by a factor of 35, reaching

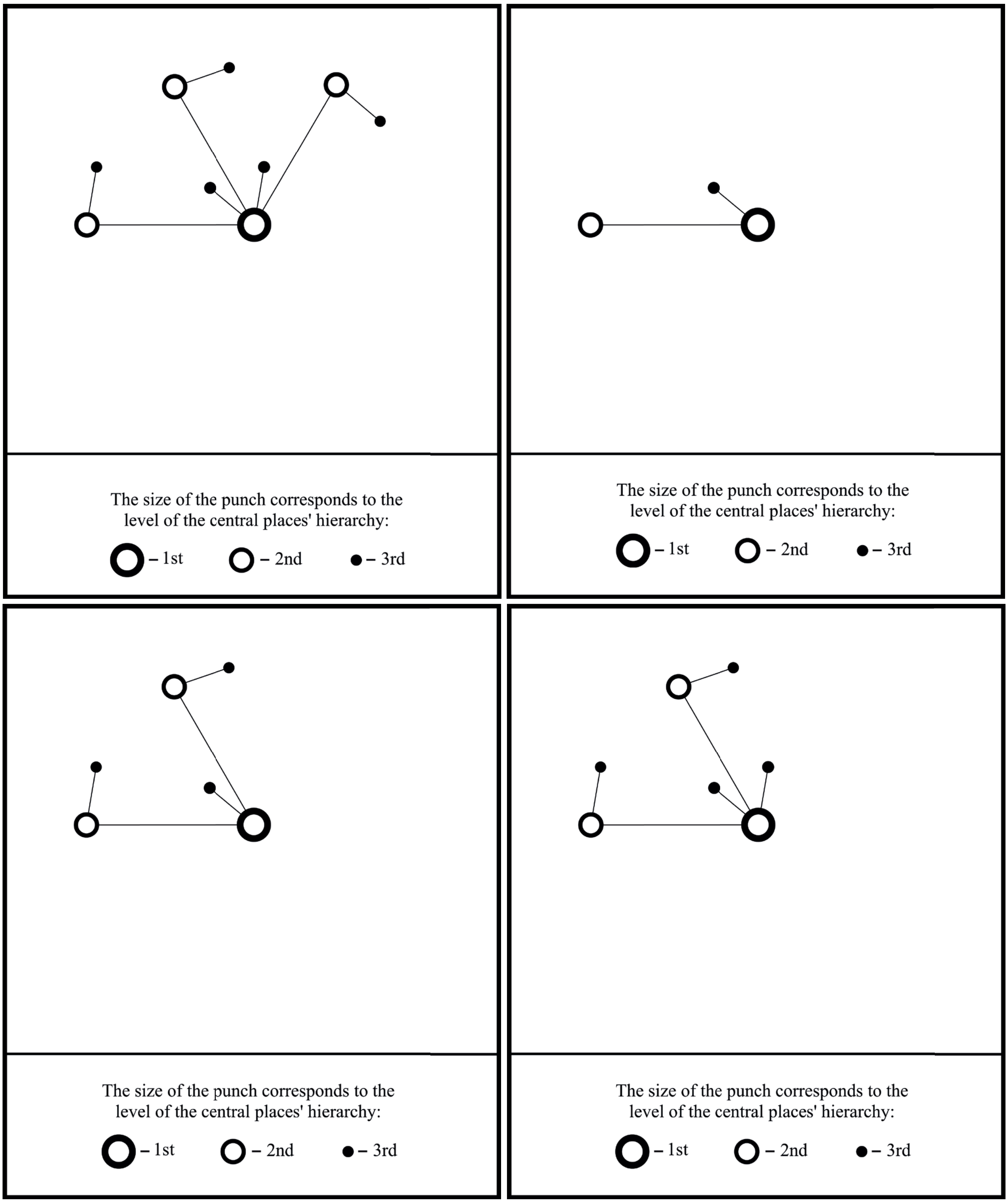

Figure 2. *The ideal grid structure corresponding to the central place system of Northeast India in 1941 (top left), 1951–1981 (top right), 1991 (bottom left), and 2011*
Compiled by the authors

a mere 3,000. Shillong, a city located outside present-day Assam in the State of Meghalaya, replaced Imphal in the hierarchy. Despite the relatively unchanged size of the settled area in the postcolonial period, the central place system underwent significant structural simplification by 1951 (as shown in Figure 2 and Table 4), with each of the 2nd, 3rd, and 4th hierarchy levels having only one central place. This structural simplification resulted in increased instability, as reflected by the lower isostatic equilibrium value of 2.086, compared to the optimal value of 3.000.

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Table 4

Central Place System of Northeast India in 1951–1971

1951							
Population of the system (persons), including:	**10 530 157**	**Accumulated population of the system (persons)**	**φ**	**k**	**K^r_1**	**K^r_2**	**K^r_3**
Shillong	53 756						
Guwahati	43 615	97 371	0.009	0.005	5.398	–	–
Agartala	42 595	139 966	0.013	0.005	–	4.974	–
Dibrugarh	37 991	177 957	0.017	0.005	–	–	3.511
1961							
Population of the system (persons), including:	14 500 325	Accumulated population of the system (persons)	φ	k	K^r_1	K^r_2	K^r_3
Guwahati	136 239						
Shillong	72 438	208 677	0.014	0.009	2.148	–	–
Imphal	67 717	276 394	0.019	0.009	–	2.008	–
Dibrugarh	58 480	334 874	0.023	0.009	–	–	1.771
Agartala	54 878	389 752	0.027	0.009	–	–	6.536
1971							
Population of the system (persons), including:	19 581 524	Accumulated population of the system (persons)	φ	k	K^r_1	K^r_2	K^r_3
Guwahati	200 377						
Imphal	100 366	300 743	0.015	0.010	2.014	–	–
Agartala	100 264	401 007	0.020	0.010	–	2.023	–
Shillong	87 659	488 666	0.025	0.010	–	–	1.799
Dibrugarh	80 348	569 014	0.029	0.010	–	–	6.883

Source: the authors' calculations are based on statistical data: India Towns and Urban Agglomerations Classified by Population Size Class in 2011 with Variation Since 1901. URL: https://censusindia.gov.in/2011census/PCA/A4.html *(Accessed: 14.04.2022).*

The system remained in this state for a considerable period, spanning at least 40 years, although it underwent some changes along the way. Firstly, this case supports the pattern established in theory by Dmitriev (2021a), which suggests that the replacement of the 1st-level central place occurs in the early stages of evolution. By 1961, Guwahati in the State of Assam emerged as the most populous city and continued to hold this position. Secondly, there was a gradual increase in the values of K for the lower levels of the hierarchy. However, this slow growth did not significantly impact the overall spatial structure of the system from the 1st to the 3rd level, as depicted in Figure 2.

Immediately after the system's collapse, the spatial structure exhibited a relatively low level of stability, indicated by an isostatic equilibrium value of 2.086 at the 4th hierarchy level, compared to the optimal value of 3.000. By 1961, the stability further declined to 1.518, maintaining the same optimal value. However, by 1971, following certain shifts of central places across the 2nd to 4th levels of the hierarchy, the value of isostatic equilibrium even surpassed the optimum, reaching 3.342. This energetically advantageous hierarchy of central places became a defining characteristic of the system and persisted over the years. By 1991, the top five most populous cities experienced only one change, while the spatial structure of the system underwent significant transformations, as illustrated in Figure 2. In 1991, the system changed from $K^c_1 = 2$ to $K^c_1 = 3$ (Table 5).

The composition of the top five most populous communities underwent minimal changes, suggesting that the system's present condition is influenced by its past—a concept referred to as "the memory of a system" (Vazhenin, 2010), wherein the system's optimal structural characteristics are retained.

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Table 5

Central Place System of Northeast India in 1991 and 2001

1991							
Population of the system (persons), including:	**31 547 314**	**Accumulated population of the system (persons)**	***φ***	***k***	K^r_1	K^r_2	K^r_3
Guwahati	584 342						
Imphal	198 535	782 877	0.025	0.019	1.520	–	–
Agartala	198 320	981 197	0.031	0.019	3.205	–	–
Aizawl	155 240	1 136 437	0.036	0.019	–	1.371	–
Shillong	131 719	1 268 156	0.040	0.019	–	2.009	–
Dibrugarh	120 127	1 388 283	0.044	0.019	–	3.512	–
Silchar	115 483	1 503 766	0.048	0.019	–	–	1.256
Jorhat	93 814	1 597 580	0.051	0.019	–	–	1.588
Nagaon	93 350	1 690 930	0.054	0.019	–	–	2.160
Tinsukia	73 918	1 764 848	0.056	0.019	–	–	3.030
Dhubri	66 216	1 831 064	0.058	0.019	–	–	4.751
2001							
Population of the system (persons), including:	**38 316 918**	**Accumulated population of the system (persons)**	***φ***	***k***	K^r_1	K^r_2	K^r_3
Guwahati	809 895						
Agartala	269 492	1 079 387	0.028	0.021	1.504	–	–
Aizawl	228 280	1 307 667	0.034	0.021	2.652	–	–
Imphal	221 492	1 529 159	0.040	0.021	–	1.387	–
Silchar	156 948	1 686 107	0.044	0.021	–	1.917	–
Dibrugarh	133 571	1 819 678	0.047	0.021	–	2.855	–
Shillong	132 867	1 952 545	0.051	0.021	–	5.595	–
Jorhat	120 415	2 072 960	0.054	0.021	–	–	1.182
Nagaon	108 786	2 181 746	0.057	0.021	–	–	1.416
Tinsukia	101 957	2 283 703	0.060	0.021	–	–	1.741
Tezpur	98 550	2 382 253	0.062	0.021	–	–	2.241
Dimapur	98 096	2 480 349	0.065	0.021	–	–	3.145
Kohima	77 030	2 557 379	0.067	0.021	–	–	4.615

Source: the authors' calculations are based on statistical data: India Towns and Urban Agglomerations Classified by Population Size Class in 2011 with Variation Since 1901. URL: https://censusindia.gov.in/2011census/PCA/A4.html *(Accessed 17.04.2022).*

By 2011. significant changes occurred only at the 4th hierarchy level. and overall stability deviated from the ideal, albeit in a higher direction (with the optimal value being 3.000). The isostatic equilibrium values for 1991, 2001, and 2011 were 3.877, 3.679, and 3.851, respectively. These observations indicate the potential for the system to become more complex in the near future. Thus, the case of Northeast India supports the hypothesis of wavelike fluctuations in the structure of central place systems, as proposed by Valesyan (1991). However, it is worth noting that even after more than 60 years since its collapse, the central place system of Northeast India has not fully recovered. The spatial structure that existed prior to its breakup has yet to be attained.

Conclusion

the study reveals several important findings regarding the dynamics of central place systems. When two systems unite, the disruptive effect on the system's evolution diminishes quickly, and the newly formed single system resumes continuous development. This is particularly true for systems that exhibited weak stability during their autonomous evolution. It is worth noting that achieving equilibrium, even if the isostatic equilibrium is close to the ideal, does not guarantee its longevity. The real population size of hierarchy levels does not consistently follow the theoretical forecasts based on central place theory, with odd-numbered levels growing larger and even-numbered levels becoming smaller.

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On the other hand, when a system undergoes a breakup, the intermittent effect on its steady evolution is more pronounced compared to its unification with another system. The process of adapting elements of the previous system to the new situation, including recovering the hierarchy and spatial structure, takes more time in the case of a breakup. The study supports the notion, previously only theoretical, that at the 1st hierarchy level, central places are often replaced during the early stages of system development.

Furthermore, the research highlights that central place systems benefit not only from achieving a state of isostatic equilibrium but also from maintaining a sustained optimal structure. While these concepts are closely related, they differ in that the optimal state refers to the equilibrium of individual hierarchy levels rather than the entire system. These findings contribute to a deeper understanding of the dynamics and evolution of central place systems.

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