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Carrying Capacity Assessment in Complex Systems: A Comprehensive Revisit with Enhanced Elements

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Abstract

The rapid growth of tourism necessitates sustainable resource management and effective strategies to ensure sustainable development and minimize detrimental impacts on destinations. By synthesizing existing research, this article contributes to a holistic understanding of Tourism Carrying Capacity (TCC) and its various components, aiding policymakers, planners, and stakeholders in making informed decisions for sustainable development. This research reviews CC assessment methods and formulas, focusing on Physical Carrying Capacity (PCC), Effective Carrying Capacity (ECC), and Real Carrying Capacity (RCC). Moreover, this study delves into the evolving notion of limiting factors, examining how factors such as infrastructure, resource availability, socio-cultural aspects, and environmental resilience interact to determine carrying capacity thresholds in various research realms. By synthesizing existing methodologies and formulas, this research bridges the gap between theoretical frameworks and practical implementation, fostering sustainable tourism practices that preserve natural and cultural assets while fostering economic growth. This work further advances the existing formula for TCC calculation in complex systems by providing a fresh set of correction factors *(Cf)* and Management capacities *(Mc) and* providing all possible

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values for calculating space for the displacement*(V/A) of* tourists in different types of destinations.

Keywords: Tourism Carrying Capacity, PCC, RCC, ECC, Correction Factors, Management capacities

1. Introduction

As ecosystems face mounting pressures from human activities, understanding the intricacies of carrying capacity (CC) has become paramount to ensuring the long-term health and resilience of both species and habitats. Therefore, CC has received much attention and is a highly researched theme, where the current internet search on "carrying capacity" gives 2,30,00,000 results. CC describes the numbers of a particular species that a given area or ecosystem can maintain without suffering long-term harm or exhausting the resources. Internationally, the Tourism Carrying Capacity (TCC) concept arises as a critical structure for maintaining the delicate balance between visitor influx and preserving the cultural, environmental, and infrastructural integrity of the tourism destination. The assessment and management of TCC take centre stage as a strategic approach for destinations seeking to optimize the advantages of tourism while mitigating harmful consequences for local communities and ecosystems. TCC stands for the upper limit of visitors a tourist destination can accept without jeopardizing the level of tourist experience or the destination's cultural, social, or environmental integrity. While destinations fight to control over tourism, CC studies are becoming more important in destination management, especially in third-world countries where improved visitor management methods are being introduced.

In the long COVID situation, tourists worldwide increasingly choose pristine and unspoilt locations over overcrowded locations that offer social distancing measures and are safe, secure, clean, and hygienic. In this context, sustainable management philosophies receive greater consideration, and CC has significance since it guarantees that the destination will remain fresh and pristine. Additionally, it will support the development of quality management methods like enhancing aesthetics and the destination's reputation. A positive visitor experience is ensured by TCC assessment, which contributes to the preservation of the destination considering several variables like local community, infrastructure, attractions, transportation, tourism intensity, current tourism trends, and the needs, and expectations of visitors. TCC assessments will identify any unfavourable effects, such as congestion, crowding, resource stress, environmental degradation, and cultural decline in the destination, emphasising the importance of cautious planning.

Several innovative techniques, procedures, and technological applications have evolved in TCC evaluation, addressing previously identified gaps and limitations. Notable among these are geospatial and remote sensing technologies (Zorn et al, 2020; Nghi et al, 2021), integrated and participatory approaches (Saarinen, 2019; Ninov & Vaz, 2021), agent-based modelling and simulation (Baggio & Del., 2020; Nicholls et al., 2021), social media, and big data analytics (Pantano et al., 2019; Giordano et al., 2021). The use of geographic information systems (GIS), remote sensing, and spatial analysis tools has transformed TCC evaluations. These tools allow researchers to monitor and analyse the spatial distribution of tourists, identify places of high concentration, and assess the impact on natural and cultural resources, offering a more comprehensive picture of CCA.

Even though the concept of TCC evaluation has been investigated in several previous studies, there still exists a sizable gap in the literature regarding its use in complex tourism systems. Currently, the corpus of research that predominantly emphasizes "Cifuentes" et al., (1992) formulae, appears to lack comprehensiveness when applied to diverse economic, social, and geopolitical environments. An extensive set of Correction factors (C*f*) and components related to Management capacities (M*c*) are absent while assessing ECC and PCC in diverse and complex ecosystems. These gaps necessitate further research to develop an enhanced list of C*f* and M*c* that can provide a more comprehensive assessment of TCC using the Cifuentes' formula and support sustainable tourism management in an increasingly dynamic and interconnected world. Therefore, the objective of this paper is to strengthen the concept of TCC assessment by examining previous studies, reviewing the methodology and formulae being used, and proposing additional components to enhance the existing formula to make it more usable in complex systems.

This study examined the approaches and formulae used in previous research on the TCC, identified the perspectives and elements used, and provided a revised list of components to improve its applicability in complex systems. These factors are essential when taking into consideration the dynamic nature of tourism, changing environmental circumstances, evolving traveller preferences, and the intricate interactions among industry participants and the local community.

2. Research Methodology

To identify previous research and TCC-related methodology, the study conducted an extensive literature review. Academic databases, including PubMed, Scopus, Google Scholar, and Web of Science, are used for this purpose to access a wide range of literature about TCC. Prompts with a combination of keywords and phrases like "tourism carrying capacity," "tourism impact assessment," "tourism sustainability," and "carrying capacity formula" were given to search queries. To refine the searches, boolean operators (AND, OR) were utilized. To assure relevance, the study considered research papers in the English language that were published within the previous four decades (from 1981 to 2022). A few articles written in other languages are also included since they offer unique perspectives. Studies that do not analyse CC in the context of tourism are excluded. Data was methodically retrieved from chosen studies, including TCC formulae, components, parameters, and methods, once the pertinent literature was located. To identify common elements and criteria used for TCC assessment and current challenges and constraints a thematic analysis of the data was conducted.

Based on the analysis of existing formulae and methodologies, the study proposed an enhanced list of components related to C*f* and M*c* of TCC formulae to make them more adaptable to complex systems, considering factors overarching the Triple Bottom Line of Sustainability (TBL). It emphasizes transparency and rigour in the research process. This research involves the analysis of existing literature and the development of a formula; it does not involve human subjects or confidential data, and therefore, ethical approval is not required.

3. Literature Review

3.1. The Concept of TCC

Calculating TCC regularly helps the authorities formulate a better visitor management plan by staggering arrival and departure times, promoting off-peak tourism, and creating zoning systems that designate areas for different types of tourism activities. It varies depending on the season, the type of tourist activities being undertaken, and the management practices put in place. Therefore, it is important to regularly monitor the CC of a destination and adjust and refresh it as needed.

Studies on CC have their roots in ecology and environmental sciences, and the concept has been applied to various fields, including biology, environmental management, and, more recently, tourism and recreation. 'Carrying capacity' was initially proposed in 1838 by Belgian statistician Verhulst (Aminian and Khodayar, 1986). Many studies (Melo et al., 2020; Newsome et al., 2012; Limberger & Pires, 2014; Mathieson & Wall, 1982) stated that the idea of CC was first used to address agricultural issues in the early 1920s and wildlife management in 1945. Nevertheless, Jangra & Kaushik (2021) asserted that the initial studies of the CC of animal habitats were started in 1960 by the US National Parks. Kurhade (2013) claimed that the concept of CC was employed by Lucas and Wagar in 1964 to evaluate ecological disruption within the scope of their leisure-related research. Hadwen and Palmer (1922) used Ecological Carrying Capacity (ECC) for the first time to investigate the deer population in Alaska as early as 1920. Over time, this concept has been adapted and expanded to include tourism and recreation.

The World Tourism Organization (UNWTO) coined the term "tourism capacity" between 1978 and 1979 (Long et al., 2022). In the context of tourism planning, Mathieson & Wall (1982) defined CC as "the maximum number of people who can use a recreational environment without an unacceptable decline in the quality of the recreational experience (p. 184)". Lindberg et al. (1996) described TCC as the greatest usage of a site without damaging its resources, lowering visitor enjoyment, or creating a negative impact. Similarly, UNWTO and UNEP (1992) explained CC as "the level of visitor use an area can accommodate with a high level of satisfaction for visitors and few impacts on resources (p. 18)". McIntyre (1993) considered TCC a visit by many people without causing a detrimental effect on the physical, socio-cultural, and economic environment or visitor satisfaction with the destination. CC evaluation of European travel sites under the Priority Actions Program (PAP, European Commission, 2002) has used the UNWTO criteria. Similarly, Sharma (2016) observed that a destination's CC may be evaluated by its capacity to absorb tourism growth before it becomes disadvantageous to the local community and by the threshold at which visitor flows would start to fall. The report of the Tourism Council of Bhutan (2021) also shared the same notion.

TCC definitions have recently adjusted their emphasis to include more information on the ecosystem and habitat of the destination. It gauges the highest number of people a tourist destination can accommodate without having a negative influence on the environment. In their study, Castellani and Sala (2012) defined CC "as the number of individuals of a given species that a given habitat can support without suffering irreparable harm (p. 4)". Jovicic and Dragin (2008) cited the CC definition by the Federation of National Parks of Europe (FNNPE, 1993) from an ecological perspective, which stated that CC was "an ability of the ecosystem to self-sustain and trigger the development of human activities in an unlimited scope, with no negative feedback effects (p. 6)."

3.2. Typology of CC

Various types of CC typologies have been developed over the years. Many studies have used the traditional classification of CC assessment using physical, ecological, psychological, and economic approaches (Canestrelli & Costa, 1991; Getz, 1982). The categorization of CC by Hunter & Green (1995) into social, economic, ecological, and environmental domains is often used in various research projects throughout the globe. UNWTO (1998) identified three crucial categories of CC: ecological, socio-cultural, and psychological. Four distinct forms of analysis were presented by Lee et al. (2005): facility, environmental, legal, and integrated CC evaluations. However, Kourandeh and Fataei (2013) recognized three main CC components as ecological, social, and economic. Stekerova et al. (2022) focused their studies on the psychological, perceptual, socio-psychological, and social dimensions of CC that were used as a standard in several studies in Chinese destinations. Lee et al. (2005) assessed the CC of Chi Ri National Park in South Korea, giving equal attention to tourists and the natural ecology.

Liabastre et al. (2022) utilized the concept of ECC as a tool to mitigate disturbances created by visitors in vulnerable marine ecosystems. The Tourist Environmental Carrying Capacity (TECC), formerly known as tourism volume, is another relevant field of contemporary research. Long et al. (2022) stated that TECC is "the threshold of the intensity of tourism activities that the natural, economic, and social systems of a tourism destination can withstand, and it is essentially a comprehensive reflection of the structural characteristics of the tourism environment system ((p. 2). By using ecological and environmental views, Chamberlain (1997), Gilbert & Clark (1997), and Middleton & Hawkins (1998) made several attempts to describe the CC idea. The term "recreation capacity" was first used by Wagar (1964), followed by Stankey & Manning (1986). This term relates to the volume of recreation that can be sustained in a certain location over the long term without having a significant detrimental impact on the environment. An overview of the typology of carrying capacities has been depicted in Table 1.

Study	**Typology of CC used**
Pearce, 1981	Physical, psychological, ecologic, environmental, and perceptive
Getz, 1982; Canestrelli & Costa, 1991	Physical, ecological, psychological, and economical
UNWTO, 1997	Ecological, socio-cultural, and psychological
Lee et al., 2005	Facility, environmental, law and integrated
Pires, 2005	Physical, psychological, environmental, ecological, social, perceptive, economic, materials, and landscaped
Nghi et al, 2007; Castellani et al., 2007	Physical, social, economic, and ecological

Kourandeh and Fataei, 2013	Social, economic, ecological, and environmental
Stekerova et al., 2022	Psychological, perceptual, socio-psychological, and social
Liabastre et al., 2022	Environmental

Table 1. Typology of carrying capacity.

4. Methods and Frameworks to Assess CC

Exploring a variety of methods and frameworks for capacity assessment is essential to effectively gauge the optimal thresholds and constraints within which a system can function sustainably while accommodating various factors of influence. Schuh et al. (2020) have outlined the peculiar characteristics of CC, where its value varies with changes in environmental conditions and other factors, which again can vary with the type of destination. There is no single denominator, formula, method, or unified way for measuring CC (Trumbic, 2005). There are various methods and frameworks used to estimate CC (Table 2).

Study	Year	Destination	Method / Framework used
Klaric et al.,	1999	Fuka – Matrough, Egypt	Priority Actions Programme (PAP) by Regional Activity Centre (RAC)
Coccossis et al.,	2001	European destinations	Tourism carrying capacity (TCC) planning method
Lee et al.,	2005	Chi Ri National Park	Facility – Environmental – Law carrying capacity
MOEF & NHCL	2010	Teesta Basin, Sikkim, India	Hydrometeorological studies
Castellani et al.,	2007, 2012	Oltrepo Mantovano, Lombardy Region, Italy	Drivers, pressures, state, impacts, responses (DPSIR) approach
Sharma	2016	Kerwa, MP, India	Impact method
Nasir & Ibrahim	2019	Pulau Perhentian Marine Park, Malaysia	Sustainability measures model – biophysical, social, economic, facilities, planning & control, tourist perception factors
Schuh et al.,	2020	Four destinations of Slovenia	Mixed methods

Melo et al.,	2020	Costa Rica	Visitation environmental impacts method
Stekerova et al.,	2022	Bohemia	Psychological carrying capacity method
Liabstre et al.,	2022	Coron & El Nido marine park, Philippines	Environmental carrying capacity (ECC) method
Zekan et al.,	2022	Gorizia	Human carrying capacity method
Long et al.,	2022	General case study	Tourism environmental carrying capacity (TECC)
All other major studies		Traditional method using physical, real, and effective carrying capacity calculation	

Table 2. CC Assessment Methods & Frameworks

According to Santos and Brilha (2023), the methods for assessment of TCC can be broadly grouped as quantitative and qualitative. There are several popular quantitative methods for CC assessment (Cifuentes & Arias et al., 1999; Boullon, 2006; Lozato-Giotard, 1992; Ibama, 2002; Ruschumann et al., 2016). However, qualitative methods for the assessment of CC also gained importance in the 1970s, which include Visitor Experience and Resource Protection (VERP), the Tourism Optimization Management Model (TOMM), and Limits of Acceptable Change (LAC) in protected areas (Stankey et al., 1985; US National Park Service, 1992; Manning, 2001; Miller and Twining-Ward, 2005; Coccossis & Mexa, 2017). Lobo (2015) provided insight into three methods that can be applied to geological and speleological sites using environmental zoning, fragility maps, and critical atmospheric parameters.

The traditional method of calculating physical, real, and effective carrying capacity is the most widely used technique, as it provides exact numbers and is very useful for visitor management plans. For ecotourism destinations and protected areas, the Tourism Environmental Carrying Capacity model is very useful, as it helps destination management plan regulated tourist arrivals without affecting the environment. Complex methods like Driver-Pressure-State-Impact-Response (DPSIR), impact methods, and mixed methods are rarely used as they involve more complex methodological frameworks.

The Priority Actions Program (PAP) technique was used to evaluate CC in the Coastal Area Management Programme (CAMP) in Fuka Marsa Matrough, Egypt (Klaric et al., 1999). This method employed a flexible model for analysing various scenarios of socio-demographic, physical, infrastructural, political-economic, and ecological characteristics that have been found in medium-sized and less-developed tourist locations (Klaric et al., 1999). UNEP - PAP/ RAC suggested that an effective technique for CC evaluation should be able to take local priorities into account, identify development constraints, choose a set of applicable indicators, and define scenarios for destination development (Castellani and Sala, 2012). According to Coccossis et al., (2001), the PAP of the European Commission adopted a TCC planning process that entails establishing acceptable tourism levels through a careful examination of the main factors that influence or restrain the growth of a destination's tourism industry. Based on the DPSIR framework, developed by the European Environmental Agency in 1999, Castellani et al. (2007) and (2012) suggested a technique for TCC evaluation that was used in two tourism destinations in northern Italy. Zekan et al. (2022) used an anthropogenic approach to human CC as a measure of liveability to analyze the development of a tourism destination.

Specific techniques have been employed to evaluate ecological CC. The Teesta River Basin study in India concentrated on land use patterns, socioeconomic profiles, hydrometeorological studies, water resources, and agricultural studies (MOEF & NHCL, 2010). Considering the walking path size, the amount of space necessary per tourist, and the amount of time needed to walk it, the expected CC in natural reserves in Granada and Nicaragua was calculated (Chang et al., 2006). Meanwhile, Agnew and Demas (2013) demonstrated how CC studies benefitted tourist management, mentioning the case studies of UNESCO World Heritage Sites in China. Sharma (2016) employed the Delphi technique to rate each impact indicator according to its Relative Significance Index (RII) in the study on assessing CC using impact indicators.

5. Calculation of TCC

The calculation of TCC is the most important stage of its assessment, and there are different approaches to its measurement. The most popular approach for determining TCC was developed by Cifuentes et al. (1992), and it has been successfully employed in different locations in Latin America. The Galapagos National Park management plan in Ecuador used the Cifuentes technique for the first time (Santos & Brilha, 2023). The International Union for Conservation of Nature and Natural Resources (IUCN) acknowledged and recommended the implementation of this approach and quantitative calculation formula in all categories of tourism attractions (Ceballos-Lascuráin, 1996). The three areas of PCC, RCC, and ECC for destinations are considered by this framework (Kourandeh and Fataei, 2013; Suwarno & Widjaya, 2018; Santos & Brilha, 2023).

According to previous studies (Chang et al., 2006; Kourandeh & Fataei, 2013; Jangra & Kaushik, 2017; Suwarno & Midjaya, 2018; Salan et al., 2018), the PCC is the greatest visitor number that a specific destination or attraction can physically accommodate at a given time without degrading the visitor satisfaction level or the integrity of the local environment. Meanwhile, RCC is the largest number of people a specific location or attraction can hold at any given time while considering several factors like the availability of resources, the condition of the infrastructure, and the level of visitor activity (Chang et al., 2006; Kourandeh & Fataei, 2013; Jangra & Kaushik, 2021; Suwarno & Midjaya, 2018; Salan et al., 2018). ECC refers to the optimum number of visitor numbers that a tourist destination can retain sustainably while maintaining the desired level of visitor satisfaction and environmental, social, and cultural integrity without causing harm to the environment, exceeding the capacity of the infrastructure, or negatively impacting the local community (Chang et al., 2006; Kourandeh & Fataei, 2013; Jangra & Kaushik, 2021; Suwarno & Midjaya, 2018). A representation of these three aspects in various studies is represented in Table 3.

Name of study	Destination	Type of Carrying Capacity		
		PCC	RCC	ECC
Chang et al., 2006	Natural reserves of Granada & Nicaragua	•	•	•

Name of study	Destination	Type of Carrying Capacity		
		PCC	RCC	ECC
Kourandeh & Fataei, 2013	Fandoqloo Forest, Aredbil Province, Iran	•	•	•
Hassan et al., 2014	Saint Martin's Island, Bangladesh	•	•	•
Jangra & Kaushik, 2017	Kurukshetra, Haryana, India	•	----	----
Suwarno & Widjaya, 2018	Kiskendo Forest, Indonesia	•	•	•
Salan et al., 2018	Padma Riverbank, Bangladesh	•	•	----
District Tourism Promotion Council, 2020	Kuruva Dweep, Wayanad, Kerala, India	•	•	•
Lakspriyanti et al., 2020	Cibeureum Waterfall, GGPNP, West Java, Indonesia	•	•	•
Melo et al., 2020	Caida do Morro Trail, Ilha Grande, Piaui State, Brazil	•	•	•
Jangra & Kaushik, 2021	Kinnaur, Himachal Pradesh, India	•	•	•

Table 3. PCC, RCC, and ECC in previous studies

According to Chang et al. (2006), each level of CC represents the right estimation of the one before it after considering and studying the specific factors for each set. This research further establishes a relationship between the three levels of carrying capacities, represented as PCC > RCC ≥ ECC.

5.1 Measuring PCC

Quantifying CC is a rigorous process and will vary with the types of destinations and environmental and social conditions (Tourism Council of Bhutan, 2021). The most common method to calculate PCC is by using the formula developed by Cifuentes (1992) and modified by Boullon (2006). This is a three-step process that measures CC through the rotation coefficient and the total number of daily visitors at the site.

The equation used is: PCC = A × V/a × R f

where PCC = Physical carrying capacity; A = Area available for tourism (m2); V/a = Appropriate space for the displacement of tourists/tourist density (tourists/m2); Rf = Rotation factor (number of visits per day)

The area (A) is the one that may be used by tourists or the public. It is usually calculated with respect to the physical boundary of a destination with gated entry. In natural regions, boundaries such as mountain ranges and rivers might define the area; however, in conservation or protected areas, the area or zone that is open to tourism activities can be considered. The area needed by each visitor to carry out their activities comfortably is referred to as the acceptable space for tourist displacement (V/a), which is assessed in square meters and varies with destinations (see details in Section 5.1.1). The Rotation Factor (Rf) determines how many visits are permitted within a certain period. It is typically determined by dividing the total opening hours of the destination by the average time a visitor spends in the place.

R f = Open Period/Average Time of Visit

5.1.1 Displacement of Tourists (V/A)

The number of visiting hours each day (opening hours) at the tourist location is the duration of usage. For destinations with entry fees, it is calculated as the total number of hours the site is open for visitors. For destinations without entry fees, usually the time from sunrise to sunset is taken as the opening hours. The average amount of time a visitor spends touring and seeing the area's attractions is called the visit duration.

The space needed per tourist (V/a) varies with the typology of destinations. Jangra and Kaushik (2017) considered 2.5 m2 for males and 2 m2 for females for bathing ghats, 2 m2 for walking, 5 m2 for staying, and 10 m2 for relaxation. Subsequently, Jangra and Kaushik (2021) considered 2 m2 for temples and pilgrimage sites, 5 m2 for walks and hikes, and 10 m2 for lakeside recreation. This study also assessed CC in depth, considering parking, restrooms, drinking water, and footpaths. The CC assessment of the Tourism Council of

Bhutan in 2021 earmarked 2 m2 of space for monasteries and indoor areas and 2.5 m2 for open yards. Liabstre et al. (2022), in their study on marine reef ecosystems, assigned 150 m2 for snorkeling and 1000 m2 for two divers as the minimum needed space per tourist.

The space per square meter per tourist or visitor in the previous studies can be adapted to different destinations. At the micro level, the main typology of destinations in any country or region includes beaches or coasts, leisure parks and gardens, backwater and lakefront leisure spots, heritage sites, pilgrim centers, and ecotourism sites. The minimum required space for the tourist can be fixed based on the tourist volume in each category of destination. The area per m2 needed for a visitor in different types of destinations is given in Table 4.

Type of Tourism Destination	**Area per sq. m required for a visitor**
Beach	2 m2
Parks or gardens	2 m2
Heritage site	3 m2
Pilgrim centre	3 m2
Ecotourism site, Trek, hike	5 m2
Lake, backwater front leisure sites	10 m2

Table 4. Area per m2 per visitor for calculating (V/A)

Suwarno & Widjaya (2018) calculated the average visit duration in the destination through a structured questionnaire of three different time durations for tourists and by taking the average of the responses received. The average amount of time that visitors spend at a location may be found out through a variety of sources, including destination management, direct interviews with visitors, and on-site direct observation.

5.2 Measuring RCC

The equation used is: $RCC = PCC - Cf1 - Cf2 - Cf3 \ldots Cfn$

or $RCC = PCC \times (100 - Cf1)/100 \times (100 - Cf2)/100 \ldots (100 - Cfn)/100$

where Cf is a correction factor that may be calculated using environmental, ecological, social, and managerial criteria that are specifically tied to the conditions and features of each site. These climates and other conditions, which might draw travellers or restrict tourist activities, are particularly important to the tourism industry. Some of the major correction factors used in different studies have been listed in Table 5. The correction factor is calculated using the following formula:

$Cf = M1 / Mt \times 100$

Where Cf = Correction factors; M1 = Limiting magnitude of the variable; Mt = Total magnitude of the variable

5.2.1 Correction Factors (Cf)

Study	**Destination**	**Correction factors applied for RCC calculation**
Chang et al, 2006	Natural reserves of Granada & Nicaragua	Social factor, erodibility, accessibility, inundated sections (flood), temporal closing
Kourandeh & Fataei, 2013	Fandoqloo Forest, Aredbil Province, Iran (calculated using vulnerability index)	Elevation, vegetative cover, soil erodibility, rainfall, snow, frost, strong sunshine hours, agricultural lands
Hassan et al., 2014	Saint Martin's Island, Bangladesh	Temporary closure, tourists' safety factor, fishing area, bad weather / ship cancellation, accommodation limiting factor, transportation limiting factor
Suwarno & Widjaya, 2018	Kiskendo Forest, Indonesia (calculated using indices)	Rainfall, slope, soil erosivity, vegetation
Salan et al, 2018	Padma Riverbank, Bangladesh	Excessive sunshine, humidity, rainfall, flood, overcrowding, infrastructure quality
District Tourism Promotion Council, 2020;	Kuruva Dweep, Wayanad, Kerala, India	Topsoil erosion, monsoon, elephant movement, crowd control, environmental calculations

Study	Destination	Correction factors applied for RCC calculation
Lakspriyanti et al, 2020	Cibeureum Waterfall of Gunung Gede Pangrango National Park (GGPNP) of West Java	Rainfall, slope, soil erodibility, index of landscape potential, disturbance to wildlife
Jangra & Kaushik, 2021;	Kinnaur, Himachal Pradesh, India	Rainfall, snowfall, frost, temperature, landslides, accommodation, transportation

Table 5. List of Correction Factors (C*fs)* applied in TCC Assessment

Correction factors are the restricting criteria that limit or remove visitors from tourism venues. For conducting a comprehensive CC assessment, all the correction factors or variables need to be considered for that country, region, or destination. For large countries with huge differences in landscapes, topography, climate, and biodiversity, for instance, Russia, China, India, and the US, it is a humongous task to identify all the Cf. Most of the year is comfortable for travel in tropical destinations except in high-altitude mountain ranges, as there is no significant variance in climate as in temperate countries, and therefore, most of the destinations operate throughout the year. Different locations have various correction variables or factors that rely on the altitude, geophysical conditions, climate, and numerous management-related variables in relation to the destination's geographic features. All the Cfs can be roughly categorized as being either natural or human-related. Table. 6 provides a comprehensive list of Cfs that will be applicable for destinations in common, including complex systems.

Correction Factor (C*f*)	Explanatory Note
Rainfall	Normal life is disrupted by the monsoon, which is characterized by landslides and flash floods in high ranges and inundation in low-lying midlands and on beaches in tropical regions. As a precaution, the destination management authorities issue advisories and declare destinations closed.

Correction Factor (C*f*)	Explanatory Note
Landslides	Many locations are susceptible to landslides due to the weak geotechnical profile in their mountainous high land zones. This has a negative impact on destinations in the high-range area by cutting off last-mile connectivity.
Flash floods	Flash floods are the aftereffects of intense thunderstorms, cloudbursts, or meltwater on snow-covered slopes that bring torrential rainfall in high ranges.
Flood	Flood is a recurring natural disaster in many destinations located in flat plains and river basins. Inundation is common in low-lying destinations after heavy rains.
Cyclones	Many tropical locations receive cyclone warnings whenever low-pressure belts appear in the waters because they are impacted by the marine environment. Coastal areas are most vulnerable.
Lightning and thunder	A high-risk hazard that devastates human lives. Destinations often stay closed, particularly, during the alert hours as a precautionary measure when there is a higher probability of thunderstorms.
Extreme sunshine (Temperature)	During summer, extreme rises in temperature, high UV index, high humidity, and heat waves become more common in many tropical regions which hinder visits.
Humidity	High levels of humidity may limit or slow down the movement of daytime tourists.
Snowfall (Frost)	Snowfall is a significant limiting factor in high altitudes and in most temperate nations is snowfall (frost). Although winter sports are popular tourist attractions, heavy snowfall and persistent frost can cause destinations to close for several months. Facilities will not operate, and places will be cut off owing to connectivity issues.

Correction Factor (C*f*)	**Explanatory Note**
Slopes (Elevation)	This geographic adjustment factor must be used when travelling to places with a significant slope or inclination and is common in treks and hikes. Visitors to these locations must exert more effort to navigate the elevation of the terrain thereby limiting many visits.
Soil erosion (Erodibility)	Soil erosion and soil piping are visible in mid-altitude land regions and have some effect on tourists' perceptions, but they might have a significant effect on the local ecology.
Landscape potential index	Lack of scenic and aesthetic landscaping within the attraction complexes will be detrimental to bringing tourists' attention. This factor may prevent many from visiting such sites.
Vegetation	Regional biodiversity must be considered while evaluating CC. If there are rare or endangered species in a particular location, control measures must be put in place to stop tourists from destroying the biodiversity. This will thus become a key limiting factor in locations where visitor visitation is restricted to conserve the local flora.
Animal menace	Wild animals can occasionally cause problems in ecotourism locations that are near or inside the woods. Visitors with security and safety concerns will limit their visits to such areas.
Holidays	Even though most places are open all year round, there could be specified holidays. National holidays and Grand festivals are examples of days when the locations will be closed. In addition, many places may have weekly holidays, particularly monuments and museums.
Temporary closing	During the year, destinations could also experience brief closures due to maintenance works, facility upgrades, and management choices.

Correction Factor (C*f*)	**Explanatory Note**
Seasonality	The seasonality of the destinations may be caused mainly due to climatic factors. Many hill towns witness severe fluctuations in visitor numbers and have distinct peak and low seasons. Additionally, there are pilgrim centres that are open for only a few months annually.
Lockdown (Pandemic)	Due to travel limitations and lockdowns put in place by different nations as part of the containment of the COVID-19 pandemic, many global destinations were closed for several months in 2020, 2021 and 2022. This paved the way for a new system of tourist attractions being closed off when a contagious sickness spread.
Strikes and riots	Strikes and hartals are common in several countries including India. These include rallies and activities that dramatically disrupt daily life in a particular area and state-wide and local work stoppages. These human-induced interruptions have a significant influence on industries, particularly tourism, as their ripple effects permeate daily activities and economic organizations.
Tourist safety factor	Visitor security and safety and a sound risk management strategy are mandatory for the destinations but are absent in several tourist sites.
Overtourism	Tourist congestion has a detrimental influence on the quality of the visitor experience as well as the aesthetics of the location, which is a significant constraint directly correlated to CC. Destinations may apply crowd control and reduce overtourism through effective visitor management techniques.
Lack of Accommodation	The quantity and quality of overnight accommodation units available within the destination impact tourist visits.

Correction Factor (C*f*)	Explanatory Note
Lack of Transportation	This is another limiting factor with last-mile connectivity to the destination and the availability of public transportation to be considered.
Livelihoods	Some areas of the destinations may be earmarked for the livelihoods of local communities, for instance, fishing areas in coastal destinations and farmlands in rural tourism sites.

Table 6. Proposed List of Cf for TCC Assessment

5.3. Measuring ECC

The equation used is: $ECC = RCC \times Mc1 \times Mc2 \ldots \times Mcn$

Where ECC = Effective Carrying Capacity; RCC = Real Carrying Capacity; Mc = Management capacities

Management capacity (Mc) is determined by the facilities, infrastructure, amenities, personnel, parking, and tools that are readily available, and their number can vary with destinations. The study of Jangra & Kaushik (2021) on mountain destinations in the Himalayas used all ten aspects of Mc that were suggested by Cifuentes, with the score given for each indicator being either 1 (low), 2 (medium), or 3 (high). However, the ECC estimation of natural reserves in Granada and Nicaragua (Chang et al., 2006) considered only three aspects of Mc, including equipment, the presence of the right personnel, and facilities in the reserve. Generally, twelve Mc indicators can be used in all destinations, which include parking, accessibility, public restrooms or washrooms, waste bins and disposal, lighting, drinking water, food joints, personnel, safety and security, animal menace (stray dogs and cattle), signage, and information and communication.

McCool et al. (2001); Mexa and Coccossis (2004); and Saarinen (2006) have provided a comprehensive overview of TCC concepts and their practical applications in sustainable tourism development, tourism management, and destination planning. Kozak and Martin (2012) explored its importance in the long-term management of mature tourism destinations and the development of profit-driven initiatives. Juardo et al. (2012) and Saleem et al. (2022) present an integrated method for TCC evaluation and address its implications for sustainable tourism policy and management techniques. Jurado et al. (2013) further discussed the implications of TCC in coastal destinations.

Carrying capacity studies is recently gaining popularity in the tourism scenario of India. For example, the detailed project report preparation (DPR) for the ambitious Swadesh Darshan 2.0 project of the Union Tourism Ministry has made benchmarking and gap analysis for carrying capacity mandatory (Ministry of Tourism, 2022). In Kerala, the Travancore Devaswom Board has made online booking necessary for darshan (viewing the holy image of a deity) at the popular pilgrim site of Sabarimala, limiting daily bookings to 80000 from 90000 previously. This initiative is expected to relieve pressure on the temple and its premises, which are in an ecologically sensitive forest area, as well as make pilgrim visits more comfortable (Travancore Devaswom Board press release, 2024). In another case, the Madras High Court recently ordered in April 2024 that CCA be conducted on the ghat roads leading to the Nilgiris and Kodaikanal, as the locations are experiencing heavy traffic and overtourism, particularly during peak seasons. Furthermore, the court further ordered that all cars visiting the sites during the peak tourism season in May and June use an e-pass (W.P.No.15120 of 2019; W.M.P.Nos.15112 of 2019 & 8422 of 2024; Madras High Court, 22.04.2024 & 29.04.2024). These references shed light on the practical uses of TCC evaluations in tourism management, policy formulation, destination planning, and the promotion of sustainable tourism practices.

This review's limitations include potential publication bias, the omission of works in other languages, and research that was released before 1981. While the aim of this study is to address some significant gaps in the existing literature on TCC assessment, it paves the way for future research and development that will concentrate on further enhancing this framework through the addition of new components and customization of the model for various kinds of tourist destinations. This research provides important insights for estimating CC and TCC by redefining priorities. The CC formula developed by

Cifuentes (1992) and modified by Boullon (2006) is a useful tool for sustainable tourism planning, and it becomes even more reliable when additional correction factors (Cf) in RCC estimation and Management capacities (Mc) in ECC estimation are included. Therefore, to provide a more comprehensive framework for ecological sustainability and the estimation of TCC, Cifuentes' formula has been expanded in this study to include new variables in Cf (Table 6) and Mc. Furthermore, this study will help to obtain a more accurate CCA of a destination by adding possible measurements for space for displacement (V/A) while assessing PCC. Future studies might evaluate TCC using the elements suggested by this study at a variety of different tourist sites.

Conclusion

TCC ensures that tourism is sustainable and that its benefits are shared equitably. TCC has implications in several areas of tourism and assists stakeholders to ensure the long-term viability and competitiveness of tourism destinations. By understanding the CC of a destination, Destination Management Organizations (DMOs) can take steps to guarantee that the economic benefits of tourism are maintained and are shared more equitably among all stakeholders, such as local businesses, employees, and the resident community. Further, TCC helps DMOs take steps to limit visitor numbers, prevent overtourism, and manage visitor flows within the tourism site. TCC research will become more important in the future as tourism grows, the effects of tourism become more complicated, and there is a growing desire for sustainable tourism.

This study examined the crucial idea of TCC and provided a thorough approach for assessing Cf and V/A within tourist locations. The proposed method provides an authoritative basis for determining the thresholds beyond which negative impacts on the destination's integrity and visitor pleasure become apparent through a systematic investigation of numerous ecological, social, and infrastructural characteristics. This method helps policymakers, planners, and stakeholders make decisions that promote responsible tourism planning, development, and management by considering variables including resource availability, infrastructural capacity, and socio-cultural consequences.

Conflict of Interests

The authors declare no competing interests.

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