METHODOLOGY OF ECOSYSTEM ASSESSMENT IN URBAN CATCHMENT AND CASE STUDY

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ABSTRACT The degradation and loss of vital ecosystem status in urban areas have been an inevitable consequence because of urbanization. Therefore understanding of how urban development influence catchment ecosystem is a crucial task in order to preservation and enhancing the important services in the urban environment. This paper established a methodology for eco-region classification and assessment of the status of the terrestrial and aquatic ecosystems. It is designed to serve as a framework for assessment, monitoring, and management of urban catchment ecosystems for river basins. In this paper urban eco-regions were classified in terms of natural and anthropogenic indicators, such as geographical conditions, vegetation and impervious area. Furthermore, ecological status of different eco-regions can be accessed through indices of ASPT and EPT. A testing case study was carried out in an urban area in Trondheim, Norway. In each eco-region, according to the above defined indicators, the ecological characteristics were identified from the status of the landscape pattern. Further analyses focus on the relationship between the river catchment land use types and the river ecosystem status. MLR models and spatial analyses are employed to examine the statistical and spatial relationships of land use and the water quality on catchment scale. It is hoped that the methodology and the case studies can provide some practice and scientific background to support decision makers of protection and rehabilitation of river ecosystem and sustainable urban planning and implementation of EU Water Framework Directive.

1 INTRODUCTION

Over the last several decades, intensive human activities in urban area have brought numerous changes in natural environment. Land use was changed, infiltration capacity within watershed decreased due to the increase in impervious area, which has resulted in large volumes of surface runoff and urban flood risk [1][2][3]. Meanwhile changes of water cycle caused habitat alternations to both in-stream and riparian zones and loss of critical aquatic habitats, even biodiversity and species composition [4][5]. As another important sign of human activities, agricultural areas have made negative impacts on river system [6][7][8], including nutrients loss that leads to water pollution, soil erosion and so on. There has been an increasing awareness that physical environment are changing, water quality and river systems are deteriorating gradually. Under increasing demand by human beings and the ecological systems for cleaner rivers and lakes, groundwater and coastal beaches, the EU Water Framework Directive was put forward as guideline to restore water courses to “good ecological conditions” by 2015 and calls for catchment wide management of water resources [9].

In order to fulfil the goal of the EU Water Framework Directive, definition of eco-region can be used as tools. Eco-regions proposed by J.M. Omernik are geographical areas with general similarity in ecological characteristics and in type, quality, and quantity of environmental resources but relatively homogeneous patterns in comparison to that of other areas [10]. Each eco-region should be able to well describe biotic and abiotic components of terrestrial and aquatic ecosystems and exhibit the difference than other eco-regions. This spatial ecological framework can serve for the research, assessment, monitoring, and management of ecosystems components and ecosystem conditions.

In Trondheim, monitoring of water bodies in relation to the targets set in the implementation of the EU Water Framework Directive, which included swimming area, drinking water resources, urban and agricultural stream. Water quality and biological survey were conducted in selected streams to assess the degree of pollution and environmental conditions in the aquatic environment. Monitoring results from report with moderate even poor conditions in some sites still reflected some ecological problems [11]. Therefore, achievement of a good and stable situation in water bodies, area sustainable development and effective resources management are focuses we should concern and research mission at present.

The aim of this study is to set up eco-regions in Trondheim municipality. This ecological framework can reflect the features and gradients of surface land form, landscape and the effects of urbanization. Each eco-region can be regarded as a relative independent system or unit. Their characteristics are summarized and ecological status is assessed through special index. MLR (multiple linear regression) models and spatial analyses are employed to examine the statistical and spatial relationships of land use and the water quality on catchment scale. The result can be useful reference for basin management and be foundation for further study of improving ecological status.

2 METHODS

2.1 Study area

Trondheim lies at the mouth of the Nidelva River on the south shore of Trondheimsfjord, one of the largest fjords in Norway. It is the municipality in Sør-Trøndelag county and third largest city of Norway with a population of 181,513 (October, 2013) [12]. Top elevation is Storheia hill, the highest mountain in Bymarka, 565 meters above sea level. Trondheim city has a predominantly hemiboreal Oceanic climate, but borders on humid continental and subarctic climate. The part of the municipality further away from the fjord has colder winters, the part close to the fjord, such as the city center, has milder winters. From eKlima [13] (Norwegian Meteorological Institute), there have a mean monthly minimum temperature -4.1°C in February and a mean monthly maximum temperature 19.4°C in July at Voll weather station from 1997 to 2013. Two pluviometer stations, Leinstrand and Risvollan, are distributed within the city borders [11].

In the municipality, Nidelva River flows through the city from south to north before reaching Trondheimsfjord. The flat middle part of city is urban area, location of downtown buildings. Further east towards fjord landscape is characterized by lowland and farmland. Southeast part of Nidelva distributed with forest reserve and Lake Jonsvatnet, which is the main source of drinking water for the City of Trondheim. Southwest of Nidelva finds Heimdal plateau, and further west are the flat and fertile loam areas, where there are vast farmland.

2.2 Eco-regions classification process

Each geological area is a complex and nonlinear eco-system. There are many elements that affect the processes of land and water ecosystems from different aspects and at different scales. Take consideration of spatial and temporal influence on stream channels [14], indicators that reveal geomorphological, climate, land use and topographic characteristics and water quality and at several temporal and spatial levels are selected in order to evaluate the ecological conditions (see Figure 1).

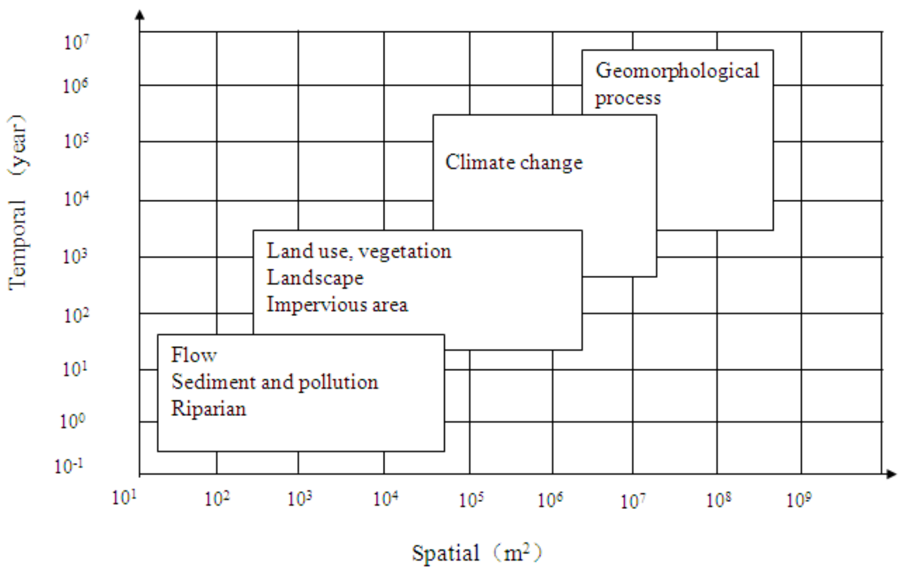


Figure1 Different elements which affect catchment process with temporal and spatial scales

Ecological zone classification is a process of delineating and classifying ecologically distinctive areas of the earth`s surface. According to spatial area of municipality and presence of urban area, we take mesoscale as interest scale. Since there almost have no climate difference in the extent of Trondheim municipality, climate factor can be ignored. Based on data we obtained, terrain, land use and impervious ratio are employed as key factors to carry out ecological zoning.

The three most important component maps were analysed in the GIS platform to sketch out regions that were relatively homogeneous in land surface form, land use and impervious conditions. After comparing and overlaying three component maps, different eco-region boundaries can be identified to delineate each typical eco-region conditions.

Based on built up eco-regions, area and land use composition of each eco-region can be summarized and nominations can be given to each eco-region according to its characteristics of location and land use composition.

2.3 Assessment of ecological status of the eco-regions

Assessment of ecological status using data on benthic community structure and functional structure in rivers designated as one of the quality elements of the EU's Water Framework Directive [9]. ASPT (Average Score per Taxon) index and EPT index are applied to express tolerance and biodiversity of benthic community. ASPT index is regards as important index for evaluating eutrophication and organic load of rivers or streams. EPT index is an index of water quality based on the abundance of three pollution-sensitive orders of macroinvertebrates relative to the abundance of a hardy species of macroinvertebrate [15].

According to Trondheim municipality`s macroivertebrate monitoring studies, ASPT index and EPT were observed in some selected stream sites to describe and assess water quality and ecological status of stream. In order to do the analysis, data from the survey sites that cover Trondheim geographical boundary were collected and divided by eco-regions into four classifications. Survey results were summarized and box-plot graphics were used to reveal the differences and tendency of ecological status in spatial eco-regions from 2009 to 2011.

2.4 Influence of landscape on water quality

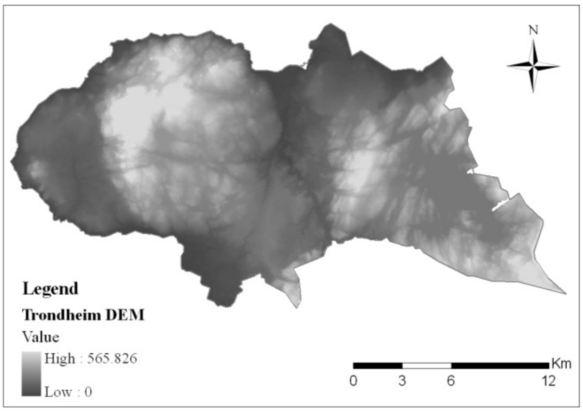
As a part of ecological status assessment and in order to reveal the relationship of a collection of landscape metrics to water quality of E.coli and total phosphorus (TCB and TP), multiple linear regression (MLR) analysis was carried out to study what kind of land type, how composition and configuration, what kinds of topological parameters can contribute or reduce the water pollution. 10 sub-catchments extracted based on water quality sample sites were delineated through ArcHydro Tool, forestry, agriculture, marsh and settlement areas in each sub-catchment were chosen as main landscape types since sum of four type area are account for more than 85% of sub-catchments` total area. Percentage of area, patch density of each land use type can describe composition and extent of fragment comprehensively. Therefore, two metrics of each landscape, topological parameters and monthly precipitation, which may influence this process, were incorporated in to model. Average values in monthly measurements of TCB and TP from 2007 to 2011 have been obtained as dependent variables. The value of water quality variables were $\log_{10}(x)$ or ln(x) transformed. Stepwise variable selection with a variable significance cutoff of 0.05 was used in selecting independent variables to determine the best models (SPSS, Version 19).

3 CASE STUDY AND DATA COLLECTION

3.1 Data about terrain and land use

In order to carry out eco-region classification in Trondheim municipality, the geospatial data and land use data were collected. As shown in figure 2. Digital elevation model (DEM) covered city area with 25-m resolution can reflect land surface form. Based on these spatial data, 10 water quality monitoring sample sites were used to extract 10 sub-catchments in GIS platform, its area, river density and average slope were calculated respectively.

Land use data describes the different types of land use and their distribution. Landscape metrics which reflect composition and configuration can be obtained by FRAGSTATS software [16]. We take PLAND and PD to represent landscape pattern, where PLAND, presenting the percentage of landscape, is a measure of landscape composition, specifically, how much of the landscape is comprised of a particular patch type. PD, patch density, representing the number of patches of the corresponding patch type divided by landscape area, is a good reflection of the extent to which the landscape is fragmented.



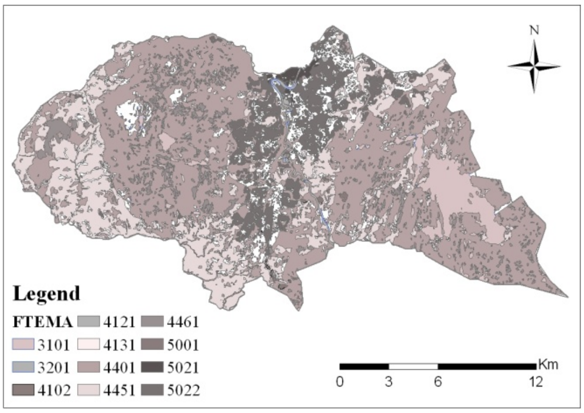


Figure 2 Digital elevation model and land use in Trondheim municipality
(Code in right figure stand for different land use, they are 3101— lake, 3201— stream, 4102— quarry, 4121— graveyard, 4131— sport, 4401— forest boundary, 4451— agricultural area, 4461— marsh, 5001— building area, 5021— city centre, 5022— settlement area)

3.2 Data of impervious ratio

Calculation of impervious ratio can be started from definition of impervious area. In land use map, building area, city centre, settlement area, and paved roads were taken as imperious area, and others landscape such as forest area, marsh area or agriculture area were regarded as pervious area.

City centre and building area were taken as impervious area with the impervious score of 1, which means these areas are imperious totally. Settlement area was considered as semi-pervious area with 0.5 impervious score, because there have grassland or marsh area around each house can play important role of infiltration. And pervious area is given the score of 0. Based on land use grid data with cell size 2.5m*2.5m, each grid was assigned a value according to definition above. Then, the spatial analyst tool of FocalStatistics (MEAN) is used in zoom area with 5*5 cells to calculate the average of score in zoom. Therefore a new grid data about area`s impervious ratio generated. Results are shown through Figure 3.

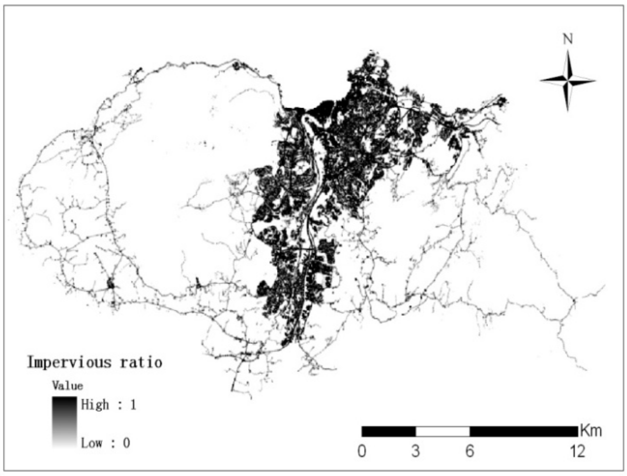


Figure 3 Impervious ratio in Trondheim

3.3 Survey of benthic data

Trondheim municipality's environmental goal is to achieve good ecological status in their suburban streams. The municipality has since 2007 carried out an annual monitoring program in selected streams, where studies of benthic community has made an important performance indicator for condition assessment in recent years. Data of field survey ASPT-index and EPT from 2009 to 2011 were collected [17][18][19], distribution of survey sites is shown in figure 4.

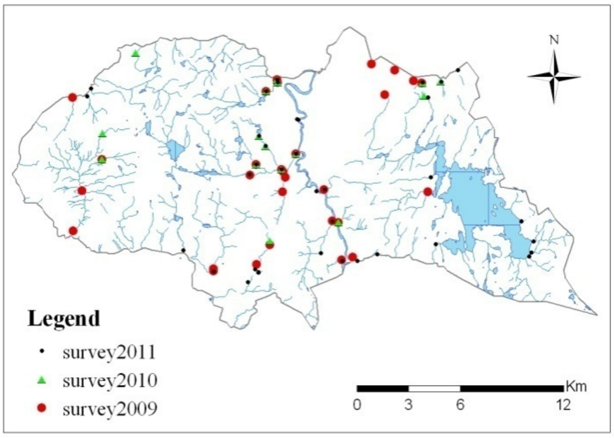


Figure 4 Sample sites from 2009 to 2011

The ASPT index is based on a ranking of a selection of the families that may be encountered in the benthic community in rivers after their tolerance organic load. Tolerance values range from

1 to 10, where 1 indicates the highest tolerance. ASPT index gives a mean tolerance value for benthic families in the sample. Measured index value shall be assessed in relation to a reference value for each water type. The reference value is set to 6.9 for the fauna of rivers. Table 1 indicates class boundaries for ASPT score [19] for benthic fauna within each condition class.

Table 1 Classification for assessment of benthic fauna in flowing water for ASPT index

ASPT class in rivers					
Natural state	Very good	Good	Moderate	Poor	Very poor
ASPT	ASPT	ASPT	ASPT	ASPT	ASPT
6.9	>6.8	6.8-6.0	6.0-5.2	5.2-4.4	<4.4
1	1	2	3	4	5

3.4 Water quality and precipitation

Water quality data and precipitation from 2007 to 2011 were retrieved from the report about "Monitoring of water resources in Trondheim" provided from Trondheim municipality, which summarizes the results of water monitoring in Trondheim Municipality. Two water quality indicators TCB and TP from outlet points of 10 sub-catchments were selected each month, which are identified as good indicators of pollution discharges from municipal sewage, buildings and agricultural activity [11]. Distribution of catchments see figure 5. Risvollan pluviometer station was taken as reference station in Trondheim area. Monthly rainfall was used in the analysis.

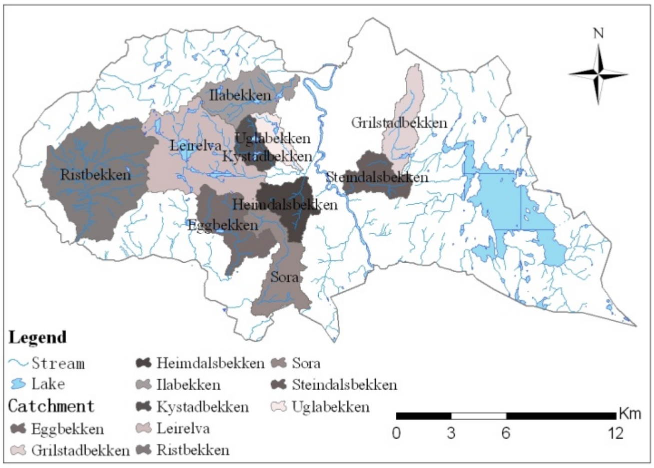


Figure 5 Distribution of 10 sub-catchments

4 RESULTS AND DISCUSSION

4.1 Eco-regions of Trondheim

Through overlaying thematic maps collected above, four eco-regions are generated. See figure 6. Each eco-region can be view as a relatively isolated eco-system, since different land surface form, land cover and composition means they have different functions and services in ecosystem and lead to totally different processes. Difference land use and calculated its area and area percentage are presented in Table 2.

Eco-region1 locates at the west part of city with ca. 68.1 km^2, more than70% of total area is covered by agriculture area. The east part of city is Eco-region 2 with total area 123.5 km^2, 13% and 64% of total area are important lake as drinking water resources and forest area. Eco-region 3 locates at Heimdal plateau, total area is 88 km^2, forest area account for 82% of whole area. City centre and settlement area are mainly distributed in eco-region 4 with total area 60 km^2. Main land use types and area percentage have showed.

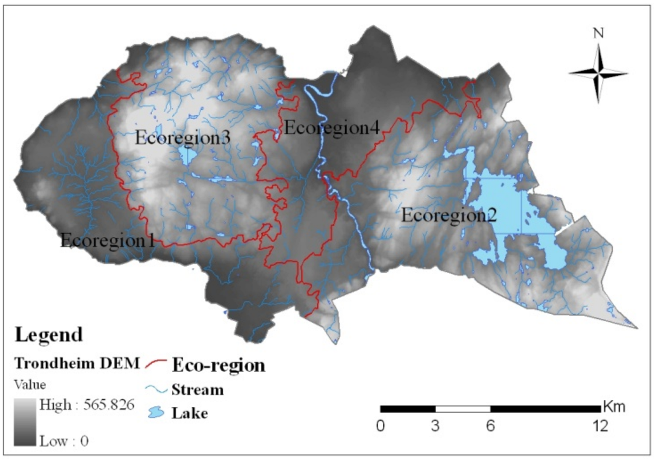


Figure 6 Four eco-regions in Trondheim

Table 2 Area percentage about main type of land use

Land use	lake	forest	agriculture	marsh	city centre	settlement
Eco-region1 (%)	0.01	24.46	70.73	4.15	--	0.28
Eco-region2 (%)	13.13	64.32	16.26	4.95	--	0.22
Eco-region3 (%)	3.01	81.6	3.01	12.08	--	0.29
Eco-region4 (%)	--	13.29	7.98	0.06	2.76	72.98

4.2 Ecological status of different eco-regions

Survey sites from 2009 to 2011 were separated according to their location. Since survey results ASPT index were monitored in 2010 and 2011 and EPT were observed in 2009 and 2011, interregional and interannual variability can be expressed by box-plots (See figure 7 and 8).

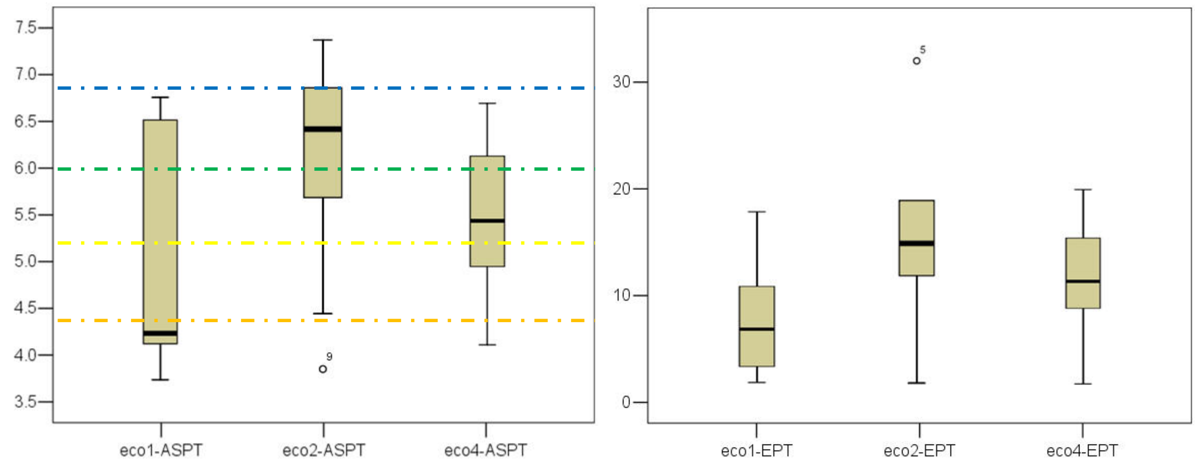


Figure 7 Distribution of ASPT index and EPT in eco-regions in 2011. Box represents the 25th, 75th percentiles, whiskers represent the 5th, 95th percentiles, thick line represents the median values, and circles represent outliers.

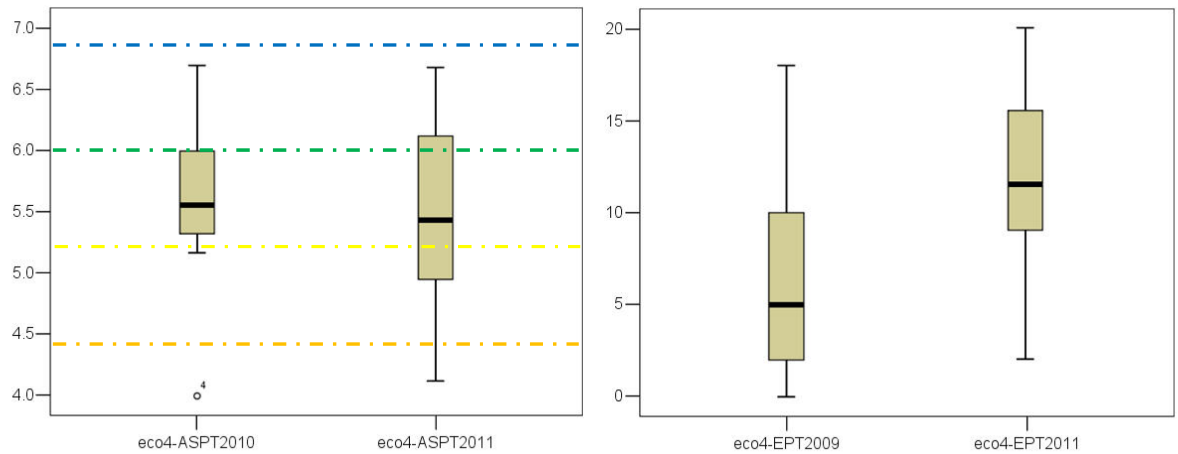


Figure 8 Distribution of ASPT index and EPT in eco-region4 from 2009 to 2011

Figure7 show the clear variations of ASPT index and EPT among eco-regions. According to the data and analysis result in 2011, eco-region2 (forest and drinking water area) has median ASPT value 6.5 with "good" condition according to ASPT classification, eco-region4 (urban area) is worse than eco-region2 with "moderate" condition, the worse one is eco-region1, farm land area, has reached “very poor” level. This illustrate that eco-region2 as drinking water resources has best ecological status in Trondheim, farmland area condition is much worse than urban area. EPT index among eco-regions have almost same tendency. In perspective of eco-region4, median values of ASPT remain the same basically, keep “moderate” level from 2010 to 2011, but EPT increased from 5 to 11.5 when compare 2009 with 2011.

It is concluded that both ASPT index and EPT in eco-region1 and eco-region4 are worse than it in eco-region 2, so we can realize that clear ecological differences emerge among eco-regions with regard to landscape pattern. Furthermore, agricultural area has worse ecological conditions than urban area.

4.3 Relationships between landscape metrics and water quality

Since weaker correlation between TCB and TP, Spearman correlation coefficient was 0.35, separate MLR models were run for each water quality variable to explore different contributions from landscape metrics and other data set to stream pollution. Monthly measurements of TCB and TP in 10 sample sites from 2007 to 2011 were used. Landscape metrics and topographical parameters (size, slope) of sub-catchments were incorporated into the models as explanatory variables. All variables listed in Table 3, which can express anthropogenic and natural gradients.

Table 3 Variables were incorporated into MLR models

Variables	**unit**	**Abbreviation**
Forest area	%	Fpland
Agriculture area	%	Agpland
Patch density of agriculture	number per 100 hectares	Agpd
Urban and settlement area	%	Urbpland
Patch density of Urban and settlement area	number per 100 hectares	Urbpd
Marsh area	%	Mpland
Road density	m/ ha.	Roden
Precipitation	mm	Prec
Sub-catchment area	km^2	Area
River density	km/km^2	Rivden
Mean slope of sub-catchment	degree	Catslp

Since Trondheim experiences moderate snowfall from November to March, we considered snow affect surface run off and pollution delivery until April. Therefore we distinguish snow season from November to April and rainy season from May to October. The relationships were examined in snow season and rainy season separately.

Panel Data at two seasons were used to develop MLR model. The adjusted r-squared across snow season were 0.525 (0.42) for TCB model and 0.584 for TP model, were 0.39 for TCB model and 0.607 for TP model with rainy season. The four and five independent variables used to estimate TCB and TP during the snow season (TCB_S , TP_S) were related to landscape metrics and topological parameters. The equations take the form:

$$\ln(TCB_S) = 9.464 – 0.039\ Fpland + 0.585\ Agpd – 2.114\ Rivden + 0.084\ Area \quad (1)$$

$$\ln (TP_S)= 10.688 – 0.147Fpland – 0.086Urbpland – 0.066Agpland + 0.591Agpd + 0.403Catslp \quad (2)$$

The four and five independent variables used to estimate TCB and TP during the rainy season (TCB_r ,TP_r) were related to landscape metrics and topological parameters. The equations take the form:

$$\log10 (TCB_r) = 5.19 – 0.042Fpland + 0.107Mpland + 0.136Agpd – 0.83Rivden \quad (3)$$

$$\log10 (TP_r) = 6.889 – 0.081Fpland + 0.212Agpd – 0.051Agpland – 0.054Urbpland + 0.114Catslp \quad (4)$$

In snow season, TCB were contributed from farm land and topological area. In rainy season, the increase of TCB concentration mainly due to existence of marsh area and patch density of farm land. Trondheim municipality has four treatment plants in operation that treat water from approx. 99% of the city's wastewater drains, which may explain why we cannot find clue of TCB pollution from urban or settlement areas. Further research should study why TCB comes from agricultural area in snow season; during the summer period, more human activity may result in concentration of TCB increased.

Phosphorus inputs from wastewater and agricultural areas were the largest sources of phosphorus in the lakes and streams in Norway. After the waste water sources have been reduced, the focus changed to more diffuse sources in the agricultural landscape. The average yearly loss of phosphorus (TP) ranges from 0.1–7.5 kg P/ha agricultural area [20]. The difference in weather and topographical conditions, soil properties and different agricultural practice lead to large variability of Phosphorus loss [21]. Case study in Trondheim show a close correlation of agricultural area and topological parameters with TP no matter what seasons, especially configuration metric patch density, which means less fragmented of agricultural area will make increase of TP concentration than more fragmented. In the area with steeper slope, surface runoff flow down faster from highland or upstream affect the water self-purification capacity when flow through vegetated buffer zone or forestry area.

5 FINDS AND CONCLUSION

In this study a classification of eco-region in Trondheim municipality were conducted. Characteristics and gradients of surface land form, land cover and impervious ratio can be expressed in four eco-regions, which are eco-region 1 the Western agriculture eco-region, eco-region 2 the Eastern forest and drinking water protection eco-region, eco-region 3 the Midwest forest hilly eco-region and eco-region 4 the Central urban and settlement eco-region. We realize that each eco-region has its own functions and ecological process, such as hydrological process, water quality development and species conditions. For example, the Eastern forest and drinking water protection eco-region as a preserve area has “good” even “very good” ecological status, in the Western agriculture eco-region and the Central urban and settlement eco-region, water pollution and increase of impervious area lead to decline of ecological conditions.

Which kinds of factors could probably be effects on water quality and ecological conditions? From this paper, MLR models were developed to explore variations of water pollution, which link landscape metrics and topological parameters. According to models we can conclude, pollution from agriculture is worse than urban run-off, especially, agriculture patch density took more effects on water pollution. Probably it is different to change the patch density of agricultural area, but we get a new perspective of sources of water pollution.

Therefore, further effective monitoring, research and management can be undertaken under this result. It is hoped that the methodology and the case studies can provide some practices and scientific background to support rehabilitation of river ecosystem and sustainable urban planning and implementation of EU Water Framework Directive.

Acknowledgement

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