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- Everard, M. and West, H. (In press). Livelihood security enhancement though innovative water management in dryland India. *Water International*, 1874780, In press 11jan21.

Livelihood security enhancement though innovative water management in dryland India

(A case of GVNML initiative in Laporiya and surrounding villages)

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Abstract

Locally nuanced community-based shallow groundwater management interventionshave proven important in saline and sodic monsoonal regions. A mixed methods approachcharacterises achievement of regeneration of the formerly degraded socio-ecological system of Laporiya village in the semi-arid Salt Lake region of Rajasthan state (India), with a focus on locally adapted chauka systems. Local people are key participants and agents as well as principal beneficiaries of innovative nature-based management interventions. Technological innovations and governance are adapted to environmental processes and local livelihood priorities,

resisting imposed engineered solutions. Findings are transferrable to dryland areas facing similar challenges of declining water and livelihood security.

Keywords

Salt Lake region; water security; nature-based solutions; chauka; community-based management, Rajasthan

Introduction

Rajasthan state, India, spans 342,239 km², with a human population of 68.5 million (75.1% urban and 24.9% rural) (Census of India 2011). Poverty is a pressing issue, Rajasthan ranking 17th by Human Development Index out of India's 23 states in 2007-8 (IAMR 2011), with India 131st globally (UNDP 2016). Rajasthan is arid or semi-arid, 91% of its annual rainfall occurring during the south-west monsoon (July to September) varying from 1,000cm over south-eastern parts to 14cm over the extreme north-west (RajRAS 2017). Water security, defined as "the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks" (Grey &Sadoff 2007), plays a significant role in perpetuating poverty (Barker*et al*. 2000). Communities in Rajasthan haveinnovated a diversity of water management solutions, community-based and nature-based geographically adapted to promote infiltration of episodic monsoon run-off into groundwater or storage structures co-managed communally to meet year-round needs (Sharma *et al*. 2018). The long-term adoption of these nature-based solutions (NBSs) for water management, defined as solutions "…inspired and supported by nature and use, or mimic, natural processes to contribute to the improved management of water" (UN Water2018), reflects an adaptation to the challenging, erratic climate (Pandey *et al*. 2003).

However, under late British colonial rule and following Indian Independence in 1947, progressive centralisation by the state of ownership and management of water has dispossessed and disempowered local people. A "*More from further*" approach

(sensuBarraqué*et al*. 2008) continues in Rajasthan, burgeoning cities and other centres of intensive demand diverting resources from increasingly remote locations with perceived excess water. Appropriation of water is enforced, often under protests in donor regions, through power asymmetries between rural, urban and industrial stakeholders, tending to result in unequal sharing of water (Birkenholtz 2016). Water scarcity remains a major constraint upon both urban needs and development across the state (Roberts *et al*. 2013). Problems of water security are both quantitative and qualitative (Cook &Bakker 2012), including the impacts of geologically contaminated groundwater and various forms of pollution (CGWB n.d.). Problems are particularly acute in Rajasthan's Salt Lake region, where shallow, saline aquifers compound the viability of land for food production, with associated significant risks from unsustainable fresh water management (Singh 2015).

Growing water scarcity is refocusing civil action and the policy environment on reinstatement of local recharge of groundwater from monsoon run-off. Restoration of community-based groundwater recharge and stewardship infrastructure using nature-based solutions (NBSs)has enabled linked socio-ecological regeneration in villages in some rural catchments in Rajasthan (Rathore 2003; Sinha *et al*. 2013; Everard 2015) and elsewhere in the world (UN Water2018). Progressive policy-makers have paid attention to successful transformation of formerly degrading socio-ecological systems into regenerative systems, where restored catchment hydrology and ecology through community-based NBS interventions provide water and livelihood security including stimulating the return of farmers who had formerly abandoned their villages. In particular, the Government of Rajasthan instituted a flagship *Mukhyamantri Jal Swavlamban Abhiyan* (MJSA: Chief Minister's Water Self-sufficiency Mission) programme promoted local water recharge solutions within a long-term vision of a water-sustainable Rajasthan (Government of Rajasthan n.d.). Although the MJSA programme has now finished, roll-out of related water self-sufficiency programmes are facilitated by multiple NGOs promoting local reintroduction of traditional and modified infrastructure. Restoration or strengthening of social and local governance structures is as important as physical infrastructure in achieving sustainable local water management (UN Water 2018).

Since the 1980s, Laporiya village in Rajasthan's Salt Lake region has implemented a diversity of water interception and conservation measures under communal stewardship. These have restored supporting ecosystems, grazing and livelihood security, including substantially improving drought resilience even after the long, dry summer of 2019 (Singh 2019a). Over the same period, socio-ecological systems in many adjacent villages without comparable water management interventions have continued to degrade, with subsequent outmigration and abandonment (Everard 2018).

Nature-based solutions (NBSs) work with natural processes, protecting and generally enhancing the capacities of ecosystems to produce to range of linked ecosystem services. The Millennium Ecosystem Assessment (2005) classification of ecosystem services, defined as "…the benefits people obtain from ecosystems", spans qualitatively differing provisioning, regulating, cultural and supporting service categories. Specifically, exploitable fresh water (a provisioning service) is enhanced through hydrological and other ecosystem interventions through NBSs, co-beneficially enhancing linked services such as biomass for grazing with associated benefits to farming and food security. In this study, amulti-methods approach – informant interviews in Laporiya and the adjacent village of Antoli, field observations and literature review – informedecosystem service assessments using the Rapid Assessment of Wetland Ecosystem Services (RAWES) approach (described in the Methods section). Findings were further stratified using the STEEP (social, technological, environmental, economic, political) framework to contextualise outcomes within the wider socio-cultural system. Analysis of remotely sensed data triangulated the empirical findings. Transferrable lessons were derived for regions facing similar problems.

Methods

A multi-methods approach,comprising informant interviews, field observations, literature review and analysis of remotely sensed data, is used in this study for temporal comparison of pre and post water management interventions in Laporiya,

and spatial comparison with a broadly similar adjacent village (Antoli) lacking as intensive water management. These comparisons were made using the RAWES approach, with findings further stratified using the STEEPframework to contextualise outcomes within the wider socio-cultural system.

Laporiya and Antoli villages and their recent history of water management

The Salt Lake region of Rajasthan has low-gradient slope and receives average annual rainfall of 323mm (Baruah 2008). Saline and sodic shallow groundwater and soils present significant problems, necessitating efficient capture and retention of moisture from monsoon run-off in the soil's surface layers to store exploitable water, refresh grass and other vegetation maintaining grazing and agriculture, and support trees. An estimated 18-20% of the area of all villages in this region comprise pasture, 5-7% are covered post-monsoon by water bodies, 65-70% are agricultural, and 5-10% are barren (Singh 2019b).

The adjacent villages of Laporiya and Antoli(Figure 1) within Rajasthan's Salt Lake region are similar in area, geographical features and population, yet differ in terms of the extent of nature-based water management interventions specifically including chauka. (Descriptions of the villages and their recent history of water-related interventions is outlined in Annex 1.)Physical works implementing chauka (described below) and other water-harvesting structures (WHSs) in Laporiyacommenced in 1987. These were innovated and led by the local NGO GVNML (*Gram Vikas Navyuvak Mandal Laporiya*). Laporiya's novel water management interventionswere largely completed by the late-2000s. By comparison, as of early 2018, water management and general conditions in Antoli were approximately where Laporiya was prior to major water management interventions from 1987, with similar geography, culture and area. Antoliis therefore a relevant spatial comparator to Laporiya to assess how chauka implementation has influenced water availability and associated ecosystem services.

Figure 1: Location map of Laporiya and Antoli villages, noting key features

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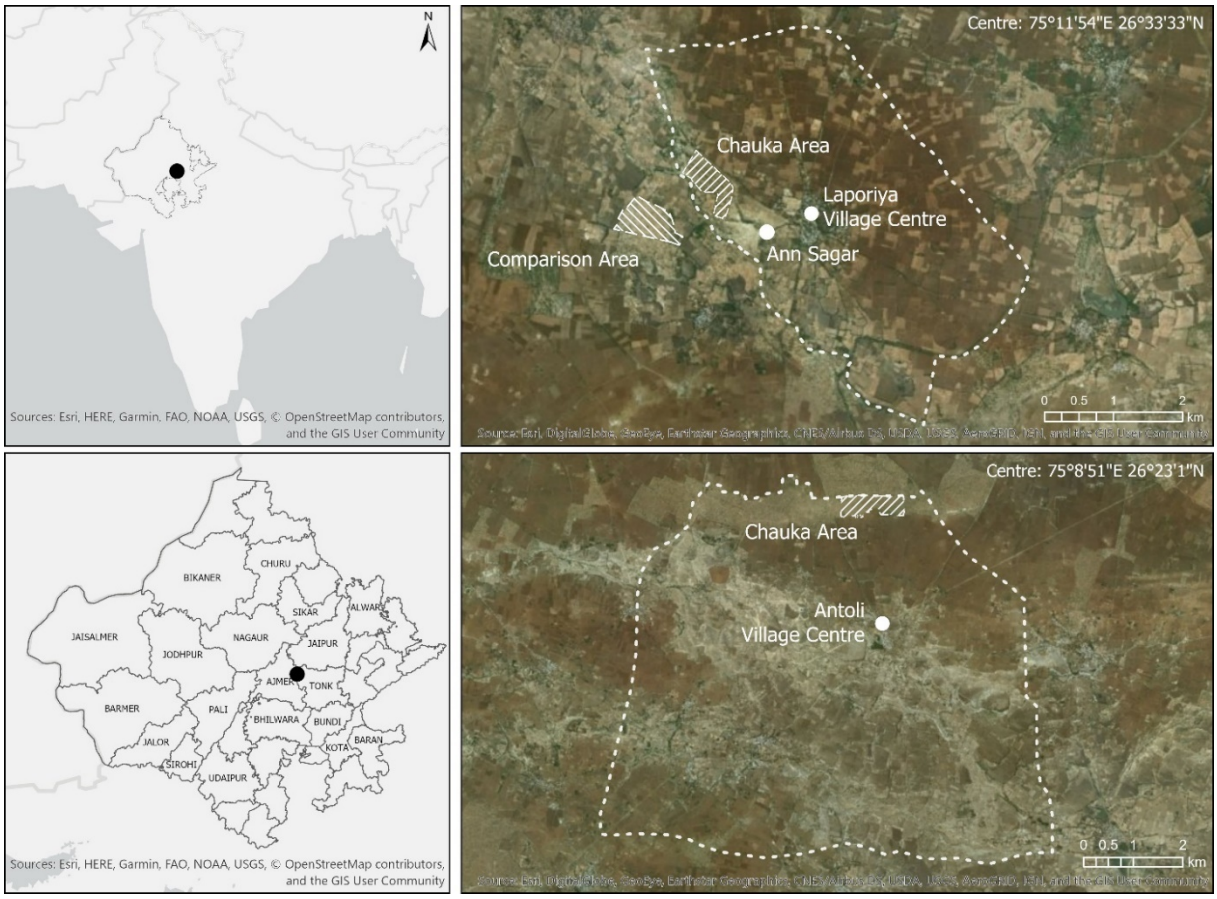
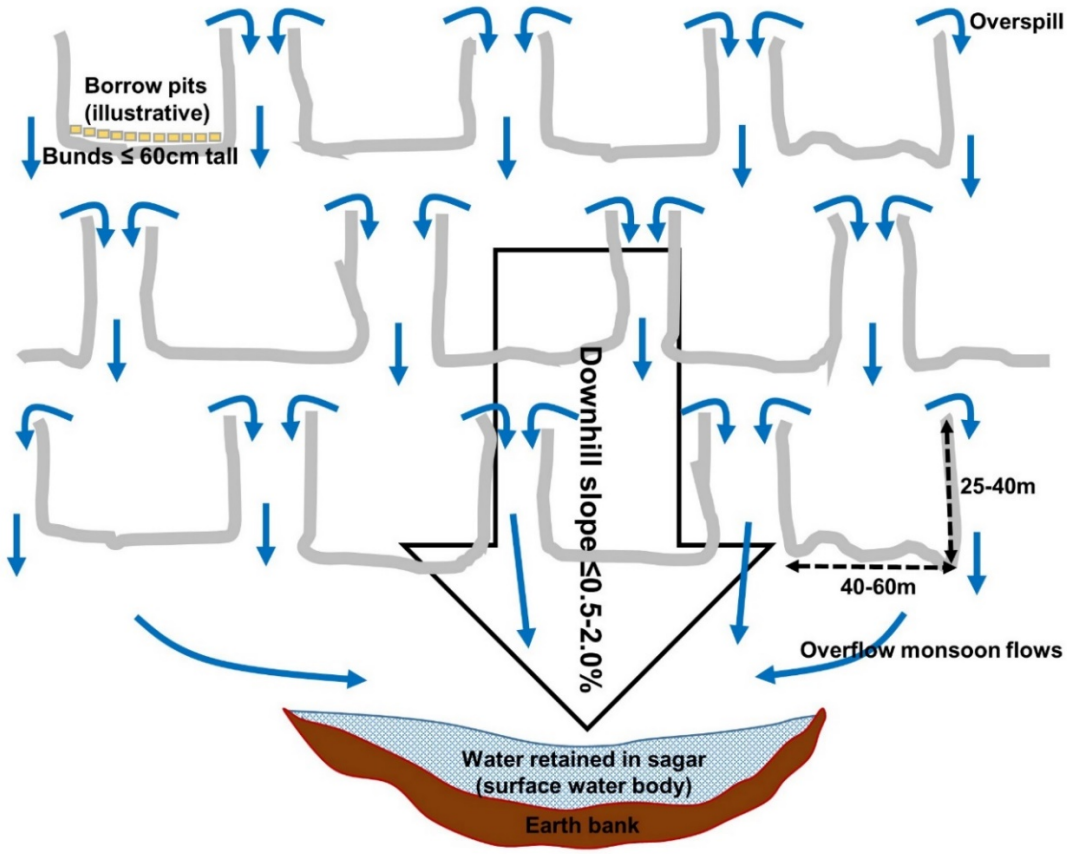


Chauka are a geographically-specific water-harvesting nature-based solutions (NBSs), implemented on common grazing land, innovated specifically addressing the unique low slope and saline conditions of this Salt Lake region of Rajasthan. Chauka comprise interlocking networks of low bunds on three sides of a rectangle on non-arable areas built from spoil won from pits inside the rectangle (Figure 2). Spillways at the upstream edges of the bunds allow the free flow of water into adjacent bunded rectangles, and from field-to-field. Water intercepted from monsoon run-off is detained in the chauka, increasing soil moisture and recharging shallow groundwater. A participatory approach that seeks to provide for local needs is an important aspect of chauka design, maintenance and consensual agreements about use to optimise benefits for the community as a whole. Agreements include leaving cow dung in situ to rebuild organic matter and nutrient content, refraining from grazing the chaukas for one-and-a-half months following the monsoon to enable the grass to flourish and produce seed, promotion of native trees, and annual maintenance to which every

villager contributes.Further details of the characteristics and operation of chauka are provided in Annex 1.

Figure 2: Schematic of chauka construction and surface run-off flows (Image © Mark Everard)



Water management solutions in Laporiya are planned in synergy with the water cycle and are implemented communally, as effective collaboration using nature-based solutions is vital as groundwater even a few metres below the soil surface in this region is highly saline. The replenishment of shallow groundwater is therefore critical for avoiding groundwater contamination, many areas around adjacent villages are visibly lacking vegetation owing to soil salinisation. Effective fresh water management is also vital to sustain grazing, agriculture and hence food sufficiency, most cropping occurring in the khariff (wet, post-monsoon) season. However, there are significant areas, particularly downstream of Ann Sagar (the largest impoundment storing monsoon run-off and promoting groundwater infiltration) in

Laporiyawhere replenished groundwater supports spray irrigation for a rabi (dry season) crop (typically chilli, tomato, aubergine, onion and wheat). On some areas, a third jayad (summer) crop is also produced. Private owners of land in better-watered land downstream of naadi (ponds) can produce 250-1,000 kg per hectare of rabi crop, depending on rainfall in any specific year. Under the communal protocols described above, grazing rights to common land enriched by chauka is shared equitably amongst villagers. Compared to the water and food insecurity of many adjacent villages, Laporiya is water-secure and sells water to surrounding villages during dry seasons, with 75% of families producing a marketable surplus of milk, sales of which are used, amongst other purposes, to buy fodder (Padre 2008).

Key informant interviews in Laporiya and Antoli village surveys

Evidence-gathering at Laporiya took the form of semi-structured interviews with a number of informants (N=20) involved in village governance, or with knowledge about other attributes of the village. 14 men and 6 women contributed their views in response to research team questioning. Evidence-gathering at Antoli village took the same form with a number of informants (N=9) involved in village governance, or with knowledge about other attributes of the village, comprising 6 men and 3 women. Informants from Laporiya and Antoli villages and their affiliations, roles and other details are documented in Annex 2.

Discussions took place primarily in Hindi. Questions were introduced by conversation in locally relevant terms and in a semi-structured way rather than through a rigid questionnaire, reflecting the cultural differences between researchers and local people and the diversity of views of the interviewee group (following Everard *et al*. 2019). This approach enabled interviewees to respond freely rather than asking them rigorously to stick to precise questions. Gender sensitivity was considered by selecting informal interviewers fluent in Hindi as suited the respondents. Informants were generally interviewed individually to avert dominance by other individuals, or the withholding of information in public. In all cases, conversation flowed freely with no evidence of withholding information. The note-

takers structured discussion around the ecosystem services framework, concluding discussions when all ecosystem service categories had been covered. Written notes were taken in English, captured at the time of interview but subsequently transferred into digital format. Responses were anonymised so that respondents felt free to express their views.

Interviewees were asked prior to interview for their consent for feedback to be recorded and used in a non-attributable way for research purposes. Interviewees were also offered the right to withdraw from the process at any time via contact details provided for one or more fieldwork facilitators. Additional input was derived from literature searches, as seen in the citations used in this paper.

Assessment of ecosystem services outcomes based on the RAWES approach

Informant interviews and direct field observations in Laporiya and Antolisupported by literature review informed both spatial and temporal comparison of ecosystem services, structured using the RAWES approach. RAWES was developed to support ecosystem service assessment recognising practical time and resource limitations faced by operational staff, being both genuinely rapid and cost-effective, and also as a means to integrate different types of evidence to inform semi-quantitative assessment of all ecosystem servicesacross the four Millennium Ecosystem Assessment (2005)categories (provisioning, regulating, cultural and supporting) on a systemic basis (McInnes &Everard 2017; RRC-EA 2020). Though specifically developed for wetland assessment, RAWES is adapted from an approach applied to a range of habitat types, and can be used across a range of scales from whole landscapes to localised zones of large and complex ecosystems (McInnes &Everard 2017), as for example by Everard (2009), Everard & Waters (2012) and Everard *et al*. (2020). RAWES was adopted by a resolution of the Ramsar Convention in October 2018 as a globally standard means for assessment of wetland ecosystems on a systemic basis (Ramsar Convention 2018).

RAWES assessments score the significance of each ecosystem service, as well as the geographical range over which the benefit is realised, on a scale from 'significantly positive' (++) through 'neutral' (0) to 'significantly negative' (--) or 'unknown' (?) as outlined in Table 1. Data captured in hand-written RAWES field assessment sheets were transposed into spreadsheet format, with some modification in dialogue amongst assessors and other experts where more information became available. (Spreadsheets containing RAWES data are submitted as Supplementary Material.) To express and compare production of the four ecosystem service categories at Laporiya and Antoli, assigned importance scores were numerically transformed as outlined in Table 1to derive an ecosystem services index (ESI). Derivation of an ESI entails summing significance scores within groups of ecosystem services (by Millennium Assessment category or for all services) and dividing by the number of contextually relevant services(RRC-EA 2020). The potential ESI range is from +1 to -1, calculated for each of the four ecosystem service categories, or for the 24 relevant services in total. The same mathematical transformation was used to calculate ESI for total ecosystem service benefits accruing across the four geographical ranges in the RAWES field assessment sheet (local, catchment, national, global) for the 24 relevant services, geographically-based ESIs potentially exceeding 1.0 where benefits accrue across multiple scales.

Table 1: Transposition of RAWES 'importance of service' scores into numeric values for ESI analysis and representation

Assigned importance	**significantly positive**	**Positive**	**Neutral**	**Negative**	**Significantly negative**	**Unknown**
Importance score	**++**	**+**	**O**	**-**	**--**	**?**
Numerical value	1.0	0.5	0.0	-0.5	-1.0	Remove from analysis

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Contextualising outcomes within the socio-cultural system

Ecosystem services outcomes – benefits within the socio-ecological axis – occur within complex societal dynamics. The STEEP (social, technological, ecological, economic, political) framework, developed as a systems model, was used to understand systemic connections in the cultural system enabling socio-ecological regeneration. Though STEEP was initially adapted from a range of allied classification schemes for analysis of an organization's operating environment and preparing for organizational transitions, it has been applied to meeting the goals of sustainability (Steward &Kuska 2011) and for addressing systemic interdependences relating to water systems and associated ecosystem services in India (Everard 2015) as well as Africa (Everard 2013; Everard *et al.*2019) and Europe (Everard *et al*. 2012). STEEP thus contextualises social and environmental outcomes from water management interventions at Laporiya within the broader systemic, influential contexts of surrounding governance, technological choice and deployment, and economic dimensions.

Ground-truthing though interpretation of remote sensing data

Monitoring of moisture in vegetation and soil moisture via remote sensing in dry and arid environments can take the form of estimation of soil moisture content (through active and passive microwave sensors) or through inference based on vegetation condition (West *et al.* 2019).

Various active and passive microwave satellite missions are specifically dedicated to monitoring soil moisture. These include the NASA SMAP (Soil Moisture Active Passive) and ESA SMOS (Soil Moisture and Ocean Salinity) missions. However, these sensors have coarse spatial resolutions resulting in variable success in monitoring local, field-scale conditions (Tavakol*et al.*2019; Quinn *et al.*2019; 2020).

The Sentinel-2 missions comprise of a pair of polar orbiting optical satellites, launched respectively in 2015 and 2017. Sentinel-2 has 13 spectral bands, with the general near-infrared (NIR) band (8) and visible bands (2, 3, 4) being at a notably

finer (10m x 10m) spatial resolution compared to earlier Landsatimagery (Drusch*et al.*2012), and has been noted as being of particular importance for the monitoring of agriculture and vegetation at the local/field/village scale(e.g. Clevers*et al.* 2017; Lambert *et al.* 2018; Vanino*et al.* 2018). This enhances the potential for monitoring vegetation and water resources, the distinctive spectral signature of water in the near-infrared region also allowing for quick identificationof surface water in droughty and semi-arid environments.

NDVI (Normalised Difference Vegetation Index) (Tucker 1979) is a commonly used vegetation condition index in the monitoring of droughty and semi-arid environments (West *et al.* 2019), demonstrated as effective for assessing vegetation response to soil moisture fluctuation under extreme drought using Sentinel-2 data (West *et al*. 2018). The logic behind using the NDVI is that soil moisture plays a significant role in the sustained growth and condition of vegetation (Lavender & Lavender 2016). Longer time series datasets for higher spatial and spectral resolution multispectral imagery were lacking for the study area (Sentinel-2 datais available only from late 2015 onwards). Therefore, as no relevant data preceded the substantial completion of physical water management interventions inLaporiya by 2000 preventing temporal comparison, spatial comparison of Sentinel-2 imagery was undertaken given the close geographic and demographic similarities between the area within Laporiya village in which chauka had been constructed, an adjacent unmodified area of land to the immediate south (just over the village boundary), and the area of Antoli village subsequently converted to chaukaonly in 2018.

To provide contextual information, rainfall estimates were sourced from the Global Precipitation Measurement (GPM) mission for the local region over the full length of the study period, creating a clear illustration of the seasonal monsoon and drought periods. Visual interpretation of the Sentinel-2 imagery was also undertaken to identify whether surface water was present in Ann Sagar (the largest impoundment) in Laporiya.

Results

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Ecosystem service assessment

RAWES assessments, collating evidence from interviews, field observation and literature sources, are recorded in a spreadsheet submitted as Supplementary Material. Key findings are summarised here. In all, 24 of 36 ecosystem services in the RAWES assessment sheet were found to be relevant in Laporiya and Antoli (4 out of 9 provisioning services; 9 of 14 regulating services; 6 of 7 cultural services; and 5 of 6 supporting services). Figure 3 displays ESI scores respectively for current, post-intervention conditions in Laporiya and for pre-intervention condition (combining temporal comparison with spatial comparison with Antoli), broken down by ecosystem service category. Figure 4 presents ESIs for the geographical scales over which services are expressed.

Figure 3: ESI scores for ecosystem service categories, respectively at Laporiya (post-intervention) as compared to Antoli currently and Laporiya (pre-interventions)

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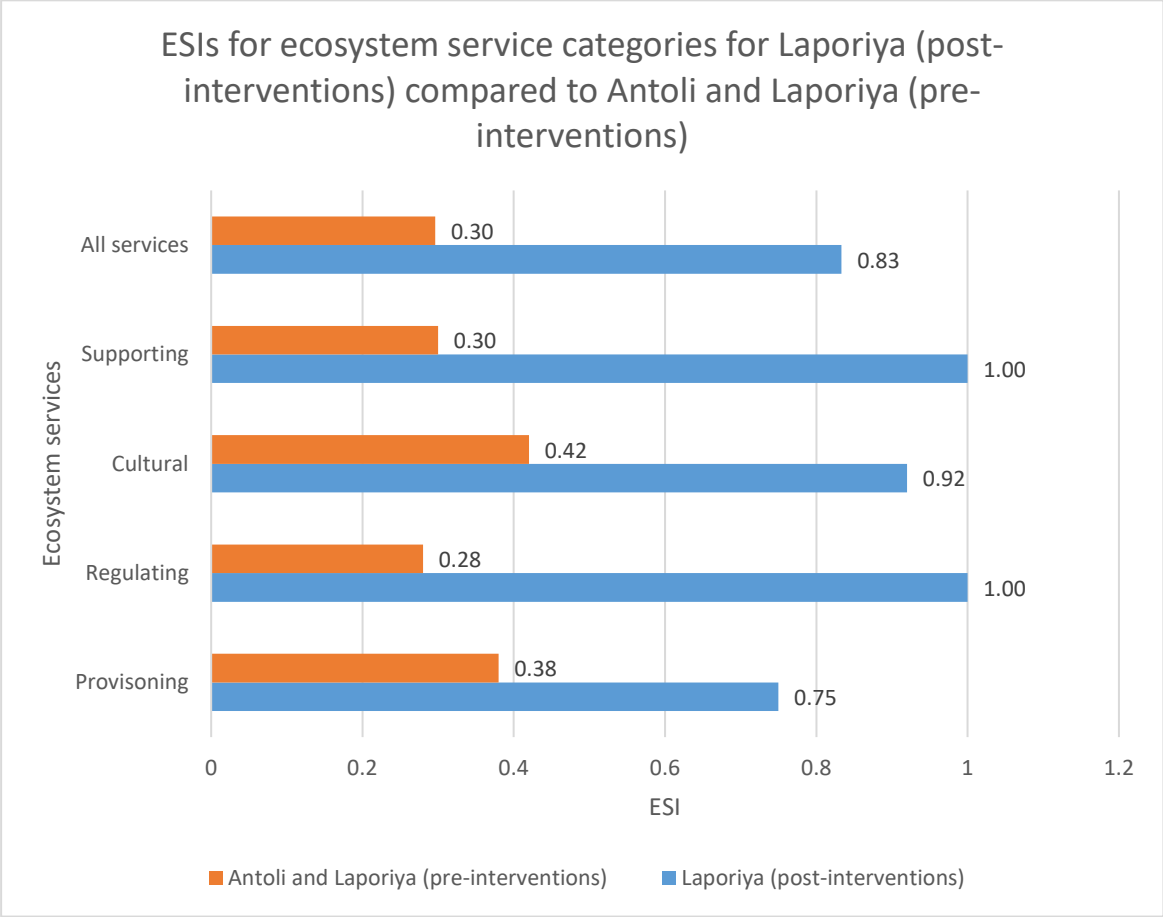

Figure 4: ESI scores for geographical scales over which benefits are delivered by ecosystem services category, respectively at Laporiya (post-intervention) as compared to Antoli currently and Laporiya (pre-interventions)

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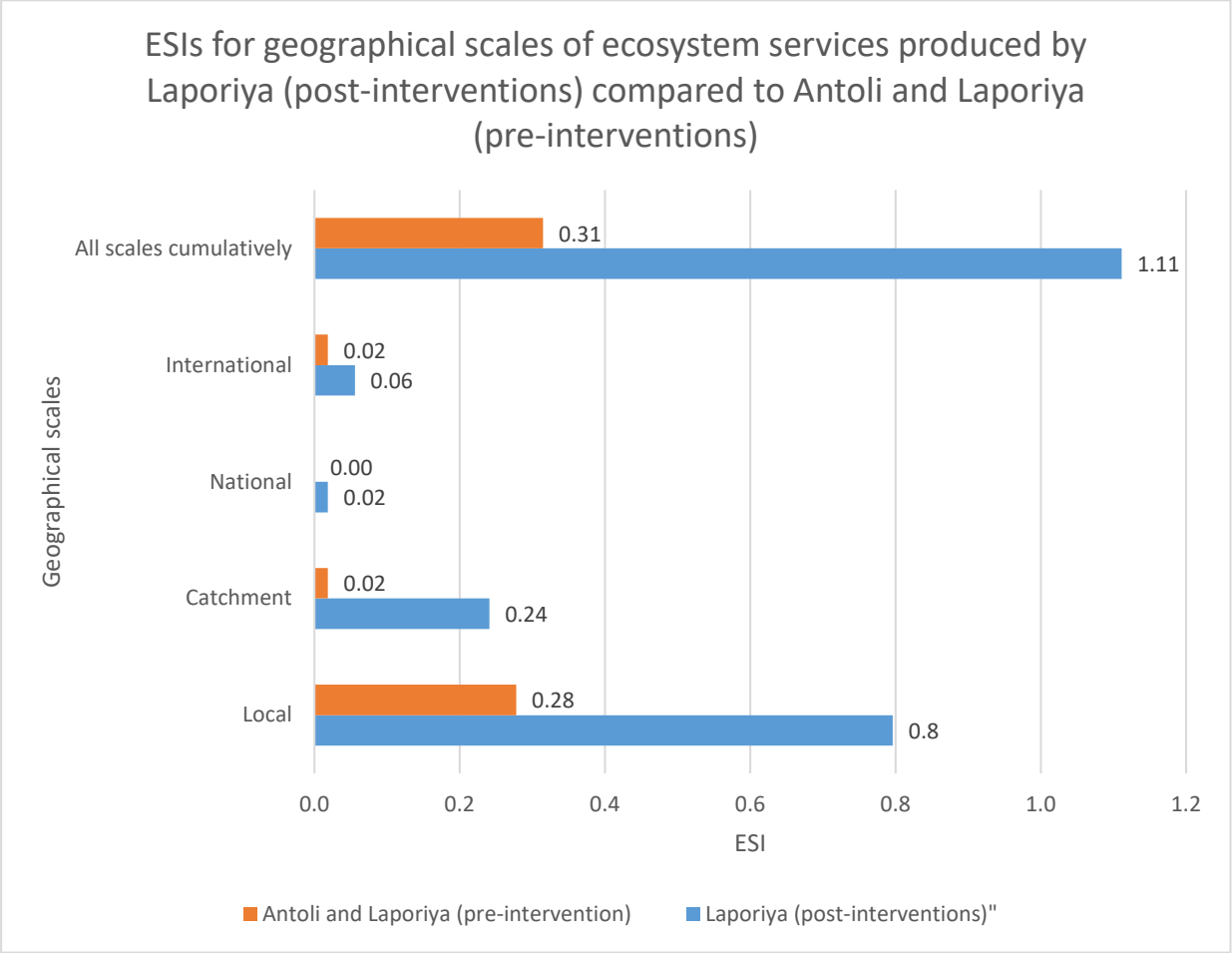

These results demonstrate a very high interdependence of local people with their supporting ecosystems in post-intervention Laporiya (ESI = 0.83 for all services) compared to inferred pre-intervention Laporiya/Antoli (ESI = 0.30) where people were disconnected from the ecosystems and services potentially supporting their wellbeing. For comparison, Everard *et al*. (2019) found combined ESIs of 0.52 and 0.58 respectively in the populated Gosaba Island and the protected Sudhanyakhali Island in Sundarbans of West Bengal, and Everard *et al*. (2020) observed a very high combined ESI score of 0.85 in Lileng village in a tribally controlled rain forest region of Arunachal Pradesh state (north-east India) where community governance maintains close connections between people and the surrounding forest and river resources supporting their livelihood needs.

Benefit realisation at Laporiya is overwhelmingly at local scale (ESI = 0.80 and 0.28 respectively post- and pre-interventions). For the post-intervention state, contributions of services to the wider catchment were the next most significant (0.24) whereas Antoli and Laporiya in a pre-intervention state made little catchment contribution (0.02). Neither pre- not post-intervention conditions made significant contributions at national scale (ESI = 0.02 and 0.00 respectively), nor at global scale (ESI = 0.02 and 0.02 respectively). The cumulative ESI scores across all geographical scales of 1.11 compared to 0.31 respectively for post- and pre-interventions demonstrate the greater societal benefits generated by transformations achieved in Laporiya.

Socio-cultural context

These ecosystem-human interdependencies happen within complex socio-ecological systems, with highly interdependent governance arrangements, technology choice and economic considerations. It is for this reason that the STEEP (social, technological, environmental, economic, social) framework was also used to stratify the information gathered and to explore systemic interdependencies between different components using key and contextual questions. Table 2 outlines interdependencies between elements of this framework through which ecosystem service benefits are governed and realised.

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Table 2: Interdependencies between STEEP components observed in the achievement of transformations at Laporiya broken down by key questions (each component, in grey cells) and contextual questions (systemically connected to other components, in white cells)

	Social	Technological	Environmental	Economic	Political
Social	**There is some historic hierarchy within the village community, but social structure is shaped by communal stewardship of supporting natural ecosystems about which the community holds substantial traditional knowledge**				
Technological	Collective decision-making to steward the primary natural resources underpinning livelihood security for all in the village includes technology choice that is by over-whelming majority nature-based, though using mechanisation to aid transport and harvesting	**The predominant focus of techniques and technologies (such as chauka, anicuts, open wells, sagar, use of forests, birds for natural seeding and fertilisation, and strictly time-controlled grazing) is working with, rather than against, natural processes**			

Environmental	There is a high shared regard for and indigenous knowledge about nature and natural processes, including water flows and retention, seeding, pollination and natural fertilisation including soil fauna, the value of trees in the landscape, and the spiritual and other values of water and water bodies	Water management innovations, particularly chauka, work with natural low topography, timing of monsoon run-off, the seeding cycle of plants, the workings of the natural infrastructure supporting soil moisture and well replenishment, and annual regeneration of grazing	**Multiple regulating and supporting services served by intact or functionally enhanced habitat provide a range of benefits underpinning the linked sustainability of the environment and tribal livelihoods, with active measures to restore the capacities of supportive ecosystems**	
Economic	Economic activities are geared towards subsistence for all in the village, including optimal benefits from shared ecosystem resources through collaborative management	Intensive mechanisation of water management, and of heavy industrial development, is actively discouraged in order to protect the benefits that flow from well-functioning ecosystems	Management of the ecosystem and natural resources is focused on sustainable benefits from maintaining and enhancing their viability and the services they provide, as a primary resource underpinning continuing and collective wellbeing	**The economic system is substantially informal and local, serving the needs of the local community rather than liquidating assets for quick financial gain**

Political	Governance systems are predominantly participatory via the elected Village Development Committee, annual Pad Yatra, and other engagement processes such as agreements amongst grazers about optimal regeneration and use of grazing on the chauka	Decision-making about technology choice and development is founded on working with and enhancing natural regenerative processes upon which communal wellbeing is founded, with all participating in investment of money and labour as well as maintenance	The continued viability, and measures to enhance, the supporting ecosystem are the central preoccupation of governance decision-making in Laporiya, focusing on sustainable livelihoods rather than a 'global north', market-based model of development	Decision-making is founded on sustainable benefit to all in the village, based on security of foundational natural resources rather than intensive profit-taking that skews benefits towards the most privileged	**Decision-making is through Village Development Committee (VDC), resisting state intervention via Gram Panchayat. Agreements reached about development and maintenance of infrastructure, achieved mainly through the VDC and with annual Pad Yatra, are consensual with all participating in required labour**

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Remote sensing data analyses

Amongst the findings arising from analysis of remotely sensed Sentinel-2 data, three sets of results are of particular significance: time series Normalised Difference Vegetation Index (NDVI)to infer vegetation condition in the cropped area downstream of the Ann Sagar impoundment; comparison of NDVI signatures of the area of chauka at Laporiyawith the adjacent non-converted area; and time series NDVI from both Antoli and Laporiya.

Figure 5 outlines NDVI values of the cropped area downstream of Ann Sagar in Laporiya correlated with rainfall, noting presence of water in Ann Sagar. Rises in NDVI lag rainfall. In late 2018, NDVI values also follow the khariff (post-monsoon wet, first) cropping season running from June to October (NFSM 2018), rising sharply after planting following rain and with a corresponding sharp fall after cropping. NDVI values during the rabi (dry season, second) cropping season from February to April (NFSM 2018) witnessed a similar rise and fall. Similar khariff peaks were not observed in 2016 and 2017 (no NDVI data points appear during and shortly following rainfall in Figure 5) due to lack of remotely sensed data caused by cloud cover during rains, though a similar rise and fall can reasonably be assumed during these unmonitored Khariff months in those years. Sampling frequency increased from the 2018 seasonfollowing the launch of the second Sentinel-2 satellite in late 2017. Data for the late-2017/early-2018 period show evidence that the drought conditions experienced at that time resulted in correspondingly low NDVI values, correlated with the complete drying of Ann Sagar (noted by the orange dashes in Figure 5).

Figure 5: January 2016 to April 2019 time series correlation of Normalised Difference Vegetation Index (NDVI) readings (green line) from the cropped area downstream of Ann Sagar with rainfall (blue histogram), and presence (blue dashes under the X-axis) or absence (amber lines under the X-axis) of water in Ann Sagar.

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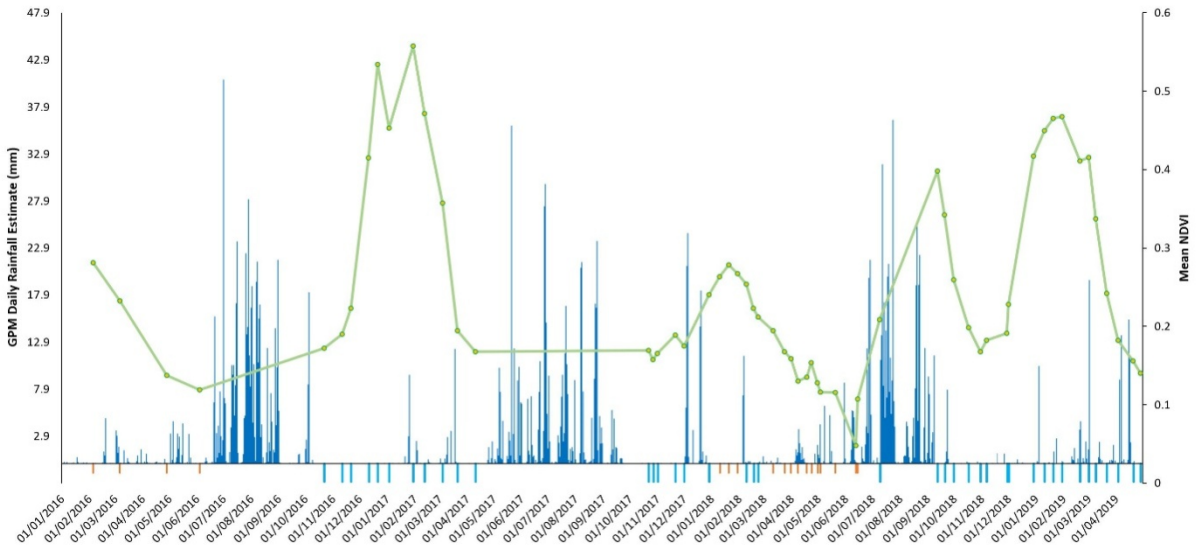

Figure 6 outlines the vegetation response (NDVI values) of the chauka area in Laporiya and an otherwise similar area separated by only 0.5km to the immediate south (identified as 'Comparison area' in Figure 1), along with rainfall data and presence of water in Ann Sagar. NDVI values from the two adjacent land areas track each other closely. However, the NDVI for the chauka area was typically consistently higher (on average 14% higher, increasing to around 38% higher in early 2019) than that for the comparator untreated adjacent fields, except for the driest part of the year immediately before the onset of the monsoon (early June), and in the response of vegetation during extreme drought conditions from April to June 2018. In general, NDVI values for vegetation in the pasture converted to chauka indicate healthier vegetation for a longer period. NDVI could not be calculated for the 2016 and 2017 monsoon periods again, but are assumed on the basis of the consistently higher values on the chauka pastures to follow a similar pattern to that observed for 2018.

Figure 6: January 2016 to April 2019 time series correlation of NDVI readings from the chauka area of Laporiya (green line) with NDVI in an adjacent land area to the immediate south (purple line), mapped over rainfall (blue histogram) and presence (blue dashes under the X-axis) or absence (amber lines under the X-axis) of water in Ann Sagar.

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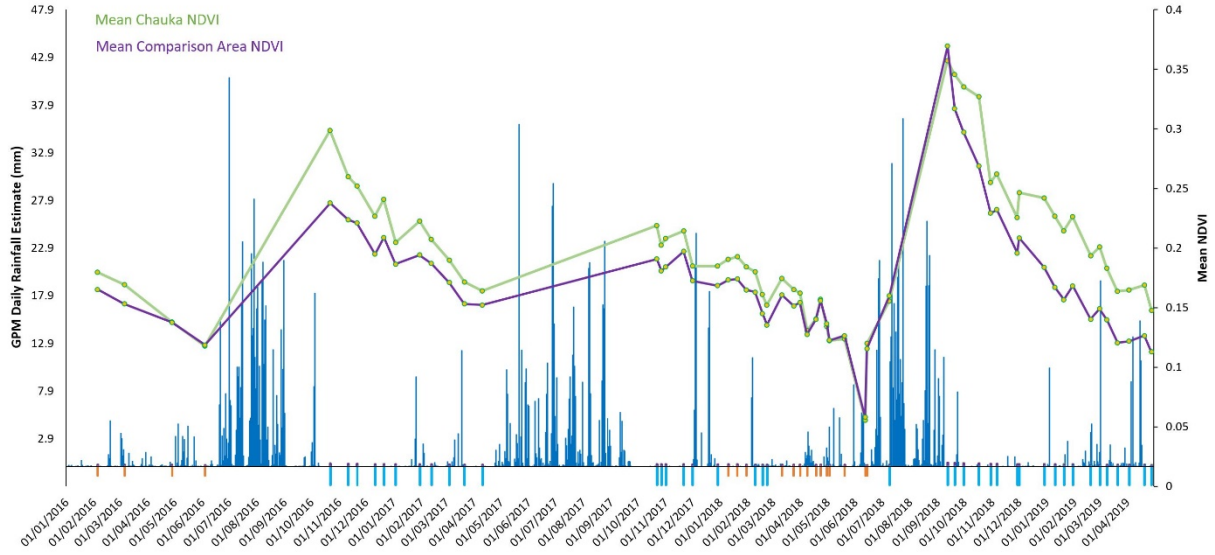
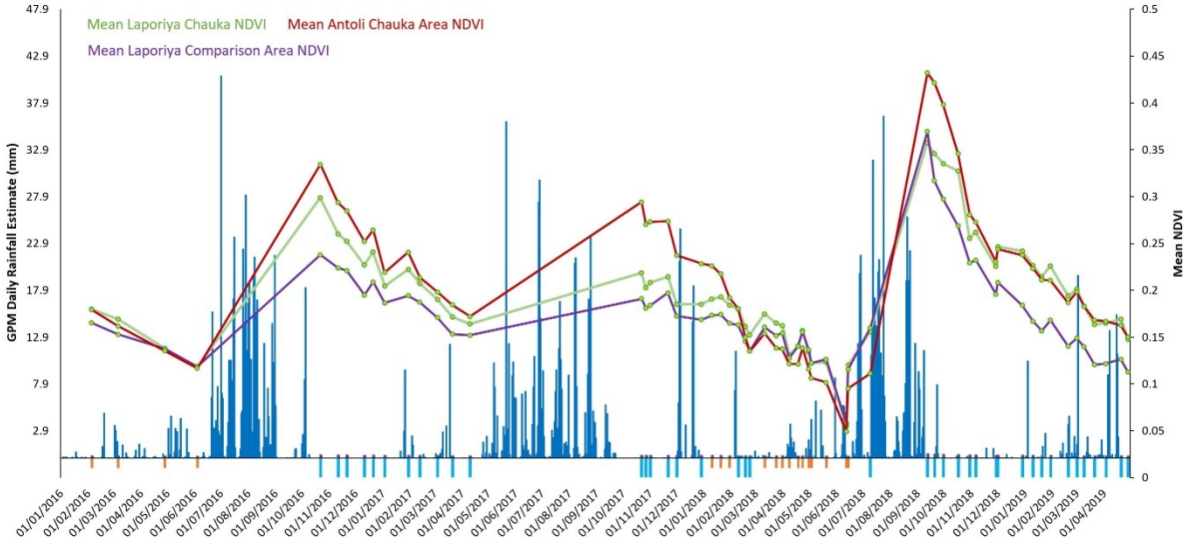


Figure 7 outlines the vegetation response (NDVI values) of the chauka area in Laporiya, the otherwise similar adjacent comparator area without chauka to the immediate south, the area in Antoli on which chauka were dug in April 2018,along with rainfall data and presence of water in Ann Sagar. NDVI values from the chauka and adjacent land areas track each other closely. The high NDVI readings at Antoli prior to 2018 appear anomalous as there were no completed interventions in this area, but are explained by a dense infestation of alien invasive *Prosopis juliflora* trees present at the time that villagers were required to clear before funds were released for chauka construction. Beyond April 2018, after chauka had been constructed at the defined areas in Antoli, NDVI values closely tracked those on the chauka area of Laporiya.

Figure 7: January 2016 to April 2019 time series correlation of NDVI readings from the chauka area of Laporiya (green line) with NDVI in an adjacent land area to the immediate south (purple line) and the area of Antoli on which chauka were constructed in April 2018 (red line), mapped over rainfall (blue histogram) and presence (blue dashes under the X-axis) or absence (amber lines under the X-axis) of water in Ann Sagar.

- Everard, M. and West, H. (In press). Livelihood security enhancement though innovative water management in dryland India. *Water International*, 1874780, In press 11jan21.



Discussion

The mixed methods analyses – the ecosystem service-based RAWES approach including ESI calculations,STEEP analysis of systemic interactions across the socio-cultural system, and interpretation of Sentinel-2 Normalised Difference Vegetation Index (NDVI) data– reveal differences in vegetation condition and resultant societal benefit flows across sampled areas. The RAWES approach enabled integration of different types of knowledge, both rapidly-gathered statistical and non-statistical evidence, articulating in semi-statistical terms (ESIs) the tangible spatial and temporal differences in ecosystem service production in the chauka-modified Laporiya village landscape. ESI scores are substantially higher for all ecosystem service categories in contemporary Laporiya. Remote sensing interpretation reveals improved vegetative condition in, and downstream of, water management interventions in Laporiya, tracking rainy and dry seasons, and in the chauka area of Laporiya compared to an adjacent, unmodified tract of land. Remote sensing analyses corroborate evidence primarily derived from reportage of ecosystem services by informants from the villages (noting the anomaly caused by formerly dense invasive tree cover).

Close interdependence between people and supportive ecosystems is further endorsed by exploration of systemic linkages between the key social, technological, environmental, economic and political dimensions under the STEEP model, stronger integration across this cultural-ecological system evident at the now more water secure Laporiya village. Systemic interconnections between these five components demonstrate how societal benefits flow from landscapes with improved water management, resulting from social appreciation of the values of nature governing technology deployment and participatory management, and governed locally through an informal Village Development Committee prioritising village needs over perceived outside state interference. The engagement of the whole community of Laporiya in collaborative action and physical, ecosystem-centred management of their supportive landscape leads to linked improvements in ecology and water and livelihood security. This effect of local empowerment protecting or regenerating supportive ecosystems of linked socio-ecological benefit occurs as local people play important roles in the management of ecosystems supporting their needs (Folke*et al*. 2005). This pattern is consistent with greater ecosystem service benefits returning to people owning and framing ecosystem resource decisions for local benefit under protected tribal rights in north east India, compared with more directly government-controlled regions of the central Indian Himalayas (Everard *et al*. 2020)

We acknowledge the limitations and uncertainties inherent in this study, in which different forms of knowledge are integrated to seek understanding of, and transferrable principles from, the successes observed in Laporiya. Limitations in the quantity of relevant literature are also recognised. Ideally, further research would replicate these surveys and analyses in many more villages to deepen understanding of sustainable ecosystem-community relationships. Nevertheless, although the findings of this study are subject to some unquantifiable uncertainty, they illustrate how different governance arrangements have profound impacts on whole socio-ecological systems and the sustainable accommodation between people and the natural systems that support them. This knowledge is transferrable to other situations, noting that specific details relevant to the Salt Lake region require adaptation to other ecosystem types.

Conclusions

Spatial and temporal comparisons reveal how novel nature-based water management solutions, particularly the context-specific innovation of the chauka system, have made significant contributions to water security in the challenging environment of Rajasthan's Salt Lake region.

Nature-based solutions for sustainable water management depend on consensual stewardship by communities, abiding by agreements consistent with natural processes regenerating water and ecosystems, enhancing resources supporting beneficial use of water, farming and livelihoods.

Analysis of remotely sensed data can provide corroboration of outcomes of water management over broad landscapes.

Further research can help address limitations and uncertainties in this study arising from the local focus, sparse literature and lack of long time-series remotely sensed data, though knowledge generated can be transferred to other regions facing similar challenges noting that specific details relevant to the Salt Lake region require adaptation.

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Annex 1: Characteristics of Laporiya and Antolivillages and chauka systems

The adjacent villages of Laporiya and Antoli are similar in area, geographical features and population, yet differ in terms of the extent of nature-based water management interventions, specifically including chauka. They are therefore used for comparative purposes to assess the outcomes of these interventions, and how these are influenced by governance and decision-making by the respective village communities.

A1.1 Laporiya village and its recent history of water management

Laporiya village has an overall area of approximately 51km^2 situated in Dudu tehsil and Jaipur District, with a population of 1,764 in 236 households (Census of India 2011). The NGO (non-government organisation) GVNML (*Gram Vikas Navyuvak Mandal Laporiya*) was established in Laporiya in the early 1980s, initially with a focus on schooling, but the emphasis shifted in 1987 towards work on water management particularly in communal pasture land (Ashoka 2011).

Lakshman Singh, the founder of GVNML, came to the realisation that "*The village was bankrupt with water*", surrounded by various defunct tanks, silted ponds and washed out bunds where community-based management had been abandoned (Padre 2008). A substantial and varied programme of water management work has since been undertaken in Laporiya village under the promotion of GVNML, supported by other NGOs such WaterHarvest (see Table A1.1). Prominent amongst these interventions has been the innovation, implementation and communal management of a novel chaukanature-based solution (NBS)system.

Table A1.1: Development works undertaken at Laporiya under GVNML leadership

Type of works	Examples
Building water bodies	Three sagar (lakes) were built in Laporiyasagar, each

	serving different purposes: Ann Sagar ('crop lake') primarily for food production; Ful Sagar ('flower lake') reserved for nature; and Dev Sagar ('holy lake') reserved for spiritual purposes
Innovating the chauka system	Chauka systems are discussed in detail below
Promoting other water management interventions	Additional water management structures promoted by GVNML in collaboration with villagers include: Many naadi (ponds) built upstream of the main sagar, including connected talaabs (pools) over 25km spanning the four villages from upstream to downstream: Benekhera; Rahalana; Gagardu; and Laporiya (Padre 2008); Kundi (infiltration pits) dug into the drier, upstream areas of chauka; and Check dams on seasonal streams. The combined approaches help to slow flood flows, promoting the infiltration of water into soil and groundwater
Nature-centred interventions	Two 'ecoparks' have been established in Laporiya, fenced off and not used or accessed by people or livestock but reserved entirely for nature. They are dedicated to nature, but also regarded as sources of pollinators, pest predators and seeds (neem tree seeds spread by parrots and desi babool seeds spread by other animals) Villager concerns about the need to remove household

	pests but a desire not to kill them also led to the establishment of another nature reserve area known as a chuhagher ('mouse house') where rodents trapped in households are taken for release into the wild
Establishing institutions	GVNML has instigated a Village Development Committee (VDC) in Laporiya, which sets rules by consensus and controls natural resource management (including establishing ecoparks, rules for use of different water bodies, prohibitions on cutting trees, a ban pesticides, etc.) Ongoing work includes promoting women's organisations, including the Mahlila Mandal a village institution seeking women's empowerment) Ongoing efforts involve promotion of public health, children's rights and other aspects of sustainable and equitable development

All water management solutions in Laporiya are planned according to the workings of the water cycle, and are implemented communally. Effective collaboration using NBSs is vital as groundwater even a few metres below the soil surface in this region is highly saline. The replenishment of shallow groundwater is therefore critical for avoiding groundwater contamination, many areas around adjacent villages are visibly lacking vegetation owing to soil salinisation. Nevertheless, despite all of these interventions, some of the 103 wells in Laporiya have high fluoride concentration due to the underlying geology, though these are known and used only for agriculture and not for drinking.

A participatory approach prioritising the meeting of local needs is an important aspect of chauka design. GVNML (n.d.) produced a *Chauka manual* to promote the approach. Other key interventions included establishing governance structures such

as the Village Development Committee (VDC) that, though not recognised by the state, governs decisions pertaining to natural resources in Laporiya. Laporiya village resists control by the Gram Panchayat (the community-based institution recognised by state government) as it is seen as implementing government policies rather than prioritising local needs. Mistrust of higher tiers of formal government extend to refusal to designate forest areas in the village, ensuring that they do not fall under control of the state Forest Department. Physical works implementing chauka and other water-harvesting structures (WHSs) in Laporiya were largely completed by the late-2000s, but substantial work still continues in developing institutions, gender equity and governance systems as well as routine maintenance of the physical infrastructure.

The influence of GVNML is undoubtedly enhanced by its leaders coming from a Thakur family (formerly part of a ruling dynasty, though this influence is eroding substantially in contemporary India). However, outcomes from chauka and other water management interventions for water security and the regeneration of wildlife and livelihoods has proven a more powerful driver of acceptance and wider dissemination. Compared to the water and food insecurity of many adjacent villages, Laporiya is water-secure and sells water to surrounding villages during dry seasons, with 75% of families producing a marketable surplus of milk, sales of which are used, amongst other purposes, to buy fodder (Padre 2008).

As a dryland region, most of the cropping in Laporiya is in the khariff (wet, post-monsoon) season. However, there are significant areas, particularly downstream of Ann Sagar (the largest impoundment storing monsoon run-off and promoting groundwater infiltration) where replenished groundwater supports spray irrigation for a rabi (dry season) crop (typically chilli, tomato, aubergine, onion and wheat). On some areas, a third jayad (summer) crop is also produced. Private owners of land in better-watered land downstream of naadi (ponds) can produce 250-1,000 kg per hectare of rabi crop, depending on rainfall in any specific year.

The spiritual importance of water is evident throughout Laporiya village, for example in the shrine to a local matriarch goddess by some wells, and Devoothnigyaras (the

11th day after Diwali) is considered very holy, with people in Laporiya paying particular regard to the symbolism of water (Singh 2019b).

A1.2Antolivillage and its recent history of water management

By contrast, Antoli village has an area of 35km^2 within Malpura tehsil and Tonk District, with a population of 2,271 in 415 households (Census of India 2011). There are 150ha of common grazing land and 3,000ha private cropped land, the remainder comprising government and fallow land, seasonal rivers and water bodies (Singh 2019b). The land is generally flat, and the area is saline with salty wells. Unlike Laporiya, water is tankered into Antoli village for drinking and domestic uses during dry periods, with villagers paying contractors for their water. Four seasonal streams crossing Antoli village feed into the Sodra River.

Plans for and implementation of chauka and other communal water management interventions are in their infancy in Antoli, recently agreed amongst Antoli's villagers based on observation of the successes of water management solutions in Laporiya in addressing common problems. The NGO WaterHarvest started supporting Antoli from December 2017, requiring them first to clear invasive gandababool trees (*Prosopis juliflora*, also known as mesquite or muscat) as a gesture of intent before releasing funds to support construction of chauka in April-June 2018. The Antoli community now has plans for a further 15ha of chauka, for which it is seeking government or other funds.

As of early 2018, water management and general conditions in Antoli were approximately where Laporiya was prior to major water management interventions from 1987, with similar geography, culture and area. It is therefore a relevant spatial comparator.

A1.3Characteristics of the chauka system

The chauka NBS system is an innovation of the NGO GVNML, adapted specifically to address water-harvesting in the low-gradient and high sodic water table in the Salt Lake region of Rajasthan in which Laporiya and Antoli are situated. 'Chauka', the Hindi word for 'four corners', comprise interlocking networks of low bunds on three sides of a rectangle on non-arable areas with relatively permeable sandy loam and loam soils and a slope no greater than 0.5-2% (Mahnot*et al*. 2012). Chauka bunds are no more than 60cm high, typically extending 40-60m across the slope with side bunds of 25-40m, their small size and low height are essential to avert too great a pressure of water eroding the bunds. Spillways at their edges allow the free flow of water into adjacent bunded rectangles, and from field-to-field. A line of rectangular borrow pits, or chauka cells, along the long bund running across the slope provide a source of earth to build the bunds. These smaller chauka cells are typically 3 x 1.6m in area and 0.3m deep.

Water depth within individual chauka cells during monsoon rainfall is never excessive, up to 0.75m, to avoid drowning soil animals and grass roots (Padre 2008). Shallow sub-surface groundwater is thus recharged with fresh monsoon run-off, and soils within the chauka are enriched by silt, all supporting improved communal grazing. Some chauka cells also have deeper wells dug within or adjacent to them, particularly in drier, up-slope areas of the rectangle, promoting percolation of water through the soil and replenishment of the water table. Surplus run-off downstream of networks of chauka is typically diverted into sagar (larger impoundments) or naadi (smaller storage ponds).

Chauka are implemented on common grazing land, and also specifically addressing the unique low slope and saline conditions of this Salt Lake region of Rajasthan.

Chauka implementation in Laporiya from 1987 attracted early support in the form of payments for food to support village engagement, provided by Christian Relief Services (Padre 2008). Subsequently, in 1994, Rajasthan State Government and the charity Oxfam offered additional funding. There also followed support from the NGO WaterHarvest (then known as Wells for India) to increase the extent of chauka. As chauka are a system developed to promote grazing on common land, typically 90%

of their costs are covered by grants, but it is expected that 50% of the costs should be matched for naadi or other interventions on private land.

Chauka management decisions on communal land are by consensus, agreed by an informal Village Development Committee (VDC) established by GVNML. Annual Pad Yatra (village gatherings) provide a forum for major, community-wide decision-making including contributions to the annual chauka repair cycle. Agreements about chauka management at Laporiya include leaving cow dung in situ to rebuild organic matter and nutrient content, refraining from grazing the chaukas for one-and-a-half months following the monsoon to enable the grass to flourish and produce seed. Goats are also prevented from grazing the beans of desi babool (*Vachellianilotica*) trees, and collection of the beans is also prohibited until decided by the VDC in order to promote regeneration of native trees. Chauka typically have a ten-year maintenance cycle of bund repair and cell desilting. Chauka are desilted annually by *shramdan* (honourable physical labour looking for no reward), to which every villager contributes.

Chauka put control of water into the hands of villages, rather than fostering a reliance on government and on dam schemes, with everyone participating in decision-making (Baruah 2008). These measures are all predicated on promoting ecosystem regeneration, ultimately maximising the benefits of chauka. Chauka development and other linked water management structures and institutions have further benefits, including drought-proofing the rain-starved village of Laporiya (Anand & Anand 2017a, b). Slowing of flows by chauka also reduces flood risk, and the loss of soil quality and quantity through erosion.

In 2008, the NGO WaterHarvest started funding the extension of chauka development into other villages in the region, as a proven means to reverse of cycles of drought, hunger, caste violence and migration to cities in this particular set of geographical conditions (Baruah 2008). GVNML has been successful in attracting additional international aid investment, although in the early stages of the project chauka implementation was funded solely by villagers. At present, roughly 75% of investment in chauka construction still remains through voluntary village labour.

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Chauka have now been tested on hundreds of hectares of land in 58 mainly neighbouring villages (Mahnot*et al*. 2012).

End of Annex 1

- Everard, M. and West, H. (In press). Livelihood security enhancement though innovative water management in dryland India. *Water International*, 1874780, In press 11jan21.

Annex 2: Key informants and (translated) quotes from village surveys

A1.1 Interviews in Laporiya village

Evidence-gathering at Laporiya took the form of semi-structured interviews with a number of informants (N=20) involved in village governance, or with knowledge about other attributes of the village. These comprised 14 men and 6 women contributing their views in response to research team questioning. Informants from Laporiya village and their affiliations, roles and other details are documented in Table A2.1, with unattributed quotes listed in Table A2.2.

Table A2.1: Informants from Laporiya village

Name	Gender	Role/affiliation
Geeta Kanwar	Female	Secretary of the Laporiya Women's Self Help Group (SHG)
Mandori Devi	Female	President of the Laporiya SHG
Sayar Devi	Female	Member of the Laporiya Village Development Committee (VDC)
Mamta Devi	Female	Village-level Health Worker
Shankar Bhadu	Male	Secretary of the Laporiya VDC
Laxman Doi	Male	Member of the Laporiya VDC
Rampal Mali	Male	Vice-President of the Laporiya VDC
ChotuDabhai	Male	Member of the Laporiya VDC
PanchuPoar	Male	Member of the Laporiya VDC
Mangal Singh	Male	Farmer and Member of the VDC
Gita Kamaar	Female	Member of the Gram Panchayat

Norat Mali	Male	Farmer in land downstream of Ful Sagar
Tej Singh	Male	Board member of GVNML
Jagveer Singh	Male	Chief Executive Officer of GVNML
Lakshman Singh	Male	Founder of GVNML
Mansingh	Male	Associate of GVNML
Rahamashwar	Male	Botanical specialist working with GVNML
Sangsham	Male	Associate of GVNML
Sangdru	Female	Employee of GVNML
Thashrath	Male	Associate of GVNML

Table A2.2: Unattributed (translated) quotes from informants from Laporiya village

"GVNML taught us the domestic rain water harvesting technique and my family is self-dependent in terms of drinking water requirement. Everyone should do such work."
"Chauka takes away the 'Fodder Scarcity Problem'. I have sufficient income from animals and animal have sufficient fodder in pastureland where Chauka applied."
"Inclusive development is only possible when women have equal opportunity in learning and decision making process, it established in Laporiya by GVNML."
"Livelihood support structure have been strengthen in Laporiya by GVNML."
"Animal Husbandry occupation redefined in Laporiya and that has enhanced per family income many times."
"Rain water Harvesting, Harnessing, conservation and management has changed

the destiny of Laporiya village."

"Now Laporiya have a well reputed village among all Rajasthani villages because we have better understanding of Natural Resource management."

"Tree for life and life can be survived if we have tree in good number."

"Our village is better than others."

"Before GVNML interventions, the Ful Sagar (it was not yet named) was very small and so was Ann Sagar. There was nothing in landscape, and water flowed away. There was no water storage, no trees and few grasses. The grasses present had thorns. The cattle went everywhere but did not feed well; our productivity was very low. The youths of Laporiya sat together and discussed what they could do to have livelihoods, but no solutions were found."

"We got together as shaaddaam, starting to work on tanks. We heard of the Nehru Youth Centre, supporting informal youth clubs by providing small funds for food, so we got food and served it to the village."

"Before the chaukas, they started discussions with villagers to stop cutting trees. They were mainly *Prosopis juliflora*. We stopped the cutting the trees. There as confrontation as our body had no authority. But we won by dialogue with the village. Lakshman is part of this movement. After this, a few chauka were started with shaad naam. We had some local budget and government funding too."

"On 21st January 1986, moved onto a formal basis as a village youth club. It became a society registered with Government of Rajasthan with a governing board (people from an agricultural college, and with engineering and other relevant backgrounds)."

"The water situation before GVNML was that we had more rain, but it flowed away. When we had good rains, fields could be ploughed to break the soil surface to allow water percolation on several occasions, and we had a rabi crop too. Now there are long dry spells."

"Now there is less rain, but more of it is captured."

"The biggest changes isSumjhadaari ("understanding of the people"). There was a lot of water in the rains, but people let it flow away."

"If we had not had all the interventions, we'd suffer the same problems of many villages in the vicinity. Many villages get water by tanker, but Laporiya has its own water."

"In drought, people no longer migrate for food, though youth still migrates for a more western lifestyle (electricity, etc.)"

"Now conditions are improved but the rainfall has declined. There used to be go rain every two years. Ann Sagar used to be small but was often full. 50 years ago, we could irrigate every year; now we can only do it every other year. There are tube wells now. Recharge was good. Now the rains are poor. Water used to flow through the farm after the well filled."

A1.2 Interviews in Antoli village

Evidence-gathering at Antoli village took the same form of semi-structured interviews with a number of informants (N=9) involved in village governance, or with knowledge about other attributes of the village. These comprised 6 men and 3 women. Informants from Antoli village and their affiliations, roles and other details are documented in Table A2.3, with unattributed quotes listed in Table A2.4.

Table A2.3: Informants from Antoli village

Name	Gender	Role/affiliation
ShivrajBairwa	Male	President of the Antoli Village Development Committee (VDC)
Kartar Singh	Male	Member of the Antoli VDC and Secretary of the

		Cooperative Society of Antoli village
Ram Niwas	Male	Member of the Antoli VDC
BhanwarKhatic	Male	Member of Antoli VDC and Ward Member in the Gram Panchayat of Antoli
Ratani Devi	Female	Member of the Antoli VDC and Leader of the Antoli Women's Self Help Group (SHG)
Sosar Devi	Female	Member of the Antoli VDC and Member of the Antoli SHG
Hemlata Devi	Female	Member of the Antoli VDC and Member of the Antoli SHG
Bhanwar Singh	Male	Headman of the Antoli VDC
Jagveer Singh	Male	Chief Executive Officer of GVNML

Table A2.4: Unattributed (translated) quotes from informants from Antoli village

"We are learning from Laporiya and we have dreamt that one day our village will be better than Laporiya."

"We developed Chauka in Pastureland and now we will harvest and conserve rain in Agriculture land though cooperative system."

"We are developing the understanding of Antoli villagers so that our future can be better."

"We will add govt. Support in GVNML's efforts for making Antoli village 'A better village of Tonk District'."

"We will give our 100 role for village development, we are facilitated to give our role for village development and this is happening 1st time in our life."

"We will develop our SHG better than any other village in Malpura Block."

- Everard, M. and West, H. (In press). Livelihood security enhancement though innovative water management in dryland India. *Water International*, 1874780, In press 11jan21.

"We have been taught many new things and in coming time we will action for overall village development, we have to do hard work and lot more to be done in the village under GVNML's guidance."

"Our land is sloping, so water flows to other areas. Pasture only has small grasses, useful only for rabbits. After seeing Laporiya, we decided to try the methods here. We graze cows, buffalo, sheep and goats. Animals are now kept out until grass has seeded."

"Chauka have been here for one monsoon. All of the VDC visited Laporiya, which motivated the village to construct chauka, talaab, anicuts on common land. Ecoparks have not yet been built. It was only a small monsoon; we saw a small difference but not big (benefits of chaukas tend to improve year-on-year)."

"Before we were helped to build chaukas, we were given an exercise to remove gandababool [Note from authors: the invasive alien tree *Prosopis juliflora*]. Ganda babool has not used, offered no shade, and was useful only as fuel wood. Ganda babool is OK if scarce, but no use if plentiful. Desi babool [Note from authors: a native tree species] is useful as was can make use of its leaves, beans and wood (for feeding goats and for furniture) and it is self-planting."

"Some chana [Note from authors: chick peas] plants are having their roots cut by larvae, so there is at present an imbalance… ecoparks and birds may help."

End of Annex 2

FULL TEXT:

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THE FOLLOWING ITEMS HAVE BEEN ATTACHED AS DIGITAL SUPPLEMENTARY MATERIAL IN EXCEL SPREADSHEET FORMAT, BUT ARE PRINTED HERE AS 'SCREEN GRABS' TO AID REVIEWERS

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Livelihood security enhancement though innovative water management in dryland India

Supplementary Material 3: RAWES field assessment sheet for benefit realisation in Laporiya

Relates to the following paper:

- Livelihood security enhancement though innovative water management in dryland India
- Journal: *Ecosystem Services*
- Authors: Dr Mark Everard and Harry West
- Corresponding: Dr Mark Everard, mark.everard@uwe.ac.uk

Background information about Laporiya village

Laporiya village has seen education inputs by the NGO GVNML since 1980, but interventions shifted significantly into water intervention since 1987. Physical interventions were largely completed by around 2009 but continuing education, women's empowerment, health and other interventions continue. Total village area is 4,400 hectares spanning 320 households, including 120 hectares of (common) grazing land of which 80 hectares are now under chaukas, 3,800 hectares of (private) croplands. There is one seasonal stream, the Bahalla, that runs successively into the Massi, Bandi and Banas rivers (joining the lower river below the Bisalpur Dam). More details are in the body of this paper.

Background information about Antoli village

Antoli village is in the same Salt Lake region of Rajasthan as Laporiya, with similar topogrphy, saline and sodic gorundwater and povery challenges. A number of sagar are in teh village, but it hs not embarked on chauka development until April 2018. It is therefore a spatial comrator to conditions in which Laporiya before extensive water management interventions were put in place. More details are in the body of this paper.

Key informants included:

In addition to literature searches, and field and remote sensing observations, a number of interviewees were polled for their knowledge of current and historic/pre-intervention conditions in Laporiya village and also the situation in Antoli village

- Informants from GVNML, Laporiya and Antoli are listed in the body of this paper
- Informats were thanks for their inputs, and asked for their consent to use them for research purposes in anonymised form
- We accept your input as permission for its use for research purposes - you have the right to withdraw at any time
- All informants were also given the right to withdraw at any time

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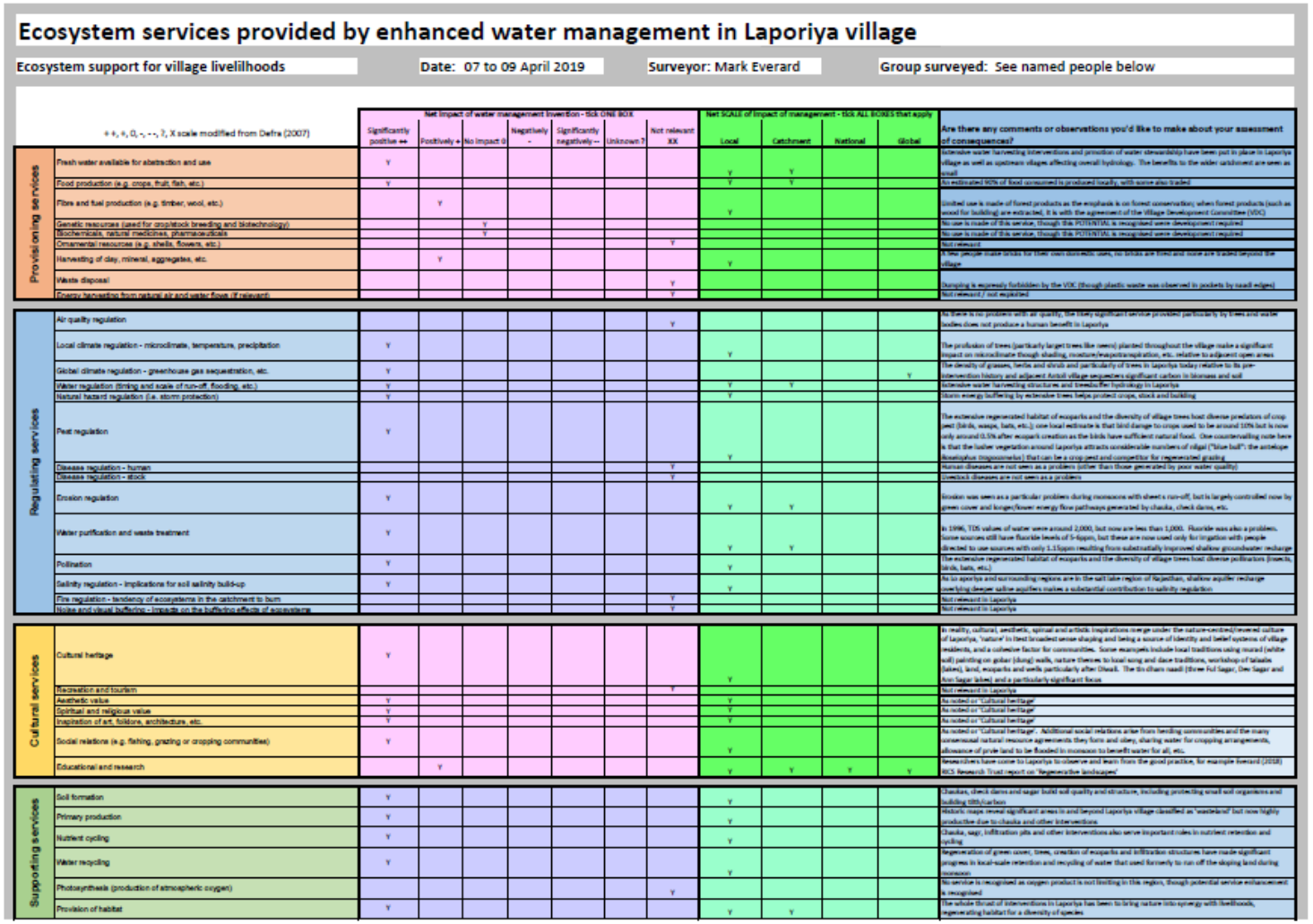

Ecosystem services provided by enhanced water management in Laporiya village

Ecosystem support for village livelihoods | **Date: 07 to 09 April 2019** | **Surveyor: Mark Everard** | **Group surveyed: See named people below**

		Net impact of water management invention - tick ONE BOX							Net SCALE of impact of management - tick ALL BOXES that apply				Are there any comments or observations you'd like to make about your assessment of consequences?
	+, +, 0, -, --, ?, X scale modified from Defra (2007)	Significantly positive ++	Positively +	No impact 0	Negatively -	Significantly negatively --	Unknown ?	Not relevant XX	Local	Catchment	National	Global	
Provisioning services	Fresh water available for abstraction and use	Y							Y	Y			Intensive water harvesting interventions and promotion of water stewardship have been put in place in Laporiya village as well as upstream villages affecting overall hydrology. The benefits to the wider catchment are seen as small
	Food production (e.g. crops, fruit, fish, etc.)	Y							Y	Y			No estimated 90% of food consumed is produced locally, with some also traded
	Fibre and fuel production (e.g. timber, wool, etc.)		Y						Y				Limited use is made of forest products as the emphasis is on forest conservation; when forest products (such as wood for building) are extracted, it is with the agreement of the Village Development Committee (VDC)
	Genetic resources (used for crop/stock breeding and biotechnology)			Y									No use is made of this service, though this POTENTIAL is recognised were development required
	Biochemicals, natural medicines, pharmaceuticals			Y									No use is made of this service, though this POTENTIAL is recognised were development required
	Ornamental resources (e.g. shells, flowers, etc.)							Y					Not relevant
	Harvesting of clay, mineral, aggregates, etc.		Y						Y				A few people make bricks for their own domestic use, no bricks are fired and none are traded beyond the village
	Waste disposal							Y					Dumping is expressly forbidden by the VDC (though plastic waste was observed in pockets by road edges)
	Energy harvesting from natural air and water flows (if relevant)							Y					Not relevant / not exploited
Regulating services	Air quality regulation							Y					As there is no problem with air quality, the likely significant service provided particularly by trees and water bodies does not produce a human benefit in Laporiya
	Local climate regulation - microclimate, temperature, precipitation	Y							Y				The profusion of trees (particularly largest trees like neem) planted throughout the village make a significant impact on microclimate through shading, moisture/evapotranspiration, etc. relative to adjacent open areas
	Global climate regulation - greenhouse gas sequestration, etc.	Y										Y	The density of grasses, herbs and shrub and particularly of trees in Laporiya today relative to its pre-intervention history and adjacent Ardoli village sequesters significant carbon in biomass and soil
	Water regulation (timing and scale of run-off, flooding, etc.)	Y							Y	Y			Extensive water harvesting structures and treeshelter hydrology in Laporiya
	Natural hazard regulation (i.e. storm protection)	Y							Y				Storm energy buffering by extensive trees helps protect crops, stock and building
	Pest regulation	Y							Y				The extensive regenerated habitat of ecoparks and the diversity of village trees host diverse predators of crop pest (birds, wasps, bats, etc.); one local estimate is that bird damage to crops used to be around 10% but is now only around 0.5% after ecopark creation as the birds have sufficient natural food. One countervailing note here is that the lusher vegetation around Laporiya attracts considerable numbers of nilgai ("blue bull"; the antelope Boselaphus tragocamelus) that can be a crop pest and competitor for regenerated grazing
	Disease regulation - human							Y					Human diseases are not seen as a problem (other than those generated by poor water quality)
	Disease regulation - stock							Y					Livestock diseases are not seen as a problem
	Erosion regulation	Y							Y	Y			Erosion was seen as a particular problem during monsoons with sheet & run-off, but is largely controlled now by green cover and longer/slower energy flow pathways generated by chauka, check dams, etc.
	Water purification and waste treatment	Y							Y	Y			In 1996, TDS values of water were around 2,000, but now are less than 1,000. Fluoride was also a problem. Some sources still have fluoride levels of 5-6ppm, but these are now used only for irrigation with people directed to use sources with only 1.15ppm resulting from substantially improved shallow groundwater recharge
	Pollination	Y							Y				The extensive regenerated habitat of ecoparks and the diversity of village trees host diverse pollinators (insects, birds, bats, etc.)
	Salinity regulation - implications for soil salinity build-up	Y							Y				As in aporiya and surrounding regions are in the salt lake region of Rajasthan, shallow aquifer recharge overlying deeper saline aquifers makes a substantial contribution to salinity regulation
	Fire regulation - tendency of ecosystems in the catchment to burn							Y					Not relevant in Laporiya
	Noise and visual buffering - impacts on the buffering effects of ecosystems							Y					Not relevant in Laporiya
Cultural services	Cultural heritage	Y							Y				In reality, cultural, aesthetic, spiritual and artistic inspirations merge under the nature-centred/revered culture of Laporiya, 'nature' in best broadest sense shaping and being a source of identity and belief systems of village residents, and a cohesive factor for communities. Some examples include local traditions using murad (white soil) painting on gobar (dung) walls, nature themes to local song and dace traditions, workshop of talaabs (lakes), land, ecoparks and wells particularly after Diwali. The tin dham naadi (three Pal Sagar, Dev Sagar and Ann Sagar lakes) and a particularly significant focus
	Recreation and tourism							Y					Not relevant in Laporiya
	Aesthetic value	Y							Y				As noted on 'Cultural heritage'
	Spiritual and religious value	Y							Y				As noted on 'Cultural heritage'
	Inspiration of art, folklore, architecture, etc.	Y							Y				As noted on 'Cultural heritage'
	Social relations (e.g. fishing, grazing or cropping communities)	Y							Y				As noted on 'Cultural heritage'. Additional social relations arise from herding communities and the many conventional natural resource agreements they form and obey, sharing water for cropping arrangements, allowance of prvie land to be flooded in monsoon to benefit water for all, etc.
	Educational and research		Y						Y	Y	Y	Y	Researchers have come to Laporiya to observe and learn from the good practice, for example Everard (2018) WCS Research Trust report on 'Regenerative landscapes'
Supporting services	Soil formation	Y							Y				Chaukas, check dams and sagar build soil quality and structure, including protecting small soil organisms and building SOM/carbon
	Primary production	Y							Y				Historic maps reveal significant areas in and beyond Laporiya village classified as 'wasteland' but now highly productive due to chauka and other interventions
	Nutrient cycling	Y							Y				Chauka, nagi, infiltration pits and other interventions also serve important roles in nutrient retention and cycling
	Water recycling	Y							Y				Regeneration of green cover, trees, creation of ecoparks and infiltration structures have made significant progress in local-scale retention and recycling of water that used formerly to run off the sloping land during monsoon
	Photosynthesis (production of atmospheric oxygen)							Y					No service is recognised as oxygen product is not limiting in this region, though potential service enhancement is recognised
	Provision of habitat	Y							Y	Y			The whole thrust of interventions in Laporiya has been to bring nature into synergy with livelihoods, regenerating habitat for a diversity of species

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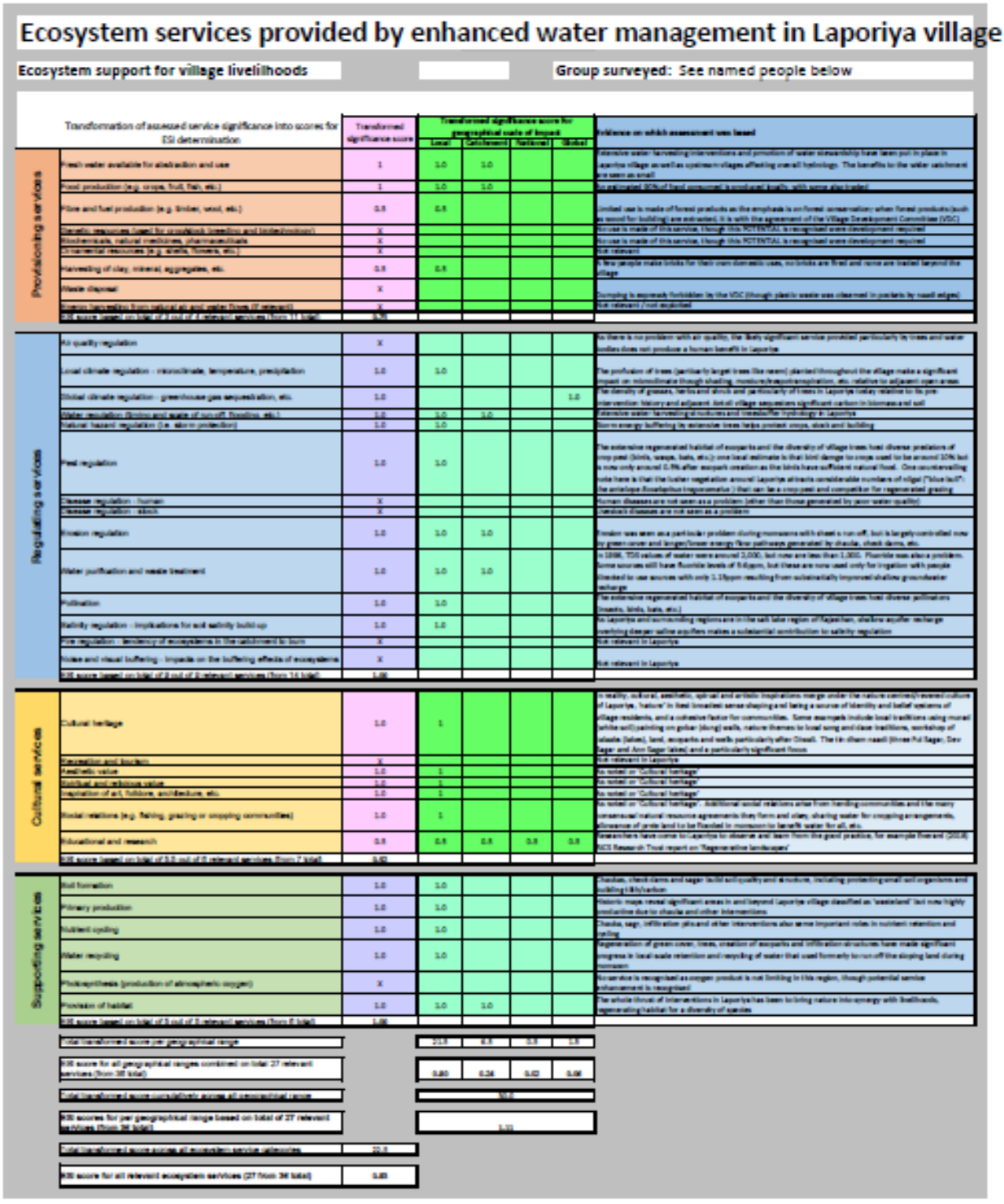

Ecosystem services provided by enhanced water management in Laporiya village

Ecosystem support for village livelihoods | **Group surveyed: See named people below**

	Transformation of assessed service significance into scores for ESI determination	Transformed significance score	Transformed significance score for geographical scale of impact: Local	Catchment	National	Global	Evidence on which assessment was based
Provisioning services	Fresh water available for abstraction and use	1	1.0	1.0			Extensive water harvesting interventions and promotion of water stewardship have been put in place in Laporiya village as well as upstream villages affecting overall hydrology. The benefits to the wider catchment are seen as small
	Food production (e.g. crops, fruit, fish, etc.)	1	1.0	1.0			An estimated 30% of food consumed is produced locally, with some also traded
	Fibre and fuel production (e.g. timber, wood, etc.)	0.5	0.5				Limited use is made of forest products as the emphasis is on forest conservation; when forest products (such as wood for building) are extracted, it is with the agreement of the Village Development Committee (VDC)
	Genetic resources (seed for cropstock breeding and biotechnology)	X					No use is made of this service, though this POTENTIAL is recognised were development required
	Biochemicals, natural medicines, pharmaceuticals	X					No use is made of this service, though this POTENTIAL is recognised were development required
	Ornamental resources (e.g. shells, flowers, etc.)	X					Not relevant
	Harvesting of clay, mineral, aggregates, etc.	0.5	0.5				A few people make bricks for their own domestic use, no bricks are fired and none are traded beyond the village
	Waste disposal	X					Dumping is expressly forbidden in the VDC (though plastic waste was observed in pockets by road edges)
	Human fatalities from natural air and water flows (if relevant)	X					Not relevant / not exploited
	ESS score based on total of 0 out of 0 relevant services (from 11 total)	0.00					
Regulating services	Air quality regulation	X					As there is no problem with air quality, the likely significant service provided particularly by trees and water bodies does not produce a human benefit in Laporiya
	Local climate regulation - microclimate, temperature, precipitation	1.0	1.0				The profusion of trees (particularly large trees like neem) planted throughout the village make a significant impact on microclimate through shading, moisture/evapotranspiration, etc. relative to adjacent open areas
	Global climate regulation - greenhouse gas sequestration, etc.	1.0				1.0	The density of grasses, herbs and shrub and particularly of trees in Laporiya today relative to its pre-intervention history and adjacent Aravalli village sequesters significant carbon in biomass and soil
	Water regulation (timing and scale of run-off, flooding, etc.)	1.0	1.0	1.0			Extensive water harvesting structures and transformed hydrology in Laporiya
	Natural hazard regulation (i.e. storm protection)	1.0	1.0				Storm energy buffering by extensive trees helps protect crops, stock and building
	Pest regulation	1.0	1.0				The extensive regenerated habitat of ecoparks and the diversity of village trees host diverse predators of crop pest (birds, wasps, bats, etc.): one local estimate is that bird danger to crops used to be around 30% but is now only around 0.5% after ecopark creation as the birds have sufficient natural food. One countervailing note here is that the richer vegetation around Laporiya attracts considerable numbers of nilgai ("blue bull") the antelope Boselaphus tragocamelus) that can be a crop pest and competitor for regenerated grazing
	Disease regulation - human	X					Human diseases are not seen as a problem (other than those generated by poor water quality)
	Disease regulation - stock	X					Livestock diseases are not seen as a problem
	Erosion regulation	1.0	1.0	1.0			Erosion was seen as a particular problem during monsoons with sheet s run-off, but is largely controlled now by green cover and longer/lower energy flow pathways generated by chaulas, check dams, etc.
	Water purification and waste treatment	1.0	1.0	1.0			In 1996, TDS values of water were around 2,000, but now are less than 1,000. Fluoride was also a problem. Some sources still have fluoride levels of 1.0 ppm, but these are now used only for irrigation with people directed to use sources with only 1.1 ppm resulting from substantially improved shallow groundwater recharge
	Pollination	1.0	1.0				The extensive regenerated habitat of ecoparks and the diversity of village trees host diverse pollinators (insects, birds, bats, etc.)
	Salinity regulation - implications for soil salinity build-up	1.0	1.0				In Laporiya and surrounding regions are in the salt lake region of Rajasthan, shallow aquifer recharge overlying deeper saline aquifers makes a substantial contribution to salinity regulation
	Fire regulation - tendency of ecosystems in the catchment to burn	X					Not relevant in Laporiya
	Noise and visual buffering - impacts on the buffering effects of ecosystems	X					Not relevant in Laporiya
	ESS score based on total of 5 out of 5 relevant services (from 14 total)	1.00					
Cultural services	Cultural heritage	1.0	1				In reality, cultural, aesthetic, spiritual and artistic inspirations merge under the nature-connected umbrella of Laporiya 'nature' in their broadest sense shaping and being a source of identity and belief systems of village residents, and a cohesion factor for communities. Some examples include local traditions using mural artists and painting on gobar (dung) walls, nature themes in local song and dance traditions, worship of shrubs (babul), land, ecoparks and wells particularly after Diwali. The tin dham naadi (three Pal Sagar, Dev Sagar and Ann Sagar lakes) and a particularly significant focus
	Recreation and tourism	X					Not relevant in Laporiya
	Aesthetic value	1.0	1				As noted on 'Cultural heritage'
	Spiritual and religious value	1.0	1				As noted on 'Cultural heritage'
	Inspiration of art, folklore, architecture, etc.	1.0	1				As noted on 'Cultural heritage'
	Social relations (e.g. fishing, grazing or cropping communities)	1.0	1				As noted on 'Cultural heritage'. Additional social relations arise from herding communities and the many consensual natural resource agreements they form and obey, sharing water for cropping arrangements, allowance of grain land to be flooded in monsoon to benefit water for all, etc.
	Educational and research	0.5	0.5	0.5	0.5	0.5	Researchers have come to Laporiya to observe and learn from the good practice, for example Everard (2018) RICS Research Trust report on 'Regenerative landscapes'
	ESS score based on total of 5.5 out of 7 relevant services (from 7 total)	0.93					
Supporting services	Soil formation	1.0	1.0				Chaulas, check dams and sagar build soil quality and structure, including protecting small soil organisms and building life/carbon
	Primary production	1.0	1.0				Historic maps reveal significant areas in and beyond Laporiya village classified as 'wasteland' but now highly productive due to chaulas and other interventions
	Nutrient cycling	1.0	1.0				Chaulas, sagar, infiltration pits and other interventions also serve important roles in nutrient retention and cycling
	Water recycling	1.0	1.0				Regeneration of green cover, trees, creation of ecoparks and infiltration structures have made significant progress in local-scale retention and recycling of water that used formerly to run off the sloping land during monsoon
	Photosynthesis (production of atmospheric oxygen)	X					Its service is recognised as oxygen product is not limiting in this region, though potential service enhancement is recognised
	Provision of habitat	1.0	1.0	1.0			The whole thrust of interventions in Laporiya has been to bring nature into synergy with livelihoods, regenerating habitat for a diversity of species
	ESS score based on total of 5 out of 5 relevant services (from 6 total)	1.00					
	Total transformed score per geographical range		21.5	8.5	3.5	1.5	
	ESS score for all geographical ranges combined on total 27 relevant services (from 36 total)		0.80	0.31	0.13	0.06	
	Total transformed score cumulatively across all geographical range		34.5				
	ESS scores for per geographical range based on total of 27 relevant services (from 36 total)		1.28				
	Total transformed score across all ecosystem service categories	22.5					
	ESS score for all relevant ecosystem services (27 from 36 total)	0.83					

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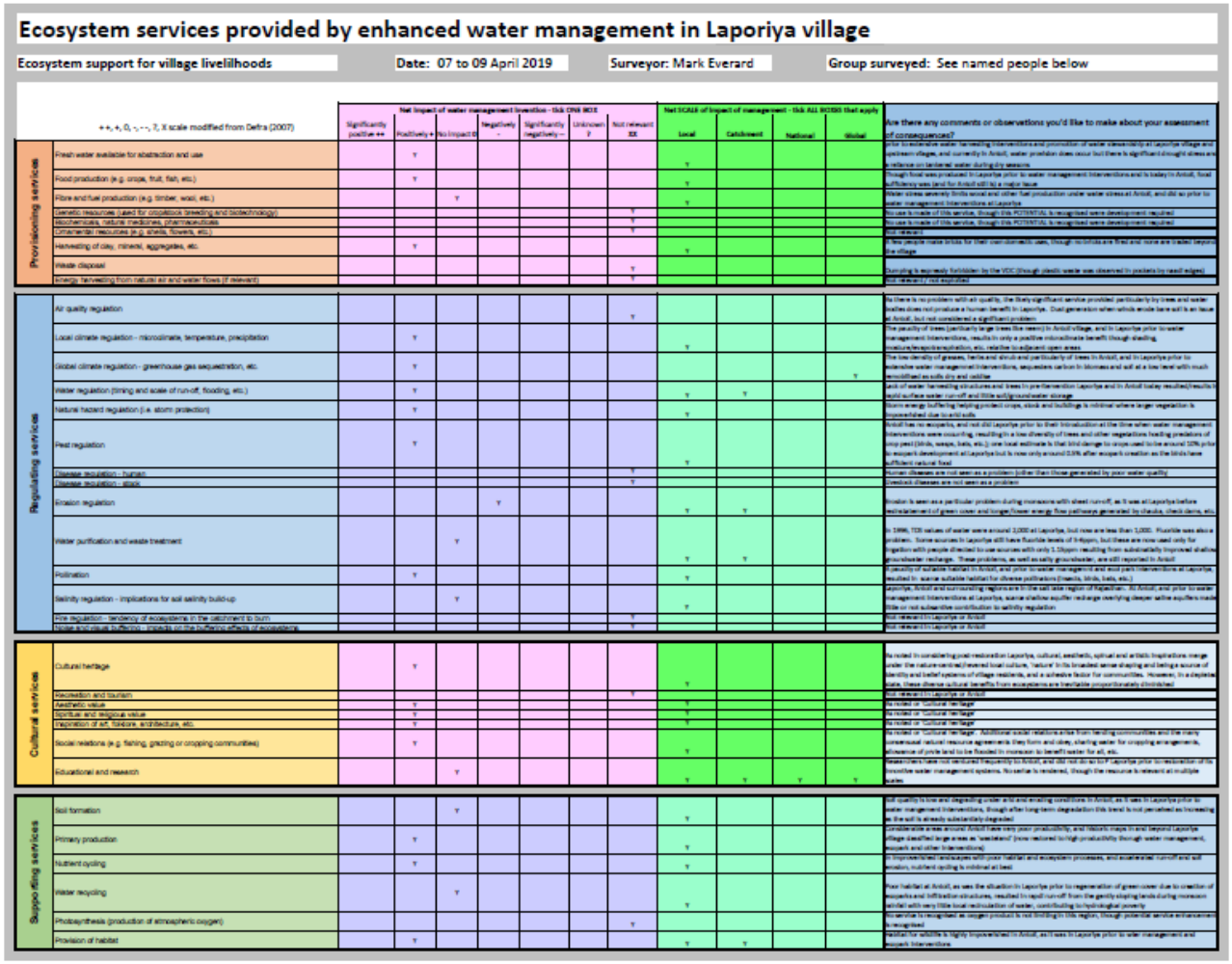

Ecosystem services provided by enhanced water management in Laporiya village

Ecosystem support for village livelihoods | **Date: 07 to 09 April 2019** | **Surveyor: Mark Everard** | **Group surveyed: See named people below**

++, +, 0, -, --, ?, X scale modified from Defra (2007)	Net impact of water management investion - tick ONE BOX: Significantly positive ++	Positively +	No impact 0	Negatively -	Significantly negatively --	Unknown ?	Not relevant XX	Net SCALE of impact of management - tick ALL BOXES that apply: Local	Catchment	National	Global	Are there any comments or observations you'd like to make about your assessment of consequences?
Provisioning services												
Fresh water available for abstraction and use		Y						Y				Prior to extensive water harvesting interventions and promotion of water stewardship at Laporiya village and upstream villages, and currently in Ankoli, water problem does occur but there is significant drought stress and a reliance on tanker-led water during dry seasons
Food production (e.g. crops, fruit, fish, etc.)		Y						Y				Though food was produced in Laporiya prior to water management interventions and is today in Ankoli, food sufficiency was (and for Ankoli still is) a major issue
Fibre and fuel production (e.g. timber, wood, etc.)			Y					Y				Water stress severely limits wood and other fuel production under water stress at Ankoli, and did so prior to water management interventions at Laporiya
Genetic resources (used for crop/plant breeding and biotechnology)							Y					No use is made of this service, though this POTENTIAL is recognised were development required
Biochemicals, natural medicines, pharmaceuticals							Y					No use is made of this service, though this POTENTIAL is recognised were development required
Ornamental resources (e.g. shells, flowers, etc.)							Y					Not relevant
Harvesting of clay, mineral, aggregates, etc.		Y						Y				A few people make bricks for their own domestic use, though no kilns are fired and none are traded beyond the village
Waste disposal							Y					Dumping is expressly forbidden by the VDC (though plastic waste was observed in pockets in reed-edges)
Energy harvesting from natural air and water flows (if relevant)							Y					Not relevant / not exploited
Regulating services												
Air quality regulation							Y					As there is no problem with air quality, the likely significant service provided particularly by trees and water bodies does not produce a 'human benefit' in Laporiya. Dust generation when winds erode bare soil is an issue at Ankoli, but not considered a significant problem
Local climate regulation - microclimate, temperature, precipitation		Y						Y				The paucity of trees (particularly large trees like neem) in Ankoli village, and in Laporiya prior to water management interventions, results in only a positive microclimate benefit though shading, moisture/evapotranspiration, etc. relative to adjacent open areas
Global climate regulation - greenhouse gas sequestration, etc.		Y									Y	The low density of grasses, herbs and shrubs and particularly of trees in Ankoli, and in Laporiya prior to extensive water management interventions, sequesters carbon in biomass and soil at a low level with much remobilised as soils dry and oxidise
Water regulation (timing and scale of run-off, flooding, etc.)		Y						Y	Y			Lack of water harvesting structures and trees in pre-intervention Laporiya and in Ankoli today resulted/results in rapid surface water run-off and little soil/ground water storage
Natural hazard regulation (i.e. storm protection)		Y						Y				Storm energy buffering helping protect crops, stock and buildings is minimal where larger vegetation is impoverished due to arid soils
Pest regulation		Y						Y				Ankoli has no wasperia, and not did Laporiya prior to their introduction at the time when water management interventions were occurring, resulting in a low diversity of trees and other vegetations hosting predators of crop pest (birds, wasps, bats, etc.); one local estimate is that bird damage to crops used to be around 33% prior to wasperi development at Laporiya but is now only around 0.5% after wasperi creation as the birds have sufficient natural food
Disease regulation - human							Y					Human diseases are not seen as a problem (other than those generated by poor water quality
Disease regulation - stock							Y					Livestock diseases are not seen as a problem
Erosion regulation				Y				Y	Y			Erosion is seen as a particular problem during monsoons with sheet run-off, as it was at Laporiya before re-establishment of green cover and longer/lower energy flow pathways generated by shrubs, check dams, etc.
Water purification and waste treatment			Y					Y	Y			In 1996, TDS values of water were around 3,000 at Laporiya, but now are less than 1,000. Fluoride was also a problem. Some sources in Laporiya still have fluoride levels of 3-4ppm, but these are now used only for irrigation with people directed to use sources with only 1.5ppm resulting from substantially improved shallow groundwater recharge. These problems, as well as salty groundwater, are still reported in Ankoli
Pollination		Y						Y				Paucity of suitable habitat in Ankoli, and prior to water management and wild park interventions at Laporiya, resulted in scarce suitable habitat for diverse pollinators (insects, birds, bats, etc.)
Salinity regulation - implications for soil salinity build-up			Y					Y				Laporiya, Ankoli and surrounding regions are in the salt lake region of Rajasthan - but Ankoli, and prior to water management interventions at Laporiya, some shallow aquifer recharge overlying deeper saline aquifers made little or not substantive contribution to salinity regulation
Fire regulation - tendency of ecosystems in the catchment to burn							Y					Not relevant to Laporiya or Ankoli
Noise and visual buffering - impacts on the buffering effects of ecosystems							Y					Not relevant to Laporiya or Ankoli
Cultural services												
Cultural heritage		Y						Y				As noted in considering post-restoration Laporiya, cultural, aesthetic, spiritual and artistic inspirations merge under the nature-centred/revered local culture, 'nature' in its broadest sense shaping and being a source of identity and belief systems of village residents, and a cohesive factor for communities. However, in a depleted state, these diverse cultural benefits from ecosystems are inevitably proportionately diminished
Recreation and tourism							Y					Not relevant to Laporiya or Ankoli
Aesthetic value		Y						Y				As noted in 'Cultural heritage'
Spiritual and religious value		Y						Y				As noted in 'Cultural heritage'
Inspiration of art, folklore, architecture, etc.		Y						Y				As noted in 'Cultural heritage'
Social relations (e.g. fishing, grazing or cropping communities)		Y						Y				As noted in 'Cultural heritage'. Additional social relations arise from herding communities and the many consensual natural resource agreements they form and obey, sharing water for cropping arrangements, allowance of pools land to be flooded in monsoon to benefit water for all, etc.
Educational and research			Y					Y	Y	Y	Y	Researchers have not ventured frequently to Ankoli, and did not do so for Laporiya prior to restoration of its innovative water management systems. No value is rendered, though the resource is relevant at multiple scales
Supporting services												
Soil formation			Y					Y				Soil quality is low and degrading under arid and eroding conditions in Ankoli, as it was in Laporiya prior to water management interventions, though after long-term degradation this trend is not perceived as increasing as the soil is already substantially degraded
Primary production		Y						Y				Considerable area around Ankoli here very poor productivity, and historic maps in and beyond Laporiya village classified large areas as 'wastelands' (now restored to high productivity through water management, wasperi and other interventions)
Nutrient cycling		Y						Y				In improved landscapes with poor habitat and ecosystem processes, and accelerated run-off and soil erosion, nutrient cycling is minimal at best
Water recycling			Y					Y				Poor habitat at Ankoli, as was the situation in Laporiya prior to regeneration of green cover due to creation of wasperis and infiltration structures, resulted in rapid run-off from the gently sloping lands during monsoon rainfall with very little local recirculation of water, contributing to hydrological poverty
Photosynthesis (production of atmospheric oxygen)							Y					No service is recognised as oxygen product is not limiting in this region, though potential service enhancement is recognised
Provision of habitat		Y						Y	Y			Habitat for wildlife is highly impoverished in Ankoli, as it was in Laporiya prior to water management and wasperi interventions

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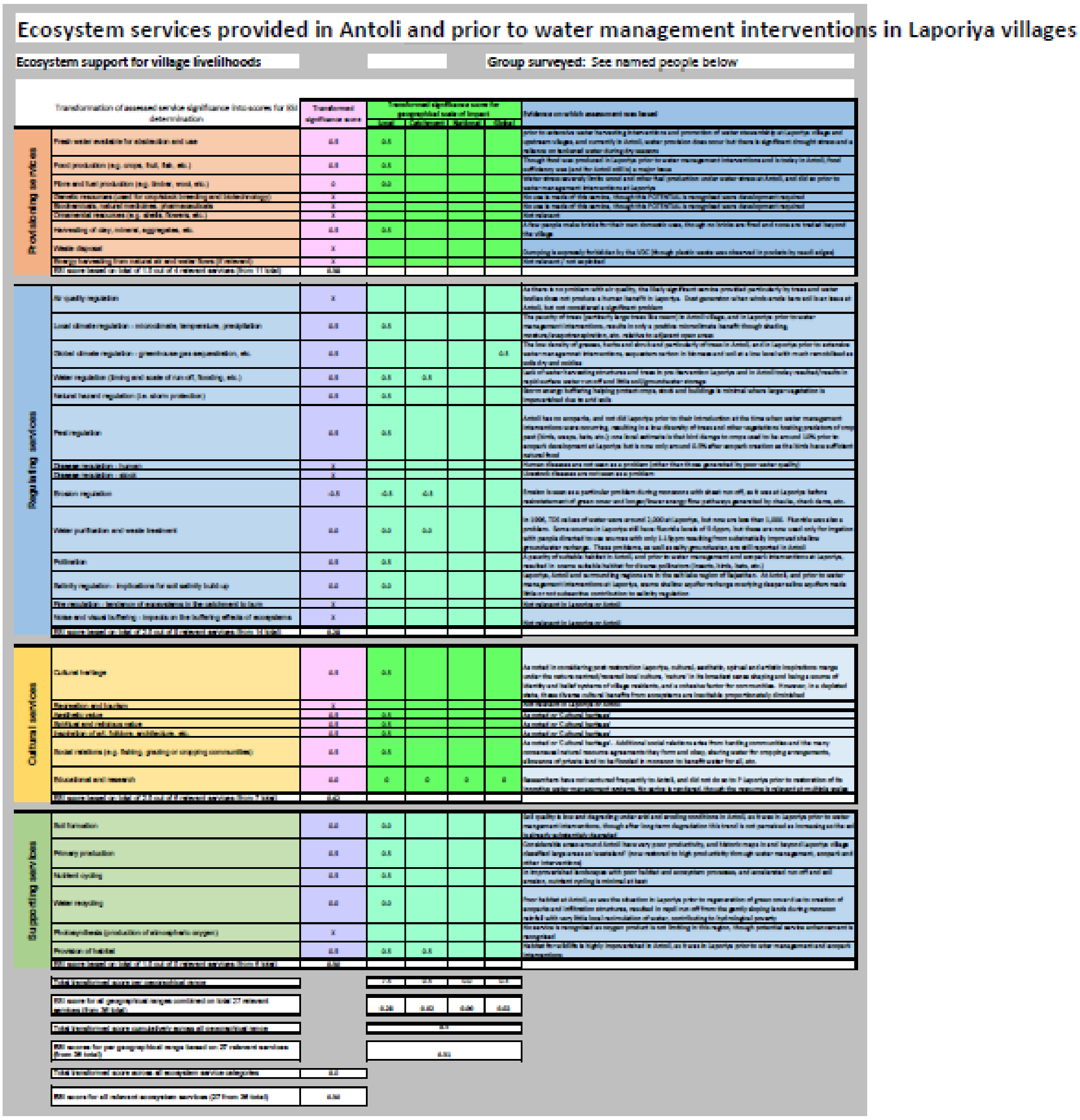

END OF ‘SCREEN GRABS’ OF DIGITAL SUPPLEMENTARY MATERIAL