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Understanding the Concept of Carrying Capacity and its Relevance to Urban and Regional Planning

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Abstract

The increasing urbanization and the rapidly accumulating population have caused tremendous changes on the earth's landscape which do not only trigger off improvement in civilization and modernization, but have also progressed global challenges such as flooding, desertification, global warming, loss of bio-diversity, housing crises and hunger among others: which have not only remained a source of concern but also a herculean task for planners and other professionals in the built environment, to contend with in the 21st century. These challenges, however, denote that an overshoot of the earth's carrying capacity has been reached [1]. And if this issue is left unattended to there is the likelihood that, far greater calamities may be engendered to make the world both inhabitable and unsustainable in the years to come. If the focus of planning is to provide a desired array of 'quality of life' to people now and without jeopardizing that of future generations, through physical and social designs of the human environment, it is therefore imperative to examine not only what is engineeringly, economically, socially, politically and legally acceptable, but also the degree to which physical and functional plans are tied to ecological systems for resource supplies and for residuals assimilation. The paper attempts to document the origin of carrying capacity as a concept, reviewing its dimensions as it relates to the understanding of urban and regional planning as a field of human endeavour. It argues that, recognizing and establishing the limits or capacities of urban activity system along the lines of the carrying capacities provides decision makers with a workable approach to assessing the natural and human viability of urban and regional planning proposals. The paper finally posits that, there is the need for all the stakeholders, urban analysts, professionals in the built environment who in their operations, are to inbuilt the finiteness of the earth's capital assets into the existing and potential goals and aspirations of man in the 21st century.

Introduction

The advent of globalization and the quest for development have triggered off impressive economic progress, creating materials and luxury of life. At the same time, this progress and its associated benefits have imposed a tremendous cost to the global environment. In spite of the serious challenges and threats introduced into our common global environment in return, it is certain; according to IIT (2012) that development around the world is taking place at a faster rate [2]. As Onibokun pointed out cities will continue to grow while challenges will continue to become more complex as development continues to take place in the different spheres of the world [3]. Therefore, the actions we take now will determine whether or not the current course of development will be sustainable for the future, or will merely produce deleterious repercussions that are capable of destroying us.

Consequently, recent data suggests that many of the global environmental problems we are experiencing today such as overpopulation, rapid urbanization, green house effect and global warming, biodiversity loss, desertification, depletion of ozone layer, acid rain, oil spills, dumping of hazardous waste and a host of others are simply, an expression of the earth's 'overshoot' or feedback arising from the overloading of the earth's support [1]. The realization of these challenges has culminated in growing concerns among world leaders, policy makers and professionals in the built environment, on the trend or type of best practices to adopt to make the earth a sustainable place to live in. Achieving this requires a critical understanding of the sustainable limit or cut-off point the earth can safely support without any jeopardy for its current and future inhabitants.

In their contributions to the sustainable development debate, Ewing et al. assert that we cannot make meaningful decisions about where we need to go before we know where we stand [5]. This suggests that, knowing the limit to which development is feasible within the context of the carrying capacity of our natural ecosystems becomes imperative so as to be able to withstand the changes arising from human actions. Ewing et al. argument appears to be in tandem with those of the World Development Report (2003) which stipulates that sustainable development in our planet earth and its entire fabric requires an understanding of the limit of growth [5]. In view of this, therefore, the paper focuses on carrying capacity as an issue that needs to be critically examined if the present rising wave of humanity is going to be supported indefinitely by the earth's dwindling resources. In doing this, the paper is sectioned into five phases. Following the introductory section is the meaning and definition of the concept of carrying capacity and its evolution/historical and conceptual background. Next to this is the consideration of the various dimensions of concept, while the last section addresses the relevance and applicability of the concept to the practice of Urban and Regional Planning in Nigeria.

Meaning and Definitions of Carrying Capacity

The term "carrying capacity" can simply be defined as the

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maximum population that can be supported or sustained by an ecosystem over time [6,7]. Carrying capacity can equally mean "the maximum pressure or load that a system can conveniently withstand before breaking down". A system breaks down when it can no longer cope with the pressure from the loads it is carrying. In like manner, when the carrying capacity of the earth as a system can no longer sustain the pressure of population explosion, the unacceptable impacts occur in the form of deteriorating or negative effects. In other words, carrying capacity of an area refers to an extreme limit. This limit defines the population carrying capacity of the area. If this limit is crossed then the nature will react by imposing pressure to resist the abrupt growth and development of the people resulting into equilibrium. These pressures can be in form of floods, droughts, famines, landslides, etc.

Carrying capacity has been conceptualized differently among various professions. For instance, in the construction industry, the term is used to refer to the ability of the foundations, materials or structures to accommodate a given load (load-bearing capacity), in terms of either weight or volume and number of cars a freeway or a bridge can carry smoothly [8]. In international shipping activities, it may be defined by the quantity of cargo an ocean-going freighter or steam boat can carry [9,10]; and from the perspective of tourism management, carrying capacity denotes the number of people who can use a given area without an acceptable alteration in the physical environment. In urban and regional planning, carrying capacity can be seen as a tool for achieving sustainable development. This is because it determines the level of human activities, population growth, patterns and extends of land use, physical development that can be sustained by the urban environment without causing serious degradation and irreversible change.

Dimensions and factors affecting the carrying capacity of an area

Carrying capacity of an area is not static; it exhibits a kind of lead-lag relationship between man and the environment. For example, it is possible for a region to take steps to exceed its carrying capacity temporarily [11]; and a renewable resource base cannot indefinitely sustain a population beyond its carrying capacity. The carrying capacity of an area may vary for different species and change over time due to a variety of factors such as:

1) Population: this relates to the number of plants or animal species occupying a place. If the number exceeds the space be affected.

2) The natural resources; food availability and water supplies are vital to the survival of any population. Resources from the environment are needed for sustenance of industries to enhance quality of life. If the resources are exceeded the carrying capacity may be affected.

3) The waste they generate and subsequently dispose of by means of natural sewage systems (soil, sea, atmosphere); if waste generation far exceeds beyond the limit the environment can cope with or assimilate, the carrying capacity may be altered.

4) The technologies (tools and systems) they apply to exploit the habitat;

5) The species in-built resilience for systematic or sporadic perturbations or threats to the environment.

However, if the carrying capacity of a population's species is exceeded, the following repercussions may occur:

1. The species or the organisms may become locally extinct;
2. The environment may be permanently altered or destroyed;
3. In case of too many animals, overgrazing may occur, loss of vegetation cover, irreversible changes to soil quality and productivity, which in turn leads to a reduced carrying capacity for the livestock of the area concerned.

Humans today extract and use around 50% more natural resources than only 30 years ago [12]. For example, International Energy (2012) equally observed that the world energy-consumption patterns escalated from 4,672 million tonnes of energy in 1973 to 8,677 million tonnes of energy in 2010. This increasing resource extraction does not just lead to environmental problems, but it is often linked to social problems such as human rights violation and poor working conditions. These negative environmental and social impacts are mostly felt in Africa, Latin America and Asian countries with low environmental and social standards [13]. Given current growth, world extraction of natural resources could increase to 100 billion tonnes by 2030 [12]. It must be noted that people in the rich countries consume up to 10 times more natural resources than those in the poorest countries. On the average, an inhabitant of North America consumes around 90 kilogram (kg) of resources each day. In Europe, the consumption is around 45 kg per day, while in Africa, people consumes only around 10 kg per day [12].

One important dimension of carrying capacity as introduced into literature is that carrying capacity is conceptualized as a payload or maximum load [9]. This signifies that, the tariff system imposed on cargos carried by ships and steam boats in several centuries back was recorded based 'register tonnage' regardless of how much cargo the ship carried on a particular voyage. In this perspective, the meaning of carrying capacity refers to the amount X that Y was designed to carry.

However, the adoption of carrying capacity as the core concept in range management was in 1886 in New Zealand where the meaning of "carrying" changed from the literal to much more figurative sense [14]. By 1889, carrying capacity had become a measure of rangeland management. As at 1920s and 1930s, the early wildlife managers have started applying the concept of carrying capacity to wildlife in hopes of understanding and increasing the number of deer, quail and other game various places could produce.

However, the usage of carrying capacity crept into population biology and global human population almost at the same time after World War II. According to [9], the concept of carrying capacity to humans expanded its scale to continent and entire globe giving rise to Malthusian sense of carrying capacity that pervades general use of the term today. This development provided a bench mark against which to evaluate population dynamics in the field setting.

In the global human population parlance, Odum formulated a carrying capacity with expressed precision of what could be

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expected if a population lived without relation to the environment. Although, this may not happen empirically, knowledge of such norm nonetheless, allowed every observed deviation from it to appear as an actual shortage of some environmental resource. In other word, as long as the population grows in relation with the environment, environmental limitation is bound to occur which formed the basis of Malthus's arguments about two hundred years ago. That is, lack of environmental constraints will escalate the population of the earth exponentially. But, critics of Malthus postulations argued that development in trade and technology have traditionally pushed back the "limit" to "growth" and will continue to do so indefinitely. This thinking believed that resource depletion is no consequence and sustainability is best assured by staying on our growth-oriented course [15]. By contrast, many ecologists and earth scientists have argued that the explosion of human populations and cultural artifacts made possible by trade and technology can only be temporary, and the mode of industrialized production and consumption has proven costly, with social dislocation, economic inequalities and environmental degradation becoming global problem [16].

Consequently, arising from the arguments of Vogt and Hardin (who equate the world with a pasture that can only support a finite number of animals/humans), Ehrlich concluded that "the key to understanding overpopulation is not population density but the number of people in an area relative to its resources and the capacity of the environment to sustain human activities. The question now arises, when is an area overpopulated? The simple answer is, when the population of the area cannot be maintained without rapidly depleting non renewable resources (or converting renewable resources to non renewable ones) and without degrading the capacity of the environment to support its population. In short, if the long-term carrying capacity of an area is clearly being degraded by its current human occupants, the area is overpopulated". By this standard, the entire planet and virtually every nation is already vastly populated (Ehrlich, 1990). To this end, there is a growing evidence to support the view that we are now beginning to push up against the biophysical limits that our landscape can support. Postel pointed out that our population size, consumption patterns, and technological choices have made us to surpass the planet's carrying capacity [17]. Other indicators which point to the earth's carrying capacity being exceeded are: peak oil [18]; climate change [19]; water shortage [20]; population pressure [16], among others.

However, one of the pioneer attempts to estimate the level of environmental degradation by the dwelling population in the urban area is the mathematical calculations developed by Ehrlick in the 1970s called IPAT equation (IIT, 2012) [2]. In this formulation, "*I*" refers to the impact on the environment, "*P*" refers to the size of the human population, "*A*" refers to the affluence or the level of consumption by that population and "*T*" refers to the processes used to obtain resources and transform them into useful goods and wastes.

Conceptual considerations concerning carrying capacity

The concept of 'carrying capacity' originated from ecology and mainly focused on environmental and man-made physical factors over a long period of time; and the concept generally denotes the maximum number of individual that can be supported in an environment without experiencing decrease in the ability to support future generations within the area. [11,21]. In humans, there is maximum number of individual that can be supported indefinitely in a given environment. It is possible for humans to exceed the carrying capacity of an area. When this happens, an overshoot is said to have been reached. The concept of overshoot is germane in carrying capacity studies. The term 'overshoot' connotes a situation or condition that arises when a population surpasses its carrying capacity. Populations always decline to (or below) the carrying capacity, how long they stay in overshoot depends on how many stored up resources are available to support their inflated numbers. Resources may be food, but they may also be any resource that helps maintain their numbers. For humans, one of the primary resources is energy, whether it is tapped as flows (sunlight, wind, and biomass) or stocks (coal, oil, gas, uranium etc.).

Postel observed that when overshoot occurs, ecosystems are stressed and these stresses are translated to economic problems [17]. These in turn, produce social stresses such as hunger, demoralization, forced migration, higher infant mortality, reduced life expectancy [22] or sharpened group conflict, sometimes leading to repressive government actions [23].

Figure 1 below depicts the position of an overshoot when carrying capacity is exceeded by increasing consumption of earth's finite resources by its inhabitants.

Another important concept that is central to carrying capacity is the ecological footprint which signifies a measure of human demand on the Earth's ecosystems. The ecological footprint gives an idea of the amount of biologically productive land and water area required to produce all the resources needed by the population for its consumption and developmental activities as well as to absorb the waste generated. This means that, every one of us occupies a portion of finite earth's surface with resources to support our existence [25,26]. Humanity's ecological footprint per person exceeds the earth's biological capacity to replenish renewable resources and absorb wastes by 15% (Global footprint Network, 2010) [5]. Corroborating this, McGingley calculated that average world citizen has an eco-footprint of about 2.7 global average hectares, while there are only 2.1 global hectare of bio-productive land and water per capita on earth [27]. McGingley observes that humanity has already overshot global bio-capacity by 30% and now lives unsustainably by depleting stock of natural capital" [27]. If these estimates were correct, Miller (2005)'s assertion that, it will take the resources of 1.15 planet earth to indefinitely support the current use of renewable resources [6]. The

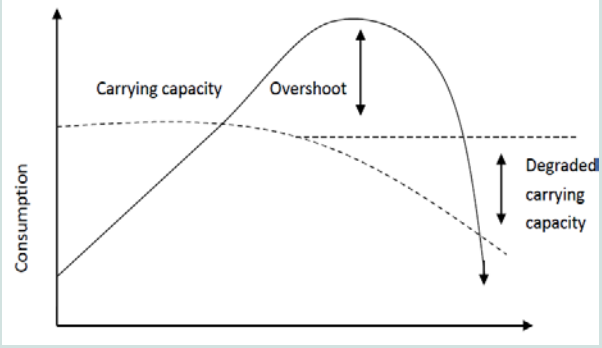

Figure 1: Carrying capacity and overshoot [24].

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footprint of the Netherlands shows that the country needs 15 times more land [26].

More so, population density is another concept commonly applied to both living organisms and particularly humans. It relates to the measurement of a population per unit area or unit volume. It is a key factor in urban and regional planning because it reflects the distinction, for example, between a community of a single family dwelling and a community or multi-storey apartments. Cities with high population densities are, by some, considered to be overpopulation, though, they depend on factors like quality of housing and infrastructure and access to resources. Some of the most densely populated in the world can be found in south and East Asia while Lagos, Cairo and Johannesburg in Africa fall into this category.

Application of Carrying Capacity to Urban and Regional Planning

The central goal of urban planning is to achieve effective and efficient use of resources and prevention of degradable spatial quality which are essential in sustainable urban development and environmental management to providing a desired array of quality of life to humanity in return. The tasks of planners and other professionals in the built environment in this changing world, therefore, require an in-depth understanding of carrying capacity and its application to keep a balance between built environment and natural environment in solving the challenges associated with burgeoning urbanization that is becoming a defining feature of 21st century, especially in the developing countries. However, the application of carrying capacity concept enables planners to determine the optimum population that can be supported within a given area with adequate infrastructure facilities so that development is environmentally hazard free and sustainable [2].

First and foremost, carrying capacity is considered an effective tool for infrastructural development in the urban areas. Here, the intensity and pattern of resource usage is estimated for the development of infrastructure such as water supply system, sewage system, transportation system, waste disposal system, among others. For example, Young sees carrying capacity as an insightful tool for the selection of proper solid waste disposal method that is not only engineeringly and economically feasible and socially, politically and ecologically sound in terms of resource supply and waste assimilation [28]. The same author observes that prior 1960, the solid wastes disposal method adopted in New Castle County were incineration or open dump often accompanied by open burning, but later, when the air pollution and health hazard from these practices became unacceptable, development of new technique such as landfill around 1968 was encouraged. In the same vein, the conditions of most urban roads in developing countries especially Nigeria suggests that their carrying capacities have exceeded what they were designed to carry. There is too much pressure on the road network. It is therefore pertinent for planners to determine the load-bearing capacity in terms of tonnage, weight and volumes, a freeway can carry conveniently in order to avoid an overshoot.

In addition, guiding against pressure on the water supply system both supply of quality and drinkable water by many activities on the catchment areas requires planting of vegetation as conservation to delay water runoff. Again, protection of water sources against pollution requires a control of water discharges from households, industries and agriculture. Carrying capacity can equally be set within the range of available water in minimum situation as the base line for water carrying capacity for an area, district or cities. However, when calculating the carrying capacity of minimum water requirement of an area, irrigation for agriculture is very important and should be taken into account. For example, in Indonesia the household consumption of water ranges from 60-150 litres per capital per day, and carrying capacity could be set in between this range [29].

Another area where carrying capacity is aptly applied to the practice of urban and regional planning is the area of legal and political framework (institutional capacity) developed to checkmate the developmental activities of human in the urban areas. This is concerned about enforcement acts like environmental protection act, biodiversity conservation act as well as zoning and regulations, building permits, land-use ordinances, etc, which provide standards to control the haphazard development in the urban environment. Since carrying capacity is concerned with an extreme limit that defines the supportive and assimilative capabilities of an area to withstand its load, standards become a tool of compliance to ensure this limit is not crossed; otherwise, an overshoot will react by imposing all manners of environmental challenges that beset the global environments today as sanctions. Meanwhile, in urban and regional planning, standards are set as a basis for people to know the extent or limit their operations can be carried out in space to achieve the goals of an economy, beauty, harmony, convenience, easy and efficient circulation, aesthetics and a host of others. Development control remains a strong and potent weapon of compliance used in physical planning to ensure that developers do not deviate from plans approved for them in the course implementation of their developmental projects. Development control is aimed at enhancing environmental quality, improved housing condition and free flow of air among others.

Among many activities of man that often cross their limits of their operations are the land use change and or conversion; which are a fast growing phenomenon in the cities of developing countries, especially Nigeria. Lands that were supposed to be used as green areas, open spaces, buffer zones, etc, have been converted to residential, commercial or even industrial uses as a result of pressure of overpopulation on urban lands. The destruction of natural habitats for paved land uses, capacity augmentation through densification/ infilling has made the environment to be vulnerable to all manners of environmental catastrophes such as flooding, erosion, degradation, pollution etc. Hence, robust literature has clearly indicated that various methods and tools that are often indispensable in assessing the carrying capacity of an urban areas such as infrastructure and land use based (Oh, et al., 2005), Visual and threshold carrying capacity (Oh, 1999), relative carrying capacity based on grey relevant degree (21), environmental carrying capacity (Xu, 2010) and comprehensive carrying capacity [4].

Summary and Conclusion

Although carrying capacity as a concept has its origin from disciplines so far in relationship to urban and regional planning, and has come to be applied so meaningfully in the discipline today. Equally, the paper intends to align the origin and historical background of the concept of carrying capacity to international shipping activities in 1845 where tariffs were levied based on ship's

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registered tonnage regardless of how much cargo the ship could convey. Carrying capacity has come to be applied in such other disciplines as engineering, ecology and biology, range and wildlife management, economics, to mention but a few.

While relating the concept of carrying capacity to Urban and Regional Planning, the concept has become bedrock which planners can make use of to examine not only what is environmentally and economically feasible, but what is socially, politically and legally acceptable in today's world. For instance, efficient and sustainable means of managing both liquid and solid wastes must be adopted and adapted. Therefore, having considered the myriads of global development challenges and threats arising from resource exploitation and consumption in meeting the demands of the burgeoning world population; and if planners actually intend to hand over the planet earth with its environment clean and intact to the future generation, the paper considers carrying capacity as a fundamental issue that needs to be considered as part of the critical thinking being advocated in the urban and regional planning.

Recommendation

For planners to achieve a sustainable environment, one that meets the needs of the present without compromising the ability of future generation to satisfy their own needs, traditional approaches which mainly focus on supplying physical facilities need to be shifted towards more practical method of incorporating the concept of carrying capacity into managing the urban areas.

Since the earth's finite resources is being gradually abused by the increasing number of earth's inhabitants, the professionals in the built environment should try and enforce the ethics of their professions towards best practices in the world. There should be invocation of sanctions to everybody who defies existing standards and regulations on best practices. Negative and positive sanctions should be introduced to ensure judicious use of planet's capital assets. For example, while prizes like national awards are being given to willing compliance with environmental planning standards, defaulters should be sent to jail without option of fines.

Secondly, mass enlightenment towards the dire implication of carrying capacity should be provided to the people through the medium of all national agencies and media houses such as radio, television and print media. And finally, organization of seminars and conferences in the domain of all professionals should key into carrying capacity awareness, among others.

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