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A climate services perspective on Norwegian stormwater-related databases

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A R T I C L E I N F O

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A B S T R A C T

Floods and stormwater events are the costliest natural catastrophes. Costs are expected to increase due to urbanization and climate change. Mitigation is needed. Different stakeholders with different motivations unfortunately often evaluate vulnerability by using fragmented and incomplete data sources. This paper intends to review the different approaches for collecting and analyzing data, and to evaluate their usefulness within the proposed framework for a "smart" use of data. The objectives of this work have been to review qualitatively and quantitatively a selection of Norwegian stormwater-related databases and to propose measures for improvement. The findings are seen according to the climate services literature and show that that data is spread around a heterogeneous community of stakeholders concerned with different motivations, different needs, and different levels of data processing. In general, the needs of the different stakeholders have not been surveyed and defined systematically enough and there is a substantial potential in upgrading from the delivery of passive raw data to the delivery of knowledge-driven decision-support tools.

Practical implication

Climate adaptation requires a more efficient implementation of stormwater-related databases. The main measures for improvement are:

- Exploiting more efficiently available sources of data and exploring alternative sources of data,
- Achieving a more efficient transformation of data into knowledge via the development of analytical tools. This requires the identification of needs of relevant end-users and the integration of several sources of data in a dynamic and request-based way.
- Providing ergonomic and user-friendly digital solutions to support workers in their daily tasks and to efficiently document the actions within the system,
- Triggering the implementation of evaluation processes within the national agencies for business purposes, and at a national scale for providing the policymakers with useful knowledge about the societal risks associated with climate changes.
- Implementing all innovations with a direct participation of the users. Focus should be directed on the support systems and the networks surrounding the databases, beyond the technical development of the databases.

1. Introduction

1.1. Background

1.1.1. Why stormwater matters

Stormwater, which is sometimes also referred to as "urban flooding" or "pluvial flood", corresponds to the event when rain overwhelms drainage systems and waterways and makes its way into streets and properties. Stormwater may also be referred to as "surface water flooding" under the general definition of "non-fluvial floods" (Bernet et al., 2017). There are several ways in which stormwater can cause the flooding of a property: overflow from rivers and streams, sewage pipe backup into buildings, seepage through building wall and floors, and the accumulation of stormwater on property and in public rights-of-way (The Centre for Neighborhood Technology, 2014). Floods and stormwater events are the costliest natural catastrophes (Cigler, 2017) and costs are expected to increase due to urbanization and climate change. More specifically, stormwater damage has increased significantly the last years due to increasing property values of buildings, extended use of buildings – i.e. basements – more deliberate property owners and more intense rainfall. New solutions are therefore needed to cope with intense storms and to reduce the risks to people, buildings and infrastructure (Arnbjerg-Nielsen et al., 2013). Risk analyses have been identified as a prerequisite to the effective mitigation of the negative consequences of floods and stormwater events (The European

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Parliament and the Council of the European Union, 2007).

1.1.2. Different knowledge needs

Different stakeholders with different motivations unfortunately often evaluate vulnerability by using fragmented and incomplete data sources. To help researchers and policy makers assess national progress in reducing vulnerability, reasonably accurate assessments of damage are needed. However, the actual need of knowledge varies greatly between stakeholders and sometimes between decisions (Messner et al., 2006). At least three different levels have therefore different needs for increased knowledge: the national level addresses the needs of policy makers, the local level addresses the needs of municipalities e.g. for urban planning issues, and the individual level addresses the needs of private firms and private owners.

1.1.3. Data quality is critical

The largest technical challenge when manipulating stormwater-related data is likely to be the completeness of data, defined as the proportion of stored data against the potential of “100% complete” (Dama United Kingdom, 2013). Hazard impact data is usually missing (Elmer et al., 2010), extreme events suffer from a lack of information due to their rareness while frequent events do not cause enough damage to trigger assessment (Elmer, 2012) and the lack of systematic, reliable methods for obtaining damage estimates has been often reported (Skaaraas, 2015; Downton et al., 2005). Accuracy, defined as the degree to which data correctly describe the “real world” (Dama United Kingdom, 2013) is a particularly challenging aspect of data quality within the context of stormwater databases due to the difficulty to identify, to measure and to model indirect losses (Skaaraas, 2015; Council, National Research, 1999; Downton et al., 2005). Consistency issues, defined as the difference of two or more representations of a thing against a definition (Dama United Kingdom, 2013), arise when attempting to integrate isolated data sets, hosted in different ways by many organizations, by different stakeholders, for multiple purposes, and at different times. Finally, timeliness, defined as the degree to which data represent reality form the required point in time (Dama United Kingdom, 2013), remains a major challenge since damage assessment needs to become independent from occasional interest, temporary resources and assessment campaigns.

1.1.4. The Norwegian context

The present annual precipitation average in Norway is 20% higher than 100 years ago and an additional 20% increase is expected at the end of this century together with an increase in the number of extreme weather events, according to projections obtained with RCP8.5 (Riahi et al., 2011). This will further intensify already heavy loads on drainage and strains on surface water systems, and will increase water damage to buildings and infrastructure (Hanssen-Bauer et al., 2015). At the same time, substantial challenges for flood and landslide management cooperation between Norwegian stakeholders were identified in previous studies (Fossestøl and Breit, 2014). Identified causes included: organizational issues, the large number of actors and professions involved, and the different views on the need for data coordination. The challenges for increasing stormwater-related knowledge in Norway are therefore significant and at the same time pivotal to prepare the society for climate changes.

1.1.5. Aim of the paper

The main motivation of this paper is to define a framework for designing efficient and appropriate data-driven decision-support tools to reduce stormwater risk for the society.

The objectives of this work have been:

- to review qualitatively and quantitatively a selection of Norwegian stormwater-related databases,
- to define a framework for assessing about the “smart” use of data
- to evaluate the current Norwegian situation with respect to this framework
- to assess the findings according to the climate service literature and,
- to propose measures for improvement under the form of innovations

1.2. State of the art

1.2.1. From natural hazards to stormwater-related databases

Access to loss data is critical to reduce risks associated with natural hazards and the quality of assessments has gained increasing attention in recent years. Rudari et al. (2017) compared the three mostly used world-wide loss data repositories, i.e. Emergency Events Database (EM-DAT) organised by Centre for Research on the Epidemiology of Disasters, NatCatSERVICE by Munich Re and SIGMA by Swiss Reinsurance. They showed that all three databases are event-based and have a global coverage on a national scale, but they differ in nomenclature, classification of hazards, uncertainty methods, data sources and data sharing policies. The national loss databases Slovenia National Database, Moldova National Database, United States SHELDUS database and Colombia Desinventar database were also presented as examples of good practises of handling loss data.

Whereas the abovementioned databases have a broad scope covering natural hazards in general, and in some cases also events with industrial or man-made causes, more specific event databases also exist focusing on e.g. flood. The Swiss flood and landslide damage database from the Swiss Federal Research Institute WSL (Hilker et al., 2009) and the Australian Flood Studies Database developed by Geoscience Australia (Australian Government, 2011) are examples of event based national databases with the objective to understand flood risk better. The German flood damage database HOWAS21 is a more object-oriented database (Kreibich et al., 2017) giving both direct and indirect flood losses on buildings, inventory, businesses and other premises for an event.

1.2.2. Loss data is critical

Recent international agreements like The Sendai Framework for Disaster Risk Reduction, the 2030 Agenda for Sustainable Development and the IPCC Conference of the Parties 2015 points out the necessity for collecting and standardizing loss data to ensure a successful implementation of these frameworks (Serje, 2017). Loss data in this context relates to all kinds of hazards, including natural, and the emphasis is on risks related to climate change. Recommendations focus on indicators for monitoring progress in reducing risks and address the key challenges to have a unified terminology, scope and scale (Ehrlich et al., 2017).

1.2.3. Databases as a climate services decision support product

“Climate services” denotes services helping stakeholders in decision making processes for climate adaptation. This includes most forms of knowledge distribution and information about climate change (data, tools, documents, maps, webpages, social networks etc.), targeting decision-makers at all levels (Vaughan and Dessai, 2014; Meadow et al., 2016). All these diverse types of climate services and tools are aiming at improving decisions about adaptation. Main types include (NRC, 2009):

- *Decision support products:* Products as data, maps, scenarios, models, documents etc. that contain information to support decision processes;
- *Decision support services:* Consultations, teaching or interactions making the users more capable of using decision support products. These services are less visible, but are as important as the products;
- *Decision support systems:* Networks between individuals, municipalities, and organizations supporting how to use products and services.

Databases are a type of *decision support product*.

1.2.4. Decision support systems are essential to decision support products

There is an important relationship between the different types of *decision support products*, *services* and *systems*. Teaching and network is essential to ensure that the *decision support products* (e.g. databases and guides) are taken into use (Hauge et al., 2017). Social psychology offers valuable insight into typical challenges found within human behaviours, perceptions, and motivations when meeting climate change (Clayton et al., 2016; Stoknes, 2015), and may therefore contribute to explaining what happens within networks that make them so important for decisions for climate adaptation. Learning in climate adaptation networks takes advantage of the social mechanisms that influence our attitudes and actions. The power of social networks is mostly due to the "descriptive social norms": the knowledge (imagined or real) of what others would say or do in one's situation. People look to others to find out how to behave, and try to resemble the people they think of as significant in the groups they want to belong to (Klöckner, 2015; Tajfel, 2010). Even if many people would state that what their peers' actions have little effect on their own environmental habits, research states the opposite (Stoknes, 2015; Sussman and Gifford, 2013). The use of climate *decision support products* therefore rests on the social arenas they are presented and developed in.

1.2.5. Climate services with a focus on users

The quality of the *decision support products* depends on cooperation with the users. Climate service providers should work with users to contextualise scientific knowledge to allow climate information to be both created and tailored to specific decision-making situations (Meadow et al., 2016; Goosen et al., 2014; Swart et al., 2016; Vaughan and Dessai, 2014; Hygen et al., 2016; Lucio and Grasso, 2016; Swart et al., 2017). The dialog between users and providers of climate services contributes to legitimacy, and encourages trust in the services (Lemos and Morehouse, 2005). McNie (2013) states that obtaining climate-science information that is contextual, credible, trusted, and understood by users, requires an alignment between climate services' information and the users' needs. Vaughan and Dessai (2014) argue for the "co-production" of climate services, with scientists, users and policy makers working closely together in a process of joint problem solving. In addition, accuracy is improved when specifying the target groups and the channels that they are available through, and communication is therefore more effective when targeting specific groups rather than at a general audience (NRC, 2009). NRC (2009) emphasizes the focus on the users by suggesting six principles for effective climate services decision support: 1) begin with the users; 2) prioritize process over product; 3) link information producers and users; 4) build connections across disciplines; 5) seek institutional stability; and 6) design the process for learning. These principles set the user needs as the starting point and acknowledge that the process – the networks and the teaching arenas – are as significant as the product. A valuable *decision support product* also depends on institutional stability; establishing and maintaining long-term networks with information producers and users who continually interact to refine and revise the tools (Meadow et al., 2016). These principles are applicable to communication of science in general. Climate adaptation are just one of many arenas where scientific findings *must* reach the users and impact their actions. Lack of relevance and usability, cultural differences between science and society, communication styles, complexity, and power asymmetries, are just some of the barriers between scientists and users (McNie, 2013; Vaughan and Dessai, 2014).

1.2.6. Stormwater-related databases in the context of the data-information-knowledge hierarchy

Henry (1974) first distinguished among data, information, and knowledge, initiated what would be later referred to as the Data-Information-Knowledge Hierarchy. According to this theory, data items are simply "facts" that have been collected in some storable, transferable, or expressible format (Westfall, 2013). Data simply exists and has no significance beyond its existence (Masud et al., 2010). Information is "data in context" (Mosley et al., 2010), for which meaning has been given by way of relational connections (Masud et al., 2010). For example, a data item stored as the number 53 does not by itself provide us with any usable information. By adding context, e.g. a definition such as "the number of centimetres water has risen"; a timeframe such as "in July 2013"; and relevance such as "after a heavy rain event in Oslo"; that data item is converted to information.

Information in and of itself is not useful until human intelligence is applied to convert it to knowledge through the identification of patterns and trends, relationships, assumptions, and relevance (Westfall, 2013). Knowledge is obtained when comparing this piece of information with the previous water levels (trend) after heavy rain events (relationships), and when it is concluded that a corrective action is needed (assumption) resulting in an improvement of urban drainage systems (relevance). Knowledge is eventually the appropriate collection of information such that its intent is to be useful (Masud et al., 2010).

2. Materials and methods

2.1. Informants

The following criteria were used to select relevant Norwegian participants to the survey:

- the participant should either own, maintain, or use a database,
- the database should provide a record for a selection of objects or events, and
- at least part of the registered objects should be either related to stormwater systems or potentially exposed to damages due to stormwater, or
- at least part of the registered events should be related to causes or consequences of stormwater events.

Based on these criteria four participants were selected, three infrastructure owners and one municipality, see Table 1. Anonymity has been ensured by removing any personal information related to respondents or their employers.

2.2. Fact-based questionnaire

The fact-based questionnaire was designed in such a way that it could address both event-based databases, e.g. databases used by infrastructure owners to map all their belongings, and object-based databases, e.g. databases used by infrastructure owners to plan and perform operational procedures. The fact-based questionnaire was sent by email to all selected participants and was received back after some months. The following categories (see Fig. 1) and the corresponding keywords were used to map the characteristics of each database:

- Object:
  - o Temporal characteristics: deadline for registration, temporal coverage, updating frequency
  - o Spatial characteristics: geospatial component, spatial resolution, geographical coverage
  - o Object characteristics: classification levels, properties types
  - o Stormwater specificities: hydrology, terrain, vulnerability, consequence of failure, risk analysis
- Event:
  - o Routines: operational routines, work order, extraordinary events
  - o Reporting: registration, relationship, keywords
  - o Treatment of non-conformities: registration, report, treatment, analysis
  - o Stormwater specificities: extraordinary events, non-conformities, reporting, analysis
- Data:

Table 1
Informants.

	Short name	Database type	User profiles in the face to face interviews
Infrastructure owner 1	IO1	Object-based	Three end-users: – responsible for daily follow-up of work orders – responsible for budget
Infrastructure owner 2	IO2	Object-based	Three end-users: – responsible for safety, accessibility and quality of the facilities – responsible for the correct implementation of work order data within the database – responsible for deviation treatment
Infrastructure owner 3	IO3	Event-based	One project leader: – responsible for design and implementation of a new event-based database
Municipality	MUN	Object-based	Three end-users: – two of them responsible for technical treatment of deviations – One of them responsible for administrative treatment of deviations

- o Usage: user groups, accessibility, motivation, frequency, criticality, analysis
- o Quality: correctness, completeness, consistency, user-interface, homogeneity, quality system, peer-reviewed publication
- o Maintenance: frequency, responsibility
- o Sources: internal sources, external sources, dynamic relationship, traceability, frequency

– Implementation:
- o Interface: digital format, online accessibility, graphical user interface, request, automatic reports
- o IT characteristics: entries, IT solution

2.3. Face to face interviews

After receiving the fact-based questionnaire, an interview-process was implemented in order to clarify some points from the fact-based questionnaire, and most importantly to hear about personal and sometimes "non-official" opinions. The interviews were not recorded or transcribed, only notes were taken. The interviewed persons were required to either use or maintain the identified databases. General questions were employed to focus the discussion towards the participants' own perception of the usefulness of data and databases:

– What do you need the data for? Is data critical for your daily work?
– How are your tasks related to stormwater issues?
– How often do you access the data?
– Is your user interface/database user-friendly enough? What could be improved?
– What is missing? What is unnecessary?

3. Results

3.1. The global picture

Selected participants were showed to own and/or maintain several databases each according to their needs and responsibilities: IO1 uses its database as display solution for providing different types of information to its employees, IO2 uses its database to efficiently document and follow-up all maintenance routines for its employees, IO3 uses its database for informing the general public about past events and future forecasts related to natural hazards, MUN uses its database (based on Gemini software product (Holte, 2010)) to efficiently distribute tasks to its employees and to collect reports. The identified databases, their motivations and their communication methods are summarized in Table 2, together with the main thematic focus of the database: road, rail, or geohazards. API stands for "Application Programming Interface".

3.2. Stormwater-related specificities

Stormwater specificities were addressed in different ways depending on the participant/motivation behind the database.

- IO1 registers properties such as: maintenance responsible, construction year, normal water depth, geometric properties, soil conditions, presence of heating cables, owner, producer, area of use, connection method, etc. for stormwater-related object categories which include: pond, river, hydrant, manhole, spillway, culvert, pump station, pipe etc.

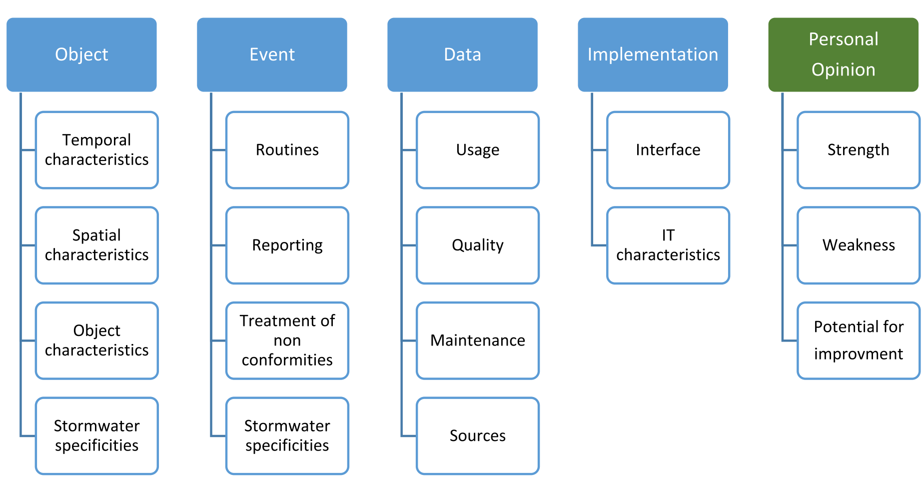

Fig. 1. Structure of the questionnaire.

Table 2
Short overview of data sources available in Norway.

Databases (main topic)	Availability	Map-based	API	Main Motivation	Specific goals	End-user(s)	Main developer (contributors)	Web-reference
Database 1 (rail)	On-request	Yes	Yes	Active documentation system	To send automatically working orders	IO2	IO2	None
				Reporting tool	To provide an easy-to-use tool that supports in an efficient way the following actions: control, repair, and report			
Database 2 (rail)	Open and On-request	Yes	No		To provide most of available information within Database 1 together with warnings from IO3	General public	IO2 (IO3)	Yes
Database 3 (rail)	On-request	No	No	Documentation system	To collect activities within the maintenance plan together with risk analyses	IO2	IO2	None
Database 4 (rail)	On-request	No	No	Documentation system	To collect technical drawings and reports	IO2	IO2	None
Database 5 (rail)	On-request	No	No	Documentation system	To collect all documentation related to each object under a unique digital location	IO2	IO2	None
Database 6 (road)	Open and On-request	Yes	yes	Data & information display	To support optimal management, maintenance and development of the infrastructure	IO1	IO1	Yes
					To display effective information system related to the infrastructure	General public		
Database 7 (geohazards)	Open	Yes	Yes	Data & Information display	To support preparedness, monitoring and warning of flood, landslides and avalanches	External experts	IO3	Yes
Database 8 (geohazards)	Open	Yes	Yes	Registration tool	To register observations related to snow, flood, ice and landslides	General Public	IO3	Yes
Database 9 (geohazards)	Open	Yes	Yes	Data & information display	To display information related to ice covered lakes	General public	IO3	Yes
Database 10 (geohazards)	Open		Yes	Data & information display	To provide warnings for avalanche, floods, landslides, and icemelting	General public	IO3	Yes
Database 11 (geohazards)	Open	Yes	Yes	Data & information display	To display daily updated maps of snow, weather, water conditions and climate	General public	IO3 (met.no)	Yes
Database 12 (geohazards)	Open	No	No	Data & information display	To display hydrological real-time data	General public	IO3	Yes
Database 13 (road))	Internal	No	No	Documentation system	To support and document electronic reporting & following-up.	IO1	IO1	None
					To document tasks related to operation- and maintenance contracts			
Database 14 (geohazards)	Open	Yes	yes	Data & information display	To collect observations, experiments and modelling related to hydrological topics	General public	IO3	Yes
Database 15 (geohazards)	On-request	Yes	No	Data & information display	To keep a good record of the structural assets of a utility and the maintenance history on each asset	MUN	MUN	None
Database 16 (geohazards)	Open	Yes	No	Registration tool	To register observations and complaints from customers to the municipality	General Public	MUN	None
Database 17 (geohazards)	Open	Yes	Yes	Analytic tool	To provide geomorphological information of floods and stormwater events	Municipalities Other stakeholders IO3	IO3	Not implemented yet

- IO2 inspects stormwater-related objects such as: closed/open drainage systems, manholes, and culverts. Deviations specific to stormwater events include for example: damaged object, flooded object, or non-functioning object.
- All measurements and observations performed by IO3 staff connected to stormwater events refer to a specific procedure issued within a well-defined framework. The following properties are registered: ID number, location, date and time, duration, measuring station, water level and water flow, damages and pictures, weather conditions, warnings, "free" data such as picture or free text. Analyses are performed to determine the following properties: flood type, cause of flood, cause of damage/injuries, recurrence period, etc.
- MUN keeps the record of the completed work orders and other occurrences on the network for stormwater events, e.g. breaks, flushing, leaks, inspections. The number of recorded stormwater events has been unusually higher in 2001, 2007 and 2014, but in general, some dozens of events are registered each year, evenly distributed within the municipal and private pipe networks.

3.3. Interactions with other systems/databases

Depending on the participants, the interaction with other systems range from very little interaction with other systems, except at a very local level when individuals are willing to do so, to fully integrated solutions with internal and external systems. Interaction with internal systems are usually related to reporting tools, map-based tools, maintenance tools, documentation tools, measuring stations databases, modelling tools.

Popular external systems to collaborate with were observed to be:

- Meteorological Institute weather services for government agencies and businesses such as Halo (Meteorologisk institutt, 2015). The service provides location-based weather forecasts designed specifically for businesses' needs. Examples include turbulence warning for aircrafts or calculation of how oil spill moves in the ocean.
- Registration applications where the general public can register own observations, measurements and complaints.
- Public displays with daily updated measurements and warnings.

3.4. Identified challenges with the databases

The following challenges were identified during the face-to-face interviews:

- Adoption of digital solutions is still not widespread: hand-written documents are sometimes still in use, leading to the lack of updated status indicators. In some cases, inspections are only visual – due to lack of time – and demonstrate the lack of quality assurance system. Data validation is in general not robust enough.
- Even when digitization level is satisfying, real-time data is difficult to implement. Stormwater-related objects are not adapted to real-time control, meaning the stakeholder has very few possibilities to "act preventively" in case a warning of extreme rain event is issued.
- In some cases, registration applications, where the public should be able to register own observations, are not sufficiently advertised and/or user-friendly.
- Lack of relevant data for stormwater event is observed in some cases. Among others, information on flooding of basements, e.g. height of water ingress, is seldom recorded and made available to interested parties.
- No structured information related to potential vulnerability of areas is available, which hinders decision-making process. Risk analyses, if any, are performed at management levels with a limited top-down dissemination and depend a lot on the business model behind the database.
- Costs are not widely available, nor is life cycle cost data. When costs are entered as data, they anyway do not correspond to total damage cost estimation.
- Budget prioritization follows in worst case a top-down approach without real feedback taken out from the data/database. In other cases, the distribution and prioritization of budget is based on facts and reported needs, but there is no automatic analysis tool from the database that support such decisions.
- In some cases, interviewed users are skeptical to the usefulness of decision support systems. A significant need for knowing what is behind such algorithms was expressed, together with a significant doubt about "black-box" systems.
- There is too little automation when a deviation (or a warning) is registered (or received). Even when deviation messages come automatically, decisions are to be taken "manually" at the time the incident occurs. There is also no automatic relationship provided between recorded events and meteorological conditions.
- Very little attention is given to impact of climate change on daily activities, only when deciding to replace objects related to water managements system. Rule of thumb is to replace old objects by new over-dimensioned objects to account for increased occurrence of extreme rain events.

3.5. Framework for smart use of data

The framework shown in Fig. 2 has been developed to reflect different data-related processes based on the Data-Information-Knowledge hierarchy (see Section 1.2).

- Monitoring is defined as a short-term collection of data and information, which does not take into account outcomes and impact. Data may come from sensor measurements, human observations, or data exchange with other databases. Data may be collected with different time-schedules and different time delays, e.g. real time or once a year for the previous year.
- Reasoning is defined as any data analytic process that enables to transform data into valuable knowledge. In such a process, relevant data are extracted and categorized, and then used to identify behavioural patterns by different techniques, e.g. data mining, forecasting, statistical analysis, optimization, simulation, etc. Reasoning also includes data visualization techniques to help people understand the significance of data by placing it in a visual context.
- Acting is defined as the short-term result of access to new knowledge. End-users are usually expected to take decisions, which can then create specific tasks to be performed by specific persons or specific equipment. The decision may be taken within the reasoning process, as part of generation of new knowledge.
- Evaluating is defined as the process to assess outcomes and long-term impact of previous actions, decision and data collection. The evaluating process is a management tool.

Results from the study show that in general, the databases are used mostly for monitoring, sometimes for reasoning, very rarely for acting towards climate adaptation, and never for evaluating.

- Challenges related to monitoring were mostly related to data sources that were either scarce or not exploited in an efficient way. Among other issues, inspection procedures lacked quality system. In some cases, inspections or working routines such as geocoding were performed "manually", which led to additional workload and additional potential sources of errors.
- The use of reasoning-related tools was hardly observed, mostly because of passive use of data. Although most of the databases were used as powerful and robust dashboards containing and displaying a substantial amount of information, the active use of data to support decision-making processes appeared as limited.

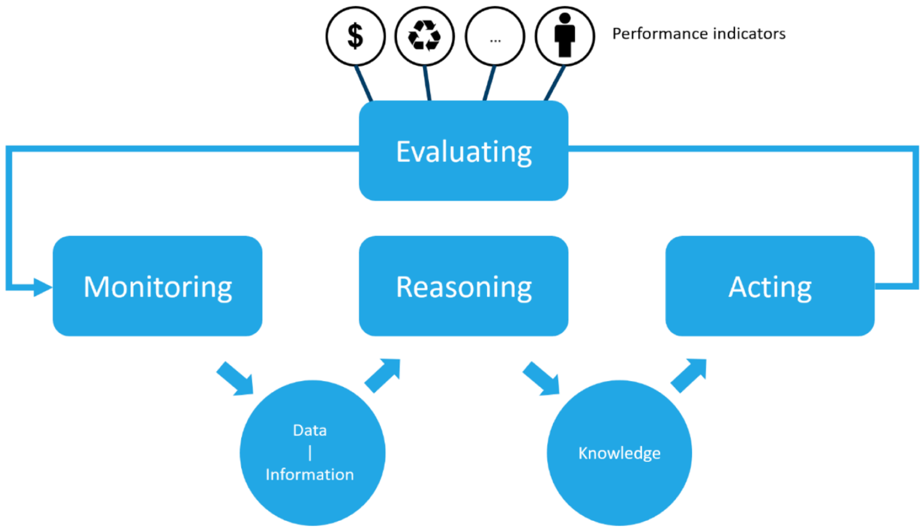

Fig. 2. Schematic representation of a smart use of data cycle.

- "Acting" in the sense of climate adaptation and prevention was mostly based on raw data, rather than on knowledge built out of analytical tools. Decisions were consequently mostly addressing short-term solutions, rather than long-term evaluations needed for supporting climate adaptation.
- The evaluating part is the last one within the data cycle and is also the most important for enabling improvement at a system scale. However, this is also the aspect which has been observed to be the least implemented within the informants, most probably because it requires all digital connections to be implemented upstream. An efficient evaluating process is based on the assumptions that the whole data cycle is continuously digital, that workflows are efficiently designed, and that analytical tools are appropriate to management purposes, and this was not observed within the selection of databases.

4. Discussion

The discussion will go through the innovation opportunities of the four main pillars of the framework for smart use of data; monitoring, reasoning, and acting (see Section 3.5), and evaluate these in relation to the climate services literature.

4.1. Innovation opportunities within monitoring

The following innovation opportunities are identified within the monitoring pillar:

- The development of relevant sensors is an efficient way to increase amount and quality of data, and enables further data processing to transform data into knowledge. All technologies related to the "Internet-of-Things" (IoT) represent potential additional sources of data whose relevance should be investigated in a systematic way with respect to technical, societal, and business aspects.
- The participation of citizens to smart cities-like purposes is getting more and more interest. The development of dedicated and easy-to-use "apps", together as the application of game-design elements and game principles in non-game contexts – coined as "gamification" – is an efficient way to enhance the involvement and contribution of citizens to mitigation of climate changes within an urban environment. At the same time, by creating such redundant low-cost sources of data, data is likely to come with a higher quality. Further studies are however necessary to improve ergonomics of such "app" solutions, to map the real interest of citizens for such collaborative solutions, to understand how to entice citizens into providing data – e.g. via incentives – and to promote efficiently such solutions via marketing.
- It is essential that collected data items are registered together with their location. Location should imperatively be coded under both a readable street address/place name and GPS coordinates for ensuring correct understanding from human users, and efficiency from machine-controlled algorithms. A research project from The Western Norway Research Institute (Brevik and Aall, 2014), together with Finance Norway and some other local and regional authorities, assessed the potential and preconditions for strengthening the prevention of climate-related natural hazards through assessing the usefulness of access to the damages data of insurance companies. Studies to select available and relevant geocoding – and reverse geocoding – tools are necessary to enhance the quality and usefulness of collected data. Geocoding and reverse geocoding have raised potential privacy concerns, especially regarding the ability to retrieve street addresses from published static maps, with a potential effect on sale value of properties (Brevik and Aall, 2014). Societal studies should be performed to evaluate the risks associated to making such information available to the general public, and to propose appropriate measures.
- Data should ideally be open and datasets should be collected under a common and secure platform. Open data is expected to contribute to the following positive developments: efficiency and innovation, industrial development, democratization, and transparency. Governmentally maintained platforms such as data.norge.no are ideal candidates for such purposes. However, issues such as handling of business sensitive information, treatment of classified information, and treatment of data with third-party copyright still must be investigated.

All these opportunities rely on competence and knowledge. The use of the databases ("*decision support product*") depends on the "*decision support services*"; consultations, teaching or interactions, to make the users more capable of using the data bases (NRC, 2009; Hauge et al., 2017). The implementation of IoT technologies, sensors, and big data together with the users represents a need for generating better *decision support systems* for competence development.

4.2. Innovation opportunities within reasoning

The following innovation opportunities are identified within the reasoning pillar:

- Analytics is a well-developed field whose technical implementation is relatively easy if precise specifications are given. Mapping relevant groups of end-users and their corresponding needs is therefore crucial for the customized development of relevant analytic tools. Standard procedures for mapping end-user needs and their corresponding technical specifications should be defined.
- Depending on the actual needs, data from several databases may be required for supporting the development of customized analytic tools. A relevant solution is to use Application Programming Interfaces (APIs) for selecting and exchanging data in an “automatic” and structured way.
- APIs are the technical solution to select and use data originating from different sources, but their presence is not enough to guaranty an efficient integration of data sources afterwards. A common terminology must be ensured so that different data sources can communicate between each other, and can eventually be integrated within the same analytic tool. The best-known technical solution to the problem is represented by the development of ontologies. An ontology is a controlled, logically structured representation of the world (more usually part of it) that is both human and machine readable (Buttigieg, 2015). Ontologies have recently been developed for the specific field of natural disasters, for example in the framework of the EU project “INFRARISK” (Collaborative project FP7, 2015) whose main goal was to evaluate the risks associated with multiple infrastructure networks for various hazards. Other attempts include studies from De Wrachien et al. (2012), Scheuer et al. (2013), Kuziemsky et al. (2014), and the European project “Disaster 2.0” (Aston University, 2013).

Many of the databases are not user-friendly enough because of lack of user involvement in developing the databases, and lack of focus on the end-users and their needs. Climate services providers should work with users to contextualize scientific knowledge, allowing climate information to be both created and tailored to specific decision-making situations (Swart et al., 2017; McNie, 2013).

4.3. Innovation opportunities within acting

The following innovation opportunities are identified within the acting pillar:

- The provided tools must be digital to ensure a direct data flow from workers to the system, so that data quality is increased and procedures are efficiently enforced.
- Studies to improve ergonomics and graphical-user-interface (GUI) design are needed to ensure good adoption of the tools by the workers.
- The use of map-based tools should not be limited to the “acting” part and should enable a wider adoption of GIS benefits, which include (ESRI, 2016):
  - cost savings to optimize e.g. maintenance schedule,
  - better decision making about location e.g. route selection and evacuation planning,
  - improved communication: GIS-based maps and visualizations are a type of universal language that improves communication between different teams, disciplines, professional fields, organization, and the public,
  - better record-keeping e.g. for maintaining authoritative records,
  - the development of a new management approach: managing geographically, meaning understanding what is happening and what will happen in geographic space.

Decision support systems or *services* are seldom linked to stormwater-related databases. The technical aspect of these databases is often considered as more important than the system and networks surrounding the databases. This is detrimental to climate adaptation in general and to prevention of stormwater-related events in this specific case.

4.4. Relevant innovation opportunities within evaluating

The following innovation opportunities are identified within the evaluating pillar:

- Dataflows should be used for business purposes whereas they have been originally designed to serve operational purposes. Important properties such as costs, which are not needed for supporting operational tasks, must therefore be added within the dataflow. This requires e.g. the database solution to be flexible enough for authorizing inclusion of new properties and/or new categories. Responsibilities also need to be precisely defined regarding evaluation tasks, reporting tasks, and final decision-making process. Both technical and organizational studies are needed to provide guidance to organizations for implementation of an efficient evaluating process.
- An efficient evaluating process is based on the definition of relevant performance indicators. Such indicators must be mapped and defined by the management system itself, depending on its specific business model. Business process modelling of activities should be developed to support both forecast and benchmarked performance as key insight tools.
- Societal risk associated with climate changes should be evaluated at a national level. This ambitious goal requires all digital connections in all systems from all organizations to be implemented upstream. Although some historical data exist, the delivery of the first relevant results would necessitate several years of monitoring. Implementation of such an overall evaluation system would provide policymakers precious knowledge for evaluating and eventually adapting their policy.

5. Conclusion

This study has reviewed qualitatively and quantitatively a selection of Norwegian stormwater-related databases. The results have shown that data are spread around a heterogeneous community of stakeholders concerned with different motivations, different needs, and different levels of data processing. In general, the needs of the different stakeholders have not been surveyed and defined systematically enough.

A framework for assessing about the “smart” use of data has been defined, and the current Norwegian situation has been evaluated with respect to this framework. Regarding national stormwater-related inventory databases, there is a substantial potential in upgrading from the delivery of passive raw data to the delivery of knowledge-driven decision-support tools. Technical challenges can relatively easily be solved by digitization and its opportunities for improving the workflow and for increasing the quality of data. The findings have been seen according to the climate service literature. Organizational challenges must be solved by an end-users-focused approach to identify needs and expectations.

Conflict of interest

No potential conflict of interest was reported by the authors.

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