Citizen science and web-based policy support systems for water and land resources management

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Citizen science for data and knowledge co-generation

Participation of general public (i.e. non-scientists) in the generation of new scientific knowledge (Buytaert et al., 2014)

‘scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions’, (OED, 2014)

• New technologies (user friendly) for data generation and communication – application of sensor based instruments (Hart and Martinez, 2006; Buytaert et al., 2012)
• Improving ecological datasets and environmental education through community based monitoring to internet based crowd-sourcing (Dickinson et al., 2012)
• Participatory monitoring/modelling of ecosystem functionalities

A bottom-up approach for ecosystem services management and sustainable development
Science driven community based decision making to maximize resources utilization (sustainably) for human wellbeing
Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development

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A review of citizen science and community-based environmental monitoring: issues and opportunities

Cathy C. Conrad · Krista G. Hilchey

The current state of citizen science as a tool for ecological research and public engagement

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Abstract Worldwide, decision-makers and government organizations are increasing use of citizen volunteers to enhance their ability to monitor and manage natural resources, species at risk, and conserve protected areas. Over the last 10 years of relevant literature, science literature for areas of consensus, science, and knowledge gaps. Different community-based monitoring (CBM) activities and nance structures were examined and contrasted.
Why do we need citizen science for water and land resources management?

• Lack of actionable data and knowledge especially for remote and data poor environments

• Need locally relevant data and knowledge for detailed understanding of ecosystem functioning, services generation..................

• Rural areas - limited opportunities other than water and land resources based livelihood activities

• Increasing uncertainties: hydro-climatic behaviour (changing rainfall and snowfall patterns), land use change, global warming

• Public engagement in a breadth of natural and socio-ecological science topics (bio-physical production of ecosystem services, trend, geographical distribution and consumption...)

• Engaging with fundamental science and working with local communities for better research and policies
Mountain EVO based hydro-meteorological data monitoring in Mustang region of Nepal - realtime data on hydro-climatic features, publicly available, ready to use..................
Participatory methods

• Participatory discussion at community and institutional levels
• Resources mapping for better understanding of land and water resources uses
• Use of citizen science data into relevant policy support systems (such as WaterWorld and Co$ting Nature)
• Integration of citizen science data into water resources management practices
• Multi-dimensional analysis of poverty and livelihood strategies
Making citizen science more useful at local decision making

What is the purpose of data generation? How can they become more relevant to decision making? Can we use them to characterize the trend of services generation and flow across the landscape?

What is the monitoring mechanism and who do this? What is the communication strategy? & Policy impact?
Policy support systems

Why do we need policy support systems?

• Ecosystem services are spatially explicit (biophysical production, distribution and consumption all in a certain geographical scale)

• A wide variety of natural environment data (including citizen science collected data) are not appropriately used in decision making processes

• Spatial and modelling tools are widely recognized for their role in decision making

• Linking past land use legacies and future land use trajectories in mountain regions

Why low uptake of policy support systems in decision making?

• Lack of or expensive data

• Lack of training or capacity

• Availability of good data

Explicit recognition of Policy Support Systems in various levels of ecosystem services assessment (for e.g., Crossman et al., 2013)
<table>
<thead>
<tr>
<th>Tools, accessibility and key references</th>
<th>Type of model and development stage</th>
<th>Valuation approach</th>
<th>Policy implication</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial Intelligence for Ecosystem Services (ARIES); Web-based application <a href="http://www.ariesonline.org">http://www.ariesonline.org</a>; (Villa et al., 2005; Bagstad et al., 2011, and Villa et al., 2014)</td>
<td>An artificial intelligence and semantic modelling platform; Bayesian Network based model; Open source; documented some components of the model</td>
<td>Quantitative – biophysical values; can be monetized, limited use for non-monetary &amp; cultural valuation; uncertainty analysis through Bayesian networks and Monte Carlo simulation</td>
<td>Suitable for ecosystem services assessment, can be integrated into local decision making processes such as PES scheme and conservation planning</td>
<td>No datasets provided; needs moderate to high level of expert knowledge; limited functionality for climate change and land use change scenarios</td>
</tr>
<tr>
<td>WaterWorld model; <a href="http://www.policysupport.org/wwaterworld/">http://www.policysupport.org/wwaterworld/</a>; (Muligan and Rutke, 2005; Bruijnzeel et al., 2011 and Muligan, 2013)</td>
<td>Detailed and process-based model; raster based modelling system; open source; current version 3.1.3; documented</td>
<td>Quantitative – hydrological fluxes &amp; spatially detailed hydrological services; uncertainty analysis using plausible scenario (land use and climate) and management interventions</td>
<td>Used in policy and decision making processes, useful for scenario analysis for LUCC and climate change; can be integrated into local decision making for water and land management</td>
<td>Local data required; Cannot estimate subsurface and dry season flow; no models for floods/GLOF and their mitigation by ecosystems</td>
</tr>
<tr>
<td>Water Evaluation and Planning System (WEAP); Web based application <a href="http://www.wrap.w2.org">http://www.wrap.w2.org</a>; (Yates et al., 2005 and Steber and Turkay, 2011)</td>
<td>Process based hydrological model with scenario analysis; current development stage (version 3.43); well documented</td>
<td>Quantitative – biophysical values; limited physical processes; uncertainty analysis using LUCC and climate change scenarios</td>
<td>Suitable for water resources based policy and decisions, can be implemented into local decision making processes</td>
<td>Limited physical processes for scenario analysis, substantial data required for detailed hydrological modelling</td>
</tr>
<tr>
<td>Integrated valuation of Ecosystem Services and Trades-off (INVEST); Web-based application <a href="http://www.naturalcapitalproject.org">http://www.naturalcapitalproject.org</a>; (Tallis and Polasky, 2006; Daily et al., 2009; Kareiva et al., 2011 and Tallis et al., 2013)</td>
<td>An advanced model for quantifying and mapping multiple ecosystem services; open source; current development stage - version 3.0.1; well documented</td>
<td>Quantitative – biophysical values; can be monetized; limited use for cultural &amp; ecosystem values; uncertainty analysis using LUCC and climate change scenarios</td>
<td>Widely used in policy and decision making for water and land resources management; can be integrated into local decision making processes</td>
<td>Limited data availability; needs expert knowledge on GIS techniques</td>
</tr>
<tr>
<td>Toolkit for Ecosystem Service Site-based Assessment (TESSA); Web-based platform of different approaches; (Fei et al., 2013)</td>
<td>A collection of models for quantifying and mapping values of multiple ecosystem services; Suitable for landscape based assessment</td>
<td>Quantitative – biophysical values; can be monetized; also good for non-monetary and cultural values; uncertainty analysis using LUCC and climate change scenarios</td>
<td>Suitable for ecosystem services based policy and decision making, can be integrated into local decision making processes</td>
<td>Substantial data are required to assess the bundle of ESS</td>
</tr>
</tbody>
</table>
Most policy support systems are now web-based and freely available (some are also provided with global and regional datasets – crucial to data poor environments)

However, methodological approaches and their current development stages vary significantly

Specific vs. entire portfolio (WaterWorld for water related services and ARIES, INVEST & Costing Nature for a number of ecosystem services)

Most spatial based decision support systems are good at regional scale assessment but very little focus on detailed mapping and modelling of ecosystem services at local scales

The selection of spatially explicit decision support system depends on the types of ecosystem services, data availability and any specific research or policy question to be addressed

It should be quantifiable, replicable, flexible, easy to use and also affordable to local decision making authorities
Policy Support Systems

We believe that policy for sustainable development can be better (more equitable and more effective) when based on the available scientific evidence. We have thus focused on bridging the gap from scientific data and knowledge to policy and management decision-making by building and deploying data-intensive, science-based, spatial policy support systems which are delivered on these pages. These PSS deliver science in a more actionable form.

policy-support.org is home to a range of web-based policy support systems developed, since 2003, collaboratively by King’s College London and AmbioTEK CIC, with a range of other partners as specified for each system. The systems are based on the common eXtreme Framework for developing web based policy support systems (AmbioTEK) and SimTerra databases (AmbioTEK and King’s College London) but are very varied in their focus. Click the links for more information on and to access these systems. Take a look at and subscribe to our blog. Users and usage of these systems is described here.

[Tweets by @policySupport]

[Tweets by @markmuligan]

for #WorldWaterDay 12 new #exitation raingages for #Ghana and #BarkinaFaso. Colective noun for raingages?
1. Sophisticated spatial models
2. Self-parameterising (delivered with all required data)
3. Web-based (little local capacity required)
4. Policy exercises and analytical tools
Web-based policy support systems

**Ecoengine** (framework) – for the development of web-based policy support tools (DESURVEY, FIELSA, AguaAAndes, Companedes, WaterWorld, Co$ting Nature).

1. Global simTerra database (500+ grids) at 1-square-km and 1-hectare resolution some new, some re-processed .
2. Analytical and visualisation tools
3. Web based user interface
4. Modelling system
5. In the Cloud (Amazon EC2)

**WaterWorld** (tool, V.1, V.2.6dev, V3.0dev)

1. detailed process-based modelling of water quantity, quality and some regulation ecosystem services
2. scenario tools for climate change and land use change
3. policy option/intervention tools for e.g. land management

**Co$ting Nature** (tool, V.1) – simpler tool for modelling a much wider range of ES (water, carbon, tourism, hazard mit., biodiversity), pressures,threats and thus overall relative conservation priority
Developer objective

For WaterWorld – To provide a spatially detailed hydrological baseline and quantitative understanding of the likely hydrological outcomes of scenarios of land use and climate change impacts, policy options and management interventions.

For Costing Nature - Focuses on relative conservation prioritisation based on: wide range of ES, biodiversity, delphics, current pressures, future threats. To understand land use change alternatives and their impacts, changing priorities and values.

User objectives -

1. To provide answers rapidly
2. To require only an hour of training
3. To assess at different spatial scales - local, basin, regional and national
4. Datasets are provided (local data can be used where there is available)
5. Not required high level of expertise to use the tools
Outline of policy support systems in EcoEngine framework

Step 1 Define area
Run anywhere globally for 1 degree (100km) tiles at 1-hectare grain, OR 10 degree (1000km) tiles at 1-square-km grain.
Step 2 Prepare data

All data required for operation available globally (either new datasets or datasets homogenized from existing sources).

>140 maps required

If you have better data for a site you can use those instead
Step 3 Start simulation

Users first run a baseline simulation to produce mean 1950-2000 baseline. This is then used as comparator for running scenario or policy option ‘alternatives’
Step 4 Policy exercises
Land use or climate change scenario, land management interventions or anything else (by map upload) to understand impacts relative to baseline
e.g. applying climate change scenario

CLIMATE CHANGE: choose the scenario that you wish to apply.

Choose an existing IPCC downcaled GCM scenario: New

Apply downscaled results from IPCC GCM scenarios using range of scenarios, downscaling teams, models and time periods or a representation the mean of all models available for a given IPCC scenario.

Compare scenarios and GCMs

Please make a selection in all fields.

Choose the following: Assessment > Scenario > Downscaler > GCM > Year

or import new IPCC downcaled GCM scenario: New

or choose an existing CIAT CLIMGEN scenario: New

or import new CIAT CLIMGEN scenario: New

or copy your own scenario: New

or upload your own scenario: New

or develop your own simple scenario: +

All available IPCC AR4 scenarios (17-21 models each) or connect to CIAS CLIMGEN scenarios or upload your own
Step 5 Results maps

Visualise and adapt maps online and through geobrowsers (Google Maps/Earth) or download results for further GIS analysis.
e.g. visualisation of baseline water balance by km pixel, catchment or administrative area
Step 6 Results over time – to visualise or download as Excel

Step 7 Results narrative
Simple text summary of what happened

The simulation is a baseline simulation with baseline policy options and default parameters and was carried out by dmarkmulligan@gmail.com

The main results indicate:

For the baseline run:
Water balance (mm/yr) for the area was on average 1,500 with a 25th percentile of 1,200 and a 75th percentile of 2,000, an absolute minimum of -1,100 and maximum of 5,200. This reflects an area average precipitation (mm/yr) of 2,200 with an absolute minimum of 0 and maximum of 5,000. Actual evapo-transpiration (mm/yr) ranges from 5.3 to 1,300 with a mean of 720. Veg inputs are low in relation to precipitation at 4.0% on average, amounting to 83 mm/yr on average but ranging from 0 to 470 mm/yr.

Seasonally, precipitation for the area has a maximum of 240 mm/month in March and 250 mm/month in April and a minimum of 120 mm/month in August and 130 mm/month in July. Water balance for the area (mm/month) is positive on average and negative for no months. Actual evapo-transpiration for the area varies from a minimum of 50 mm/month in June to a maximum of 68 mm/month in October.
e.g. visualise or download seasonal change in hydrological baseline
Summary of Functions

**Visualise**
- summarise by zone (e.g. Admin region, IBA,KBA..)
- change colour scale
- change min max
- log scales
- maps/ map animations
- time series
- scatterplots of relationships
- Google Earth or Google Maps
- Permalink
- Frequency distributions

**Download**
- output Maps: Geo-ARCASCII, GeoTIFF, IDRISI etc
- output data as Excel
- output data as KML

**Analyse**
- map statistics
- scatterplots of relationships
- seasonality
- sensitivity

**ROI (Region of Interest)**
- values for points of interest
- values (min, max, mean etc) for zones of interest
Summary of WaterWorld Outputs

**Annual:**
- Total annual actual evapo-transpiration (mm/yr)
- Per capita water availability (Mm^3/person)
- Annual total water balance (mm/yr)
- Annual total soil deposition (mm/yr)
- Total fog deposition (mm/yr)
- Annual total gross soil erosion (mm/yr)
- Fog inputs as a percentage of water balance (%)
- Fog inputs as a percentage of total precipitation
- Total annual fog runoff (m^3)
- Total annual fog runoff (mm/yr)
- Total fog inputs (mm/yr)
- Annual total gross hillslope soil erosion (mm/yr)
- Annual total hillslope net soil erosion (mm/yr)
- Total annual hillslope runoff (m^3)
- Total fog impaction (mm/yr)
- Mean percentage of water may be polluted (%)
- Annual total net soil erosion (mm/yr)
- Annual % of runoff generated by fog (%)
- Runoff ratio by subcatchment (fraction)
- Total annual runoff (m^3/s)
- Total annual runoff (m^3)
- Total annual runoff (mm)
- Total annual potential evapo-transpiration (mm/yr)
- Total wind-corrected rainfall (mm/yr)
- Water storage capacity (mm)
- Mean annual terrain corrected wind speed (m/s)
- Difference between rainfall and wind driven rainfall (mm/yr)
- Freq. of potentially condensing conditions (%)
- River network (dimensionless)
- Total annual rainfall (not wind corrected) (mm/yr)
- Mean annual wind exposure (topex scale)

**Monthly:**
- Terrain-corrected wind direction (degrees from N)
- Actual evapo-transpiration (mm/hr)
- Water balance (mm/hr)
- Water storage (mm)
- River flow generated from fog inputs (mm/hr)
- Hillslope Runoff (mm/hr)
- Percentage of runoff derived from fog (%)
- Percent of water that may be polluted (%)
- Wind-corrected rainfall (mm/hr)
- Runoff (mm/hr)
- Snow Pack Water Equivalent (mm)
- Fog inputs as a % of total precipitation (%)
- Meltwater production (mm/hr)
- Mean terrain-corrected wind speed (m/s)
Summary of WaterWorld Scenarios and interventions

CLIMATE
Inbuilt: IPCC AR4 A2a, A2, B1, A1b, 17GCMs 2020s, 2050s, 2080s
(now also available of IPCC 5th Assessment CMIP5 (RCP) scenarios)
By connection: UEA/Tyndall Centre CIAS CLIMGEN
By upload: Your own
By specification: simple seasonal temperature and precipitation changes

LAND USE
Afforestation/Deforestation: according to pre-defined rules
Afforestation/Deforestation: specify rule e.g. deforest a particular IBA
Change to land cover type: according to pre-defined rules
Change to land cover type: specify rule e.g. deforest a particular IBA
Upload your own land cover type maps

LAND MANAGEMENT
Riparian buffer strips, bench terracing, contour ploughing, check dams, dams

OTHERS
By upload of appropriate input ARCASCII maps
# Summary of Costing Nature Outputs

**Analyses, metrics and reporting**

- Hazards and hazard mitigation
  - Key output maps

<table>
<thead>
<tr>
<th>Name</th>
<th>Explanation</th>
<th>Show</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative aggregate development priority index (realised services)</td>
<td>Pressured with low conservation priority and realised service provision</td>
<td><img src="image1" alt="" /></td>
</tr>
<tr>
<td>Relative aggregate development priority index (potential services)</td>
<td>Pressured with low conservation priority and potential service provision</td>
<td><img src="image2" alt="" /></td>
</tr>
<tr>
<td>Relative aggregate nature conservation priority index (realised services)</td>
<td>Pressured and threatened conservation priority areas with high realised service provision</td>
<td><img src="image3" alt="" /></td>
</tr>
<tr>
<td>Relative aggregate nature conservation priority index (potential services)</td>
<td>Pressured and threatened conservation priority areas with high potential service provision</td>
<td><img src="image4" alt="" /></td>
</tr>
<tr>
<td>Relative biodiversity priority index</td>
<td>Relative richness and endemism for redlisted mammals, reptiles, amphibians, birds</td>
<td><img src="image5" alt="" /></td>
</tr>
</tbody>
</table>

| Relative delphi conservation priority index | Conservation priority by overlap of EBAs (Birdlife), Global200 Ecoregions (WWF), Hotspots (CI), Last of the Wild (WCS.CIESIN), Important Bird Areas (Birdlife) and Key Biodiversity areas (IUCN, BI, PI, CI) | ![](image6) |
| Relative pressure index                   | Current pressure according to population, wildfire frequency, grazing intensity, agricultural intensity, dam density, infrastructure (dams, mines, oil and gas, urban) density | ![](image7) |
| Relative threat index                     | Future threat according to accessibility, proximity to recent deforestation (MODIS), projected change in population and GDP, projected climate change, current distribution of nighttime lights | ![](image8) |
| Relative total potential bundled services index | Total potential services including water, carbon, nature based tourism and hazard mitigation services | ![](image9) |
| Relative total realised bundled services index | Total realised services including water, carbon, nature based tourism and hazard mitigation services | ![](image10) |
| Greatest relative total realised bundled service | Greatest realised service (water, carbon, nature based tourism and hazard mitigation) | ![](image11) |
Application of WW/CN model at country scale

Land cover map of Nepal

Bare cover

Herb cover

Tree cover
Percentage impact of human footprint and protected areas on freshwater ES of Nepal
Deforested protected area and replaced with herbaceous cover. Results in decreases in water on the forested cloudy N slopes but increases in the already sparse S slopes (towards Kathmandu). Impacts on erosion also variable.
Mustang region – a high mountainous region of Nepal

Geographic location of Mustang region

Landsat-based rescaling of MODIS VCF (2010) map of Upper Kaligandaki watershed (WaterWorld v2, 2016)

a) Tree cover  
b) Herb cover  
c) Bare cover
A case study of Phlayak and Dhakarjhong villages

- Semi-arid environment with an average annual rainfall of 300 mm
- Densely populated villages where local people exclusively rely on land and water resources

a) Phalyak village

b) Dhakarjhong village
Water resources management – Key issues

A marginal change in hydrological services has a significant impact on agricultural practices.

A substantial amount of water resources is lost due to lack of proper management practices.

Lumbuk stream (Khola): a snow-fed stream
Increased uncertainties on water availability – due to changing snowfall pattern in the higher mountainous area
Sudden and destructive debris flow – threat to water infrastructure
Application of web-based policy support systems

Hydrological modelling tool (WaterWorld v2, 2016) for assessing hydrological services

a) Annual rainfall (mm/yr)
b) Annual water balance (mm/yr)
c) Annual runoff in Lumbuk stream (Khola) (WaterWorld, 2016)

d) Human footprint of water resources (Co$ting Nature, 2016)
Comparison of modelling result with observed values

c) Annual runoff (WaterWorld, 2016)

<table>
<thead>
<tr>
<th>Month</th>
<th>Flow volume (m³)</th>
<th>Precipitation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>82210</td>
<td>9.72</td>
</tr>
<tr>
<td>February</td>
<td>70558</td>
<td>13.62</td>
</tr>
<tr>
<td>March</td>
<td>77187</td>
<td>19.19</td>
</tr>
<tr>
<td>April</td>
<td>81105</td>
<td>14.89</td>
</tr>
<tr>
<td>May</td>
<td>107630</td>
<td>14.03</td>
</tr>
<tr>
<td>June</td>
<td>259858</td>
<td>23.51</td>
</tr>
<tr>
<td>July</td>
<td>667672</td>
<td>63.01</td>
</tr>
<tr>
<td>August</td>
<td>781229</td>
<td>53.03</td>
</tr>
<tr>
<td>September</td>
<td>379580</td>
<td>33.28</td>
</tr>
<tr>
<td>October</td>
<td>165964</td>
<td>17.83</td>
</tr>
<tr>
<td>November</td>
<td>109739</td>
<td>4.84</td>
</tr>
<tr>
<td>December</td>
<td>90555</td>
<td>8.08</td>
</tr>
<tr>
<td>Annual</td>
<td>2873287</td>
<td>275.02</td>
</tr>
</tbody>
</table>

Annual runoff = 2.87 M m³
Major uncertainties

- Lack of consistent data on hydro-climatic features (spatially and temporally) especially in remote areas
- Monitoring of hydrological attributes (quantity and quality)
- Changing hydro-climatic pattern and resulting impacts on hydrological system
- Current pressures like land use change and future threats of climate change and land management practices
- Socio-economic and demographic issues
- Lack of capacity at policy and decision making levels
The way forward

• Needs strong citizen science perspective for better understanding of ecosystem functioning in mountain environment such as changing snowfall & rainfall patterns

• Advancing citizen science practices and integrating them into decision making processes

• Integrating new data and knowledge system into relevant policy support systems (such as WaterWorld, Costing Nature and InVEST)

• Capacity building at local level on how to use science based ecosystem services data and knowledge into decision making for sustainable mountain development
Thank you!!!