The development, composition and application of the social-ecological system framework (first draft)

(WG03: Panel Title- Applications of the Social-ecological Systems Framework…so far!)

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1. Introduction

The paper presents the development, the composition and the application of the social-ecological systems framework. The paper lays the theoretical and methodological foundation of a research on analysing urban lake systems in India using the social-ecological systems framework. The discussion on urban lake systems in India, however, is kept outside the paper. The social-ecological system framework has a deep intellectual foundation of the philosophy and works of Elinor Ostrom and Vincent Ostrom. The chapter begins with a discussion on the works of the Ostroms that led to the development of the social-ecological system framework. The next section is about the SES and includes description of the structure and the component parts of the framework. The final section describes the current applications of the SES and the possible opportunities and challenges of application of the framework with respect to analysing urban lake systems. The paper is a first draft and work in progress and suggestions and comments are highly appreciated.

2. Development of the Social-ecological systems Framework

The social-ecological systems framework (*hereafter referred as* SES) (Ostrom, 2007-2012) is developed at The Elinor and Vincent Ostrom Workshop in Political Theory and Policy Analysis, of Indiana University, Bloomington. The Workshop's salient and known research is focussed on the 'commons[1]' and the 'governance' (Aligica and Boettke, 2011). The concern for matching institutions to the physical environment can be found in the early works of Vincent (1953) on 'State Administration of Natural Resources in the West,' when he highlighted the imperatives imposed by the physical nature (and climatic environment) of a commons and suggested that resource administration requires regional solutions surpassing the state boundaries. A subsequent paper by Ostrom et.al., (1961) introduced the concept of polycentricity by elaborating on a multi-centric political system in metropolitan governance. The basic idea is that group of individuals facing collective problems are capable of addressing those problems in whatever way they see fit before turning to some government organization for an authoritative (or coercive) decision. This was later formulated into the concept of self-organization and collective action (Ostrom, 1990 1991). The following process of finding solutions to collective action problems in resource management through extensive field works and reviews of case-study and theoretical literature on rules led to the development of the design (eight) principles for sustainable management of the commons. Ostrom (1990) also referred to them as rules (-in-use) of sustainable management of the commons. The urge to bring in the physical and cultural factors of the resource along with the rules that the actors use in decision making, led to the development of the Institutional Analysis Development framework (Kiser and Ostrom, 1982). The idea of Institutional Analysis Development framework (hereafter referred as IAD) was to recognize the institutional diversity similar to the natural ecosystem diversity. The IAD showed us how to combine observations of cultural, legal, and physical factors into a coherent mode of institutional analysis. The concept of nested level of rules was introduced with the idea that decisions made at one level of action are influenced by what is happening at other levels and

[1] The term commons is used to refer to public goods, common pool resources, club goods or any area with uncertain property rights. It is important not to confuse commons with the term common property regime. Commons means a wide diversity of non-private good or anything that is not for private use is a commons. Control over the use is considered a crucial aspect to analyse in the commons studies (Ostrom, 2011). The study of forests, lakes, rivers, bio-diversity and other modern infrastructures including knowledge reside in the commons. A large database on the study of commons is available in The Digital Library of the Commons (http://dlc.dlib.indiana.edu/dlc/).

in return also influences the other levels of action. Understanding the levels of analysis became crucial in analyzing any action situation and in the applications of the IAD. The IAD is the heart of the works of the Workshop. The structure of the focal action situation of the IAD and the rules-in-use that affect the focal action situation are extensively used by the researchers interested in analyzing actors and the circumstances in which actors make certain decisions and actions. The physical and cultural factors of the resource were usually considered as given (or as exogenous) variables in the institutional analysis. Realising the importance of the physical and cultural factors of the resource as crucial to the analysis of the focal action situation, the SES is conceptualised as an extension of the IAD with the notion of integrated analysis of ecological diversity along with institutional diversity as the focal action situation (Ostrom, Y673 lecture, 2011). McGinnis (2011) calls SES an on-going effort to revise the IAD, and the revision is to provide equal attention to the bio-physical/ecological foundations as it is provided to the institutional systems in the IAD.

3. Foundation of the Social-ecological systems Framework

SES has its foundation in the term social-ecological system. The term social-ecological system is generally used as concept, model, and theory and their interpretations are linked to the development of SES. It is important to clarify that the SES is referred here as a 'framework'.

Box 1. Distinction between framework, theory, model and concept

Framework organizes diagnostic, descriptive, and prescriptive inquiry. It identifies, categorizes, and organizes the characteristics deemed most relevant to understanding some phenomenon. Framework provides the most general list of characteristics (often relevant concepts) that can be used to analyse all types of settings ranging from Wisconsin lakes (Brock and Carpenter, 2007) to the Planet Earth (Rockström et.al., 2009). Framework provides a meta-theoretic language that is necessary to talk about theories and that can be used to compare theories. They attempt to identify the universal characteristics that any theory relevant to the same kind of phenomena would need to include. Many differences result from the way these characteristics combine with or interact with one another. One uses theory to predict outcomes of these relationships. The elements contained in a framework are the basic concepts that researchers interested in the same general phenomena need, but if they come from diverse disciplines, how the concepts are defined and ontologically linked may differ substantially. Thus, framework helps the researchers to generate the questions that need to be addressed when first conducting an analysis (Ostrom, 2005). For example, the characteristics of the current lake governance are described through the ontology of the SES framework in the research.

Theory posits causal relationship among some subsets of characteristics or categories of factors. It enables researchers to specify the characteristics that are relevant for certain kinds of questions and to make broad working assumptions about these characteristics. Theories focus on parts of the framework and make specific assumptions that are necessary to diagnose a phenomenon, explain its processes, and predict outcomes. Researchers select one or more theories in generating predictions about expected patterns of relationships. Several theories are usually compatible with a framework. Empirical research narrows the range of applicable theories over time by showing the superiority of the remaining theories to explain the data. Theories like collective action theory, microeconomic theory, game theory, transaction cost, social choice, public choice, constitutional and covenantal theory, and theories of public goods and common pool resources are compatible with the SES framework (Ostrom, 2005). The characteristics driving the current lake governance like collective action towards lake sustainability are identified, described and explained in the research.

Model specifies the specific functional relationships among particular characteristics that are hypothesized to operate in some well-defined set of conditions. It enables researchers to make precise assumptions about a limited set of characteristics. Logic, mathematics, games, experimentations and simulations, and other means are used to explore the consequences of these assumptions systematically on a limited set of outcomes. Models are associated to case specific situations like empirical analysis. Multiple models are compatible with most theories. Model is also referred as a repeatedly observed pattern. A pattern of collective action situation towards lake restoration for improving the ecological conditions of a lake is explained in the research. Models enable to analyse in a precise manner a sub-part of a theory like collective action leads to improved lakes. Models are extensively used in contemporary policy analysis by officials from all levels of government and non-government organizations (Ostrom, 2005).

Concept is a common feature, a characteristic or an attribute (Kant in Hartman and Schwarz, 1988). Concept has a definitional structure. It is generated through comparison, reflection and abstraction of a mental image (terms). A concept is a list of features to articulate the necessary and sufficient conditions for the membership in the referent class. They are used to demonstrate a model, theory or framework. Some concepts also have fuzzy membership of a class as evident in SES framework. Clusters of concepts grouped together into categories form the ontology and structure of a framework.

In the above analogy, SES is a framework that is composed of different concepts as part of its structure and that theory and model are applied or may be built using the concepts to analyse a phenomenon of interest/need.

Source: Adapted from Ostrom, 2011, Y673 Course

A social-ecological system (*hereafter referred as ses*) is defined as, *an ecological system linked with and affected by one or more social systems in complex way where, an ecological system broadly means an interdependent system of natural or biological units, and social system broadly means that individuals tend to form groups and interdependent relationships with others of one's kind (adapted from Anderies et.al., 2004).* At the core of it remains the notion that, *'in nature nothing exists alone'* (Carson, 1962). A ses emphasizes on the linkages between the relevant characteristics of both the social and the ecological sub-systems particularly, the ecosystem, organisational, spatial, and temporal linkages. The linked system is also referred as coupled system (Liu et.al., 2007) and integrated system (Berkes and Folke, 2004), etc. The linkages are direct and feedback; and they have evolved from direct to more indirect interactions, from adjacent to more distant interrelations, from local to global scales, and from simple to complex patterns and processes (Liu et.al., 2007). Ostrom (2008) defines ses as complex adaptive system involving multiple sub-systems, as well as being embedded in multiple larger systems. Both social and ecological systems contain units that interact interdependently and each contains interactive subsystems as well. For the linkages of the ses, Ostrom (2009) refers to the foundation of self-organization of the social systems (see Ostrom, 2007) and relating it to the self-rejuvenating processes evident in the ecological systems (see Levin, 1999). The emphasis is on the necessity of recognising the non-linear, multivariate, self-organising and changing aspects as well as the multiple objectives and the spatial and temporal scales involved in the study of ecology and institutions (Hess and Ostrom, 2004); in other words, recognizing ses as complex systems (Holling, 2001). Berkes and Folke (2004) in studying resilience and sustainability of ses emphasize on the integrated concept of humans-in-nature where, social systems deal with property rights, land and resource tenure systems, systems of knowledge pertinent to resources, world views and ethics concerning resources and the ecological systems (ecosystem) deal with the conventional ecological sense of natural environment. They also emphasize that the delineation of the social and ecological systems is artificial and arbitrary. Anderies et.al., (2004) in studying robustness of ses from institutional perspective refer to ses as the subset of social systems in which some of the interdependent relationships among individuals are mediated through interactions with biophysical and non-human biological units.

The SES, thus, has its foundation in the ses studies. The genesis of ses studies is from the presumption that researchers till then studied independently either the ecological systems or the social systems and the need for interdisciplinary approach to address the problems of resource and resource management and sustainable development. Integrating various disciplines is slowly gaining acceptance in ecological as well as social science and a new science of social-ecological system is emerging. With the ses approach, the idea is that researchers are able to conduct integrated studies on the social as well as ecological characteristics of a resource and resource management. The SES is one of the frameworks to conduct integrated studies on social as well as ecological characteristics of a resource. The other studies similar to ses are coupled human and natural systems (Liu et.al., 2007); human-

environment system (Levin and Clark, 2009); human ecosystems (Tillman, 1985); human ecological (McHarg, 1981); man and environment (McHarg, 1963; Rappoport, 1977).

SES is a structure composed of relevant characteristics belonging to a particular social and ecological context for the purpose of analysing (understanding/ studying/ assessing/ evaluating) a particular a social-ecological system in observation (problem/ question/ interest). Those relevant characteristics are referred as variables (and sub-variables) in the SES. The strength of SES is in its disparate number of variables (and sub-variables) that encompass almost every characteristic that are necessary to understand fully about a ses. The other studies are yet to have a comprehensive analytical framework as SES.

4. Motivation for the development of SES

The arguments that ecological diversity play crucial role in the way actors design governance systems for themselves and for the ecosystems; and that the institutional diversity can be explained like the complex ecological diversity lay the keystones of the SES (Ostrom, 2007). Ostrom (2007) draws simile between institutional diversity and ecological diversity by referring to Levin who in his study of complex adaptive systems says that, *"Ecosystems are complex, adaptive systems and hence, are characterized by historical dependency, complex dynamics, and multiple basins of attraction. The management of such systems presents fundamental challenges, made especially difficult by the fact that the putative controllers (humans) are essential parts of the system and, hence, essential parts of the problem. An important lesson is the importance of experimentation, learning and adaptation"* – Simon A. Levin (1999, pp.2). Similarly, in the research group like the Governance of Complex Systems (GOCS) at the department here, Teisman et.al. (2009) refer governance as complex process system, just like the ecosystem complexity of Levin. They elaborate complexity of governance from evolutionary approach and point that governance systems are often in the states of change which make them difficult to manage (Gerrits, 2012). The concept highlights the diversity and dynamics involved in the governance systems, just like the ecological systems.

The development of SES is also with the presumption that understanding of the processes that lead to upgradation or deterioration (basically change) of ses is limited, since science is divided by disciplines, sectors and regions. Scientific disciplines use different concepts and languages to describe and explain the already complex social and ecological phenomena. In addition, scientific concepts are part of complex, linguistic ontology in which one concept is a sub-concept of another which is a sub- concept of still another (Ostrom, 2007, 2009). Research in multiple disciplines acknowledge the need for multi-disciplinary studies but face the fact that without a framework to organize relevant variables identified in theories and empirical research in different disciplines, isolated knowledge acquired from studies of diverse resource systems in different countries is not likely to cumulate and further not help to solve the real world social and ecological problems. Without cumulating the knowledge in systematic way understanding and managing of the ses is difficult. The purpose of SES is to build a common understanding of the ses amongst various disciplines through overcoming the linguistic and disciplinary barriers existing in the different academic disciplines and policy spheres that result in the varied and often conflicting understanding of the ses (Ostrom, 2007). The classificatory framework is also aspired to facilitate more trans-disciplinary works on ses and help the policy makers and decision makers in government and non-government organisations in solving the complex problems of the real world (Ostrom, 2009). Thus, SES is intended to be a step towards building an interdisciplinary science of complex systems that

will enable future researchers/policy makers to match governance arrangements to specific problems embedded in a social-ecological context.

SES challenges the overly relied approach of looking for panaceas in solving the world's problems. Ostrom (2009) argues that developing simple panaceas for complex ses problems and prescribing universal solutions will not work in the long run and that moving beyond panaceas is must should we wish to reduce the world's problems. We must build 'understanding' of the system before reaching conclusions and providing simple solutions and policy recommendations to complex ses problems. The often-used one-size-fits-all approach to policies aimed at achieving sustainable ses needs to be updated with this diagnostic toolbox to help the researchers/analysts better frame the question and think through the variables. SES encourages diagnostic method, through its classification of variables in a nested series of tiers, for analysing the outcomes achieved in any ses.

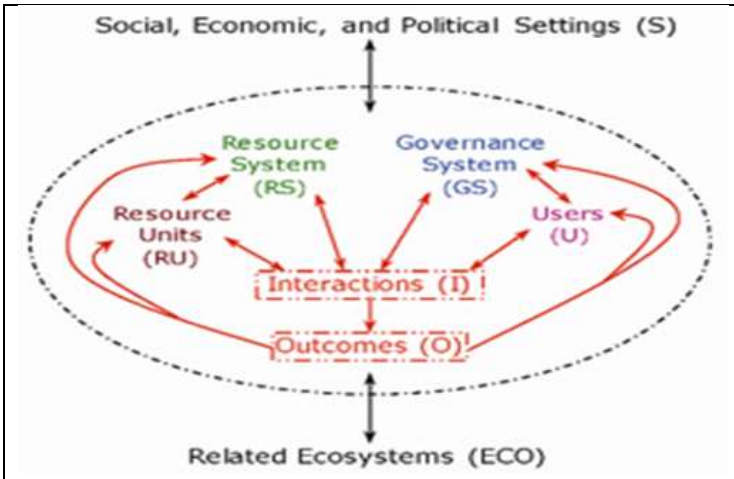
Integrated studies of social systems and ecological systems reveal new and complex patterns and processes that were not evident when studied by social or ecological researchers separately. Researchers across disciplines have recognized the complexity of the non-linear, multivariate, self-organising and changing systems; as well as the multiple objectives and the spatial and temporal scales involved in the study of ecology and institutions (Hess and Ostrom, 2004). Ostrom (2009) argues that the study of complex systems need not be complex; instead we must learn how to dissect and harness it into smaller systems or sub-systems. A large number of potentially relevant variables are required to address a particular puzzle of change in the ses and the related other smaller and larger systems. Developing cumulative capacities to diagnose the problems of the linked social and ecological systems is crucial to understanding the change and effectively addressing important questions related to change in the ses is a step towards sustainability (Ostrom, 2007).

5. SES Structure

SES is an ontological framework of the important social components and ecological components of a ses. A large number of potentially relevant variables influence the patterns of interactions and outcomes of different ses. The variables interact with each other at a point in time and place what is called the focal action situation. The variables interact with each other in several different ways to create one or several action situations (Ostrom, 2009).

The structure of the SES is composed of the variables arranged in a nested series of tiers, using a set of generic categories intended to be applicable to diverse resource sectors, geophysical regions, political entities, and cultural traditions (Ostrom, 2007). There are eight main (also called first-tier) variables that form the broad structure of SES:

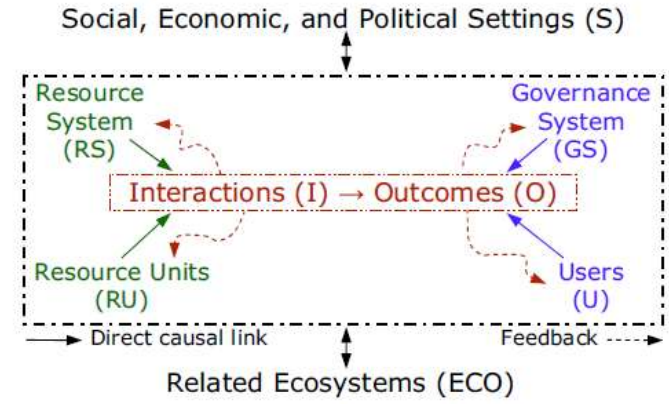
i. Resource System
ii. Resource services and units
iii. Actors
iv. Governance System
v. The Socio- Economic, Political Settings
vi. The Related ecosystems
vii. Interaction
viii. Outcomes



a. Source: Ostrom, 2007 in PNAS; Ostrom, 2009 in Science;

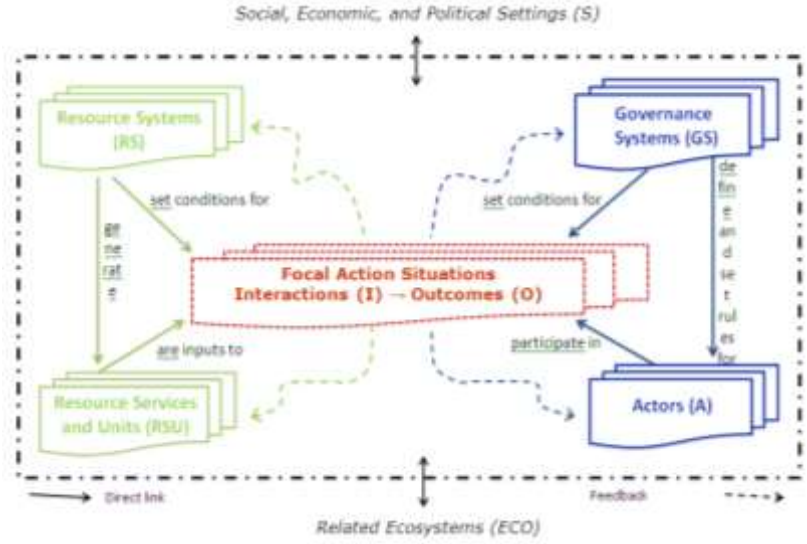
Legend
- Direct Linkage
- Feedback linkage
- Action Situation

Highlights: Shows all possible linkages with the two sided arrows.
The colours of the main components implicitly reflect the categories of the different classification which is a kind of broadly distinction of disciplinary and policy spheres



b. Source: Ostrom, 2010 in Science;

Highlights: More explicit about the direct and feedback linkages with unidirectional and different line type arrows. The colours of the main components implicitly reflect a kind of clustering of the social (blue), ecological (green) and external (black) components and the interaction and outcome (red).



c. Source: Ostrom in Y673 lecture, 2011; McGinnis in TU Delft, 2010

Legend
- Direct Linkage
- Feedback linkage
- Action Situation
- Multi-tiers

Highlights: Describes explicitly the nature of the direct and feedback linkages.

Figure1. Development of the SES

The main variables are the explanatory factors to understand the broad structure of the interactions and outcomes of a ses. The broad structure of SES has remained same except few modifications in its look and in nomenclature of two main variables. The figure 1 presents the conceptual development of the SES. The first SES appeared in the special feature of the Proceedings of the National Academy of Sciences (PNAS) in Ostrom's (2007) paper on

'going beyond panaceas' (refer figure 1.a) followed by the essays in Science in 2009 and 2010 (refer figure 1.b). In 2009 version, the colours in the main variables implicitly reflect the different categories of the classification of the broad disciplinary and policy spheres. The 2010 version presents the direct and feedback linkages explicitly. Further from the 2010 version onwards, the colours of the main variables implicitly reflect a kind of clustering of the social (blue), ecological (green) and external (black) factors and the interaction and outcome (red). The latest version (McGinnis, 2010; Ostrom, 2010) presented the nature of the direct and feedback linkages and the notion of multi-tiers (refer figure 1.c). In this version, the nomenclature of two main variables is changed: Users changed to Actors and Resource Units changed to Resource Services and Units.

6. Main variables of the SES

The main variables of the SES are intended to enable researchers to organize analyses of how characteristics of a resource system (e.g., fishery, lake, grazing area); the resource units generated by that system (e.g., fish, water, fodder); the users of that system; and the governance system jointly affect and are indirectly affected by interactions and resulting outcomes achieved at a particular time and place. It further enables organize how these variables may affect and be affected by larger socioeconomic, political, and ecological settings in which they are embedded, as well as smaller ones. The understanding of a complex whole (social-ecological system) is thus through learning about the specific variables and how their component parts are related.

The main variables have relationships with each other as compositional and subsumption. *Compositional* relationship relates one variable as a sub-variable of another variable for example, the main (basic) variables of the SES structure. *Subsumption* relationship relates one variable that is a sub-class or specific subtype of another variable. These kinds of relationships are the basis for powerful classifications in ecological sciences and are now explored in the social sciences or social-ecological systems studies (http://socialecologicalsystems.referata.com and SES meetings at the Workshop, Fall-2011). The main variables are described as:

i. ***Resource System (RS)*** encompasses the bio-physical (natural) characteristics of the resource from which resource services and units are used/ extracted and through which the levels of the focal resource are regenerated by natural dynamic processes (Ostrom, 2009). For example, lakes, rivers, forests, grazing land. It is similar to the bio-physical conditions in the IAD.
ii. ***Resource services and units (RSU)*** in earlier versions of SES was called only resource units. It encompasses the characteristics of the units extracted from a resource system, which can then be consumed or used as an input in production or exchanged for other goods or services (Ostrom, 2011). For example, water, fish from the rivers/ lakes; woods from the forests; bio-diversity and aesthetics from the rivers, lakes, forests; fodder from the grazing land. It is similar to the material conditions in the IAD.
iii. ***Actors (A)*** in earlier versions of SES was called users. The actor specification is bit confusing in the SES. In the current SES version, actors still mean the users. They are the individuals (or community) who use/ extract resource services and units from the resource system. The user characteristics are similar to the attributes of the community in the IAD. Actors when classified as the organisations that are involved in the governance processes are referred as governing arrangement and are part of the governance system. To clarify, those organisations who are not involved in the governance processes and have the user

characteristics, those organisations are considered as part of the actors. Important to note is that some organisations involved in the governance processes also have the user characteristics.

iv. ***Governance System (GS)*** encompasses the governing arrangement and the governing mechanisms what is actor and rules-in-use respectively in the IAD. The governing arrangement refers to the different government and non-government organisations and the governing mechanisms refers to the different strategies and instruments that are used by the organisations, through which the behaviour of the abovementioned actors towards the resource system are set and revised such as, operational rules, property right, sanctions etc., besides deciding and implementing changes to the resource system itself like lake shore development, converting lake into wastewater reservoir.

Identifying the focal resource system and the related necessity resource services and units is the first step in the SES. For example, in the research RS is the urban lake and RSU are the public open space for recreation and wastewater reservoir according to the lake governing organisations. This signifies that the space (land) covered by the lake is crucial part of the resource system in order to perform the above two functions. Identifying the focal actors and governance systems is also crucial for SES. The four main variables form part of the focal action situation, in other words, the main variables to analyse. They are considered important in causing/alleviating/deteriorating change in ecological as well as social system (Geist and Lambin, 2001). They are positioned within the outer dash-dot line of the SES map.

v. ***The Socio- Economic, Political Settings (S)*** represents the broader geo-political (including the market and cultural) context within which the focal resource system, the actors and the governance systems are located.

vi. ***The Related ecosystems (ECO)*** represents the broader ecological (including the physical-urban externalities such as infrastructure) context within which the focal resource system, the actors and the governance systems are located.

In a ses analysis, the focal action situation or the main variables are considered to be located in a particular exogenous setting of the S and ECO. It is difficult to imagine a focal action situation free of S and ECO context in any empirical situation as well as any laboratory situation. Whether large or small in nature, the S and ECO are important in affecting the patterns of relationship among the variables within the focal action situation (Rudel, 2005). In other words, the context of a focal action situation matters. The importance of context makes the concept of nested systems and presence of adjacent systems more relevant as well as complex. The ses studies have brought more importance to the contextual environment. For example, focal action situations are different when a lake is located in urban area or rural area; within urban/rural area if a lake is located in Rotterdam or in Ahmedabad; and even within a city if a lake is located in the city centre or in the periphery.

vii. ***Interaction (I)*** is frequently identified as exchange between: actors and resource systems; actors and resource services and units; actors and governance systems; governance systems and resource systems; governance systems and resource services and units. Known examples from commons are harvesting, deliberation, lobbying, conflict, and several others.

viii. ***Outcomes (O)*** are general concepts that include performance of both the systems: social systems (for example efficiency, equity, accountability) as well as ecological systems (for example overharvesting, resilience, sustainability) and externalities of the social-ecological system being analysed. This is similar to the evaluative criteria of the IAD

(above descriptions of the main variables are adapted from Ostrom, 2009, 2010, 2011; McGinnis, 2011).

The main variables require more theoretical exploration to contextualize and construct the conceptual framework for analyzing urban lake systems. Many patterns of interactions and outcomes are possible among the actors, governance systems and the resource systems and resource services and units such as, actors design and apply governance system on themselves, resource system and resource services and units. More than one illustration of each of the main variables is necessary to identify for any particular application. This also applies when a particular action situation is identified in a given context. For example, different governance systems interact with each other as well as with actors or resource services and units or resource systems. McGinnis and Ostrom (2011) clarify that it is important to explicitly distinguish the interactions that occur between elements of a pair of any two of the main variables such as, resource systems and resource services and units (RS and RSU); and actors and governance systems (A and GS).

7. Sub-variables of the SES

Both the social and the ecological variables of the focal action situation are decomposable into smaller variables as well as situated within the context of broader aggregations (McGinnis, 2011). Each main variable is classified into number of sub-variables (also called second-tier variables) that together characterize the main variable. The list of sub-variables helps to define, group and classify the main variables in the tiered ontology. The sub-variables are the key characteristics that help in building or constructing certain relationships to explain a theory or a phenomenon or an action situation or a problem or simply a particular relationship of interest pertaining to social-ecological dynamics (adapted from Ostrom, Y673 lecture, 2011). The sub-variables are identified from years of researches mainly conducted on long enduring and sustainable commons managements through self-organization, for example, the International Forestry Resources and Institutions (IFRI[2]) database of repeated studies of some of the forests and water bodies were useful in identifying the sub-variables of ecological system and the several institutional analysis using the IAD were useful in identifying the sub-variables of social system Ostrom (in Y673 lecture, 2011). The SES structure with the sub-variables is presented in figure 2. The abbreviations and numbers of the sub-variables are a kind of codes for analysis.

While the main variables represent a broad scheme of the SES structure, to diagnose the causal patterns that affect interactions and outcomes among the main variables, it is necessary to look at a set of sub-variables that are contained within the main variables (Ostrom, 2009). The main variables and sub-variables are distinguished by the fact that sub-variables can take on values, while main variables cannot since they have the sub-variables that take on values for them.

Socio- Economic, Political Settings (S)	
S1- Economic Development, S2- Demographic Trends, S3- Political Stability, S4- Government resource policies, S5- Market Incentives, S6- Media Organization, S7-Technology**	
Resource System (RS)	***Governance System (GS)***
RS1- Sector (water, forest, pasture, fish)	GS1- Government Organization
RS2- Clarity of System Boundaries	GS2- Non- Government Organization
RS3- Size of resource system	GS3- Network structures
RS4- Human- constructed facilities	GS4- Property- rights system

[2] International Forestry Resources and Institutions at the Indiana University of Bloomington

RS5- Productivity of the system	GS5- Operational Rules
RS6- Equilibrium properties	GS6- Collective- choice Rules
RS7- Predictability of system dynamics	GS7- Constitutional Rules
RS8- Storage characteristics	GS8- Monitoring and sanctioning processes
RS9- Location	
Resource Services and Units (RSU)	***Actors (A)***
RSU1- Resource unit mobility	U1- Number of users
RSU2- Growth of replacement rate	U2- Socio- economic attributes of users
RSU3- Interaction among resource units	U3- History of use
RSU4- Economic Value	U4- Location
RSU5- Number of Units	U5- Leadership/ Entrepreneurship
RSU6- Distinctive markings	U6- Norms/ Social Capital
RSU7- Spatial and temporal distribution	U7- Knowledge of SES/ mental models
	U8- Importance of resource (Dependence)
	U9- Technology used
Interaction (I)	***Outcomes (O)***
I1- Harvesting level of diverse users	O1- Social Performance measures
I2- Information sharing among users	(efficiency, equity, accountability, sustainability)
I3- Deliberation processes	O2- Ecological performance measures
I4- Conflicts among users	(overharvested, resilience, bio-diversity, sustainability)
I5- Investment activities	O3- Externalities to other SESs
I6- lobbying activities	
I7- Self organising activities*	
I8- Networking activities*	
I9- Monitoring activities*	
Related Ecosystem (ECO)	
ECO1- Climate patterns, ECO2- Pollution patterns, ECO3- flows into and out of focal SES	

* New sub-variables in Nagendra and Ostrom, 2011.

**Ostrom (2011) presents technology as S7 which, Rolf Kunneke in a seminar at TU-Delft (in EOI, 2012) presented a complete structure made of social technical systems called the STS framework. It is re-positioned in GS in the research (refer ch. 5, 6).

Figure 2. The Sub-variables of SES
Source: Ostrom, 2009; Nagendra and Ostrom, 2011.

What makes SES different and special from other similar frameworks is the identification and classification of the set of these sub-variables. Identifying and analysing the sub-variables of research interest or necessity is what ses studies are about (Ostrom, 2011). Logically, all the sub-variables are possible to apply in one study however there is complexity in applying too many sub-variables in one study. Using too many sub-variables, on one hand, may be too general to find solutions for the problems, but on the other hand, may provide an overall understanding and overview of the situation of the social-ecological system in observation (Ostrom, 2011).

For applying the sub-variables it is important to have an understanding of the meanings of the sub-variables. The sub-variables are concepts and thus complete in themselves. Many sub-variables are defined earlier by several commons researchers including those who studied human behaviours, ecology, governance, institutions, ecosystem services and many more. To create a database of the meanings and definitions of the SES variables and sub-variables, the Workshop and the CSID are in the process of building a semantic wiki[3] for SES. The objective of the semantic wiki is to facilitate a common platform among social-ecological researchers (Ostrom, 2011)**.** Researchers involved in building the semantic wiki believe that wikis are now established method for knowledge management and an appropriate platform

[3] A semantic wiki is a wiki with a data structure behind it. This allows for a wiki to be queried the way a database is queried. It is editable by anyone who is granted access to the project/site. The semantic wiki page can be accessed through the link: http://socialecologicalsystems.referata.com/wiki/Main_Page

for the collaborative development and articulation of social-ecological concepts; which historically suffered from a lack of consensus regarding meanings of several social-ecological concepts.

The meanings to the sub-variables have a kind of bearing on their ability to self-organise. Ostrom (at keynote speech at CSID, 2009) poses a question to help explain how the sub-variables can help provide guidance for researchers and policymakers: When will the users of a resource invest time and energy to avert 'a tragedy of the commons?' She uses the following sub-variables that positively or negatively affect the likelihood of actors' self-organizing to manage a resource:

- *Knowledge of the ses*- When users (read actors) share common knowledge of relevant ses characteristics, how their actions affect each other, and rules used in other ses, they will perceive lower costs of organizing.
- *Carrying capacity of the resource*- If the resource system regenerates slowly while the population grows rapidly, users may not understand the carrying capacity of the resource and thus fail to organize; and destroy the resource.
- *Resource unit mobility*- Due to the costs of observing and managing a system, self-organization is less likely with mobile resource units, such as wildlife or water in an unregulated river, than with stationary units such as trees and plants or water in a lake.

8. Tiers and Levels in SES

SES is developed as multi-tier framework. The *tiers* refer to the decomposition or the classification of a variable into second, third, fourth degree and so on…. (refer table 1). The boxes in the SES diagram (refer figure 1.c) represent the tiers. The ses are maintained at various levels (Daly, 1991). The *levels* refer to the operation, collective choice, constitutional and meta-constitutional levels (see Ostrom, 2005). Identifying the level of analysis is important prior to operationalizing the variables and sub-variables. The combination of the levels at a place in time forms the action situation. Several action situations occur simultaneously in one level and across levels. Any action situation can be further more specific if the tiers are added into it.

Table 1. Tiers in SES

Tiers	**Numbering**	**In SES**	
main tier	1	main variable	GS
second tier	1.1., 1.2., 1.3.	sub-variable	GS1
third tier	1.1.i., 1.1.ii….; 1.2.i., 1.2.ii.,….	sub-sub-variable	GS1.i.
fourth tier	1.1.i.a.,1.1.i.b…1.2.i.a, 1.2.ii.b,….		GS1.i.a.

Here is an example of digging deeper into the tiers. Ostrom (2007) explains the congruence of multiple factors in the success of the Maine lobster fishery from the study conducted by Acheson (2003) and Wilson et.al. (2007) (refer figure 3). She identifies few sub-variables of relevance and goes into deeper tier of analysis. The depth of analysis depends on the research and researcher. In this case, it is important that researchers consider only few sub-variables at the beginning of analysis.

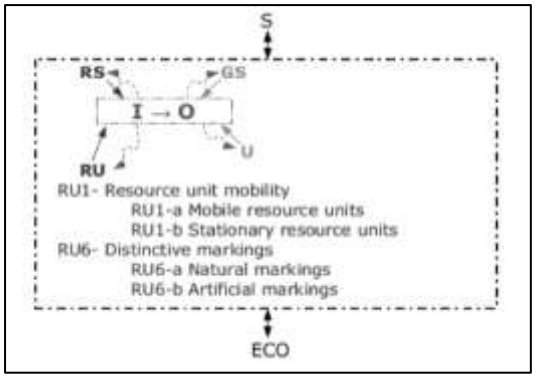


Figure 3. Example of multi-tier variables
Source: Ostrom, 2007

9. Opportunities and Challenges in the application of the SES

The basic purpose of SES is to provide researchers with important social components and ecological components and their sub-components and with different possibilities to analyse the relationship among them. It is aimed towards systematic diagnosis of the structure, interactions and outcomes of any complex ses. SES is proposed to help researchers in developing better conceptual language and theories, in diagnosing policy problem, and in designing empirical research. Researchers have interpreted and applied the SES for different resources of different scales and in different ways according to the research questions/ interests/ problems and/or necessity. For example, Berkes (2007) challenged some contemporary views of conservation in globalized world; Brock and Carpenter (2007) expanded the framework to analyse the US Northern Highland Lake District; Nagendra (2007) dug into the question of which variables in the framework are drivers of reforestation in human-dominated forests; Wilson et.al. (2007) modelled the preconditions for governance in the Maine Lobster fishery; Anderies et.al. (2007) compared it to the robust control framework in sustainability science.

i. The categorical classification of the variables and sub-variables to simply demonstrate complexity as Ostrom and Cox (2010) elaborate in the case of analysing irrigation communities (called acequia) in New Mexico (refer table 2).

Table 2. Example of categorical classification of the variables and sub-variables

Resource Systems	Resource Units	Governance Systems	Actors	Action Situations
1) Sector	1) Resource unit mobility	1) Rules	1) Group size	1) Process
2) Boundary clarity	2) Replacement rate	a) Operational rules	2) Socio-economic attributes	a) Monitoring
3) Size	3) Interactions	b) Collective-choice rules	a) Economic	i) Environmental
a) Area	a) Strong to weak	c) Constitutional rules	b) Cultural	ii) Social
b) Volume	b) Predatory or symbiotic	2) Property-rights regime	3) History of use	b) Sanctioning
4) Infrastructure	4) Economic value	a) Private	4) Location	c) Conflict resolution
5) Productivity	5) Size	b) Public	5) Social capital	d) Provision
6) Equilibrium properties	a) Large to small	c) Common	6) Knowledge of SES	i) Informational
a) Recharge dynamics	b) Trophic level	d) Mixed	7) Resource Leadership	ii) Infrastructural
b) Recharge rate	6) Distinctive markings	3) Network structure	8) dependence	e) Appropriation
c) Feedbacks	7) Distribution	a) Centrality	9) Technology used	f) Policymaking
i) Positive	a) Spatial heterogeneity	b) Modularity		
ii) Negative		c) Connectivity		
7) Predictability		d) Number of levels		
8) Storage capacity				

9) Location	b) Temporal heterogeneity

ii. Identifying few sub-variables and construct a relationship to explain a theory or a situation, for example, Ostrom (2007) explained the Tragedy of the Commons (Hardin, 1968) (refer figure 4). Alternatively, applying few sub-variables in the analysis it is also possible to construct a theory.

Ostrom (2007) constructed Hardin's (1968) 'the tragedy of the commons' using a set of sub-variables by translating Hardin's theory (calls it metaphor) into five assumptions:
- the resource system is a pasture (RS1);
- no governance system is present (no GS variables) related to the resource system;
- the mobile individual resource units (RU1, the animals grazing on the pasture) can be identified and are the property of their owners (implicitly assuming RU6) and, when fattened, can be sold for cash (RU4);
- a sufficient number of users (large U1), given the size of the pasture (RS3), are using the pasture to adversely affect its long-term productivity (RS5); and
- the resource users independently make decisions to maximize their own short-term returns (U7).

Socio- Economic, Political Settings (S)

S5- Market Incentives

Resource System (RS)	****Governance System (GS)***
RS1- Sector (pasture)	
RS3- Finite Size of resource	
Resource Units (RU)	***Users (U)***
RU1- Mobile animals on stationery grasses	U1- Large Number of users
RU4- Fattened cattle can be sold for cash	U7- Maximum of short term gains for self
Interaction (I)	***Outcomes (O)***
I1- Maximum Harvesting level by users	O2- Destruction of Ecological system

Related Ecosystem (ECO)

By using the framework to represent the small set of variables used in Hardin's theory, Ostrom points out that Hardin's 'the tragedy of the commons' was based on the sparse view of the commons. The five assumptions about second-tier variables lead to a theoretical prediction of very high harvesting of pastures (I1) and severe overharvesting or destruction of the ecological system (O2). Ostrom stresses that situations characterized by these assumptions, in which individuals independently make anonymous decisions and primarily focus on their own immediate payoffs, do tend to overharvest open-access resources. Researchers have repeatedly generated 'the tragedy of the commons' in experimental laboratories when subjects (as individuals in field) make independent and anonymous decisions in commons settings (Ostrom et.al., 1994; Cardenas and Ostrom, 2004).

Figure 4. SES interpretation 'the tragedy of the commons' of Hardin
Source: Adapted from Ostrom, E. 2007

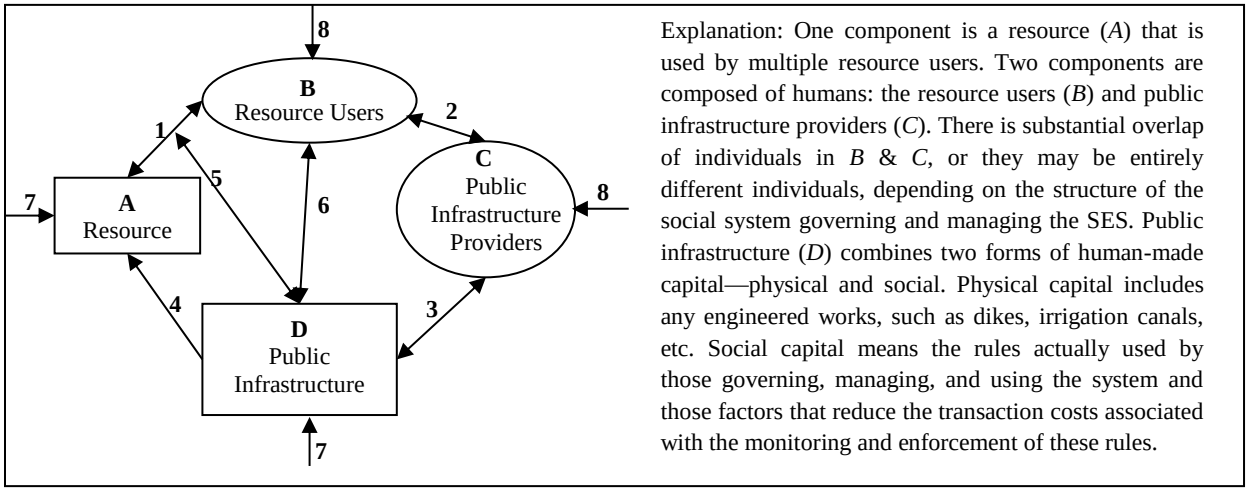
iii. Explaining the sub-variables and their positions in certain category. Basically, what the sub-variables are and why they fall in certain category, for example, Meinzen-Dick (2007) explained the factors affecting farmers in the irrigation works in north India. It is a priority in any analysis.

iv. To arrange the sub-variables based on the relevance to the theory/ problem in focus, basically listing the dominant or dormant sub-variables to explain a theory/problem. This is like rating or putting a value or weight to the sub-variables. The unit of measurement to assign weight can be categorical, ordinal (high, medium, low), binary (present, absent), statistical (-1, 0, +1), and qualitatively explanatory etc. For example, Cox (2011) assigned 'ordinal and categorical' weights to the selected sub-variables in order to find a configuration of sub-variables that helped the irrigation communities in New Mexico to sustain for centuries. Nagendra and Ostrom (draft, 18 Oct'2011) in analyzing the factors that influence collective action towards ecological performance and using a cross case analysis (of seven urban lakes in Bengaluru) method assigned ordinal weights to the selected sub-variables (refer table 3).

Table 3. Example of assigning values to sub-variables

Lakes / SES variables	Agara	Ambalipura	Bellandur	Kaikondanahalli	Mestripalya	Parappana Agrahara	Varthur
Resource System (RS)							
RS3 – Size of resource system	Moderate	**Small**	Large	**Moderate**	Small	Small	Large
RS4a – Scale and type of pollution	High, mostly sewage	**Low**	High, toxic sewage and industrial waste	**Low**	Low, dry lake	High, mostly sewage	High, toxic sewage and industrial waste
Actors (A)							
A2 – Diversity of actors	Moderate	**Moderate**	Large	**Moderate**	Small	Moderate	Large
A2a – Socio-economic groups excluded	Yes	**No**	No	**No**	Yes	No	No
A5 – Leadership	Lacking	**Present**	Present	**Present**	Present	Absent	Absent
A6 – Norms of trust, social capital	Low	**High**	Moderate	**High**	Low	High	Moderate
A8 – Importance of resource, dependence	Low	**Moderate**	Moderate	**Moderate**	Moderate	High	Moderate
Governance System (GS)							
GS5 – Operational community rules	Absent	**Present**	Absent	**Present**	Present	Absent	Absent
Interactions (I)							
I8 – Networking with government	Low	**High**	Low	**High**	High	Low	Low
I9 – Informal norms for monitoring	Absent	**Present**	Absent	**Present**	Absent	Absent	Absent
Outcomes (O)							
O1 – Social performance measure (collective action)	Moderate	**High**	High	**High**	High	Low	Moderate
O2 – Ecological performance measure	Low	**High**	Low	**High**	Low	Low	Low

v. Anderies, et.al. (2004) modified the SES structure to analyse the robustness of the social-ecological systems while studying public infrastructures from the institutional perspective. They explain with examples the potential problems of each variable and also the problems arising from the linkages between the variables (refer figure 5 and table 4).



Explanation: One component is a resource (*A*) that is used by multiple resource users. Two components are composed of humans: the resource users (*B*) and public infrastructure providers (*C*). There is substantial overlap of individuals in *B* & *C*, or they may be entirely different individuals, depending on the structure of the social system governing and managing the SES. Public infrastructure (*D*) combines two forms of human-made capital—physical and social. Physical capital includes any engineered works, such as dikes, irrigation canals, etc. Social capital means the rules actually used by those governing, managing, and using the system and those factors that reduce the transaction costs associated with the monitoring and enforcement of these rules.

Figure 5. Robustness of SES for public infrastructures
Source: Anderies, et.al., 2004

Table 4. Entities involved in social-ecological systems

Entities	Examples	Potential Problems
i. Resource	- Water source - Fishery	- Uncertainty - Complexity / Uncertainty
ii. Resource Users	- Farmers using irrigation - Fishers harvesting from inshore fishery	- Stealing water, free ride on maintenance - Overharvesting
iii. Public infrastructure providers	- Executive and council of local users' association - Government bureau	- Internal conflict or indecision about which policies to adopt - Information loss
iv. Public Infrastructure	- Engineering works	- Wear out over time

v. Institutional rules	- Memory loss over time, deliberate cheating	-
vi. External Environment	- Weather, economy, political system	- Sudden changes as well as slow changes that are not noticed

vi. Kunneke and Finger (draft, 2012) reconstructed the SES into social-technical systems framework (STS) (refer figure 6). They change the Resource System to Technical Systems; and Social, economic and political settings to Technical, social, economic and political settings. When it was presented in the EOI seminar at TU Delft, there was discussion about the extent of relevance of the SES sub-variables with regard to STS. Rolf argued that many sub-variables of the SES are suitable to analyse STS and few sub-variable may be required to contextualize for technical systems. At the core, SES sub-variables are concepts and can be applied to diverse type of resource systems. Ostrom, (2011) presents technology as S7 in the later versions of the SES. From the logic of technology used as governance mechanism, it also fits in the classification of the governance system in the SES as explored in the empirical analysis.

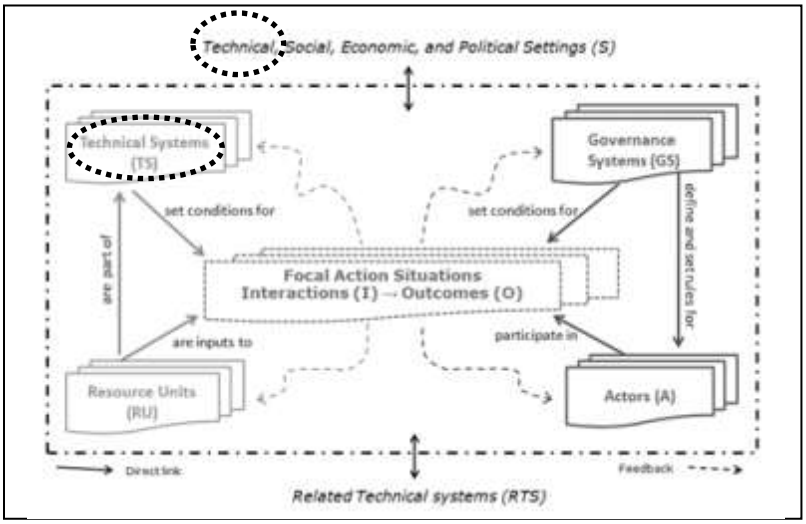


Figure 6. Social-Technical Systems (STS) framework with first-tier variables
Source: Rolf Kunneke in EOI seminar at TU Delft, on 27-4-2012

vii. The Research Institute of Humanity and Nature developed a model to analyse vulnerability and resilience of ses from the attempts of the agricultural societies in Sub-Saharan Africa towards adapting to environmental change, population increase and rural social collapse (refer figure 7).

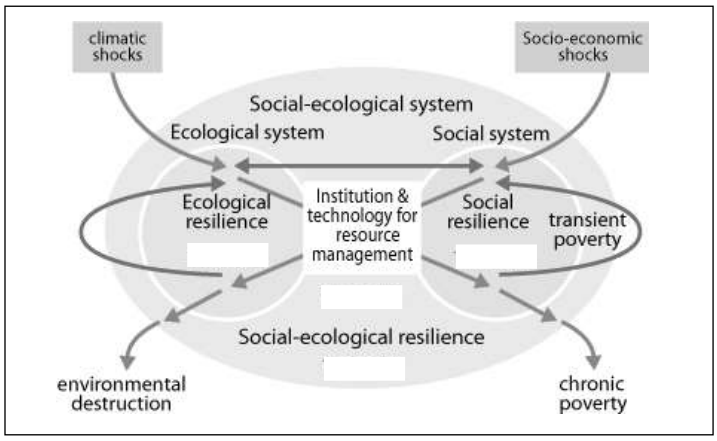


Figure 7. Building model from SES to analyse vulnerability and resilience of ses

Source: RIHN, 2009

viii. Action situations are usually 'time and place' specific. It is possible to analyse different action situations over certain time period or at certain intervals of time (like a time series analysis) and measure change in the properties of sub-variables, for example the IFRI database. Similarly, it is possible to analyse different action situations at a time over multiple cases across space (like a spatial analysis) and undertake a comparative or cumulative analysis. A combination of the above two is also a possibility. Nayak (2010) did a qualitative analysis of changes over time in six lagoon systems located across the world by doing cumulative spatial analysis and a comparative time analysis.

ix. With the inception of SES, McGinnis M. D. and Ostrom E. (2010) in their work on 'Program in Institutional Analysis of Social-Ecological Systems (PIASES) Framework' revised the design principles for long enduring resource management to dual-valued design principles for sustainable social-ecological management. In the dual-valued design principles, the social components and the ecological components of outlined separately within the structure of the original design principles (refer annex ….).

Table 5. Dual-Valued Design Principles for sustainable ses management

Resource System	Users
1e. ***Resource Boundaries***: Clear boundaries that separate a specific common-pool resource from a larger social-ecological system are present or can be constructed and maintained at low cost.	1s. ***User Boundaries***: Clear and locally understood boundaries between legitimate users and nonusers are present and this distinction is considered valid within relevant cultural contexts.
2e. ***Congruence with Local Conditions***: Appropriation and provision rules (and especially the associated levels of activities) are congruent with local environmental conditions, especially carrying capacities.	2s. ***Congruence of Appropriation and Provision***: Appropriation rules are congruent with provision rules in the sense that the distribution of (provision) costs is proportional to the distribution of (appropriation) benefits and resulting inequities are acceptable within relevant cultural contexts.
3e. ***Information for Collective Choice***: Most individuals affected by a resource regime have easy access to information about the conditions of the resource.	3s. ***Collective-Choice Arrangements***: Most individuals affected by a resource regime are authorized to participate in making and modifying its rules.
4e. ***Monitors*** who are accountable to or are the users monitor the condition of the resource and other closely related aspects of the relevant ecosystem.	4s. ***Monitors*** who are accountable to or are the users monitor the appropriation and provision levels of the users.
5e. ***Graduated Degradation and Adjustment***: Degradation of the resource starts slow but becomes increasingly noticeable if over-appropriation continues, and rules specify graduated adjustments to be made when degradation becomes noticeable.	5s. ***Graduated Sanctions***: Sanctions for rule violations start very low but become stronger if a user repeatedly violates a rule.
6e. ***Recognition of Ecosystem Conflicts****:* Tensions with other components of the local ecosystem closely related to the focal CPR are monitored and taken into consideration in governance activities (including revision of appropriation levels).	6s. ***Conflict-Resolution Mechanisms***: Rapid, low-cost, local arenas exist for resolving conflicts among users or with officials
7e. ***Minimal Isolation/Insulation from Exogenous Shocks from Nested Ecosystems***: When a common-pool resource is closely connected to a larger social-ecological system, the local cpr is not routinely subjected to excessively high levels of variation in necessary support from this ecosystem.	7s. ***Minimal Recognition of Rights and Minimal isolation/insulation from nested enterprises***: The rights of local users to make their own rules are recognized by the government and local governance activities are not routinely undermined or overwhelmed by external actors (corporations or governments or international NGOs)
8e.***Recognition of Nested Ecosystems***: When a cpr is closely connected to a larger social-ecological system, relatively autonomous subunits of these ecosystems can be identified or constructed at low cost.	8s. ***Governance by Nested Enterprises***: When relatively autonomous subunits of larger ecosystems can be identified, governance activities are organized in multiple nested layers or new arenas can be constructed at low cost.

Source: McGinnis and Ostrom, 2010

x. Applying the full set of sub-variables and describing a situation. This is a comprehensive way to present a general overview of a system. The overview may vary from a single resource system or to a larger system comprising of several smaller resource systems.

Combinations of the above ways are also possible for example like in the IAD, considering some sub-variables as given (exogenous) analyse other sub-variables from the perspectives: how do they influence and get influenced by the given conditions. Construct a matrix of dependent-independent variables. Important to note is: identifying and defining the variables and sub-variables in any analysis is a priority in SES application.

In google search of the term SES, several interesting and not so interesting conceptual maps show up. There is also quite elaborate Wikipedia page on ses. The Ecology and Society has published so far the most number of SES articles according to the ISI web of Science. Garry Peterson (2011) of the Stockholm Resilience Centre did a compilation of different conceptual maps of the SES from Wikipedia[4] where each map represents a particular social-ecological system of a particular place using a variety of approaches.

SES is proposed to remain sufficiently general to encompass all characteristics relevant for the analysis of any mode of social-ecological interaction (Ostrom, in Y673 Lecture, 2011). On one hand, the different ways in which SES is interpreted and applied reflect the flexibility and potential to work with it; on the other hand, it leaves beginners in social-ecological science studies, like me, with some unanswered queries and confusions about the SES and its application. Being a complex framework to analyse a complex system is the first hiccup to apply SES. Well, that can be only addressed by applying the SES. Some challenges that are identified in the SES application during analysing urban lake systems in India are briefly presented.

The meanings of all the sub-variables are not yet available in the semantic wiki page and SES researchers are encouraged to contribute to the work in progress (Ostrom in the SES meetings at the Workshop, 2011)**.** Besides, since the concepts used as sub-variables are constructed out of terms interpreted differently in different disciplines, sectors and regions, it is a challenge to find appropriate definitions.

The positioning of the sub-variables in particular category requires further exploration. It is not explicit in the Ostroms explanation of the SES, except that the ecological sub-variables are identified from the IFRI data base and social sub-variables are identified from the several institutional analyses.

Researchers from different disciplines agree that a core challenge in diagnosing why some ses are sustainable whereas others collapse is the identification and analysis of relationships among multiple levels of these complex systems at different spatial and temporal scales (Berkes, 1998; Janssen, 2002; Norberg, 2008). This is not simple and similarly SES is not simple. Ostrom (2009) argued that, *"if we keep it too simple, we lose an understanding of what's going on out in the real world or what is the real problem. Instead, the focus is on a subset of all the variables operating in a complex system".*

[4] (http://rs.resalliance.org/2011/10/06/5120/)

There is confusion with the level of analysis among the main variables. The governance levels are classified but logically thinking the resource system, the actors (users) and the resource services and units belong to a level higher than the operational level i.e. the physical level. It is not fully clear whether the variables of the focal action situation must belong to one level or can be across different levels for example, Meizen Dick (2007) and Cox (2011) use multiples levels in their analysing one action situation.

A common confusion begins with the notion that everything is linked to everything else (Barabasi, 2000). What it means when every variable is linked to every variable and how to analyse a particular causal pattern applying the SES? It is also not fully clear how the linkages are built to analyse patterns. The IAD is a clue to apply the SES. Since IAD has a clear causal linkage between the variables in its structure as compared to the SES in which all the variables are linked to each other. The clear causal linkage in IAD is: exogenous variables influence action situation which leads to interactions and further to outcomes, where interactions and/or outcomes can be evaluated and the finding can be sent back to the exogenous variables or the action situation as a feedback. Thus, IAD is 'one' way to apply the SES particularly to understand how the variables can be linked and how the linkages build patterns.

Further confusion is regarding adding of theory/model to the framework in the process of specifying particular interactions or priorities among explanatory variables. It is not fully clear how theory/model is applied to the framework? It is also not fully clear whether SES can be applied to dis/approve a theory/model or it can be applied only to explain a theory as Ostrom (2007) demonstrates 'the tragedy of the commons'. Further, adding more than one theory/model is likely to make the analysis more complex.

The SES has its foundation in the theory of collective action/self-organisation. It is also proposed towards sustainable resource management. The distinction between sustainable resource and sustainable resource management is unclear in the SES. There is a general ambiguity about them and it is usually exemplified with the overly relied panacea that sustainable resource management lead to sustainable resource. While Ostrom (2011) agrees that self-organisation is not a panacea and it is just one type of governance, she does not make the distinction between sustainable resource and sustainable resource management in the SES; unless we borrow her previous works where she relates long enduring self-organised institutions to sustainable resource. The categorical classification of the sub-variables is underpinned in the self-organisation of the actors engaged in the governance of the resource. This implies that the sub-variable from the outcome category is pre-determined as social performance (O1) and specifically i.e. the self-organisation. This is further clear from the sub-variables of the interactions which direct the analysis towards the performance of the self-organisation. An important question then is: should and how should be SES applied when a researcher is more interested in sustainable resource and lesser interested in governance type as long as resource is sustained? It may sound like a question from eco-theologist who believes that governance does not have answers to all the problems however the question is also relevant from the methodological perspective. It is not fully clear whether the categorical sub-variables remain the same if one starts with an outcome of ecological performance (O2) say lake sustainability or externality (O3). This is a concern because the sub-variables at the interactions will change with the change in the outcome. Three further questions arise: a. what point of reference must be drawn for generating new sub-variables for interactions; b. if new sub-variables are generated for interactions, will the other categorical sub-variables remain same or they will be generated too; c. should we look for the

sub-variables within the proposed ones? This was discussed with Ostrom few times. The sub-variables are general checklist for researchers to organise their data and information categorically within the broad structure of the SES. The list of the sub-variables is open to additions and alterations and is encouraged doing so. The sub-variables must be conceptualised according to the context and analysis (Ostrom in Y673 Lecture, 2011).

What intrigues to apply the SES is whether it is designed to address large scale commons or small scale commons. Most successful commons studies are drawn from small and homogenous community where self-organization is not so difficult (Olson, 1965). Ostrom (2011) suggest medium size community for successful collective action. Neither too small nor too large community can engage in collective action. It is unclear as 'what is that medium size community', that still holds a chance of self-organising. This is a concern pertaining to the growing size and heterogeneity of the urban centres. Besides the philosophical questions community attributes like the sense of belongingness, sense of association to the place, sense of participation (Bal, 2008); the methodological question is about the selection of the large *N* and small *n* of the system under analysis.

10. Design principles, IAD and SES

IAD is embedded in the SES (McGinnis, 2011; Ostrom Y673 lecture, 2011). Besides, since the design principles and the rules are embedded in the IAD, the design principles are also embedded in the SES. A conceptual scheme in figure 8 summarizes how the design principles, rules, levels of analysis and the IAD are embedded in the SES. This is not definitive and requires further discussion.

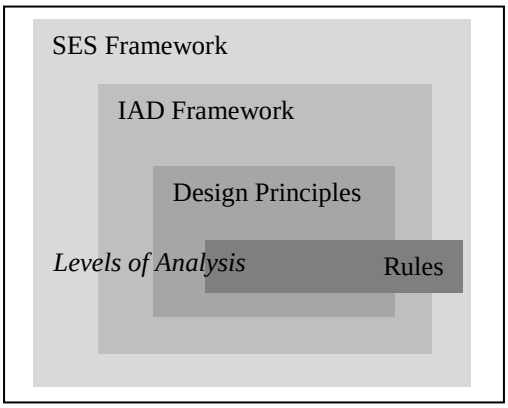


Figure 8. Development of the SES framework

The main area of advancement from IAD to the SES is the change in focal action situation form from the institutional analysis towards combined ecological as well as institutional analysis. The exogenous variables and the actors of the IAD form the focal action situation of the SES. The bio-physical condition and the material condition in the IAD are the resource system and the resource services and units in the SES. The attributes of the community in the IAD is the actors (in user sense) in the SES. The difference is: the actor in the IAD is the governing structure and part of the governance system in the SES. The rules-in-use (belonging to all levels) in the IAD are the governing mechanisms and they are part of the governance system in the SES. The clearly defined boundaries of the design principles is in the resource system of the SES; proportional equivalence between benefits is in the resource services and units of the SES; monitoring, graduated sanctions, and collective-choice arrangements are in the governance system of the SES; and conflict-resolution mechanism

and minimal recognition of rights to organize are in the interactions of the SES. A simulation of broad relationship between design principles, IAD and SES is presented in figure 9.

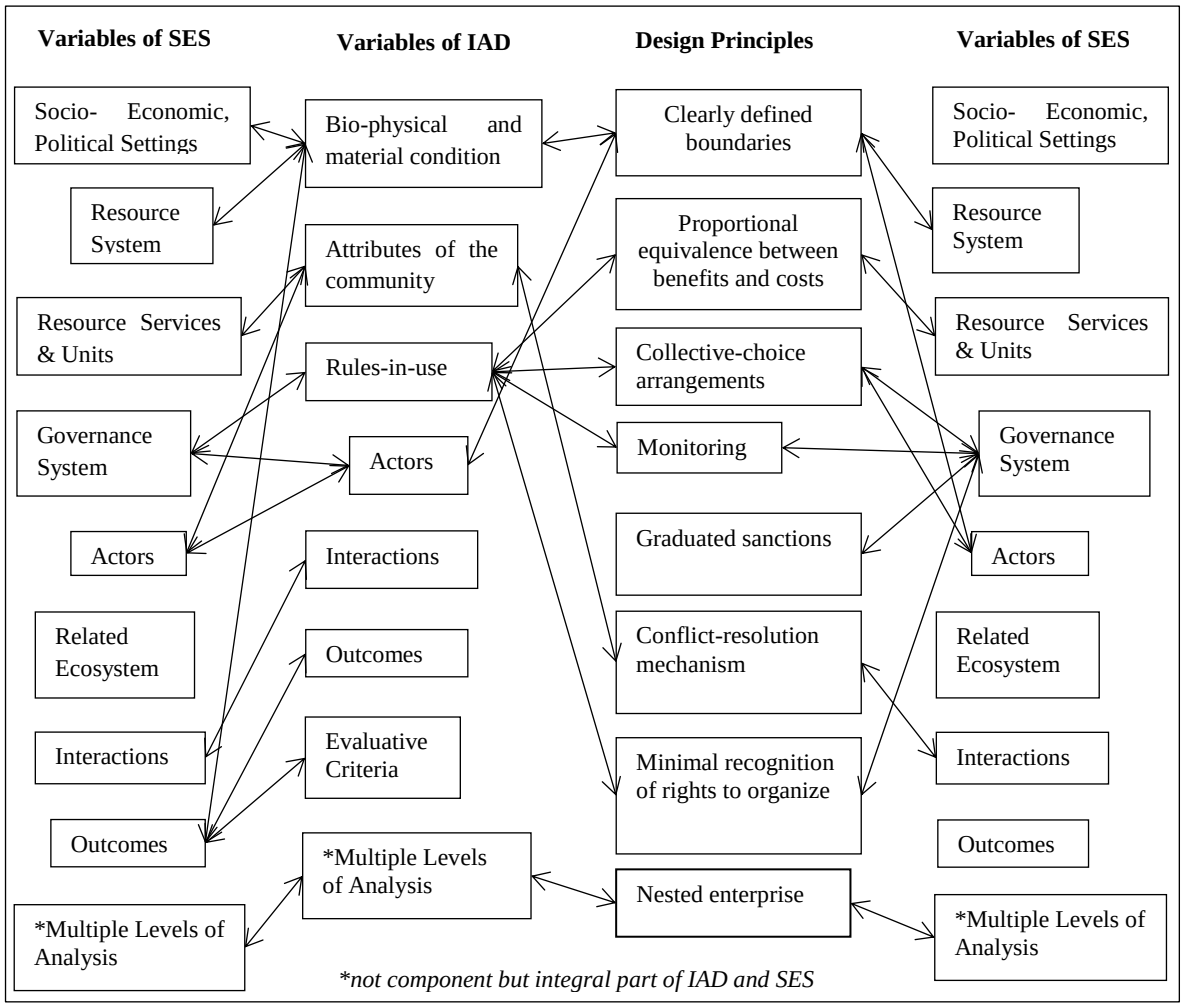


Figure 9. Design Principles, IAD and SES

11. Discussion

Researchers (including Ostrom) are striving to understand the commons governance with specific efforts to relate the self-organisation to the practical challenges of implementing it in the real world. The SES has the foundation in the self-organisation and is directed towards long term sustainable resource management. SES is a product of the learnings from multiple disciplines about the complex linkages between the social and ecological systems and also about recognizing the problem of developing the science of ses. While IAD is a methodological legacy in institutional studies, SES is proposed to grow as crucial methodological framework for linked institutional and ecological studies. SES is conceptualised to help multi-disciplinary researchers to organise their data and information from diverse disciplines into a common framework of analysis. The larger goal is also to make SES a platform for multi-disciplinary researchers speak a common language of the commons and share the commons problems and solutions across disciplines, sectors and regions. At the core of it lies the sustainability of ses. For sustainability of ses it is important to build understanding of how the systems are progressively linked to ever larger systems and how upward and downward causation linkages occur within the systems and subsystems as well as across diverse sectors and scales. SES is a general system framework which has the

ability to address multiple aspects, multiple tiers and nested analysis of diverse social and ecological sub-systems. The strength of the SES lies in its categorical classification of large number of potential main variables and sub-variables which is useful to move beyond the panacea and understand a system. SES is a methodological framework that allows applying multiple methods to understand a system. The categorical classification is a checklist and requires conceptualising the variables with regard to study of urban lake systems. It requires digging deeper into the concepts of the main variables and thus going back to the disciplines from where they originated.

There are unanswered queries about SES and its application with regard to the analysing urban lake systems. To answer them it requires back and forth investigation of the framework and the urban lake systems. The important lesson is: ses are complex systems and understanding complex systems requires knowing about the large number of variables and sub-variables and the linkages they establish with each other within the system and with the other systems and sub-systems. SES is a step towards understanding the complexities involved in a social-ecological system like urban lakes.