Analyzing Indus Delta as a Coupled Social-ecological System

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Abstract

This study applies Elinor Ostrom's Social-ecological framework for the interdisciplinary synthesis of the Indus Delta degradation problem apparently caused by various human and environment induced pressures. The primary objective of the paper is to assess the extent to which the application of SES framework may enhance our interdisciplinary understanding of the delta problems, help raising unasked questions and develop new set of testable hypotheses. The preliminary results from the work done so far reveals that despite high potential of the framework to fulfil its promise, it is a data and expertise demanding framework. Given that time-series data exists or can be generated and interdisciplinary teams can be gathered, the framework can have dynamic application even on a single case like the Indus Delta region

Introduction

Deltaic regions are the microcosms of global environmental change problems and understanding their dynamics has important implication for future directions of global environmental sustainability narrative (Brondizio et al. 2016, Sebesvari et al. 2016). Deltas' strategic location at the confluence of river and sea make them not only the regions high economic and ecosystem productivity but also geographies of high human concentration, recipients of all inland water pollution and battlefields of increasingly harsh sea-land interactions (Tessler et al. 2015, Syvitski et al. 2009, Wolters and Kuenzer 2015, Foufoula-Georgiou et al. 2011). Furthermore, reductions in the volume and timing of river flow and sediment regimes together with rising sea levels force deltas to rollback their pre-Anthropocene progression and sink into seas at an alarmingly faster rate (Tessler et al. 2015, Syvitski et al. 2009, Syvitski and Saito 2007). This reinforces the urgency of understanding of biophysical and human processes in delta regions and invites scientists and policymakers to play their role without any further delay (Foufoula-Georgiou et al. 2011).

It is not say that deltas had been totally ignored by scientists and policymakers in the past. In fact, deltas have long been the subject of disciplinary scientific inquiries. The recent calls for scientific research on deltaic region demand their understanding as coupled social-ecological systems (SES). The SES view considers deltaic ecology and society interdependent and interacting with larger land and sea ecosystems and processes at different spatial and temporal lags (Foufoula-Georgiou et al. 2011). Despite slow progress as noted by Foufoula-Georgiou et al. (2011), there are handful of studies which use SES conceptualizations to understand the dynamics deltas (Sebesvari et al. 2016) but yet more are required. Some of the most prominent SES conceptualization of delta regions include but are not limited to Elinor Ostrom's general SES framework used Brondizio et al. (2016), Driver, Pressure, State, Impact, Response (DPSIR) framework used by Karageorgis et al. (2006), and Yuan et al. (2014), Sustainable Livelihood Approach used by Smith et al. (2013), and Bosma et al. (2012), and Vulnerability frameworks used in many studies reviewed by Birkmann et al. (2013).

The abovementioned frameworks are enthusiastically applied in variety of situations including delta regions by the researchers of diverse backgrounds (Reference), Ostrom (2011) rightly identified the best utility of any frameworks is of a meta-theoretical language that helps organize variables and raise new questions which then can be answered through multiple theories and methods. The Ostrom's general SES framework has certainly edge over various other frameworks on account of its evolutionary history, flexibility due to generalized nature but ability to take analysis at desire depth and responsiveness to various disciplinary criticisms (e.g., Epstein et al. 2013) that ultimately shaped it as a more balanced tool that gives almost equal treatment to social and ecological components. Quite implicitly, but the interdisciplinary focus of framework promise that it would help generate a set of new questions which usually go unnoticed when seen through disciplinary lens. We will use the SES-DELTAS (Brondizio et al. 2016) which is the customized version of Ostrom's framework particularly suitable for diagnosis and interdisciplinary synthesis of Delta problems. Relying on various existing and new data sets we will use SES to assess the degree to which it helps raising new questions and develop testable hypothesis.

The organization of rest of the paper is as follows. Next section locates the SES framework in Human-Environmental Interactions (HEI) literature where we also assess some of SES's criticisms such its static applications and suggest our methodological stance on how we overcame this problem. Subsequently we provide details of our study area, data and methods. Subsequently in the results section we analyze irrigation development on Indus River at Basin level and its impact on hydrological flows to delta region using history and historic flow data. We show how the Indus River system emerged as the world's largest contiguous irrigation network without much regard to deltaic society and ecology and identify historic roots of collective action problem between upstream and downstream communities. We then move to show how deltaic communities have responded to hydrological changes and other environmental and economic forces by changing from an occupationally diverse society to an almost mono-occupational marine fisher community. Here we will show the collective action problem between the urban and rural dwellers of delta region and how that impacts the marine fishery and other deltaic resources particularly mangroves. Finally, we will synthesize the case and draw conclusion about the case itself and the application of SES framework for its ability to raise interdisciplinary questions for future research and policy practice.

Conceptual underpinning

[To be elaborated on following points]

- Human-environmental interaction (HEI) has been one of the most fascinating topics of intellectual deliberation throughout the traceable history of scientific thinking. Initial theories, which sought deterministic explanations, held either geography or culture as single-factor responsible for the prosperity of societies without much appreciating the reciprocal and complex nature of human-environment exchanges (Moran and Brondízio 2013, Acemoglu and Robinson 2012). These theories tried to explain problems ranging from very local to international level outcomes through either culture or evnonmental hypothesis. Plight of Human-Environment Research
- Human Environment Interaction in Sustainability Science Debate

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- Socio-ecological framework as state of the art tool to understand Human environment interaction in general and Deltaic Ecosystem in particular, and its criticism

[Figure 1 and Figure 2 Here]

Methodology

Study area

[To be shortened]

The study area hereafter the Indus Delta extends between 23.15 to 25.00 north latitudes and 67.00 to 68.15 east longitudes. The Pakistani side of Indus Delta administratively lie within the Sindh province and district boundaries of Thatta, Badin and Karachi, whereas on the Indian side, the area it is the part of Gujarat state. The Indus River accumulates huge quantities of sediment from the barren and unconsolidated landscapes of Tibetan Plateau, Karakoram and the Indus Suture Zone and has formed a broad valley and an extensive Delta along the Arabian Sea in Pakistan (Giosan et al. 2006). The tidal delta of the Indus River spans over 6,000 square kilometers between Kirthar Range in the west and Gujarat state of India in the east. Except Kori Creek, the entire Indus Delta falls within the political boundaries of Pakistan.

The Indus Delta comprises of numerous tidal links, creeks, sand dunes and mudflats of varying sizes. The soils of the deltaic region are alluvium, poorly drained, non-permeable and are enriched with the clay derived from the sediment laden flows of the Indus River (IUCN Pakistan 2005). The alkalinity (pH) of the soil ranges between 7.5 and 8.6 (Rehman A, undated cited in PFF 2008). Muddy clayey soils of the Deltaic region are poor in minerals, nevertheless it is highly rich in the salt contents such as Sodium Chloride, Sodium Carbonate, Nitrates besides containing some amount of the shell fragmented Calcium (SFD 1985) and Micas. The subsoil color ranges from brown or dark brown to dark yellowish brown; the subsoil water table at the depth of 5 to 10 feet is completely brackish and unsuitable for the human and livestock consumption (IUCN-Pakistan 2005). The underlying rocks are marine origin, highly folded, faulted and fissured, and are composed of limestone and clay (SFD 1985).

Despite that the study area falls in the warm monsoon region, hot weather remains relatively pleasant and moderate due to the sea breeze blowing for most part of the year from March to October. Except few cold waves due to western weather disturbances in January that is the coolest month, the study area has mild winter during the period from November to February. This period mostly remains dry, albeit occasional rainfall may occur. The weather turns very pleasant in May with the start of spring that lasts till April. This is followed by a warm summer when the temperature rises and the hot winds blow from the Desert making May as the hottest month. Monsoon coincides with summer (May–September) when the sky often remains cloudy but the area receives most of the rainfall during July–September.

Yearly average total rainfall over the deltaic region is about 219 millimeters; nevertheless, the years with no rainfall are also not uncommon. The seasonal variations in temperature and monsoon patterns resemble with other coastal areas of the dry tropical and sub-tropical zone. The relative humidity is normally above the comfortable level for humans but it could further aggravate during June to September and causes sweating and discomfort for the local inhabitants. The normal wind velocity ranges between 7.5 and 20.5 kilometers per hour but could substantially increase to attain the cyclonic levels making the human settlements in the study area prone to the modest frequency of tropical storms which occasionally could be very intense aw well (IUCN-Pakistan 2005).

Study approach, Data, and Methods

[To be elaborated and expanded]

- Field Survey of 250 marine fishers to understand people's response to changing river regimes (3 points in time Distant Past, Recent Past & Nowadays) See Figure 6
- Remote sensing and GIS analysis (For mangrove cover change during 1970s to 2016 four data points and mapping of other available data). Remote sensing analysis is yet not in hand but other trends are depicted [details of methods will be the supplementary material]
- Secondary statistics on flow regimes, marine fish catch, population and pollution obtained from various statistical reports and published materials.
- Historic analysis through literature review

Results

Development of Irrigation Network and its impact on river flows to Delta

The Indus has long history of irrigation development that can be traced for at least five centuries (Wescoat Jr et al. 2000, Wescoat Jr 1999). Even before British control of Sindh and Punjab there were government interventions in irrigation albeit at small scale. British pioneered the large scale irrigation projects on the Indus and developed. However, patrician of British India, subsequent signing of Indus Treaty gave Pakistan a control of the Indus Basin that has never been achieved before its history.

[Discuss Indus treaty, its environment foresights, Surgery of Rivers also discuss other institutions developed on the Indus such as Water Accord 1991 and its impact on interprovincial distribution; Collective action problem between head and tail reaches at every level of the system]. [See Figure 3]

[Discuss entities involved in various irrigation projects [See Figure 3]

Currently, the course of the Indus river system is regulated through three major dams, 23 barrages, 12 inter-river canals, 48 perennial and non-perennial canals, and about 106,000 watercourses (Hameed 2007, Kamal 2008). The regulated water irrigates about 18 million hectares, accounting for 80% of the farmlands of Pakistan (Rizvi 2001, Bengali 2009). [Length of system in miles/km and volume of water it channelized to be included]. The expansion of irrigation system had considerably altered the volume and the timing of river influxes into the delta (Figure 3). The trend over most part of last century in freshwater discharge and the number of zero-flow days to the delta region suggests that besides the drastic reduction in the volume, the timing of the discharge had also been badly interrupted. The delta, that received flooding throughout the year until half a century ago, experienced drought extending up to three quarters of the year. Consistent with the official statistics, the local communities also reported that since long the delta had been receiving meager water fluxes from July to October in the years when there is high precipitation in the river catchment. This is because the river water had been increasingly diverted to upstream agriculture as could be observed from the increasing trend in the farm-gate availability of irrigation water.

[Figure 3 here]

Local response to reduced flows to the delta region

The society, that once organized itself loosely around fishing, camel herding and crop-farming groups, could not withstand these hydrological changes. Particularly, the crop-farmers (who also kept cattle) and camel herders lost their livelihoods as these were primarily river dependent. Loss of livelihood pushed them to seek alternative livelihood that was invariably the marine fishery because of its availability at their doorsteps. Currently, 87% of locals are engaged primarily in marine fishery, despite the fact that both crop farmers and camel herders historically considered fishing as less prestigious occupation. [to be elaborated on percentage of population engaged in different occupations]

With some exceptions, all erstwhile occupational groups have perceived an overall negative change in the quality of their occupations based on their response to five dimensions of occupational quality, namely, income security, life security, labor intensiveness, job security and social status associated with an occupational activity. The original fishers, who were already at the bottom of social stratification, have witnessed a negative trend in all except the “social status” dimension of their occupation. The erstwhile camel herders who temporarily benefited from more frequent and relatively higher incomes (compared once a year and meager income when they were camel herders) but were unhappy about all other dimensions including the feeling they had to engage in an occupation that they always consider inferior. The crop farmers are the one who reported highest levels of dissatisfaction with change in different dimensions of their occupational quality over the years. All current fisher consider the once lucrative fishing grounds as no more profitable and to maintain their regular fish catch, they increasingly venture into deep and remote waters at the risk of their lives. Besides, they think that the marine fishery suffers from overcrowding, pollution and absence of river flow and that their livelihoods are once again under threat.

[Figure 6 here]

Collective action at Delta level

Elaborated on Urban/Rural communities

Pollution due to human and industrial waste

There are apparently two gigantic sources of pollution in the Indus Delta. A relatively well known sources I the domestic and industrial wastewater from Karachi metropolis. The city alone houses about 6000 small and medium scale industrial unit or 60 percent industrial base of Pakistan (Khalil 1999) and more than 18 million human populations. Everyday about 104 million gallons of sewage and 157 million gallons of the industrial effluent has been drained into the mangrove rich creeks of the Karachi Coast (Qureshi 2004). Further the polluted water from various establishments such Pakistan Steel Mills, oil pollution created the cargo operations at the Port Qasim and two oil refineries is also drained into sea through the mangrove ecosystems (Qureshi 2004). This wastewater contains various kinds of detergents, heavy metals and toxic chemicals which create algal bloom hampering the growth of mangroves and also has been considered as fatal for the aquatic resources of the Karachi Coast (IUCN-Pakistan 2005, 2003). The Government promotes the industrial expansion and trading centers and has recently established the Port Qasim Industrial Estate where the industry is yet to flourish. Expansion of Karachi City – a small fishing village before year 1839 and presently a megalopolis of more than 18 million population – in all direction including the mangrove rich creeks and islands is supposedly accelerating the extinction these coastal ecosystems.

Figure 5 here

- [Elaborate known impact of this pollution and discuss future plans that government has about this issue]
- [Elaborate on Agriculture and supermalls wastewater disarranged the Left Bank Outfall Drains]

Mangrove ecosystem

[To be written]

Other factors

[Elaborate on Seismic, oceanic factors, Sea-level rise and coastal erosion]

Conclusions and implications

[To be written]

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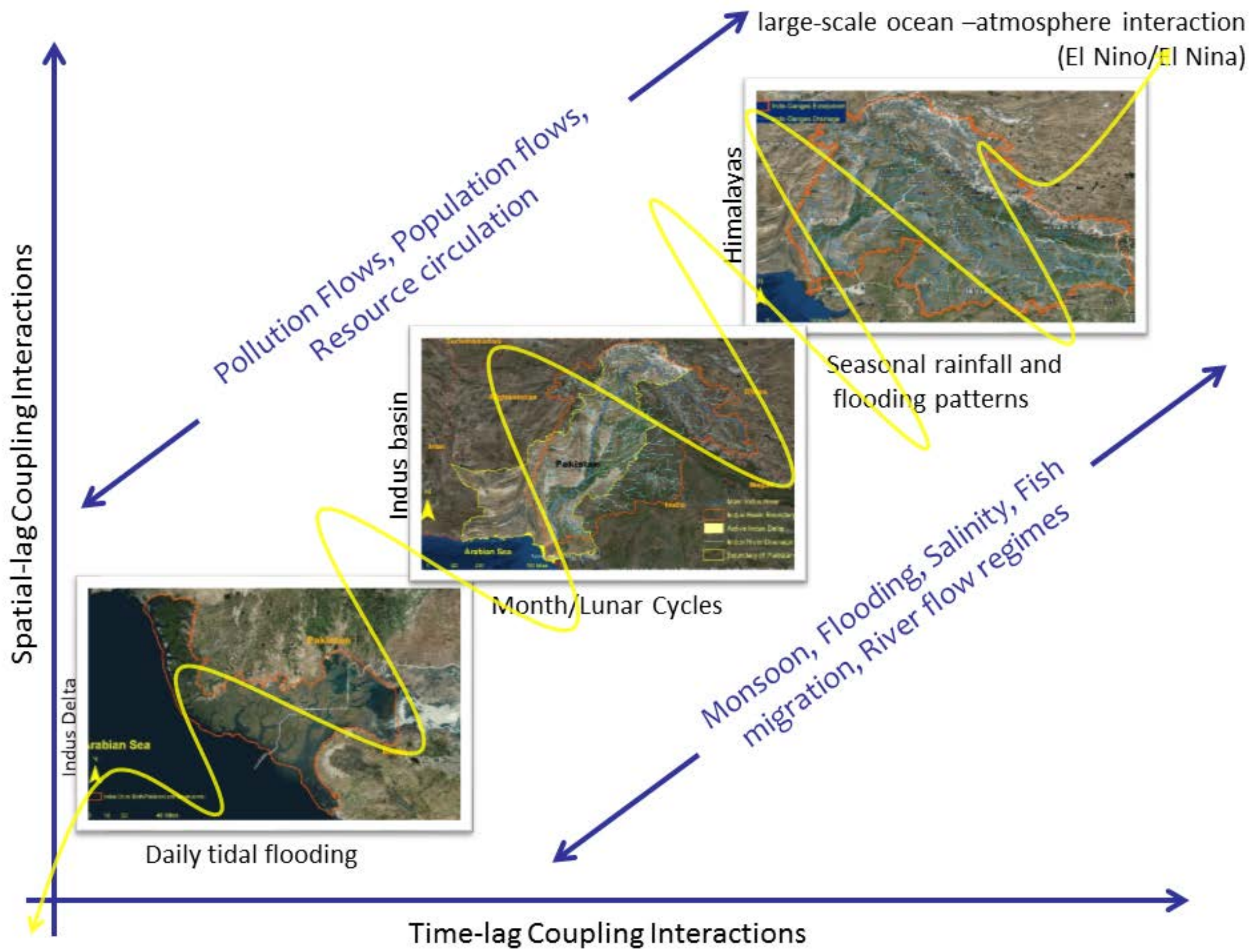


Figure 1:
Temporal and special lags influencing Indus Delta [adopted from

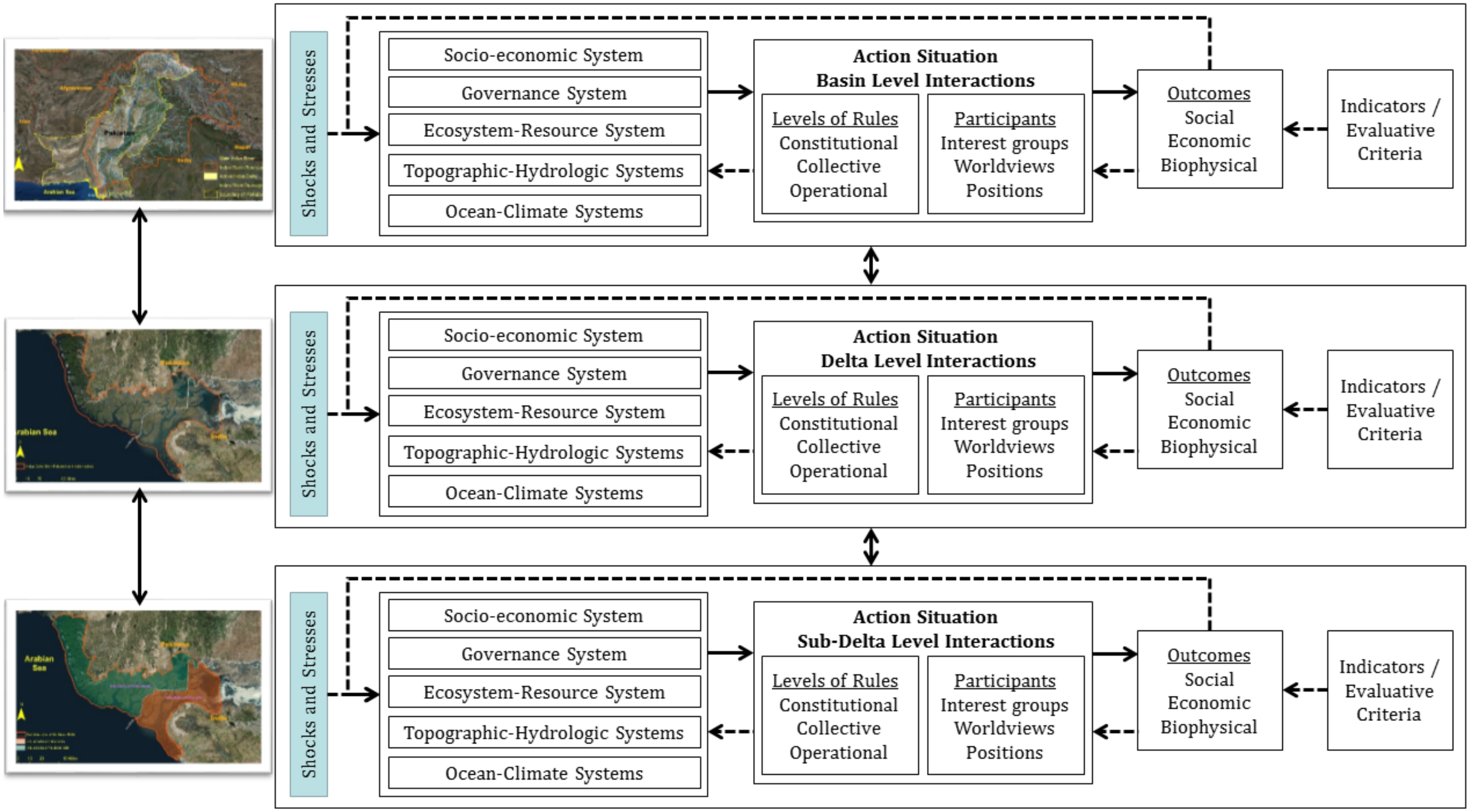


Figure 2
Multi-level collective action situations influencing deltaic ecology and society

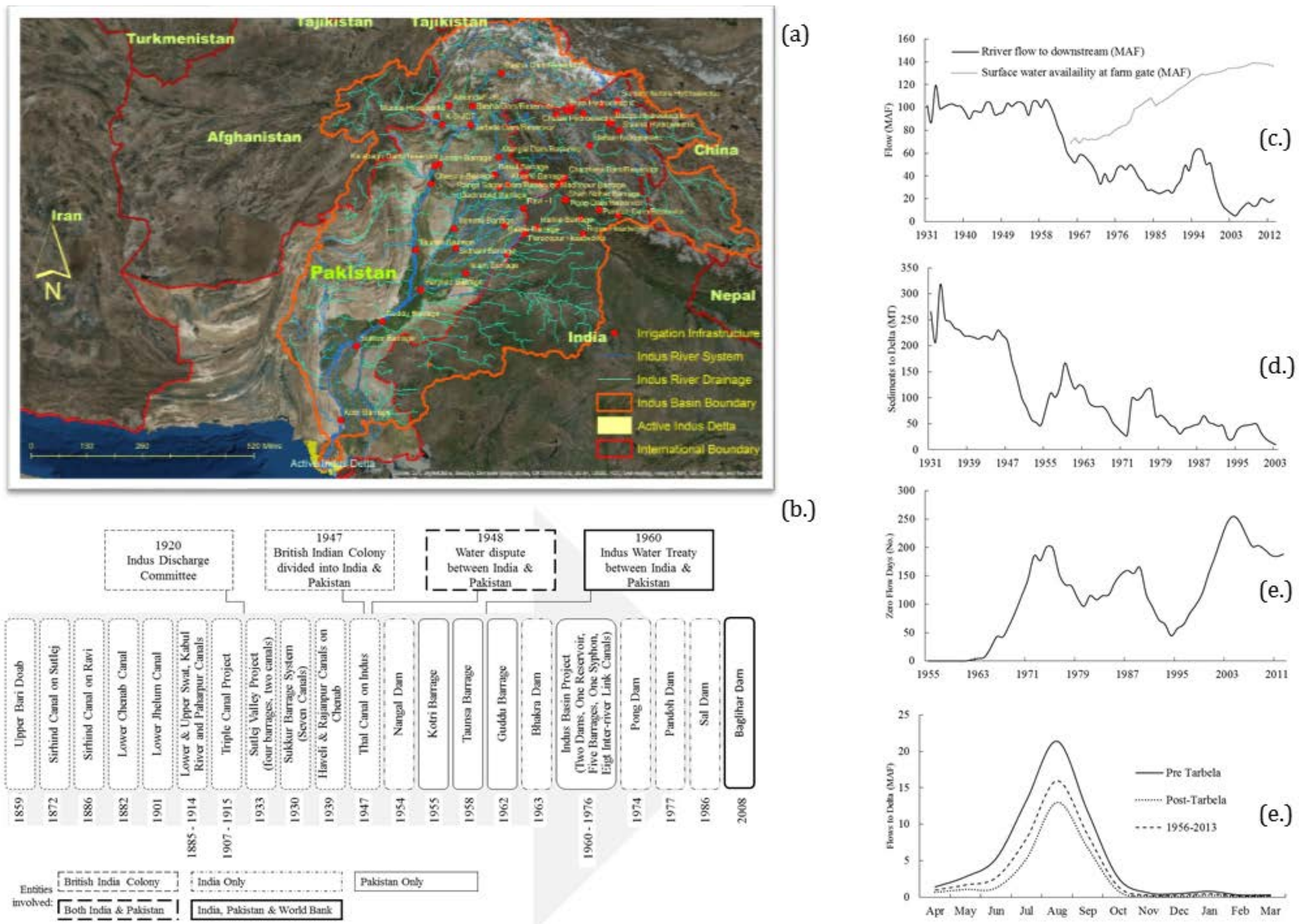
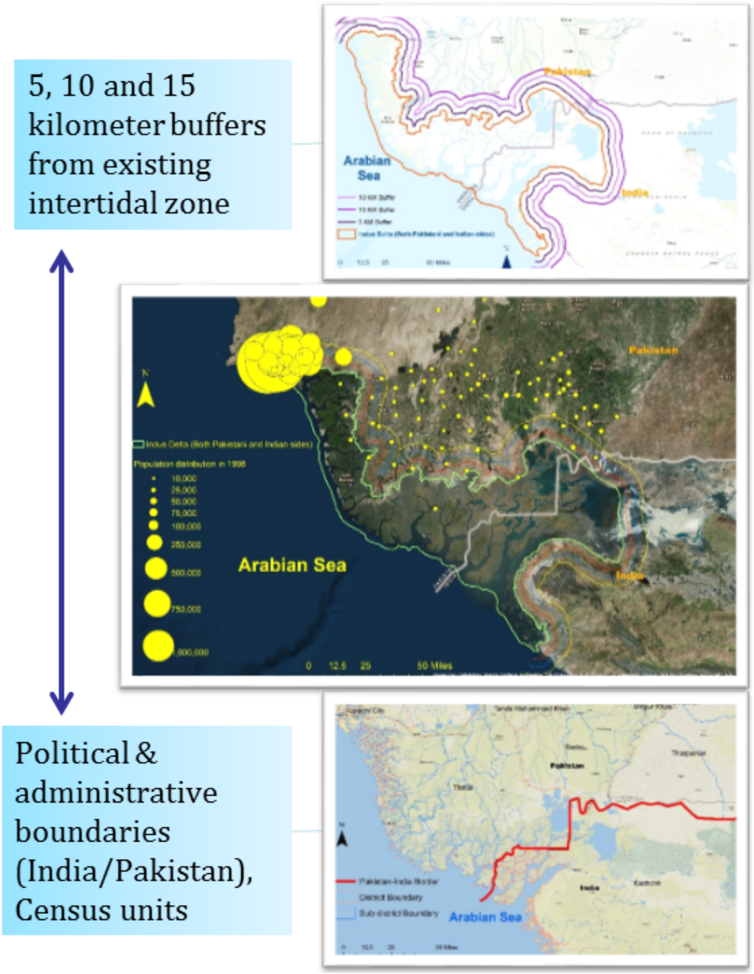


Figure 3:

Development of world's largest irrigation system on the Indus River and its impact on hydrological impact on the delta region: (a) Political and Basin boundaries and existing irrigation infrastructure on the Indus; (**b**) Timeline showing major irrigation works on the Indus, besides depicting major institutional changes in the history of river management [Drawn based on FAO xxx]; (**c** through **e**) Five-year moving averages of quantity of water, sediments, dry periods and dry period timing, respectively [trends compiled from WAPDA 1969, 1970, 1971, 1972, 1973, 1974; Giosan and others 2006; WAPDA cited in Hameed 2007 and MINFAL cited in MoF 2009]



Political and Administrative Indicators		
Countries involved	2	India & Pakistan
Districts	3	Pakistan (2), India (1)
Megacities	1	Pakistan (Karachi, 18 Towns)
Area under tidal influence		
Population in 20 km buffer	19 M[1]	Skewed towards Karachi, Pakistan. Indian side is sparsely populated
Biophysical Indicators		
Prominent Land feature	Mudflats	See Fig.xxx
Prominent vegetation	Mangroves	See Fig.xxx
No of Major Creeks	17	All except two (Kori and Nirani creeks) at Pakistani side
No of minor creeks	Numerous	See Fig
Erosion	12.7 km^2/y	Syvitski et. al, 2013
Climatic indicators		
Rainfall	220 mm	Indian side receives relatively more
Temperature	Max 33 – Min 21	Annual mean of 1961-2008
Humidity	57.14 %	Annual mean of 1960-1990
Flow regimes	35 MAF	See Fig.xxx
Sediment load	~13 Mt.	See Fig.xxx

Figure 4 :
Boundaries and buffers of active intertidal zone currently considered as Indus Delta besides showing snapshot of political, administrative, biophysical and climatic indicators and population concentration

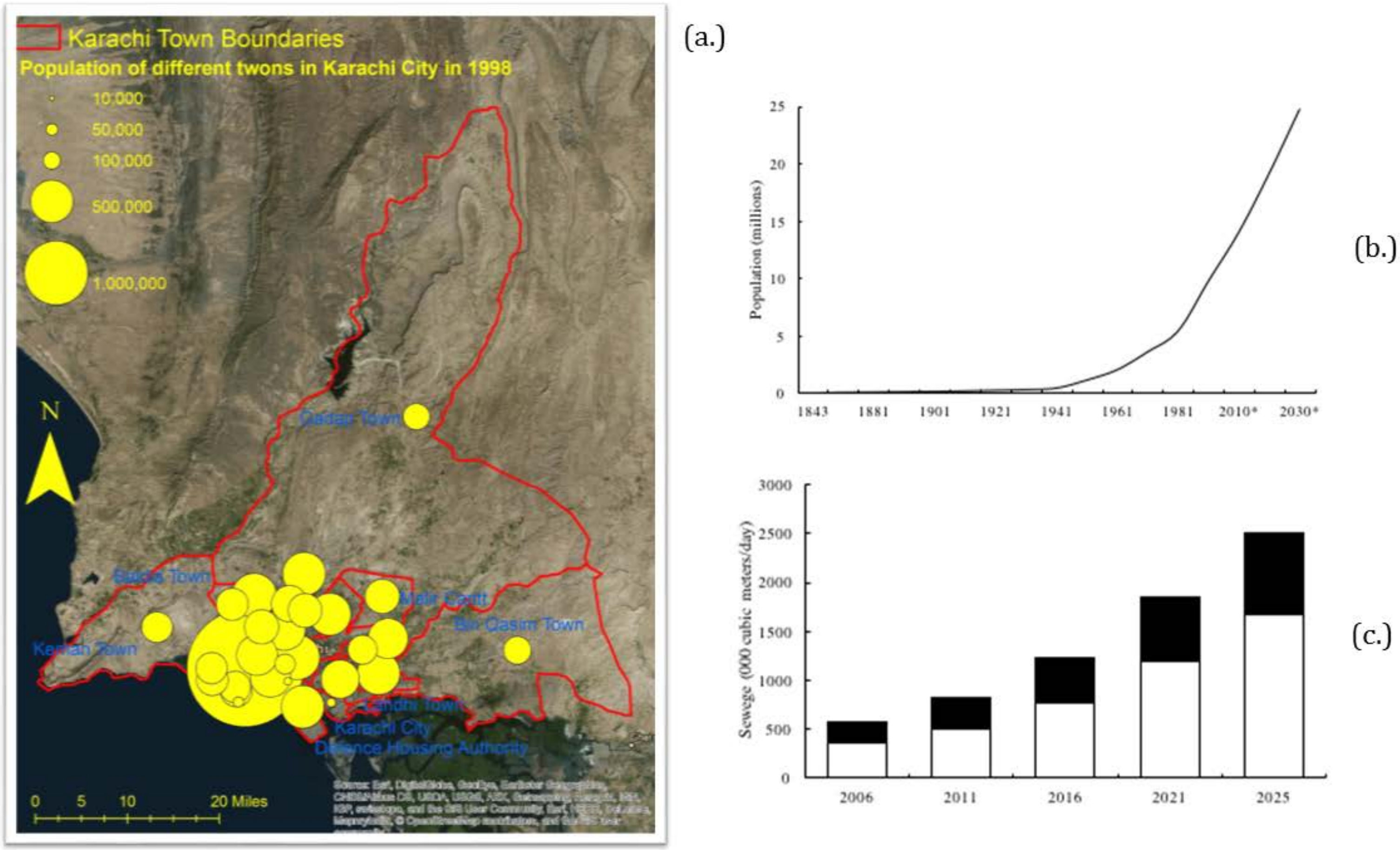


Figure 5:

A close up of major urban Development (Karachi megacity) in the Indus Delta: (a) Population distribution in 18 towns of Karachi megacity in 1998; (b) Growth of Karachi City from 1843-1998 and projections up to 2030; (c) Estimate of domestic and non-domestic sewage generation by Karachi

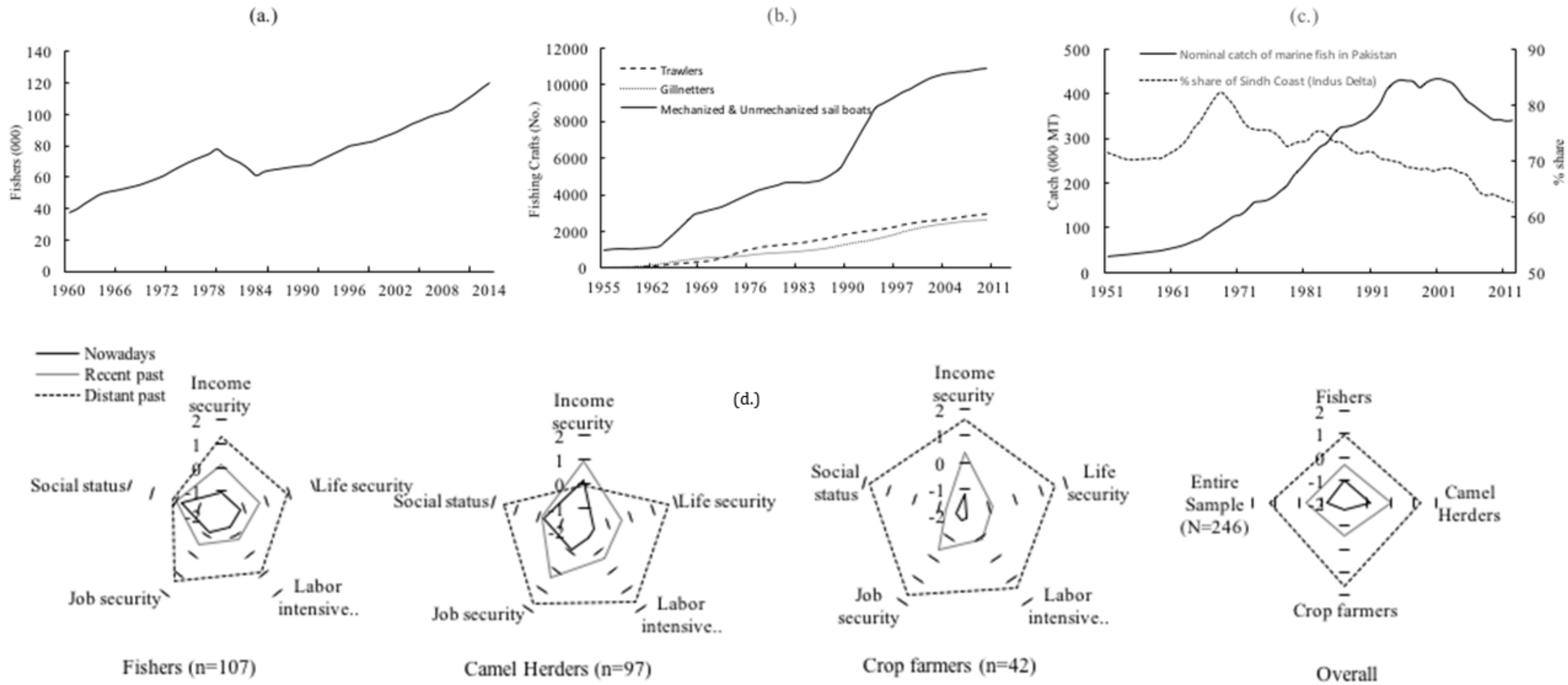


Figure 6:
Trends in marine fishery and fishers livelihoods: (**a**) Growth of fisher's population; (**b**) growth in different types of fishing vessels; (**c**) Quantity of nominal catch of marine fish and percentage share of the Indus Delta; (**d**) Self-reported change in the livelihoods of erstwhile fishers, camel herders and crop farmers who all are now primarily engaged in marine fishery (Field Survey 2009-2010)