

Linking Urban Marginality and Socio-Ecological Systems to Highlight Research Areas in Informal Settlements Upgrading: a Literature Review and Future Directions

Sina Razzaghi-Asl*

Department of Urban Design, Shahid Rajaei Teacher Training University, Tehran, Iran

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Abstract

Slums are basically recognized as a multi-causality phenomenon which is rapidly growing worldwide. While the contribution of social and ecological factors is separately well understood, the interplay of interconnected socio-ecological systems in slums, such as urban heat islands, is insufficiently addressed in research. This study identifies the most important socio-ecological research areas applicable in analyzing slum settlements by using a narrative literature review method. This type of review was applied to clarify an overview of knowledge regarding the linkage between socio-ecological perspectives and informal settlements. Further, it advances the definition and the reasons behind slum shaping. The results of this study show that there are particularly three main research areas including: urban sustainability and metabolism, climate change, and ecosystem services for slum analysis in the literature. Exploring the gaps through a slum socio-ecological research framework paves the way for studying further research. We also highlighted the need for analyzing energy efficiency and flows, application of renewable energies, drought dynamics, biodiversity services and urban heat islands more than other possible subjects for future directions in slum socio-ecological research.

Keywords: Climate change; Ecosystems services; Informal settlements; Socio-Ecological system; Slum; Urban metabolism

1. Introduction

The global population of slum dwellers is estimated in about 1 billion which this number is approximately grown every week (Butera et al. 2019; Niva et al. 2019). Unfortunately, informal settlement is one of the substantial phenomena accompanying the accelerated urbanization process worldwide (Khalifa 2015, P. Amado et al. 2016). People in these regions are facing some complicated urban problems such as health, energy, water and sanitation which are basically categorized a subset of coupled natural and human systems' components. While the literature highlights how social factors, ecological conditions and informal communities are correlated, it has not yet shown, in an integrated framework, the status quo behind these relationships.

We use the term "socio-ecological research" according to Liu et al. (2007) to refer to research that focuses on various aspects of coupled socio-ecological systems. While research on the socio-ecological systems (SES) has frequently emerged in the international peer-reviewed journals, such studies are rarely underlined in studying different factors of SESs in informal settlements cases and we do not have a general overview about what has been done and what is needed for future study. While slums have been widely studied within legal, political, anthropological, socio-spatial, agro-ecological, physical, health, formal and economic frameworks, the

characteristics of interconnected social and ecological systems in these settlements have not been sufficiently marked in the literature (Mehretu et al. 2000, Dunne 2005, Dovey & King 2011, McFarlane 2012, Von Braun & Gatzweiler 2013, Husmann 2016, Adegun 2017, Lindley et al. 2018). Some researchers have pointed out the social and ecological aspects of informal settlements independently (Fernandes 2004, Roy 2004, Shatkin 2004) which cannot provide comprehensive frameworks to analyze the complex human-environment relationships in these communities. To be more specific, the present status of socio-ecological research in the informal settlements discourse may not be whole and there is not a typology of various research regarding the aim of understanding range of subjects in this area (Miranda et al. 2016, Kovacic et al. 2016, Kovacic & Giampietro 2016, Smit et al. 2017).

This research aims to investigate linkages between socio-ecological systems and marginality. This study, therefore, is not only the first to apply the concept of socio-ecological systems on the informality theme but by using a narrative literature review of different sources, it is also unique in providing a comprehensive review about the nature of marginality and informality from the interconnected socio-ecological perspective. Analyzing peer-reviewed articles and other scientific sources, we show what areas and analytical approaches of socio-ecological systems are more investigated to better

* Corresponding Author Email Address : s.razzaghi@sru.ac.ir

understand informal settlements. Conceptualizing the linkage between socio-ecological systems' approaches and slums upgrading help urban planners, designers and geographers figure out potential inquiries, concepts, frameworks and analysis about better utilizing and planning informal settlements for the future.

2. Materials and Methods

2.1. Literature review

The methodology followed for this research includes a narrative literature review. This study is not a systematic review but attempts to incorporate the major references regarding the relationships between socio-ecological systems and slum or informal settlement concepts. It is intended to describe how different concepts and approaches of socio-ecological systems could be helpful in analyzing the main issues of informal settlements planning. Bridging this gap help clarify applicable knowledge and methodologies and draws promising pathways to slum upgrading and planning. We synthesize salient literature by searching electronic databases including Google Scholar, Web of Science and Scopus on "socio-ecological systems" factors and how these factors are related to "informal settlements" or "slum settlements" planning and upgrading.

This type of review helps us reach an overview of knowledge (Green et al. 2006). We also used snowballing technique for gathering all possible relevant literature which are not explicitly found in our search. Total 53 publications were selected primarily and then they were investigated to recognize the main theoretical approaches of our topic and those focusing on specific study areas, narrowly separated social or environmental aspects (e.g., the technical characteristics of sanitation system of specific cases), or on socio-ecological policies and management rather than on components identification and analysis, were excluded. Of these articles a total number of 30 articles were selected for further review due to their applicability in our discussion. The potential linkages between different aspects of socio-ecological systems and slums have been mentioned in these selected articles.

Specifically, we reviewed literature from the following perspectives: (1) definitions of informality/marginality and reasons behind shaping them, and (2) the variety of theoretical approaches and attributes used to describe the informal settlements' socio-ecological systems. During the second phase, all of the socio-ecological systems' components in informal settlements have been described in proposed categories.

2.2. Urban informality and slums; a review of definitions and characteristics

Informality, firmly identified as a substantial issue faced by cities and poor urban dwellers, has been a considerable debate in most fast-growing contemporary cities worldwide. many literatures define the concept of marginality and informality through some characteristics i.e. belongings of specific class, poverty, color, culture, religion, and spatial disparity (Atkinson 2000, Smit et al.

2017, Zahra et al. 2017). Marginality is usually described by means of negative characteristics such as social exclusion, rooflessness, social and environmental injustice, ethnical or racial discrimination, or illegality (Goodhand 2003, Gurung & Kollmair 2005, Mehretu et al. 2000). Urban informal dwellers have little or no access to resources and opportunities, adequate and durable housing, education, secure tenure, safe water and sanitation, drainage systems, meaningful employment, spatial advantage, freedom of choices, social cohesion, high level of infrastructure, and the development of personal capabilities (UN-Habitat 2010, Smit et al. 2017, Zahra et al. 2017, Von Braun & Gatzweiler 2013, Pandey et al. 2018, Zehra et al. 2019, Lombard 2014, Kennett & Mizuuchi 2010). Moreover, Williams et al (2019) stated that insecure employment and unemployment, poverty, the lack of alternate housing opportunities, social and economic exclusion, and the need to be located close to urban resources and opportunities, are the main causes of slum shaping.

Urban informality is described in different terms such as informal urban settlement, illegal settlement, squatter settlement, and slums (Inam 2015, Soyinka & Siu 2018, Z. Kovacic et al. 2019); however, all of these settlements lack of three required columns of sustainability (B.W. Wekesa et al. 2011, Soyinka & Siu 2018). As previously indicated, the aim of this paper is not to clarify the differences between these terms or assessing the various indicators of urban sustainability. There is a considerable body of literature regarding the evaluation of different elements of urban sustainability in slums of diverse contexts including: health assessment, sanitation, displacement, electricity, water services, hazard and so on (A. Chakraborty et al. 2015, Uddin 2018); however, there is a need for monitoring the detrimental impacts of illegal actions on environmental conditions in informal settlements. For example, the significant impacts of overfishing to illegally provide food for the urban poor on the degradation of marine ecosystems in different socio-cultural contexts must be evaluated.

To this end, while several factors have been recognized in the literature as causatives of slums shaping from different perspectives, the conceptualization of informality from a socio-ecological system approach is not sufficient. Population growth and rapid migration from rural to urban areas (B.W. Wekesa et al. 2011, Niva et al. 2019;), the high cost of land possession in the urban centers (Srinivas 1994, B.W. Wekesa et al. 2011), poor building standards, technologies and rules (B.W. Wekesa et al. 2011, Potsiou 2014), the lack of funds to provide the basic community services and infrastructure (UN-Habitat 2006), the ignorance of national rules about the basic needs of the urban poor (B.W. Wekesa et al. 2011), natural disasters (earthquakes, flooding, etc.) and climate change (Potsiou 2014, Amado et al. 2016), are some of the major causes behind informal settlements' growth. Broadly speaking, there is a need for research about coupled human-environment systems as suggested above to conceptualize slum's characteristics (Table 1).

Table 1
The main social, ecological, economic, and physical characteristics of slums

Perspective	Characteristics	Notable literature
Social	Social exclusion, ethnical or racial discrimination	Gurung & Kollmair 2005, Mehretu et al. 2000
Ecological	Environmental injustice, unsafe water and sanitation, lack of drainage systems, ecosystem loss	Goodhand 2003, Pandey et al. 2018, Zehra et al. 2019, Lombard 2014, Kennett & Mizuuchi 2010, Smit et al. 2017, Zahra et al. 2017
Economic	Unemployment, poverty, economic exclusion	Wekesa et al. 2011, Williams et al. 2019
Physical	Spatial disparity, inadequate and endurable housing, low level of infrastructure, poor building standards	Atkinson 2000, Smit et al. 2017, Zahra et al. 2017, Pandey et al. 2018, Zehra et al. 2019, Lombard 2014, Kennett & Mizuuchi 2010, B.W. Wekesa et al. 2011, Potsiou 2014

2.3. Connections between socio-ecological systems and slums

As previously indicated, marginality is a multidimensional term that includes interconnected social, legal, political, economic, physical, biophysical, and ecological systems. Doubtless, the social dimension of informal settlements has been frequently studied in previous research. Residents in these communities generally have their own social behaviors and norms which are not aligned with other relations in formal settlements and sometimes are so complicated to be realized by investigators. Understanding the social relations and everyday life in slums can provide local knowledge about their attitudes toward the environment.

On the other hand, as Husmann (2016) and Adegun (2017) state the majority of features related to slums and informal settlements do not include the ecological or biophysical domain. The insecure and low living standards of slum dwellers prevent them to shape a safe environment and therefore environmental issues specifically ecological disfunction in the face of extreme weather events arise (Niva et al. 2019). As Gatzweiler et al (2011) assume the urban marginality often is associated with the lack of appropriate location for people who illegally seize public or private lands. For instance, they must directly gather water from a well or a river because a lack of access to a safe water source or adequate durable housing material forces them to the destruction of nature and the ecosystem. The poorer people there are, the more pressures there are on limited environmental resources. In light of the lack of secure sanitary systems in poor communities, critical water resources such as rivers can rapidly become polluted. Solid household waste is also a major issue in informal communities from the a socio-ecological point of view. Municipal garbage collection does not service to slum settlements which in turn results in an enormous amount of trashes which can contaminate the environment and locate perilous disease vectors.

Routinely, the informal dwellers choose invisible or non-ownership lands for their housing which are often marked by the absence of secure land tenure and urban planning regulations, lowest environmental quality and hazardous landscapes, such as wastelands, steep hillsides, railway setbacks, floodplains, dump sites, and lack security of

tenure which are at a high risk from extreme weather events (Baker 2012, Chatterjee 2010, Douglas et al. 2008, B.W. Wekesa et al. 2011, Niva et al. 2019, Diep et al. 2019). Studying marginal sites needs to be taken into account through socio-ecological perspective because the households of these communities want to rely on illegal usage of urban infrastructures and facilities such as urban canals or rivers for drinking, cooking and washing. They use waste disposal because of their non-civil behaviors and norms in one hand and the lack of safe water supply systems on the other hand which results in deterioration of human and environmental conditions. Douglas (2012) and Joan et al (2010) report how poor sanitation, open wastewater drainage and unsafe garbage disposal spread transmissible diseases among low-income dwellers. "This leads to a collapse in livability of the urban poor" (Roy et al. 2018: 3).

In terms of health-related issues regarding slums, the data revealed that a socio-ecological degradation causes detrimental effects as the development and spread of new diseases, hunger and insecure food production. Infectious diseases such as tuberculosis, hepatitis, cholera and malaria which commonly occur in urban poor areas, for instance, are derived from poor socio-environmental conditions such as lack of access to safe water and food and poor sanitation which are typical in slums. Unplanned urban development exacerbates non-communicable diseases risks related to outdoor and indoor air pollution (WHO 2019, J. du Toit et al. 2018, Alcayna-Stevens 2015). Besides the previously-mentioned facts, drug addiction and criminal activities as societal problems in slums are considered as main roots of spreading dangerous infectious diseases such as HIV. The slum dwellers do everything for their survival and these actions lead their communities to be less vulnerable in the face of extreme weather events.

Accordingly, the vulnerability of informal settlements to the natural hazards such as flooding is so low (Güzey 2016). The location of informal settlements on floodplains and steep hillsides, and their lack of insecure waste and drainage systems associated with the low quality of road pavements exacerbate the negative impacts of flooding on the urban poor. In this respect, a wide variety of social, environmental, economic and physical are imaginable if

flood occurs (Williams et al. 2019). Additionally, informal dwellers are typically deprived from access to formal risk reduction mechanisms which occur in formal cities (Christoplos et al. 2009) due to their illegal possession of the land. Since environmental status of slums are directly or indirectly rooted in societal issues such as population growth, household characteristics and social behaviors, opting for socio-ecological system approach for analyzing complex human-environmental issues is more lucrative than separately social or ecological analysis (M. Gotts et al. 2018).

A growing body of literature argues that tackling complex real-life issues in slum settlements often require a holistic approach to the interconnected socio-economic-ecological factors (Chatterjee 2010, Agrawal 2010, UN Habitat 2016, Minnery et al. 2013, Smit et al. 2017). According to Niva et al. (2019) socio-ecological systems (SES) can provide a multi-dimensional approach to analysis different components of complex human-environmental systems. A social-ecological system can be defined as ‘a system where social and ecological systems are mutually dependent’ (Fidel et al. 2014). As Rubio Scarano (2017)

states both natural system and social system are directly or indirectly interconnected and help each other to be more efficient. “According to SES, urban areas emerge from the interaction between socio-economic-technical and ecological subsystems, and metabolism of resources, energy, policies and institutions” (Niva et al. 2019: 3). The concept of socio-ecological systems can be accurately used to explore the connections between the social and environmental systems in informal settlements. For example, in “Climate Change Vulnerability and Adaptation in Metro Manila,” Emma Porio connects social vulnerabilities to environmental degradation factors in Metro Manila as a slum (Gray and Ocampo 2017). Moreover, as M. Gotts et al. (2018) state, the feedback loops between which can crystalize the dynamics of human-environmental complex systems are crucial to understand the nature of informal settlements in face of extreme weather events such as climate change, drought, ecosystem disservices. Therefore, considering marginality in SES needs to be taken into account through concepts of resilience and adaptability (D. Callo-Concha et al. 2014).

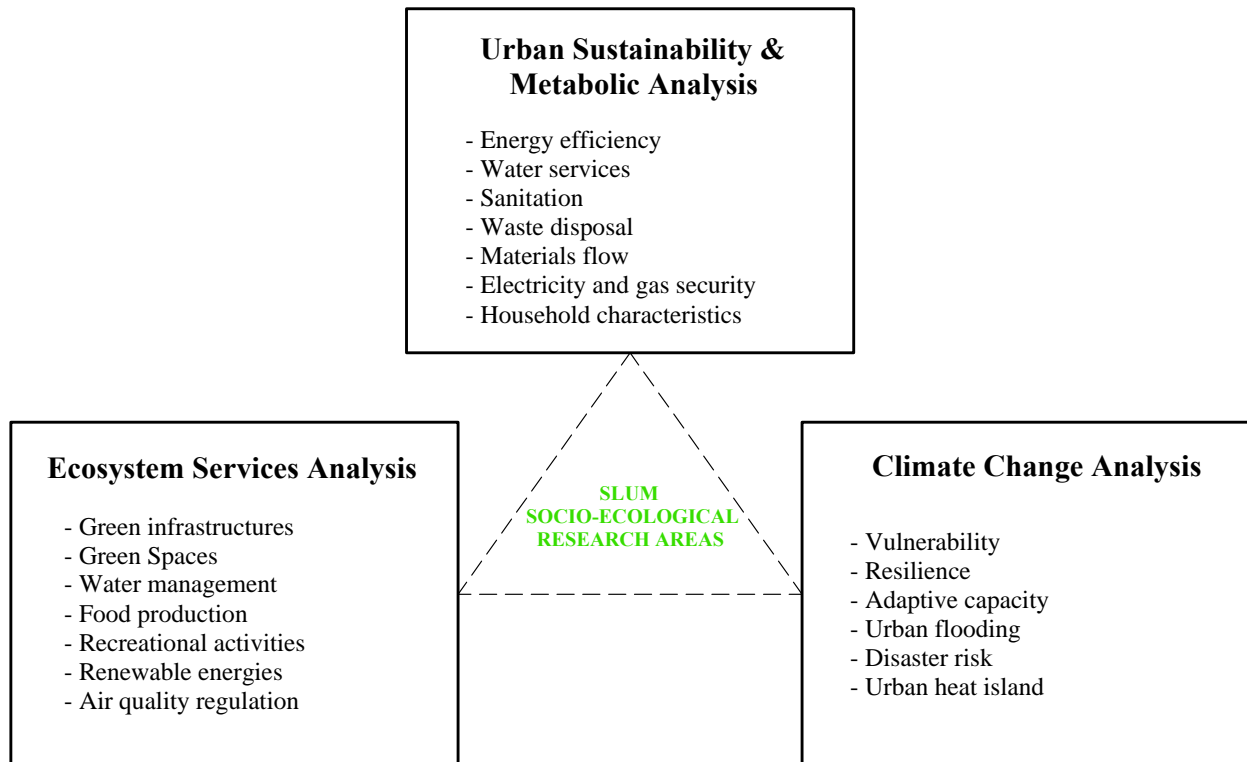


Fig.1. Slum socio-ecological research areas framework

To this end, research on marginality in the context of socio-ecological systems can be overlay categorized in some theoretical and analytical approaches that have been mostly emerged in the literature. The connection between informal settlements and socio-ecological systems reveals prospects for urban sustainability and metabolism, ecosystem services and climate change analysis as it is shown in figure 1 (Figure 1). The review analyzed 15, 13, and 12 articles in each three categories of the research including urban sustainability and metabolic analysis,

ecosystem services and climate change analysis, respectively.

3. Analysis of socio-ecological research in slum settlements

3.1. Urban sustainability and metabolic analysis of slums

The process of analysis of material and energy flow and consumption in urban ecosystems which is recognized as urban metabolism, is used as one of the related topics in socio-ecological system research (Frank et al. 2017). As

Roy et al. (2014) state the urban metabolism is a multiscale mechanism that helps us perceive the growth and emergence of informal settlements through analysis of urban flows. To our knowledge, although some authors such as Guibrunet and Castán Broto (2015) point to the need for applying urban metabolism to informal settlements, metabolic analysis in slums are limited and available for instance in the fields of waste flows (Guibrunet et al., 2016) waste-to-energy (Demaria and Schindler 2016, Butera et al. 2019), water flows (Attia and Khalil, 2015), energy flows and policies (Godshalk & Zencey 2014, Kovacic et al. 2016), food production and flow (Mollat 2014) and money flows (Smit et al. 2017; Miranda et al. 2016) (Table 2)

Some research studies use the concept of societal metabolism for analyzing metabolic patterns of informal settlements which is partially identical to the analysis of socio-ecological systems' flows in informal settlements (Kovacic et al. 2019, Attia & Khalil 2015). The majority of these literatures consider societal metabolism as the rationale behind the multiscale integrated assessment of the societal and ecosystem metabolism (MuSIASEM) approach (Robinson et al., 2013, Guibrunet & Castán Broto 2015, Kovacic and Giampietro 2016, Miranda et al. 2015, Smit et al. 2017, Kovacic et al. 2016). Of all different methods used for urban metabolism assessment, the MuSIASEM approach is assumed most helpful in examining the dynamics of slum development in terms of energy and material flow (Smit et al. 2017, Royden-Turner 2012). Although societal metabolism approach is unable to capture both informal and formal drivers of informal settlement such as political, social, cultural and economic towards their urban development, it enables an analysis of socioeconomic and socio-ecological factors related to water, energy, waste, food and money flows in cities (Makinde 2018, Smit et al. 2017). In other words, "the notion of societal metabolism is described as analyzing the 'metabolism of human society' through a characterization of the processes that a society employs to transform energy and material to ensure its continued existence" (Smit et al. 2017: 107).

Furthermore, in light of the interconnection between urban sustainability and metabolism analysis, we found some literature relating to analyze metabolism patterns of

slums from the urban sustainability point of view (Degert et al. 2016, Montoya et al. 2019). For instance, "sustainability adopts the metaphor of metabolism; a city can be defined as becoming more sustainable if it is reducing its resource inputs (land, energy, water, and materials) and waste outputs (air, liquid, and solid waste)" (Uddin 2018: 2). Accordingly, they assess sustainability indicators in Chittagong city, a slum in Bangladesh. Similarly, Montoya et al (2019) assess sustainability indicators in two informal communities in Latin American cities. Teferi and Newman (2017) apply sustainability assessment in slum settlements of Addis Ababa through integrating the extended urban metabolism model (according to Newman's (1999) model) including indicators of land, water, food, energy, building materials, solid waste, liquid waste, sewerage, air pollutants, greenhouse, gas waste, health, employment, income, education, housing, leisure accessibilities and urban design quality and sustainable development goals (SDGs). Sanitary services are considered as a significant indicator of a sustainability of the informal residents. According to UN-Habitat (2003), improves sanitation is defined as a form of private toilets or public toilets which are available for slum's households (UN-Habitat 2003). Analyzing sanitation systems in slums through a combined socio-ecological approach to support sustainability has been mentioned by some authors (Zehra et al. 2019, Kayaga et al. 2015).

Energy flows and consumption are amongst growing challenges in slums. Some studies indicate the lack of access to modern and clean form of energy which has been provided as an essential characteristic condition for defining or measuring slums. Energy used in urban informal settlements is generally low-grade fuels, which are normally less affordable (Karekezi & Majoro 2002). This happens because slum dwellers as low-income people, spend approximately one-third of their income on energy (UN-Habitat 2014). The low-grade fuels, such as kerosene and biomass, are the most popular sources of air-pollution and health-related problems in such households. Makinde (2018) indicates that the MuSIASEM approach is a lucrative framework for assess the energy metabolism of urban slums.

Table 2
The most applicable urban sustainability and metabolic themes and approaches for slum analysis in the literature

Themes	Notable literature
Waste flows	Guibrunet et al. 2016,
Waste-to-energy	Demaria and Schindler 2016, Butera et al. 2019
Water flows	Attia and Khalil, 2015
Energy flows and policies	Godshalk & Zencey 2014, Kovacic et al. 2016
Food production and flow	Mollat 2014
Money flows	Smit et al. 2017; Miranda et al. 2016
Sanitary services	UN-Habitat 2003, Zehra et al. 2019, Kayaga et al. 2015
MuSIASEM approach	Makinde 2018, Smit et al. 2017, Royden-Turner 2012

3.2. Addressing ecosystems services in slums

Human beings are both part of and benefit from ecosystem services. The concept of ecosystems services can be appropriately applied in characterizing the socio-ecological system (J.J. Waters 2013). According to J. von Braun and F.W. Gatzweiler (2013), the vulnerability of poor people in slums are more than other formal communities to the loss of ecosystem functions due to their limited access to natural resources and services. Adegun (2017) and du Toit et al (2018) suggest different ecosystems services in informal settlements, including: provisioning (e.g. food and water), regulatory (e.g. water management, moderating micro-climate, shade, carbon storage, erosion prevention, pollination, noise reduction, sediment trapping, retention of nutrients, watershed protection and air quality regulation), socio-cultural (e.g. aesthetics, recreation, religious fulfillment , educational, relieves stress, sense of place, heritage and hunting), and supporting (e.g. soil formation, critical infiltration, habitat, Maintenance of functional diversity and groundwater recharge). Informal dwellers take great advantages from ecosystem services due to their direct relationships with nature; however, their overusing or misusing the natural resources causes some cascading effects for environment (Table 3).

Doubtless, provisioning ecosystem services plays an important role in the livability of slum dwellers (Adegun 2017, Sukhdev 2009, Shackleton et al. 2014). The provisioning ecosystem services provide considerable benefits mostly to the survival of many of the poorest households. According to Du Toit et al. (2018), gathering of medicinal plants, crop cultivation for food, fuelwood , utilization for building materials, wild food, livestock grazing and fodder, fresh water from a natural source, harvesting e.g., papyrus, fish farming, hunting, wood tools, brushes, fiber and hedge have been recognized as some of the most important provisioning services in slums of Africa where the number of slums is rapidly growing. Regarding socio-cultural benefits, wetlands, lakes,

mountains and some other natural environments are identified as major places for holding religious/cultural ceremonies in slums (Negrada et al. 2013). Moreover, water provision is one of the most important examples of provisioning services in informal settlements. In light of the lack of insecure water supply system in informal settlements, residents depend on ground/surface water sources such as streams and wetlands (Vollmer and Gret-Regamey 2013). These sources supply unsafe water for drinking, cooking, bathing and laundry which are sometimes called as ‘informal water supply’ in literature (see e.g. Drechsel et al. 2006).

Furthermore, some recent literature relating to the linkage between ecosystems services and informal settlements have been published about the role of green infrastructures in slums (Adegun 2017, Diep et al. 2019, Douglas 2016, Lindley et al. 2018, Herslund et al. 2017, Roy et al. 2018). Other studies indicate green spaces (Cilliers et al. 2013), water supply management (Phukan 2014, Ochieng et al. 2011, Parikh et al. 2012, Vollmer and Gret-Regamey 2013) and urban agriculture (Webb 2011, Prain & Lee-Smith 2010, Adegun 2017) as main ecosystems services in informal communities. People who reside in informal settlements benefit more from ecosystem services specifically green infrastructures which regulate the natural environment (Adegun 2017). For instance, they mostly use the shade of trees to live at the hottest times of the year. Moreover, slum dwellers are inclined to use green and open spaces as most well-known and accessible ecosystem services for social interaction, recreational, educational and cognitive development aims (Dubbeling et al. 2009). In addition, urban agriculture as a new emerging field in cities has the strong potential to help poor people produce and consume costly food (Pingali et al. 2013). For instance, M. Gallaher et al (2013) suggest sack gardening as a form of urban agriculture in the Kibera slums of Nairobi, Kenya. They state that this form of agriculture has a positive impact on household food security and increase social capital.

Table 3
The most applicable ecosystem services themes and approaches for slum analysis in the literature

Ecosystem services	Themes	Notable literature
Provisioning	<ul style="list-style-type: none"> - Gathering of medicinal plants - Crop cultivation for food - Fuel wood - Utilization for building materials - Wild food - Livestock grazing and fodder freshwater - - Harvesting papyrus - Fish farming - Hunting - Wood tools, brushes, fiber and hedge - Water provision from ground sources 	Du Toit et al. 2018, Vollmer and Gret-Regamey 2013, Sukhdev 2009, Shackleton et al. 2014, Negrada et al. 2013, Drechsel et al. 2006, Webb 2011, Prain & Lee-Smith 2010, Pingali et al. 2013
Socio-cultural	<ul style="list-style-type: none"> - Religious/cultural ceremonies at natural resources - Social and recreational benefits from green spaces 	Demaria and Schindler 2016, Butera et al. 2019, Adegun 2017, Dubbeling et al. 2009
Regulatory	<ul style="list-style-type: none"> - Trees shading 	

3.3. Climate change analysis in slums

Generally, informal settlements and extreme weather events are mutually dependent. These settlements are the most vulnerable type of human settlements to climate change due to their hazardous locations (Revi 2008, Khalil et al. 2018). The impacts of climatic hazards on slum communities are influenced by multiscaled historical, social, economic, environmental, and political factors (Ajibade and Mcbean 2014: 84). As evident in literature, this connection occurs in two main ways. Vulnerability analysis is one, while resilience and adaptive capacity monitoring is the second form of linkage (Table 4).

The link between slums and vulnerability to climate change impacts includes flooding which has been acknowledged more than other extreme weather events such as droughts and wind in the literature (Bouchard et al. 2007, Sakijege et al. 2012, Douglas et al. 2008, Adelekan 2010, Satterthwaite 2013, Zehra et al. 2019) mainly because these settlements lack regular development and planning and have high density which in turn can exacerbate flood risk for their residents. As Grahn & Nyberg (2017) and Zehra et al (2019) state, urban informal settlements are more vulnerable to flooding according to the high population densities, located in flood risk zones near-natural drainage paths and riverine, and limited coverage of drainage infrastructure.

Community-driven research has been featured in a number of literatures specifically in flood management of informal settlements (Mulligan et al., 2016; Dobson, 2017). The main benefit of this approach is increasing social resilience of slum dwellers through including public opinion and local knowledge in climate-related issues (Christoplos et al. 2009, Elias 2011) and can be considered as an integral part of socio-ecological systems analysis in urban poor communities. According to Mensah Darkwah et al (2018), poor residents' experiences and responses to extreme weather events can mitigate some detrimental effects of climate change through producing informal urban spaces which sometimes leads to the destruction of nature. Dobson (2017) suggests six community-driven strategies, including: self-build slum upgrading, clean energy distribution, peer-to-peer exchange, slum mapping, engaging local government and situ upgrading for implementing flood resilience in slums specifically South Africa.

As megacities, like Tehran, the capital of Iran continues to grow often through rapid unplanned urbanization or slums (Madanipour, 2006), populations are increasingly concentrated in climate change-affected hazardous spaces. As previously mentioned, the people's responses to their environments will ultimately influence their vulnerability to natural disasters. Through an analysis of vulnerability in informal settlement of Kenya, Williams et al. (2019) use system dynamics and participatory mapping to understand the complexity of a socio-ecological system constructed in relation to a natural hazard in informal

settlements. Pandey et al. (2018) investigated the household vulnerability and proposed adaptive strategies for urban slum dwellers in Dehradun, Indian Himalayas. Furthermore, Alcayna-Stevens (2015) applied the conceptual vulnerability framework developed by the Research and Assessment Systems for Sustainability Program suggested by Turner et al (2003) to the slum setting of Manila to characterize of "slum socio-ecology". In this study, the dynamics of coupled human-environment systems is linked with the interactions of climate-change related hazards.

Vulnerability and disaster risk are interconnected terms which are assessed for reducing disaster consequences. Generally, there is limited literature in hazard risk management in informal settlements (Abunyewah et al. 2018). Specific socio-economic-ecological characteristics of informal settlements are the main causes of increasing vulnerability to natural hazards. Slums are complex settlements where include heterogeneous socio-cultural groups from various contexts and backgrounds. People who reside in informal settlements generally come from various cultures and background but similar economic status. Their weak capabilities for harnessing appropriate strategies for hazard risk reduction can lead to increase disaster risks. A study by Abunyewah et al. (2018) suggested three theoretical prepositions for simultaneously analysis of hazard risks, vulnerability and informal settlements including: the linkage between population density and hazard vulnerability, the importance of Vulnerability reduction policies and strategies for building resilience and the impacts of communicating existing social structures on disaster risk; however, there is a need for systematic approach to explore those characteristics which have the highest impacts on disaster risk analysis and vulnerability in slums.

The second form of connection between informal settlements and climate change literature is placed on resilience monitoring and analysis. Resilience in poor urban areas such as slums will be made up of both social and ecological components (J.J. Waters, 2013). In a slum context the concept of resilience emphasizes the need to understand informal settlement dynamics within the context of the wider urban fabric and in the extended timeframe of urban transition. Recently, the concept of resilience has been indicated to reduce the vulnerabilities of marginalized communities (Woolf et al. 2016). D. Callo-Concha et al. (2014) suggest a new framework for resilience analysis in slums from SES point of view. In this regard, marginal systems will be the most vulnerable due to their lower adaptive capacity (Bele, Sonwa, & Tiani 2014). "Adaptive capacity for marginalized groups is largely determined by household-level resources and decision-making capacity" (Pandey et al. 2018: 379). A study by Heltberg et al. (2009) revealed some adaptation strategies to mitigate vulnerability through enhancing public's ability to deal with extreme weather events' impacts.

Table 4
The most applicable climate change themes and approaches for slum analysis in the literature

Themes	Notable literature
Flood vulnerability	Bouchard et al. 2007, Sakijege et al. 2012, Douglas et al. 2008, Adelekan 2010, Satterthwaite 2013, Zehra et al. 2019, Abunyewah et al. 2018, Bele, Sonwa, & Tiani 2014, Woolf et al. 2016, J.J. Waters, 2013, Pandey et al. 2018, Alcayna-Stevens 2015
Community-driven research	
Hazard risk management	
Resilience and adaptive capacity	

3.4. Future directions

With comparison between selected socio-ecological themes featured in the literature for analyzing slums (table 1) and slum socio-ecological research areas framework (Figure 1), we can conclude some research gaps for further studies which are not fully covered in literature. Firstly, we strongly need to assess urban heat island (UHI) in slum settlements due to some illegal activities of residents (Khalil et al. 2018). Understanding the link between UHI and socio-ecological systems' components such as green spaces or sanitary services can be useful to analysis UHI effect in such a community.

Another gap which is shown, is a need to investigate potential application of renewable energies to produce durable power in informal settlements which has not been clearly conceptualized (Smit et al. 2019). Electricity and gas security as vital indicators of sustainability in disadvantaged communities need to be taken into account by means of clean low-cost energies. Although a number of literatures have indicated the low standards of housing in slums Regarding energy consumption, there is limited understanding and analyzing energy efficiency and flows of low-quality housing in slums (Muringathuparambil et al. 2017) due to this fact that overusing of energy is one of the most important impacts of illegal constructions. On the other hand, this is also important to know about energy flows in slums because in some cases, slum's residents have built their shelters by wood or mulch which

exhibits normal thermal and energy performance. In this regard, building technology solutions for efficient utilization of energy for slum dwellers should be investigated (Wekesa et al. 2011). In addition, clean energy application for improving the living conditions in slums is a crucial action that can play a fundamental role in achieving sustainable goals which has not been properly investigated by the literature.

Moreover, there is limited literature about analyzing those socio-economic features of informal households which cause drought in informal settlements from coupled human-environmental system approach. For example, digging deep wells aiming at the illegal exploitation of groundwater resources is a common action in the majority of slums which in turn cause environmental degradation such as drought especially in hot-arid climates. The last but not least, there is need to study about biodiversity characteristics in slums. The awareness of slum dwellers about the importance of biodiversity is highly crucial because plant and animal species can provide crucial services as shading, medical or food. A study of biodiversity services to slum dwellers' socio-cultural aspects will enhance understanding the potentials of such services which in turn may offer solutions for people and experts to make right decisions of improving socio-ecological systems' conditions. similar research can also suggest solutions for reducing environmental degradation.

Table 5
Most featured socio-ecological themes and components in the literature and proposed for analyzing slums

Socio-ecological research themes	Components in the literature
Urban sustainability and metabolism	waste flows, waste-to-energy, waste disposal, water flows, quality of life, energy flows, energy policies, sanitary services
Ecosystem services	green infrastructure, green spaces, water supply, urban agriculture, fuel wood, medicinal plants, crop cultivation, wild food, fish farming, hunting, irrigation
Climate change	flood resilience, disaster risk, air pollution

4. Conclusion

This paper sought to further our knowledge of the research areas in informal settlements from the socio-ecological point of view. The findings from this study build upon the literature of slums and socio-ecological systems indicate that urban sustainability and metabolism, ecosystem services and climate change are the main research areas that have been mostly investigated in this

view. The review further showed that, while current literature exists on distinct aspects of social and ecological research in informal settlements, the integrated socio-ecological research of such communities has not been studied sufficiently and as Callo-Concha et al. (2014) suggest, there is a need to pay attention to the all-interlinked components of the SES instead of concentrating on a single component. The majority of authors have highlighted the importance of environmental

systems such as water, energy or food supply in slums and have not clarified the social behaviors and rationales behind these phenomena. It appears that knowledge about the life regulation, everyday life, living standards or even slum residents' psychological status which some scholars have described as "socio-cognitive" factors is scanty (J.J. Waters 2013, Adegun 2017, Graham & Ernstson 2012).

Effective researches need to incorporate both social and ecological aspects of informal settlements in different international contexts to help recognize complex socio-ecological systems. It should be emphasized that there is a need to analyze the interactions between three research areas' components in this paper. Ecosystem services must be accompanied by climate change monitoring and materials flow for conserving biodiversity in slums. To be more specific, the application of ecosystems services for increasing resilience in marginalized communities is noticeable or the exploration of the potential green infrastructure services for conceptualizing urban agriculture in slums may be useful. Current environmental problems such as land degradation in slums require the monitoring of residents' individual or collective actions such as deforestation. Such actions should be assessed through an interconnected analysis of climate change, metabolic and ecosystem services areas. In other words, all human action in slums that might be harmful to the environment should be monitored and analyzed by using different aspects of the above three themes to achieve sustainable and resilient solutions for slum upgrading.

The author further recognizes that some research gaps can help clarify the conceptualization of, and approaches to, the socio-ecological research of slums. These aspects relate to: (i) the possible links between the usage of renewable energies and living systems in slum settlements; (ii) the linkage between local norms and energy efficiency in self-built housing of informal settlements; (iii) possible connections between slum's socio-ecological systems and urban heat island; (iv) the linkage between biodiversity and social structures in slums; and (v) the linkage between extreme weather events such as droughts and informal actions.

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