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Modelling of THM formation potential and DOM removal based on drinking water catchment characteristics

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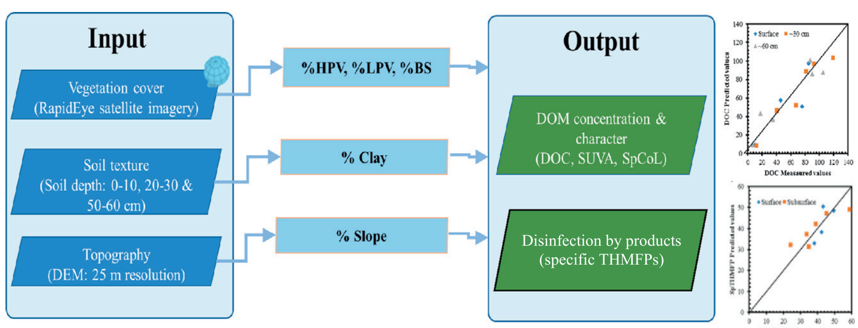
HIGHLIGHTS

- Vegetation cover extracted from satellite imagery using spectral mixture analysis.
- Models of DOM in runoff waters, based on catchment characteristics were developed.
- Models of treatability of DOM and THMFP, based on catchment parameters were developed.
- Catchment management decision support tool to estimate water quality was developed.

GRAPHICAL ABSTRACT



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ABSTRACT

Catchment properties influence the character and concentration of dissolved organic matter (DOM). Surface and subsurface runoff from discrete catchments were collected and DOM was measured and assessed in terms of its treatability by Enhanced Coagulation and potential for disinfection by-product (trihalomethane, THMFP) formation potential. Models were developed of [1] DOM character [i.e. SUVA and SpCoL] and concentration (measured as dissolved organic carbon), [2] treatability of DOM by coagulation/flocculation processes and [3] specific THMFP based on the catchment features including: (a) surface and sub-surface soil texture (% clay: 5–25%), (b) topography (% slope: 5–15%) and (c) vegetation cover [i.e. high photosynthetic vegetation, low photosynthetic vegetation and bare soil] extracted from RapidEye satellite imagery using spectral mixture analysis. From these models, a catchment management decision support tool was designed for application by catchment managers to support decision-making of land-use and expected water quality related to water resources for drinking water supply.

Software and data availability: Data sets used for models developing presented in this paper have been published in Research Data Australia (RDA) under the title of "Impacts of catchment properties on DOM and nutrients in waters from drinking water catchments".[1] These data sets are available in open access and published in June 2017.

Abbreviations: BS, bare soil; $CHCl_3$, chloroform formation potential; DBPs, disinfection by products; DOC, dissolved organic carbon; DOM, dissolved organic matter; G, grass; HPV, high photosynthetic vegetation; LPV, low photosynthetic vegetation; NV, native vegetation; NDVI, normalized difference vegetation index; P, pine; S, sandy soil; SC, sandy clay soil; SCL, sandy clay loam soil; SL, sandy loam soil; SpTHMFP, specific trihalomethane formation potential; $SpCHCl_3$, specific chloroform formation potential; SMA, spectral mixture analysis; SpCoL, specific colour; SE, standard deviation; THMFP, trihalomethane formation potential; ZOC, zero order catchment.

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[1] Link: https://researchdata.ands.org.au/impacts-catchment-properties-water-catchments/932912?source=undefined. These datasets are provided by the University of South Australia (UniSA). All data in these datasets were collected as part of the Australian Research Council project, ARC Linkage-LP110200208.

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A catchment management decision support model (CMDSM) tool was developed. Macros created using Visual Basic for Applications in Excel 2010. Excel 2010 or higher is required to open the CMDSM tool. The tool is provided by the University of South Australia (UniSA) and is not currently available on-line so please contact the corresponding author for access or further information.

1. Introduction

The quality of water in catchment-fed reservoirs is largely influenced by land management practices within the catchment (Bryan et al., 2009), and catchment properties such as vegetation type and loading (Awad et al., 2015a; Yang et al., 2013), topography (Mutschlecner et al., 2018; Nosrati et al., 2012), the timing and intensity of rainfall events (Awad et al., 2017; Yang et al., 2013) and soil type (Autio et al., 2016; Nosrati et al., 2012). Catchment surface runoff and stream water generally have higher concentrations of organics that are more aromatic and humic in nature than shallow and deep groundwater (Inamdar et al., 2012). This is attributed to either adsorption of high molecular weight (Banaitis et al., 2006) hydrophobic and aromatic compounds (Ussiri and Johnson, 2004) to clay minerals in soils or by microbial modification (Aitkenhead-Peterson et al., 2003; Sun et al., 2013) as the dissolved organic matter (DOM) moves through the soil profile. Nelson et al. (1992) found that differences in dissolved organic carbon (DOC) concentrations within a stream are dependent on the adsorption capacities of the soil types present, particularly the texture of the surface horizon. Surface horizons high in clay tend to exhibit stronger adsorption characteristics than coarse textured soils. Strong covalent bonding on the exchange complex of clay is a function of the interaction between organic matter and surface charges on the clay surface (Foth and Turk, 1972). Organic loading in watersheds is influenced by catchment slope i.e. with steeper slope sub-catchments, the DOC concentration tends to be at comparatively lower levels (Nosrati et al., 2012).

Spectral Mixture Analysis (SMA) is a widely-used technique that estimates the fractional abundance of materials or features, known as spectral endmembers, within remotely sensed data (Karimi et al., 2016; Settle and Drake, 1993). Spectral endmembers can represent any physical features such as vegetation, soil, rocks, minerals and water. The fractional cover products produced are an important source of data for a range of applications including climate change research, ecosystem monitoring and management, precision agriculture, geological mapping and water quality assessment (Lewis et al., 2017; Somers et al., 2011). In comparison to other vegetation indices (e.g., normalized difference vegetation index, NDVI), Elmore et al. (2000) found that SMA's estimation of live vegetation is superior to NDVI especially when used to explore changes in vegetation cover over time. Peddle et al. (2001) compared ten vegetation indices to SMA in order to obtain boreal forest biophysical information, also found SMA to provide significantly better predictions of biophysical and structural information.

Several studies have reported models designed to predict concentrations of total or dissolved organic carbon in watersheds and lakes based on catchment parameters. Using linear equations, Nosrati et al. (2012) reported a model to predict DOC concentration based on season (autumn-winter and spring-summer), water flow per unit area and soil organic carbon. For twenty lakes of the Absaroka-Beartooth Wilderness, Montana and Wyoming, USA, Winn et al. (2009) developed a geographic information system (GIS) model to predict DOC concentration based on vegetation cover (i.e. created by remote sensing tools) and wetland areas (slope, 0–5%). Mattsson et al. (2005) also used linear equations to predict total organic carbon in Finnish rivers based on land covers (relative abundance of wetland, peatlands and agriculture land within the catchment area) derived from satellite imagery. However, to date there have been few studies reported on the relationships between the qualities of waters (e.g., organic character with concentration) within discrete land-use catchments and the treatment needed for waters for potable supply.

Allochthonous organic matter derived from catchment sources can pose significant aesthetic problems and health risks that need to be addressed through treatment processes to generate potable supply. These risks include formation of disinfection by-products (DBP) principally trihalomethanes (THMs), haloacetic acids (HAA), iodo-acids, halonitromethanes (HAN) and nitrosamines that form when organics react with chemical disinfectants (Golea et al., 2017). The concentration and character of DOM significantly influences raw and treated water quality, coagulant demand and DBP formation in treated waters (Awad et al., 2016a; Nosrati et al., 2012; Ritson et al., 2014).

In this paper, we report power function models developed of the character and concentrations of DOM (measured as DOC), treatability of DOM and specific THM formation potential (μg THMFP/mg DOC), in surface and subsurface runoff waters within discrete zero order catchments (ZOCs), based on catchment parameters. Parameters of ZOCs include: (1) surface and sub-surface soil texture, (2) topography and (3) vegetation and soil cover estimates. The models and software tool are designed for application by catchment managers to support decision-making related to land-use selection that promotes high quality source waters for drinking water supply.

2. Material and methods

2.1. Sites description

Water samples (from surface and shallow subsurface flows collected at soil depths of ~30 cm and ~60 cm at the upper, middle, and low slope positions) were collected from six discrete ZOCs with three land management practices (native vegetation, pine plantation, grasslands), and with varying surface soil textures of the Myponga reservoir-catchment, South Australia. ZOCs were instrumented with surface and subsurface runoff collection devices as detailed by Awad et al. (2015a). Water samples were collected in winter and spring seasons (between June and November 2013, 2014 and 2015) as in summer-autumn seasons, no surface or subsurface water flows were recorded in any of the ZOCs studied. The rainfall pattern of Myponga catchments of South Australia, is strongly seasonal with hot dry summers and cool wet winters (for example, Myponga in 2013–14 had 643 mm rainfall between June and November and 178 mm between December and May). During this study, no surface water flows were recorded in two ZOCs with pine plantations (S2 and S5) in any season.

The land uses selected are the key ones of this catchment, but are also representative of land uses of other Australian drinking water catchments. The key features of the study sites are: Site 1: native vegetation on sand; Site 2: pine on sand; Site 3: grass on sand over sandy clay; Site 4: native vegetation on sandy clay loam over sandy clay; Site 5: pine on sandy clay loam over sandy loam; Site 6: grass on sandy clay loam over sandy clay.

2.2. ZOCs parameters

2.2.1. Soil and slope description

Soil samples were collected from each catchment at four random points (using create random points tools, ArcGIS 10.1) and at lower