8h International International Civil Engineering Congress (ICEC-2016)
"Ensuring Technological Advancement through Innovation Based Knowledge Corridor"
December 23-24, 2016, Karachi, Pakistan.

Ref no. 060

Spatio-temporal trend assessment for water quality of Bevern stream, UK

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Abstract

Land use and human activities in a catchment can have considerable effects on the quality of water bodies. This study is an effort to assess spatial and temporal behavior of Bevern stream, England, using trend analysis and consequently, identify sources of contamination. Monthly and seasonal trends are generated for 5 locations along the stream, for NH, nitrate, DO, and PO_4^{-3} using 10 years of data (2003-2013). Linear Regression and Mann-Kendall test have been applied. Spatial results show Spatham Lane, Plumpton Green, and Clapper's Bridge locations with higher nutrient load compared to Swansyard farm and Plumpton mill stream, justified by the presence of numerous farms and agricultural fields including municipal effluent at Plumpton Green and discharge from wastewater treatment plants at SL and Clapper's bridge.
Temporally, Plumpton mill stream show decline in quality with decrease in DO levels providing evidence to the Wales treatment plant as possible source. In contrast, Spatham Lane conditions show improvement with time, in PO_4^{-3} and NH_3. Current trend analyses further provide evidence on vulnerable quality conditions at Clapper's bridge. To conclude, Bevern stream show adequate oxygen levels overall for aquatic life but more attention is needed to control nutrient load coming from waste treatment plants, in order to avoid eutrophication in coming years.

Keywords
trend, nonparametric, Kendall's test, spatial, temporal

1. Introduction

With the growing population there comes modifications in river basins from pressures including agricultural, urban, and industrial sectors. Pollutants from agricultural fields include nutrients, pesticides, and fertilizers, along with manure waste from livestock. These pollutants when eventually discharge in rivers degrade the water quality that is threatening to aqua environment. In USA and Netherlands, 57% and around 60% of the surface waters are effected by nutrients from agriculture, respectively (Min and Jio,

2002). For the UK, Water Framework Directive (WFD) and Environment Agency (EA) are established to attain and monitor water quality standards for UK coastal and freshwaters (Gardiner and Mance, 1984).
A study done by Bowes et al. (2015) for a river in rural area highlights the concentrations of phosphorous and nitrogen dominated by sewage effluent and groundwater inputs, respectively. To reduce high frequency of concentration, they suggested improvements in sewage treatment works and agriculture.
Many of the researchers have used trend analyses to assess the water quality of water bodies. Chang (2008) tested water quality on 118 sites for a river in South Korea for 8 physio-chemical parameters. He also used Mann Kendall (MK) to test the trends where results showed strong correlation with non-point sources for pollution and he suggested spatial analysis as fundamental part in identifying spatio-temporal distribution. These case studies led to the development of spatio-temporal trend analysis on Bevern stream since the catchment involve wastewater treatment plants and agricultural lands as major threats to water quality.

1.1 Study Area

Bevern stream is a 13.7 km long stream (Geoview, 2015) with 35km^2 of catchment area. The stream joins River Ouse at Barcombe Mills, Sussex. Geographically, it is located at latitude 50°55'36.84" and longitude 0°0'51.84". The land use around Bevern stream is mostly agricultural fields and managed farmlands along with three sewerage treatment plants within the catchment at Ditchling, Wales, and Barcombe villages (Figure 1).

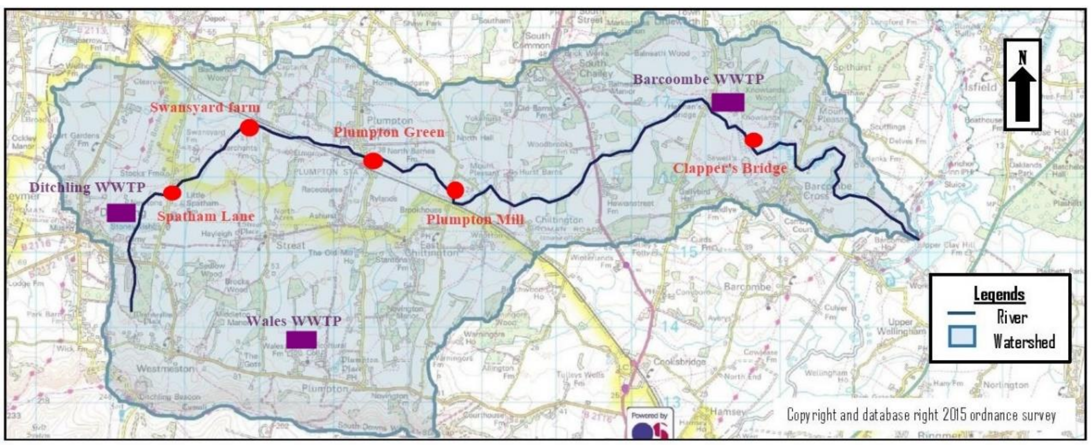

Figure 1: Land use map showing Bevern stream catchment (Source of map: Ordnance survey, 2015).

1.2 Objective

The objective of this research was to perform spatio-temporal analysis of water quality parameters for Bevern stream based on statistics and monthly and seasonal trends.

2. Material and Method

Based on availability of historic data, 4 parameters, namely ammonia (NH_3), phosphate (PO_4^{-3}), Dissolved Oxygen (DO), and nitrate (NO_3) are selected for five stations at Bevern stream. Monthly data from August 2002 till April 2014 were collected for the parameters which were then assembled for seasonal analysis. The missing values were interpolated using Grubbs' test (Grubbs, 1969).
The secondary data have been obtained from Ouse and Adur Rivers Trust (OART). For statistical analysis, Linear Regression and Mann-Kendall's test are done. Hirsch et al (1982) demonstrates that water quality

data are normally non-parametric that has higher efficiency than parametric. Mann-Kendall, henceforth, is recommended for the analysis of trends in water quality data (Lettenmaier, 1976).
Following is the methodology applied throughout the project;

1. Monthly and seasonal spatial and temporal trends of physio-chemical parameters.
2. Statistical tests using linear regression and Mann-Kendall Rank's test.
3. Identification of possible sources of vulnerable pollutants and the most vulnerable pollutant.

3. Results and Discussion

3.1 Spatial Analysis

The sampling site at Spatham Lane (SL) has farms such as Spatham farm, Stocks farm, and Hayleigh farm. Ditchling village is present just at the beginning of the stream before SL sampling site. There is a wastewater treatment plant 0.5 km before from the SL. There is another tributary from the west side that joins in with Bevern stream. Swansyard Farm (SF) sampling site is almost at the junction of the tributaries. From the SF till Plumpton Mill (PM) site, the land use comprises of one village called Plumpton Green (PG) and various farms including Elm Grove farm and North Barnes farm. There is a race course as well in Plumpton which might be noted for manure. PM site that includes water from the south end of the catchment. In the south, there are Wales farm, Plumpton Agricultural college, Stantons farm, and Wales Wastewater Treatment Plant (WWTP). Downstream of PM, a few kilometres before Clapper's Bridge (CB) is Barcombe WWTP.

Figure 2 illustrates monthly trends for all parameters downstream of the river. The x-axis starting from Spatham Lane shows the beginning of stream and CB as the nearest sampling point from the outlet. The graph elucidates that on average, there is an increase in the level of DO up to 8mg/l with a decrease in concentrations of PO_4^{-3}, NO_3, and NH_3 downstream. This trend tells that Spatham Lane has high PO_4^{-3} and nitrate levels than any other sampling site, making it a susceptible site. Figure 2 also depicts PM for having lowest load values for PO_4^{-3}, nitrate, and NH, consequently increasing DO which is highest of all sites.

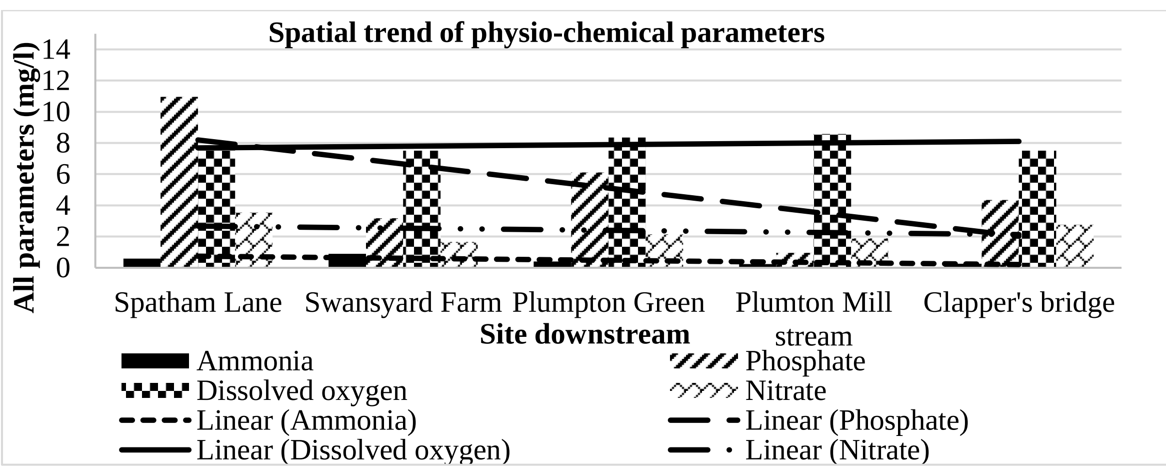

Figure 2: Spatial trend of physio-chemical parameters for Bevern stream.

Figures 3 - 6 illustrate trends for summer, autumn, winter, and spring, respectively. In summer, the level of PO_4^{-3} shows an overall decrease down the stream, starting from the highest load at Spatham Lane followed by abrupt decrease in the next site that is SF. There is an increase in DO from SF to PG.

Nitrate, like PO_4^{-3}, are also soluble. In summer high levels of nitrate are observed at Spatham lane, followed by CB. This compliments the trend of PO_4^{-3} where both parameters are high at SL, PG, and CB. From the land use map it can be justified that SL and PG have more farms than the other sites. Despite the differences of load, DO levels show consistency throughout the stream with a slight overall decreasing trend.

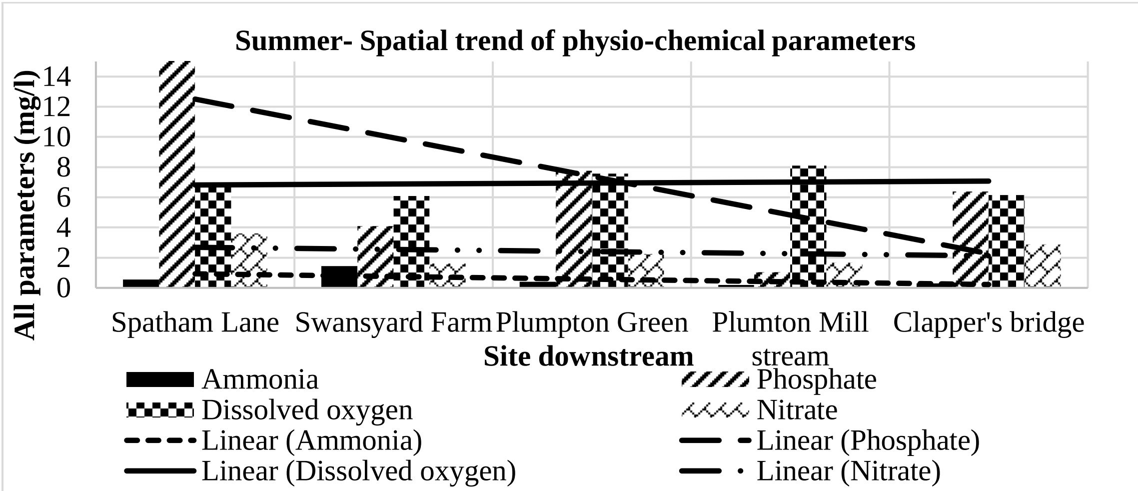

Figure 3: Spatial trend of physio-chemical parameters for Bevern stream in summer.

In autumn, similar sinusoidal pattern and concentration is observed for PO_4^{-3}. For nitrate, the levels decrease downstream from SL to SF, exceeding with increase from PM to CB. This analysis when correlated with land use map can be explained by higher number of farms at SL site and CB. Also, the sewage treatment plants add a lot to the concentration. NH_3 levels show a decrease with the lowest load at PG.

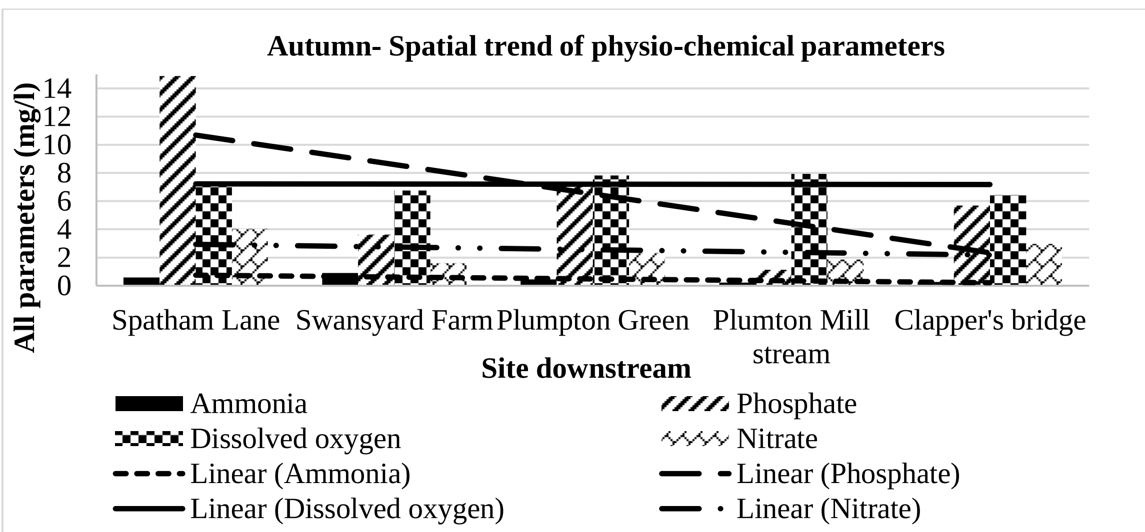

Figure 4: Spatial trend of physio-chemical parameters for Bevern stream in autumn.

For the next two seasons, winter and spring, there is increase in load of DO levels. In winter, overall oxygen rises from 8.3 mg/l to 9.3 mg/l. As for spring, oxygen remain constant at 9 mg/l throughout the stream. In contrast with summer and autumn, PO_4^{-3} show decrease in concentration. However, the sinusoidal pattern of PO_4^{-3} is also followed where load is decreasing at SL. This load, thereafter, shows increase at PG, decrease at PM, and then an increase at CB during winter. This can be explained by referring to WWTP before each of the sites. Conversely, concentration of nitrate in winter show increase at SF and PG. The NH_3 levels in winter show a smooth decrease downstream from 0.33 mg/l till 0.17 mg/l.

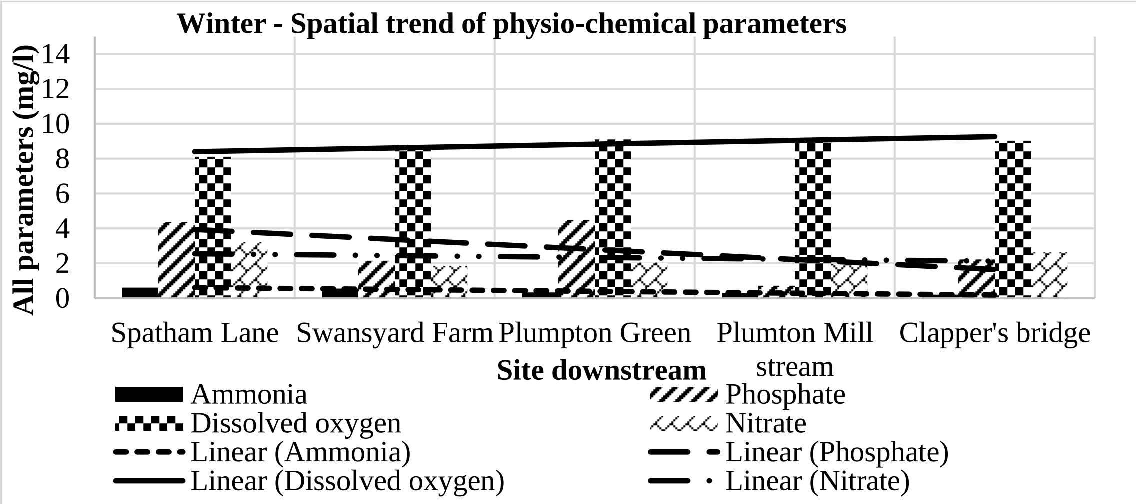

Figure 5: Spatial trend of physio-chemical parameters for Bevern stream in winter.

For spring season, PO_4^{-3} levels increase again from 4.2 mg/l in winter to 7.4 mg/l at SL. Nitrate show an overall increase of 0.2 mg/l downstream. NH_3 follows the same trend for seasons and monthly.

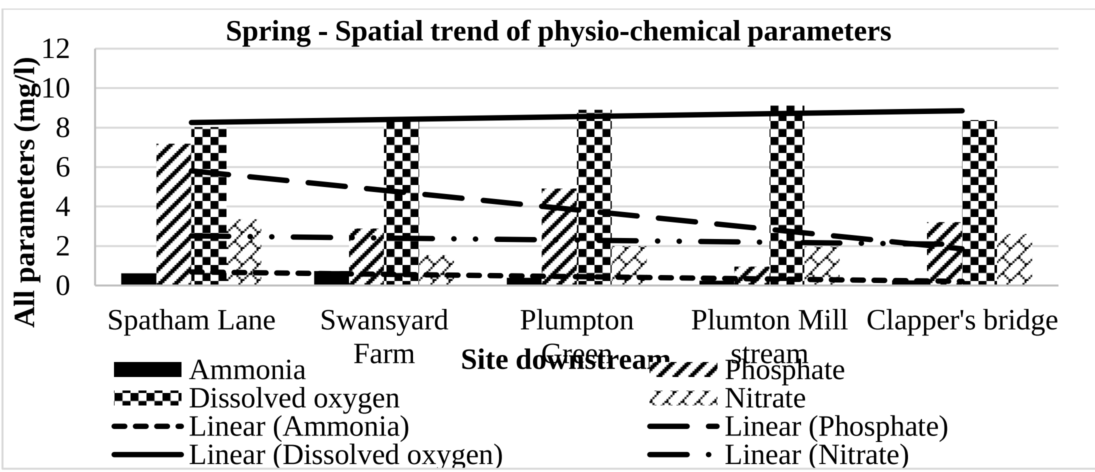

Figure 6: Spatial trend of physio-chemical parameters for Bevern stream in spring.

3.2 Temporal Analysis

The dataset is further analyzed temporally where parameters are assessed for all five sites monthly and for each season. Table 1 illustrates MK's test results and trend lines are shown as graphs in Figures 7 - 10 for monthly analysis for NH_3, PO_4^{-3}, DO, and nitrate, respectively. From Figure 7 it can be observed that for monthly NH_3 level, there is an overall increase in concentration at sites with SL showing maximum.

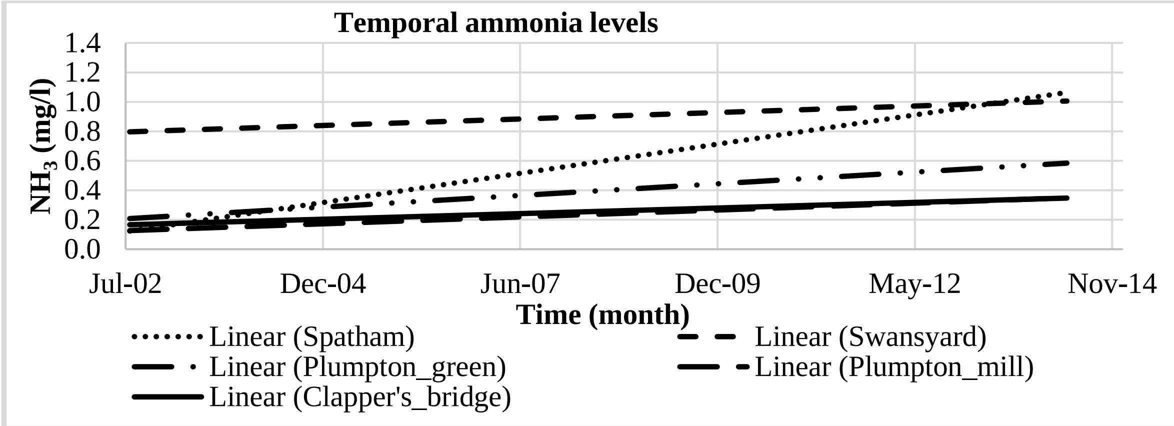

Figure 7: Temporal trend of NH_3 concentration in Bevern stream.

For PO_4^{-3}, Figure 8 illustrates that all sampling sites have increased in concentration with consistency at PG. As of MK, there is no trend in SL and CB's PO_4^{-3} levels. Figure 9 shows DO on the monthly behavior of all sites with a decrease for all sites. For PG, there is no change observed in MK. Figure 10 illustrates that nitrate levels have increased at SL, consistent at CB while decreased at SF, PG, and PM stream.

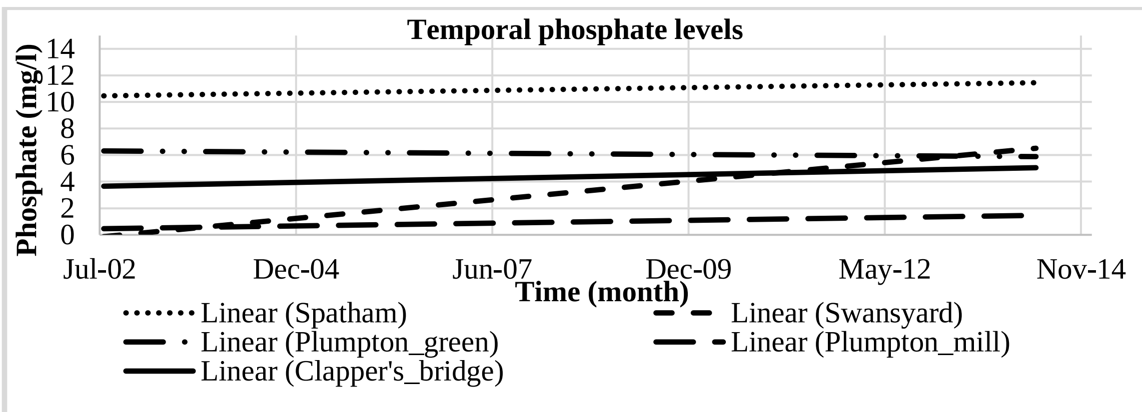

Figure 8: Temporal trend of PO_4^{-3} concentration in Bevern stream.

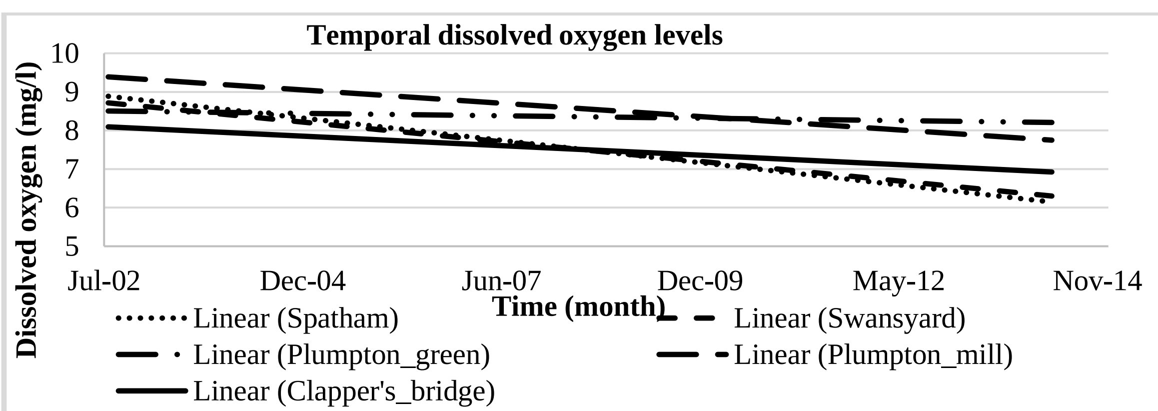

Figure 9: Temporal trend of oxygen concentration in Bevern stream.

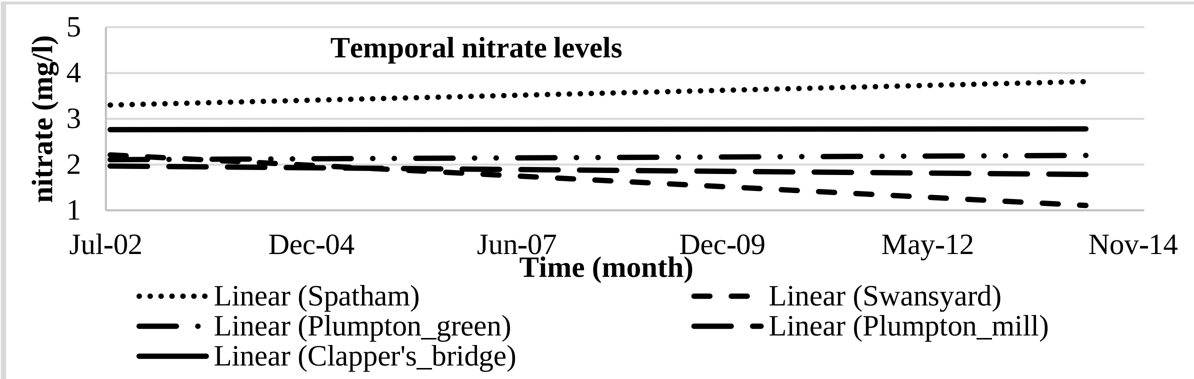

Figure 10: Temporal trend of nitrate concentration in Bevern stream.

Table 1 shows seasonal trends with respect to time. Graphs are not shown in the paper; however, the graphs generated showed increase/decrease of the trend. The analysis depicts that Mann-Kendall recognizes the trend for spring the most. In summer, DO is significantly increasing in PG and decrease in other locations. In autumn again, similar temporal is observed. With respect to time, DO is showing a decrease in winters and spring. This is a matter of concern where the seasonal variation shows the drop of DO level.

Table 1: Temporal trend for monthly and all seasons of Bevern stream using Mann-Kendall tests.

		Trend				
Stations	**Parameters**	**Monthly**	**Summer**	**Autumn**	**Winter**	**Spring**
Spatham Lane	N	Trend	Trend	Trend	Trend	Trend
	PO_4^{-3}	No Trend	No trend	No trend	No trend	Trend
	DO	Trend	Trend	Trend	Trend	Trend
	NO_3	No Trend	No trend	No trend	No trend	No trend
Swansyard Farm	N	No Trend	No trend	No trend	No trend	Trend
	PO_4^{-3}	Trend	Trend	Trend	Trend	Trend
	DO	Trend	No trend	No trend	No trend	Trend
	NO_3	Trend	Trend	Trend	No trend	Trend
Plumpton green	N	Trend	Trend	Trend	Trend	Trend
	PO_4^{-3}	Trend	No trend	No trend	Trend	Trend
	DO	No Trend	Trend	No trend	Trend	No trend
	NO_3	No Trend	No trend	No trend	No trend	No trend
Plumpton mill	N	Trend	Trend	No trend	No trend	Trend
	PO_4^{-3}	Trend	Trend	No trend	Trend	Trend
	DO	Trend	No trend	Trend	Trend	Trend
	NO_3	No Trend	No trend	No trend	No trend	No trend

Clapper's bridge	N	Trend	Trend	No trend	No trend	Trend
	PO_4^{-3}	No Trend	No trend	No trend	No trend	No trend
	DO	Trend	No trend	No trend	Trend	Trend
	NO_3	No Trend	No trend	No trend	No trend	No trend

As for chemical parameters, trends at CB are not of significance in Mann-Kendall. Nitrate trend are also not recognized by MK test other than at SL that shows increase in summer and autumn. Similarly, PO_4^{-3} levels are less at SL but SF, PG, and PM stream for winter and spring. SF shows drastic increase for PO_4^{-3}.

4. Conclusions

1. Temporally, there is decrease in DO levels. The major sources of contamination are present at three sampling points are SL, PG, and CB with SL showing the highest contamination.
2. The sources of contamination are number of farms and agricultural lands (Hayleigh farm, stocks farm, Little Spatham farm, and Garden farm) and a treatment plant near SL. It can be said that monitoring of Barcombe treatment plant at CB site is needed along with the farms nearby CB.
3. Spatial trend analysis show slight increase in DO as the range lies between 7 – 8 mg/l. The decrease in levels of PO_4^{-3} and nitrate down the stream is a justification of contamination sources upstream.

More historic data (such as temperature, rainfall, pH, etc.) can provide further justification and evidence to the results. Following are the possible recommendations to enhance the study.

1. Fencing the river banks where farm animals have easy access to river.
2. Usage of eco-friendly fertilisers (manure) to reduce contaminants in agricultural runoff.
3. Analysis in correlation with rainfall and sediments will provide in-depth evidence to the results. Software are available to simulate the watershed for non-point sources. One of the models is Agricultural Non-Point-Source Pollution Model (AGNPS) developed by Young (1987).

5. References

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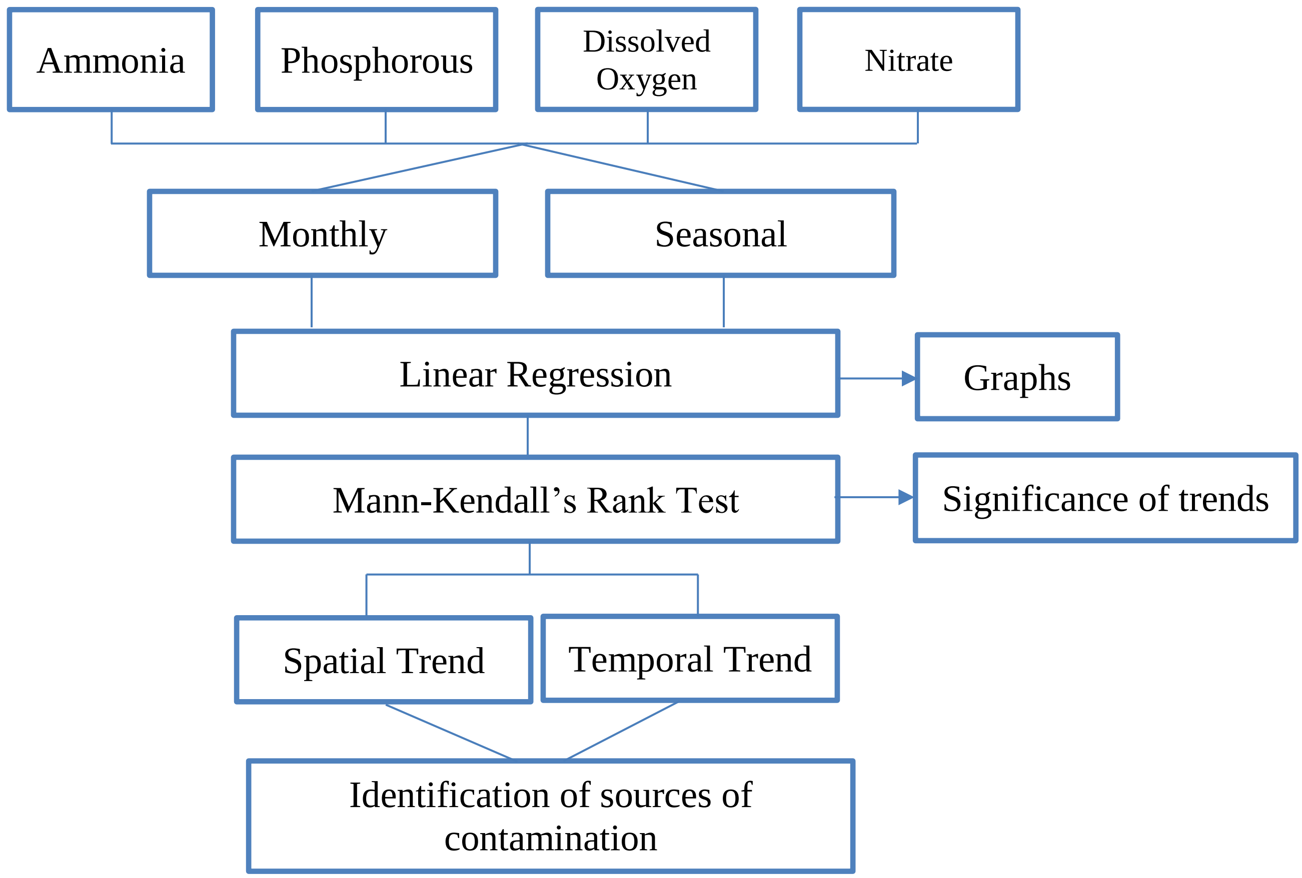
Ammonia
Phosphorous
Dissolved Oxygen
Nitrate
Monthly
Seasonal
Linear Regression
Graphs
Mann-Kendall's Rank Test
Significance of trends
Spatial Trend
Temporal Trend
Identification of sources of contamination