

Environmental Sustainability and Ecological Complexity: Developing an Integrated Approach to Analyse the Environment and Landscape Potentials to Promote Sustainable Development

Masnavi, M. R.*

Graduate Faculty of Environment, University of Tehran, P.O.Box 14155-6135, Tehran-Iran

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ABSTRACT: The notion of Sustainable Development has rapidly gained considerable attention since the last decades of the twentieth century. It has become a locus for global paradigm shift on environment and development issues particularly after Rio Conference in 1992. The comparative analysis of Agenda 21 and major UN documents, MDG, and RIO+20 as well as some major sources are made to provide a context for the assessment of landscape and environment importance for achieving sustainability. Study showed almost half of the Agenda 21 is devoted to the Environmental problems, landscape issues and protection of nature and natural resources. Landscape ecology and ecological complexity theories have been widely used in recent decades to analyze natural systems and artificial phenomena to predict the future behavior of systems; and to provide better solutions for balanced interactions of human and living organisms at larger scales. The paper investigated landscape ecology and complexity theory potentials for better understanding landscape system and its nature as an ever changing semi-living phenomenon, which plays a key role for the life of inhabitants of the planet. Using an integrated approach and analyses, this research is to develop the ecological dimensions of landscape as framework for the contribution of landscape ecology and ecological complexity towards achieving sustainable development. Analyses led the paper postulates the new dimensions: Transformation complexity and Accumulation complexity; and reveals Ecosystem complexity and Biocomplexity to expand the current dimensions of ecological complexity, with their effects on the landscape systems, environmental sustainability and hence sustainable development.

Key words: Sustainable development, Landscape, Ecology, Complexity, Theory, Environment

INTRODUCTION

The notion of Sustainable Development has rapidly gained considerable attention since last decades of the twentieth century. It has become a locus for global paradigm shift on environment and development issues, particularly after its first declaration through Earth Summit, in Rio Conference in 1992. The most well known and nowadays the classic definition of Sustainable Development is a statement presented at the Brundtland Report: *Our Common Future*, released during the 1987 United Nations World Commission on Environment and Development¹: "...development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). Brundtland identified *Environment, Society and Economy* as three interconnected aspects or pillars of sustainable development. First, the environmental or ecological

aspect which recognises the limits to the society's patterns of consumptions and productions. As part of the ecological aspect, it is recognised that natural resources are finite and the capacity of the environment to deal with production and waste is also limited (Aminzadeh and Khansefid, 2010; Yavari *et al.*, 2007). Second, the social aspect relates to the question of equity; not just equity between developed world countries and developing world countries but those future generations should have access to the same natural resources as the present. The third pillar or economic aspect recognises that the economy must be operated within existing ecological limits (WCED 1987; Mossalanejad, 2013;2011). Although the definition seems to be very simple, it has generated some controversial arguments thereafter, who discuss over either simplicity, ambiguity, or the complexity of the term.

*Corresponding author E-mail:masnavim@ut.ac.ir

During the past decades, variety of definitions has emerged after that of the Brundtland Report. Bell and Morse(2003) elaborated definition in terms of development approaches, "...The difference rests on the underlying philosophy that what is done now to improve the quality of life of people should not degrade the environment and resources such that future generations are put at a disadvantage(Alizadeh and Pishgahi Frad 2010). In other words we (the present) should not cheat the future; improving lives now should not be at the price of degrading the quality of life of future generations. At the same time, the sustainable element does not imply stasis. Human societies cannot remain static, and the aspirations that comprise a part of 'needs' constantly shift."(Bell and Morse 2003 cited in Edwards, 2009).

Daly (1991) defines sustainable development in other perspective, as one that satisfies three basic conditions: 1) its rates of use of renewable resource do not exceed their rates of regeneration; 2) its rates of use of non-renewable resources do not exceed the rate at which sustainable renewable substitutes are developed; and 3) its rates of pollution do not exceed the assimilative capacity of the environment (Daly 1991, Cited in Spiekermann and Wegener, 2003). However, Daly's definition emphasizes on environmental and ecological pillar, and pays less attention to society and economy aspects. Some put emphasis on the interconnectedness and priority of three pillars of sustainability, giving different weight often to the importance of economic growth; for example, 'Charter of European Cities and Towns towards Sustainability' indicates that the main basis for sustainable development is "to achieve social justice, sustainable economies, and environmental sustainability. Social justice will necessarily have to be based on economic sustainability and equity, which require environmental sustainability" (ICLEI, 1994).

The sustainability and sustainable development terminology thus, has been subject of much debates and different usage in academics, professional, political and social circles across many disciplines (Mossalanejad, 2012; Ferrari *et al.*, 2010). In contrast, some scholars stressed on the ambiguity of term, for example Kates, *et al.*, (2007). Benson and Roe point out that "there are arguments that 'sustainable development' is an oxymoron like 'political science', business ethics', government organisation' and 'military intelligence'. More than two decades after Brundtland report (WCED 1987) and the earth summit in Rio (1992), we can see clearly effect of the thinking that emerged (Benson and Roe 2007). They admit that, despite few pessimistic views about sustainability, the concept received overwhelmingly attention and

developed excessively in the intervening years. In addition there has been a great energy and enthusiasm from all sorts of ordinary people involved in a myriad of projects generated by sustainability issues across the world (Benson and Roe 2007). We might argue on the comprehensiveness of Brundtland definition of sustainable development; as is focused on humans, and there is no clear expression regarding the rights of other creatures in such a development. The definition seems to be formulated over humankind needs rather than all living inhabitants; hence a need for the clarification is evident (Masnavi 2012, Kates R. W. *et al.*, 2007, Masnavi, 2007). From an ecological perspective the equilibrium among all systems including ecosystems (flora and fauna species) are essential to maintain biodiversity and sustaining survivals of inhabitants in the planet.

Furthermore, some new definitions of sustainability elaborated that are broader in concept and seek to extend the definition beyond environmental considerations and include issues of social equity and justice. They encompass environmental justice and social justice as inseparable parts, because one cannot be obtained without the other. For instance, there have been arguments on the negative impacts of cities and urban settlements in the sustainability debate, where often a distinction is drawn between major environmental threats to human life on the planet earth on the one hand and local concerns, on the other. In this respect, cities and urban areas play an important role; as they contribute to a large extent to global environmental problems. However, at the same time people living in cities are confronted with environmental damage, pollution, health and social and economic problems (Asgary *et al.*, 2007). As a result, some sought to formulate the goals to make cities more sustainable e.g. by means of:

- minimising the consumption of space and natural resources,
- rationalising and efficiently managing urban flows,
- protecting the health of the urban population,
- ensuring equal access to resources and services,
- maintaining cultural and social diversity (EEA, 1995).

We might briefly think of sustainable development as the ability of society to co-exist with the nature, in a way that maintains the balance of natural environment and ecosystems (including all inhabitants), and promotes economic wellbeing in a balanced interaction, and believe in the importance of society, economy, and environment simultaneously(Mossalanejad 2011). In other words it should be such development that promotes equal opportunity for all peoples on Earth to benefit from a better quality of life in the present and in the future, with minimizing pressure and burden on environment.

While, sustainable development respects for all creatures and elements of the living systems on the planet Earth, at the same time it appreciates interconnectedness of all living systems and acknowledges the responsibility of each person to consider the effects that his/her actions have on other life forms, both living and to be born. Only when we have a healthy and nourishing natural environment, and appreciate the interconnectedness of all aspects of life coupled with social justice, we can then truly have a prosperous economy.

Although the three elements or pillars (society, environment, and economy) are important and interdependent, by and large, environment is considered as fundamental matrix since its essence - nature - is our life support means; ; hence, there is simply no way around this reality. In this regard, theories like landscape ecology and ecological complexity are considered to play an important role within environment pillar of sustainability. The objective of this research is therefore, to develop landscape potentials and significance of ecological systems in promoting environmental sustainability and hence sustainable development. .

MATERIALS & METHODS

A comparative analysis of the role of landscape and environment and ecosystem importance in the documents is undertaken using a concentrated review of the literature on the variety of official documents and white papers by UN on sustainability issue. Then an analytical approach is used to develop a conceptual framework for the analyses of complexity theory and ecological complexity.

The review of United Nation summits and documents on sustainable development, from Brundtland Report: Our Common Future, to Rio+10 and analyses of the goals and strategies of those papers are made at first instance. As the first layer of research context, the Agenda 21 and its forty chapters are examined in terms of issues and areas of action and stakeholders. Then major highlights of the Agenda are classified in terms of current patterns of consumption, environmental threats, and necessity of preservation of landscape potentials and its role in achieving sustainability. Complexity theory then is used as second layer of the study as a framework to analyse landscape elements and circumstances as inseparable component of any environmental investigation. Integration of the two layers is made in the third stage where complexity theory was applied at landscape level and environmental sustainability. Through the combination of layers, the features of dynamic

landscape and its changing conditions over the time are identified.

Agenda 21 and Sustainable Development, the big picture

Following WCED report in 1987, and to further the steps of sustainable development in the real world, the United Nation Conference on Environment and Development was held in Rio in 1992, aimed at identification of the appropriate paths for the members of UN to achieve sustainability (UNCED, 1992). Its outcome was called *Earth Summit*, and also *Agenda 21* was put forward to establish common grounds for the achievement of sustainable development in the 21st century. The necessity of changes in current unsustainable patterns of development towards a more humanistic and sustainable development is therefore, elaborated thoroughly as the main goal in Agenda 21. In the Introduction Chapter, the Agenda describes the pressing problems of today as the critical moment for humanity that is facing some challenges like poverty, health, illiteracy, and deterioration of ecosystems: "Humanity stands at a defining moment in history. We are confronted with a perpetuation of disparities between and within nations, a worsening of poverty, hunger, ill health and illiteracy, and the continuing deterioration of the ecosystems on which we depend for our well-being (UNCED, 1992).

Recognising the severity of the problem, the Agenda 21 therefore, aims at preparing the world for the challenges of the next century; in which the necessity of global partnership to overcome the problems is an urgent action. But how this great task could be achieved, and what steps should be taken by different nations? Agenda asserts that "integration of environment and development concerns and greater attention to them will lead to the fulfilment of basic needs, improved living standards for all, better protected and managed ecosystems and a safer, more prosperous future. No nation can achieve this on her own but together we can - in a global partnership for sustainable development (UNCED, 1992).

Although this has been seen as the most important challenge for the whole humanity, there is a consensus that Agenda 21 succeeded to provide a relatively firm ground on the acceptance of the need to take a balanced and integrated approach to environment and development questions among the members of United Nations. The rest of this paper discusses the importance of the environment in the Agenda 21; and how together environment, ecosystems, and landscape in particular can play role in the achievement of sustainability.

ENVIRONMENTAL SUSTAINABILITY AND LANDSCAPE COMPLEXITY

Agenda 21 and importance of environment and landscape

Among the forty chapters devoting to programs of action and objectives of Agenda 21, there several chapters which are directly or indirectly devoted to the landscape and environmental issues. The Document, throughout three sections discusses: i) the social and economic dimensions of sustainable development in eight chapters; ii) deals with conservation and management of resources for development in fourteen chapters; and finally highlights the strengthening the role of major groups and institutions, and education in seventeen chapters. The review of the Agenda 21, presented in table 1, shows that nineteen chapters out of 40(almost 50%), are devoted to environmental challenges and issues. This indicates the importance and vitality of role of environmental challenges -which mainly are associated with the roles of natural landscape, and urban settlements- towards achieving sustainability. The rest of the document discusses social, economic and institutional issues like: 'role of indigenous people, and non-governmental organizations, education and public awareness, and international institutional arrangements'; however, these are not focus of this paper. The objectives and their level of relevance to the landscape and environment (directly and indirectly) were summarised in Table 1.

Given the importance to the role of landscape and environmental issues in the Agenda 21, it is apparent that environmental and landscape sustainability are considered as fundamental for achieving sustainable development. Hence, we might now review the ways that landscape and environment are connected together and to investigate possible theoretical framework or planning and design interventions that can contribute to sustainability objectives; these are discussed in the next section.

Potentials of Landscape as an Ecological System

The role of *Landscape* in general and *Landscape Ecology* in particular are seen with great importance in sustainability discourse. Some scholars paid attention to *Landscape Ecology* as an effective means to analyze the landscape and environmental characters. For instance, Ingegnoly (2003) asserts that the urgent need for a sustainable environment today, has led to acceptance of landscape ecology by nature conservation and restoration policymakers and territorial planners. Therefore, he argues that, a need for clarification of what is the landscape ecology is evident (Ingegnoly, 2003). Many authors define this

field of ecology as a multidisciplinary field within which methods needed to study the environment at a landscape scale. Others define landscape ecology as a discipline necessary to the landscape as a level of biological organization (Green et al. 2008, Ingegnoly, 2003).

In a very broad sense, Oxford English dictionary defines Landscape as 'all the visible features of an area of land' or 'a picture representing an area of countryside' (OED, 2008). However, the word Landscape has evolved many times during the past four centuries. Some commentators traced its origins into the Middle Dutch word *Lantschap*, and later on modern Dutch *Landschap* which in turn was derived from Germanic Land and suffix *-schap* meaning 'constitution, and condition. In the sixteenth century the Old English *landscipe* became *landskip*, in the seventeenth century *lantskip*, and now landscape (Onions, 1966; Simpson and Weiner, 1989, cited in Makhzumi, and Pungetti, 1999). In general, the term "landscape" meaning "a wide view of (country) scenery" stands against the term "land" meaning "the solid dry part of the Earth's surface." Knowing the differences between land and landscape seems necessary for better understanding of their functions (OED, 2008). "Land" is known as a number of surface or close to earth parameters important to mankind. As the essence of these parameters are, both individually and in relation to one another different, variations in the properties of landscape also appear because of those dissimilarities. All these parameters together are called natural resources or ecological resources, which comprise natural resources in the main structure of land in different parts of the world. In contrast, the term "landscape" or "scenery" is used for the part of the land which can be viewed from a certain point (OED, 2008).

Landscape and its components can also be studied as the inter-related comprising parts in a complex comparative system, i.e. the Earth (Witting, 2003). What is important in defining landscape is the essence of its parts and how they are related to one another. Thus, sometimes landscape, in its broad meaning, is defined as a set of living and non-living phenomena and their inter-relations in the three-dimensional space of the Earth, which can be observed and recognized by vertical-horizontal structure and amalgamation of its details like atmosphere, topographic features, soil, water, bed stone, vegetation cover, animals and human (Cook, 1994). In other words, landscape is sometimes defined as all the biological and non-biological phenomena related to one another by means of the vertical-horizontal structure in the three-dimensional space of the Earth and combining parameters such as

Table 1. Programs and objectives of Agenda 21, in terms of their direct/indirect relevance to Landscape and environmental issues

Program and objective	Directly related	Indirectly related	Means of relation	Reference
1 COMBATING POVERTY			managing, conservation, and accessibility of natural resources	Chapter 3
2 CHANGING CONSUMPTION PATTERNS		√	Production and consumption of natural resources	Chapter 4
3 DEMOGRAPHIC DYNAMICS AND SUSTAINABILITY		√	national policies for environment and development	Chapter 5
4 PROTECTING AND PROMOTING HUMAN HEALTH	√		Reducing health risks from environmental pollution and hazards	Chapter 6
5 PROMOTING SUSTAINABLE HUMAN SETTLEMENT DEVELOPMENT	√	√	land-use planning and management consumption of raw materials/resources	Chapter 7
6 INTEGRATING ENVIRONMENT AND DEVELOPMENT IN DECISION-MAKING		√	environmental and economic accounting	Chapter 8
7 PROTECTION OF THE ATMOSPHERE	√		efficiency and consumption in main resource development and land use	Chapter 9
8 INTEGRATED APPROACH TO THE PLANNING AND MANAGEMENT OF LAND RESOURCES	√ *		Managing resource components (i.e., air, water, biota, land, geological and natural resources).	Chapter 10
9 COMBATING DEFORESTATION	√ *		management, conservation and development of forests; utilization and production of forests' goods and services	Chapter 12
10 MANAGING FRAGILE ECOSYSTEMS: SUSTAINABLE MOUNTAIN DEVELOPMENT	√ *		mountain ecosystems; watershed development	Chapter 13
11 PROMOTING SUSTAINABLE AGRICULTURE AND RURAL DEVELOPMENT	√ *		food production, potential agricultural lands to support an expanding population; conserving and rehabilitating the natural resources	Chapter 14
12 CONSERVATION OF BIOLOGICAL DIVERSITY	√ *		the natural ecosystems of forests, savannahs, deserts, tundra, rivers, lakes and seas contain most of the Earth's biodiversity	Chapter 15
13 ENVIRONMENTALLY SOUND MANAGEMENT OF BIOTECHNOLOGY		√	Enhancing protection of the environment	Chapter 16
14 PROTECTION OF THE OCEANS, AND COASTAL AREAS, RATIONAL USE AND DEVELOPMENT OF THEIR LIVING RESOURCES	√ *		conservation of marine living resources of the high seas; small islands	Chapter 17
15 PROTECTION OF THE QUALITY AND SUPPLY OF FRESHWATER RESOURCES	√ *		water quality and aquatic ecosystems; climate change; integration of land- and water-related aspects	Chapter 18
16 ENVIRONMENTALLY SOUND MANAGEMENT OF HAZARDOUS WASTES... INCLUDING INTERNATIONAL TRAFFIC IN HAZARDOUS WASTES		√	Hazardous wastes; environmental protection and natural resource management; harm to health and the environment	Chapter 20
17 ENVIRONMENTALLY SOUND MANAGEMENT OF SOLID WASTES AND SEWAGE-RELATED ISSUES	√		waste disposal and treatment on the land;	Chapter 21
18 SAFE AND ENVIRONMENTALLY SOUND MANAGEMENT OF RADIOACTIVE WASTES	√		waste disposal and treatment on the land;	Chapter 22
19 STRENGTHENING THE ROLE OF FARMERS	√		increase in aggregate agricultural production; natural resources that sustain farming activity	Chapter 32

√ *- indicates more relevance and close relation with the landscape and environmental concerns

Source: Masnavi, 2012, based on the United Nation Sustainable Development Agenda 21, 1992

atmosphere, soil, water, geo-morphology, fauna, flora, and mankind (Zonneveld, 1994).

Benson and Roe(2007) however, argue in its major modern sense that has been defined by previous version of Oxford Dictionary in 1987: 'a tract of land with its distinguishing characteristics and feature, esp. considered as a product of shaping processes and agents (usually natural)'. They assert that prior to that it had been used mostly in an evaluative sense to mean 'an ideal place', the use prevalent in the art, landscape painting and landscape design of earlier centuries (Benson and Roe, 2007). According to Berleant(2009) the first definition signifies the landscape considered visually, or what we may call the observational landscape; whereas the second implies the landscape in relation to human activities, the landscape with which we participate actively or the engaged landscape (Berleant, 2009).

The Complexity and complex system

Although the concept of Complexity has become very popular in the wide range of disciplines and scientific research in the recent years, some commentators found it difficult to present a general definition for the term. Mikulecky (1995) in an attempt to examine its usefulness as a criteria for study of living systems, maintains that complexity is "a many faceted concept and too new and ill-defined to have a universally accepted meaning"(Mikulecky, 1995). Comparing 'Complexity' with 'Life', Green *et al* (2006) argue that despite being a well-known phenomenon, it is difficult to give a general definition for it. This is because the term complexity appears in different guises in different fields. For instance, In computer science, it usually refers to the time required to compute a solution to a problem; while in mathematics it is usually associated with chaotic and other nonlinear dynamics (Green *et al* 2006:4). However, referring to Oxford Dictionary, some basic broad definitions can be found for the complex and complexity. The term 'Complex' is defined as phenomenon that is: "Made of many different things or parts that are connected; difficult to understand". Similarly the word 'Complexity' is referred to as "the state of being formed of many parts; the state of being difficult to understand"(Oxford Dictionary, 2004). These initial definitions may indicate the necessity of meaningful 'relations' and 'connections' between the different parts. Bossomaier and Green(1998, 2000) described "Complexity" as the 'richness' and 'variety' of 'form' and 'behavior' that is often seen in 'large systems'(Bossomaier and Green, 1998, 2000 cited in Green *et al.*, 2004:4).

RESULTS & DISCUSSION

Integrated Approach to environment and landscape, the new vision in the Agenda 21, MDG and UN Documents

The review of the UN Documents and Declaration such as Agenda 21(1992), MDG-Millennium Development Goals(2000), Millennium Declaration(2000), and Rio+20 Declaration, and some relevant papers have been done in relation to the suitable approach for environmental and ecological issues in sustainability. To get a wider perspective and provide better solutions to environmental problems, Agenda 21 stressed on holistic view and integrated approach as key elements; for example *Integrating Environment and Development in Decision-making*(Chapter Six), and *Integrated approach to the Planning and Management of Land resources*(Chapter Eight). Managing sustainable development of Fragile Ecosystems(Mountains), Protection of coastal areas and oceans, quality and the supply of fresh water, as well as protection of Atmosphere and conservation of Biological diversity, are just other examples that show the need to be dealt with a comprehensive plan and integrated approach(WCED 1992). For advancing sustainable development, a brief rreview of the most recent Document for RIO+20 emphasizes on strong governance as critical requirement. This is connected with dependent on strengthening framework that should take into account integrated and holistic approach in their planning, strategies, management and actions. In section IV, it is asserted that "Integrate the three pillars of sustainable development and promote the implementation of Agenda 21 and related outcomes..." is critical to achieve sustainable development (article 44). The integrated approach and holistic view is highlighted in many others articles for example on the management of water sources(article 69), and finally suggestion for "...integrated and holistic approach to planning and building sustainable cities...through improved air and water quality, reduced waste, improved disaster preparedness and response and increased climate resilience." According to article 72 (UNDP 2012).

Landscape can be considered as physical emergence of environment, a medium for pertaining soil, water, flora and fauna, food chain and life support system, and also the context for materials and energy flow. Land is primary entity of landscape in the environment. It also subject of a variety of functions and activities such as Land-use and Land development in especially for human based activities in urban settlements and rural areas. This is two folds, during time; the character of land might be altered in a tolerable

scale (by nature) or destructive outcomes (like pollution and degradation by humans). Each will have different effect or impact on the landscape and environment. BASIC experts(2011) mentioned that according to the IPCC , the primary source of the increased atmospheric concentration of carbon dioxide since the pre-industrial period results from fossil fuel use, with land-use change providing another significant but smaller contribution. Fossil carbon dioxide emissions are estimated to range from 72% to 92% of the global emissions of this gas in the 1990s. Carbon dioxide emissions associated with land-use change are estimated to range from 8% to 28% over the 1990s, although this estimate has a large uncertainty (BASIC experts, 2011).

The review of landscape concept and formation demonstrates its wide range of expression and usage; landscape as scenery is recorded in many geographical dictionaries (Clark, 1985; Stamp 1966; Stamp and Clark 1979). Landscape as specific geographical place, which was subject of 'landscape science' defined first by Johnson et al (1986), concerned mainly physical and geographical aspects such as the form of the landscape of specific regions. Landscape has also been subject of beauty and aesthetic values in the works of Ruskin(1988), Porteous(1996) and Berleant (1997) concerning conservation of natural beauties and promotion of aesthetical values, and appreciation of perceptual values(cited in Makhzoumi and Pungettie, 1999). Nevertheless, evolution of landscape function and processes in line with the new trends in environmental issues make it necessary to develop new definition based on its modern usage as a multi-facets concept. It should be defined by considering it as an entity which carries different layers of activity, function, resources, and potentials across many disciplines. Benson and Roe (2007) argue for this necessity and try to define the use of the term 'landscape' as broad as the range of profession who are now involved in the planning, design, and management of landscape. They reject the simple definition of landscape as "the appearance of the area of land which the eye can see at once" (Chambers 1993 cited in Benson and Roe 2007) to be fair enough for explanation of its contemporary use. According to them "Landscape has become an increasingly important cross-disciplinary area, which draws contributions both arts and science-based subjects including art, literature, ecology, geography and much more. The term is now used in a wider sense to mean a tract of land shaped overtime by geological (soil, water,), biological (flora and fauna), cultural processes and by human occupation and agency and by human imagination. For example Edwards (2009) went on to further elaboration of necessity of landscape to maintain sustainable development requirements:

Meeting the basic needs of all for food, clothing, shelter and jobs; and That the natural systems that support life on Earth: the atmosphere, the waters, the soils, and living organisms are not endangered. It requires that the adverse impacts on the quality of air, water, and other natural elements are minimized so as to sustain the ecosystem's overall integrity (Edwards, 2009). Because of such different interests, landscape means different things to different people. But one value, often unspoken, underlies many of these: its aesthetic value. Aesthetic interests often play a part in the value that environmentalists find in the landscape, and places of unusual natural beauty are often made into national parks and preserves. There is, too, what has been called a cultural landscape, the cluster of perceptual characteristics that gives a distinctive identity to the landscape of a particular country or region. A country's characteristic landscapes may, in turn, contribute to its sense of identity. Furthermore, typical land use patterns also contribute to forming distinctive cultural landscapes, and these change with social and technological changes, such as increasing urbanization, suburban sprawl, and the development of factory farming. The terms "landscape design", landscape planning', landscape management', and landscape science' are commonly used to describe the works of professionals who are involved in landscape practice.

All these may be seen as indications of complexity of the landscape phenomena. Although it is expressed in one word, however, the terminology does not arrive at single point. It is a multi-faceted phenomenon or medium for carrying very many concepts and functions ranging from art-based interpretation to the actual means for science-based research and analyses. This will stress on the landscape as a totally complex issue, which should be studied in detail (Masnavi and Soltanifard 2007). To discover the very nature of landscape and its share in environmental sustainability, the rest of this chapter hence, deals with the landscape complexity.

In the works of many authors the definition of complexity is connected with definition of complex system or system theory. For instance, in the works of Serrat (2009), a complex system is one in which at least two parts interact dynamically to function as a whole. The parts are interconnected, and each is composed of subsystems nested within a larger one. (For instance, a person is a member of a family, which is part of a community, institution, village, province, region, country, group of countries, the earth, the solar system, our galaxy, the observable universe, and the universe.). To Serrat, complex systems hence, exhibit properties that are not obvious from the properties of

their individual parts. Typically, they are characterized by:

- i) a number of interconnected and interdependent elements (or dimensions);
- ii) local rules that apply to each element;
- iii) constant movement and responses from these elements;
- iv) adaptiveness so that the system adjusts to guarantee continued operation;
- v) self-organization, by which new settings in the system take form spontaneously; and
- vi) Progression in complexity so that the system sometimes becomes larger and more sophisticated over time.

According to Alberti complexity emerges when interacting agents engage in the systems that are nonlinear, or open; she argues the necessity of understanding complex relations of the systems to reduce uncertainty in human-natural systems and increase the future predictability of the systems (Alberti 2008). Although a wide variety of systems are called complex, some more or less than others depending on the range of characteristics they possess, and all exhibit emergence and self-organization (Serrat, 2009). According to Norberg and Cumming (2008), Understanding and predicting complex system behaviour is becoming increasingly important as we realise that much of the unpredictable behaviour observed in everything from the financial markets to the global climate system is a function of the complex adaptive systems we are living and operating in (Norberg and Cumming, 2008).

Dimensions of Ecological Complexity

The effects of dynamisms and relations existing in a complex system can take a completely complex geometric shape or have a structural and organizational nature, which can affect both the structure of a system and its function and behaviour. In general, it can be said that different sources of complexity and their nature mainly have a direct relation with the form and amount of the complexity of a system. Therefore, in systems with more complexity and more specialized organization, the nature of complexity is richer. On this basis, Loehle (2004) has defined at least six different dimensions for ecological complexity as follows:

- Spatial complexity: referring to the distribution of species, organisms, and living patterns in the ecosystem
- Temporal complexity: caused by changes in weather conditions, sustainability of living societies (e.g. extinction, attack in plant societies), and finally by spatial complexity. Temporal changes and extinction

will increase the chance for the co-existence of different species.

- Structural complexity: deals with relations inside the system such a food network, the composition of societies and competitive networks. Internalizing the mechanism of this kind of complexity needs long-time and gradual observations.
- Functional complexity: is dependent on functions with numerous processes and parts and includes soil formation, degradation of body and decay of animals.
- Behavioural complexity: includes the behaviour of living societies dependent on the information flow (DNA). On this basis, environmental changes can interfere with the information flow and change the genomes or structures of genetic codes, and finally result in affecting the form and nature of the system. Mutation in living systems is an example of this process. Therefore, it can be said that any interference in the information flow can mean an increase in the adaptability of the system with environmental fluctuations, and this increase, in turn, is the result of behavioural complexity in a living complex system.
- Geometric complexity: in general, includes complexities concerning the geometry comprising living things and systems. It mostly pertains to fractal geometry. The most important item concerning the chaos theory is the completely continuous formation of different dimensions of complexity in landscape structure. On the basis of goals, each of the above items fluctuates in strength (Loehle, 2004).

However, as it is argued, these are least number of complexity dimensions. And there are more dimensions to be revealed as our knowledge will be expanded. For instance, Cadenasso *et al.*, (2006) discuss two extra dimensions as Ecosystem complexity, and Biocomplexity; both are relatively new to the field of ecology and many ecologist. They define it as a concept that deals with heterogeneity, connectivity and history. Here is their definition of ecosystem complexity and biocomplexity.

- Ecosystem complexity: it could be defined as the degree to which ecological systems comprising biological, social and physical components incorporate spatially explicit heterogeneity, organizational connectivity, and historical contingency through time.
- Biocomplexity: it is defined as “properties emerging from the interplay of behavioral, biological, physical, and social interactions that affect, sustain, or are modified by living organisms, including humans” (Michener *et al.*, 2001, p. 1018 cited in Cadenasso *et al* 2006)).

We may postulate two more features of ecological complexity as: Transformation complexity,

Accumulation complexity (Interaction of different features), Biocomplexity, and Ecosystem complexity follows:

- Transformation complexity: as seventh dimension where it refers to the changing processes in elements of living systems, and ecosystems, and also the landscape morphology. The Change of form and shape during the time is an important and vital feature of any living system, ecosystem, and landscape. As it can make an entirely changed elements which differs from the initial form and condition.
- Accumulation (interaction) Complexity: as the eighth dimension, aggregation complexity refers to the

effects of interactions amongst two or more dimensions simultaneously. For instance the interactions amongst distribution of plants, and flowers pollination (example of spatial complexity), during the seasonal conditions (example of temporal complexity), by means of bees (example of behavioural complexity) will generate a new complex condition which will be difficult to predict; and hence creates aggregated complexity. The elaborated four new dimensions of ecological complexity are added to the current dimensions by Loehle resulted in the Fig. 1.

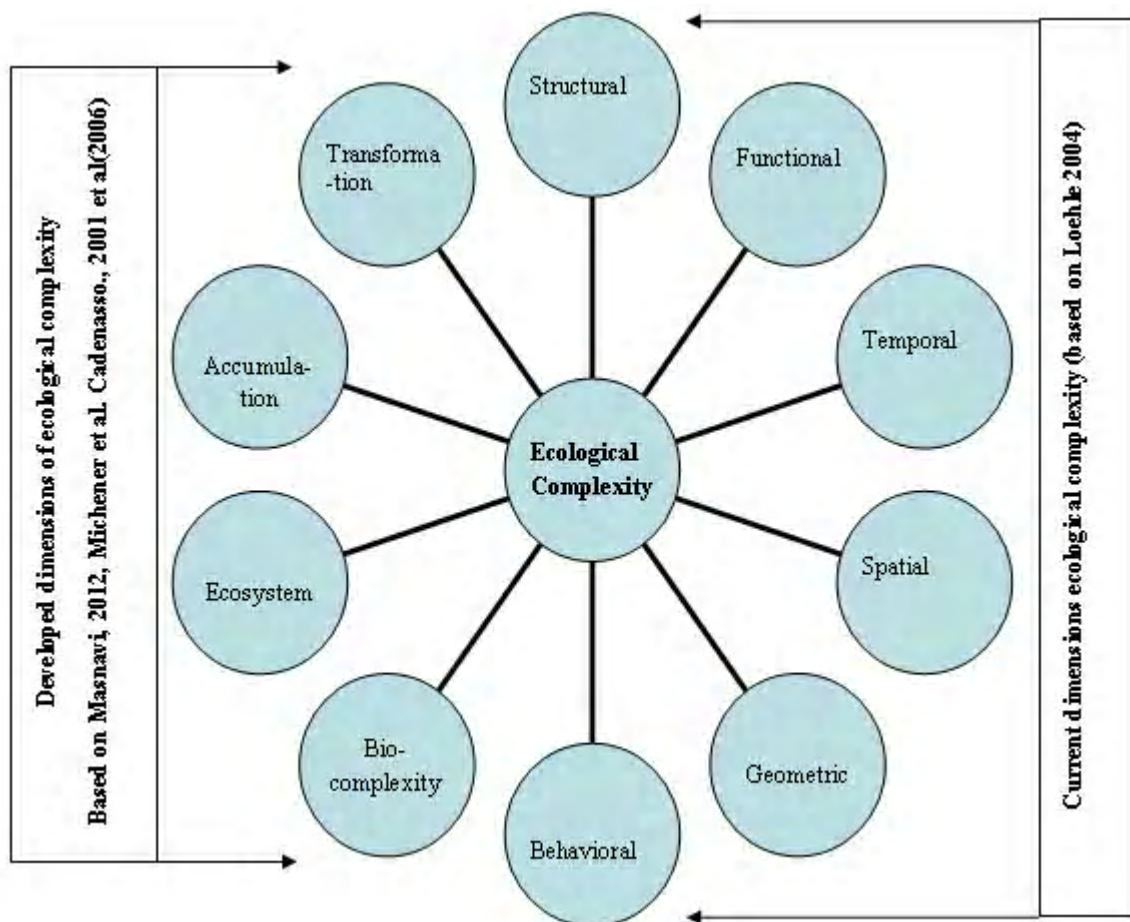


Fig. 1. Dimensions of Ecological complexity-the developed four dimensions of Ecological complexity(Transformation, accumulation, Biocomplexity and ecosystem complexity) after Loehle 2004(Author 2012)

CONCLUSION

Sustainable development is described as a multi dimension goals and actions program which seeks the solutions for reducing environmental stresses and improving quality of life of inhabitants on the planet earth. While environment, society and economy have been identified as three pillars of sustainability, the

environment has seen with a key role to play in the fulfilment of the two other. In achievement of sustainable development and environmental sustainability, important role is given to landscape and ecology. Complex systems and simple systems were identified and discussed as essential parts of a living

system in the environment. Landscape is considered a phenomenon comprising many levels of living systems, where they should be viewed and studied as simple and complex systems. The notion of complex system and complexity theory is examined to address the complexity of landscape and ecological systems. The emphases are given to the role of complexity theory to elaborate the elements of the system which shape the whole system. Two factors are seen influential in an ecological/landscape system: *Interconnectedness* and *interdependence*. The complexity theory concentrates on the issue of emergence of order out of apparent disorder in complex systems. In contrast, the study of how complex behaviour appears out of the rules in simple systems is more concerns of chaos theory. Furthermore, complexity explains the way the mechanisms of complex systems work and the way simple elements transform into complex systems. Previous studies stressed that, the existing dynamisms in an ecological complex system are related to the matter, energy and information flow into it. However, environmental and ecological degradation may cause substantial interference in the transfer of matter, energy and information. These interferences might force nature-as a medium for both order and disorder- and its subsystems i.e. ecosystems, landscape systems to react to environmental conditions properly. These systems therefore, are capable of continuous changing: *expansion* and *contraction* depends on the primary environmental factors; and eventually will lead to the widening and transformation from one state into another one, which may be termed as *dynamic sustainability*. Some other highlights of the research are as follows: The elaboration of the concepts of the ecological complexity was referred to as an effective tool in better understanding of and an integrated approach to landscape potentials and environment role towards achieving sustainable development. As sustainability is the result of correctly understanding dynamic processes in the structure of nature and framework of society and economy, nature and its subsystems are of great importance. The explanation of the dimension of complexity found to be vital in environmental and landscape analyses as well as ecological assessment in the protection of natural systems. As well as the appraisal of the current literature and theories on the complexity features, some new dimensions were elaborated. Although, six dimensions of ecological complexity proposed by previous research found essential, the need for new issues were apparent. Spatial complexity, temporal complexity, Structural complexity, Functional complexity, Behavioural complexity, and Geometric complexity are currently accepted features. However,

the drastic changes on our attitudes towards environment, economy, and society values have created new critical conditions for the planet and its inhabitants. The new conditions imply a revise in existing framework of complexity. Evidence from this research, suggested the four new dimensions. These need to be regarded as the widening new issues and their impacts on our surrounding systems including natural systems and built environment. The paper proposed four new dimensions as: Ecosystem complexity: the degree to which ecological systems comprising biological, social and physical components incorporate to internal and external relations and connectedness through time. Bio-complexity refers to the properties emerging from the interplay of behavioral, biological, physical, and social interactions that affect sustainability or is modified by living organism. Transformation complexity, deals with changing processes in the elements of living systems, and ecosystems, and also the landscape morphology. It can make entirely changed elements which differ from the initial form and condition. And lastly, accumulation or interaction complexity, which refers to the effects of interactions amongst two or more dimensions simultaneously; i.e. the interactions amongst distribution of plants, and flowers pollination (example of spatial complexity), during the seasonal conditions (example of temporal complexity), by means of bees (example of behavioural complexity) will generate a new complex condition which will be difficult to predict. Meanwhile, "landscape" as a part of the natural structure, like a living organism, includes a complex whole of comprising units and mutual relationships between them. The development and promotion of an ecological system to a higher and more complex level with more organization needs the emergence of new levels of complexity in comprising units. Landscape and its components or landscape units in particular change time to time and transforms physically and spatially simultaneously in a continuous manner. Under circumstances the decision made for the contribution of landscape planning and design in achieving sustainability should be based on ecological approach, which sees the complex systems as characteristics of ecological systems.

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