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Phosphorus Modeling, in Lake Tana Basin, Ethiopia

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Abstract:
N and P found naturally in soils, however agricultural activities increased the concentration of these nutrients resulting in poor water quality and eutrophication. Excessive concentration of P is the most common cause of eutrophication in fresh water lakes and reservoirs while N is the key controlling nutrient in ocean. According to recent researches, a comparison between N and P resulted in a general rule that reduction of N loading cannot decrease eutrophication as that of P. To be able to assess the potential of nonpoint source P pollution and to develop proper management strategies to reduce P losses to surface waters, it is essential to understand the major processes involved in P transport. Terrestrial processes are responsible for P inputs from upland and riparian areas while aquatic processes include stream bank inputs and in stream P inputs, outputs and transformations. This study focuses in modeling dissolved P load from Lake Tana Basin. Semi-distributed model is used considering the contribution of base flow; interflow and overland flow to dissolved P. Amazingly, the model predicted phosphorus load with an excellent efficiency with limited data we have and many constraints. Parameter analysis indicated that the contribution of overland flow to dissolved P is higher in most of Lake Tana Basin catchments hence agricultural could be the major source of P in the stream. The fertilized areas would also have great contribution to surface runoff P concentration. Some management practices are proposed from literatures to reduce P load.

Keywords:
Eutrophication ; Lake Tana Basin

1. INTRODUCTION

1.1 Background

Phosphorus (P) is a major nonpoint source pollutant that causes Eutrophication in surface waters. It is also essential nutrient for life and is the 11th most abundant in the earth crust [1]. However, human activities have resulted in excessive loading of phosphorus into many freshwater. This causes water pollution by promoting algae growth particularly in Lakes. Lakes that appear relatively clear in spring can resemble green soup in late summer due to algae blooms fueled by phosphorous. Water quality can be further impaired when bacteria consume dead algae and use up dissolved oxygen, suffocating fish and other aquatic life [1]. Precipitation provides the major source of energy for transport through its effect on soil erosion and is dependent on watershed morphology, hydrology and land cover and management.Under normal water flow, roughly two third of the total phosphorus load to lakes and rivers comes from non point sources such as runoff from pasture and crop lands, atmospheric deposition and stream bank erosion [1]. However, phosphorous loading contributed from pasture, grazing and crop land is largest source of non point phosphorous.

Phosphorus has two main forms: dissolved (soluble) and particulate (attached to or a component of particulate matter). Most of the phosphorous discharged by waste water treatment facilities is in the dissolved form. Because of phosphorous changes form, most scientists measure total phosphorous rather than any single form to determine the amount of nutrient that can feed the growth of aquatic plants such as algae [1].

Even though phosphorus leads to formation of algae and Lake Eutrification (i.e. formation of algae is being seen around the edge of Lake Tana), unfortunately no researches have been done on phosphorus modelingto Lake Tana basin. Recently, Tana Sub Basin Organization (TaSBO) installed water quality monitoring stations to Lake Tana basin, though the locations did not consider modeling on watershed based.Hence, the study focuses on developing a tool to predict dissolved phosphorous load (DP) from the seven watersheds (i.e. Gumara, GilgelAbay, Rib, Megech, Gumara (Este), Gumara(Gelaw) and Megech (US)) using the available few data. Better management practices to reduce phosphorus would also be suggested from literatures.

1.2 Why worry about phosphorus prediction?

1. Lake Tana clarity is important to many
2. An increase in phosphorus leads to an increase to algae growth
3. An increase in algal growth leads to a decrease in Lake Tana clarity

1.3 Objective

The main objective of the study is to develop suitable Analytical Tool, P model for Lake Tana Basin and to predict dissolved phosphorus load from the major watersheds in Lake Tana Basin. Suggestions of better management practices from literatures are also one component.

1. If we can predict phosphorus delivery, we can propose alternative management practices to reduce delivery.

2. METHODOLOGY

2.1 Description of Study area

Lake TanaBasin is found in North-west pat of Ethiopia, Blue Nile Basin, having a drainage area of around 15,000 km^2. Among which around 20% is covered by the Lake [2]. It is geographically located between 10.95°N to 12.78°N latitude and from 36.98°E to 38.25°E longitude. Gumara, Rib, Megech and Gilgel Abay contribute more than 90 % of the inflow among more than 40 rivers feeding the Lake [2]. The only surface outflow is Blue Nile, comprising 7% of the Blue Nile flow at Ethio-Sudanese border [2].

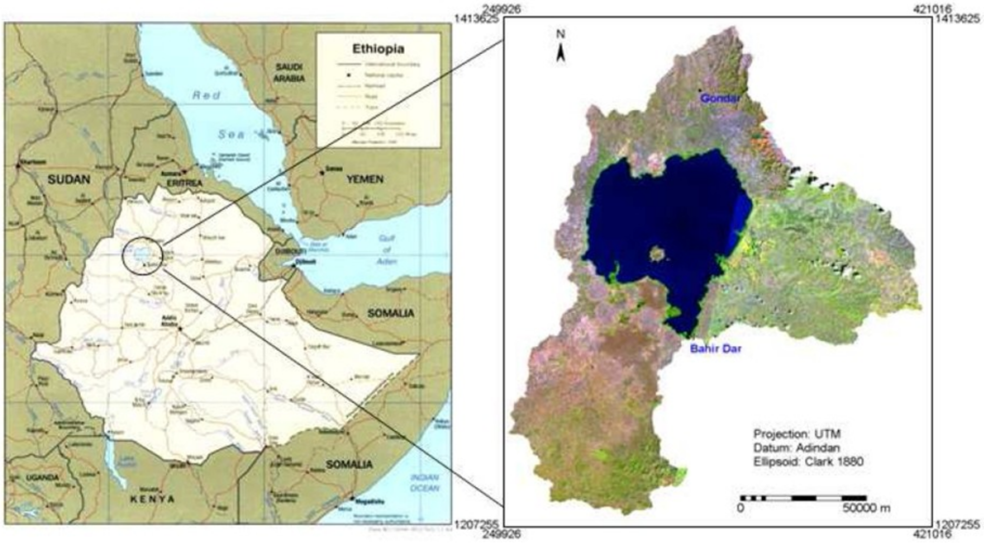


Figure 1. **Location map of Lake Tana Basin (Source: Abeyou Wale, 2008)**

Table 1. **Statistics of PO4 data.**

Stations	Sample Size	X_{av}	Median	X_{max}	X_{min}	X_{max}- X_{min}	STDV	CV
G/Abay	7	6.07	5.400	20	0.17	19.83	7.174	1.182
Rib	6	0.719	0.252	3.201	0.106	3.095	1.220	1.695
Gumara (Este)	6	1.098	0.330	5.100	0.030	5.07	1.968	1.792
Gumara (Gelaw)	6	2.830	0.320	12.00	0.060	11.940	4.738	1.674
Gumara	6	0.906	0.373	2.937	0.079	2.858	1.112	1.227
Megech US	6	0.906	0.373	2.937	0.079	2.858	1.111	1.228
Megech	6	0.439	0.238	1.380	0.007	1.373	0.525	1.198

The rainfall distribution in the basin is found to be mono-modal pattern. Considering the period 1997 to 2006, the mean annual rainfall amount ranges between 813 mm in Yifag to 1538 mm in Dangila while the minimum and maximum temperature ranges between 9.3°c in Dangila to 29.6 °c in Gorgora respectively [2]. Based on Abay river master plan study conducted by BEEOM, from 1996 to 1999, 51.47 % of the basin is covered by Agriculture, 21.94 % Agro-pastoral and 20.41% Lake. Halpicluvisol is the dominant soil in the basin covering around 20.69 % of the basin.

2.2 Data Availability and Analysis

The Meteorological data is used from Climate Forecast System Reanalysis (CFSR) from the year 1979 to 2010 except for Megech watershed (i.e. nearby Meteorological stations are used). The flow data for the watersheds are obtained from Ministry of Water Resource's measurement. PO4 data were collected for year 2012 and 2013 from water quality stations installed by TaSBO in Lake Tana Basin.

From the observed data statistics one can understand that the data is very few for modeling purpose. The variation within the data is also high leading the mean to be non representative of the whole. Therefore, the model should be able to model using the available data. Hence, we have selected semi-distributed hydrological model based on saturation excess concept to develop dissolved Phosphorus model for Lake Tana Basin and to predict phosphorous load for major watershed in Lake Tana basin.

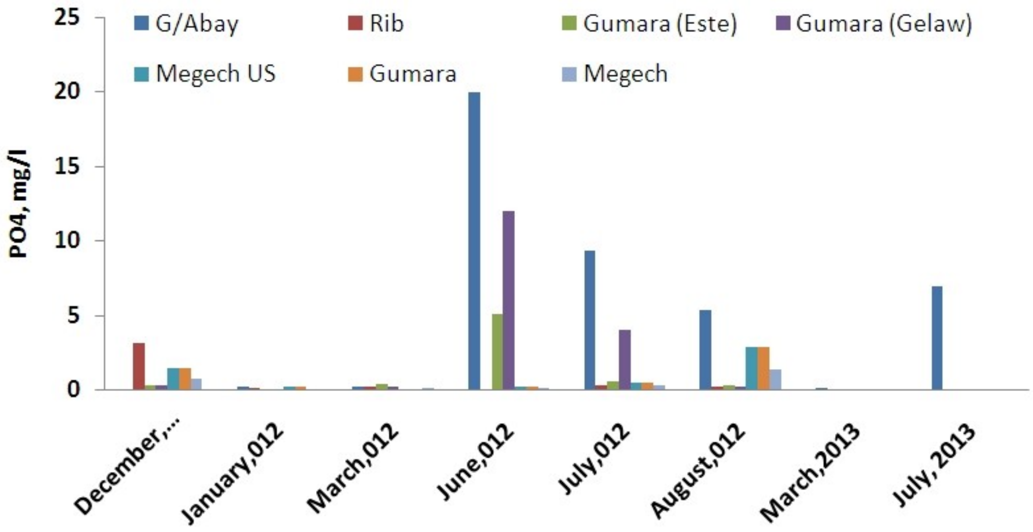


Figure 2. **Measured PO4 data for the indicated water quality stations**

Required Input data:

1. Observed Phosphorous data
2. Base flow
3. Inter flow
4. Overland flow

2.3 Model description

Total dissolved phosphorus P load can be calculated as a combination of the contribution of the base flow Qb, interflow Qi, and overland flow Qo. For simplicity we assume that we can represent the concentration of P in each of the three flow components and in the sediment constant for the data set.

The load can then be calculated as:

$$Lpo4 = QbCb + QiCi + QoCo \tag{1}$$

Where;

Lpo4 – P load in terms of phosphate

Q (b,i,o) – Base flow, interflow and overland flow respectively

C (b,i,o) – Base flow, interflow and overland flow P concentration in terms of phosphate respectively.

P concentration in terms of phosphate is then equal load divided by total flow:

$$Cpo4 = \frac{Lpo4}{Qb + Qi + Qo} \tag{2}$$

Table 2. **Model efficiency for 7 catchments in Lake Tana Basin.**

Model Efficiency Criteria	Catchments in Lake Tana Basin						
	G/Abay	Gumara Gelaw	Gumara Este	Rib	Gumara	Megech US	Megech
R^2	0.93	0.96	0.64	0.99	.92	0.964	0.97
NSE	0.94	0.96	0.64	0.99	0.92	0.964	0.97

3. RESULT AND DISCUSSION

The result and discussion part is classified in to 5 components: (1) Model efficiency (2) Model parameters (3) Phosphorous load from catchments (4) Suggested better management practices (5) Model applicability and limitation. Since phosphorus changes its forms, many scientists are interested to model total phosphorus rather than modeling any of its forms (i.e. dissolved and particulate). However, the data we have in our hand is total dissolved phosphorus which forces to model only dissolved phosphorus with the limited data we had.

3.1 Model Efficiency

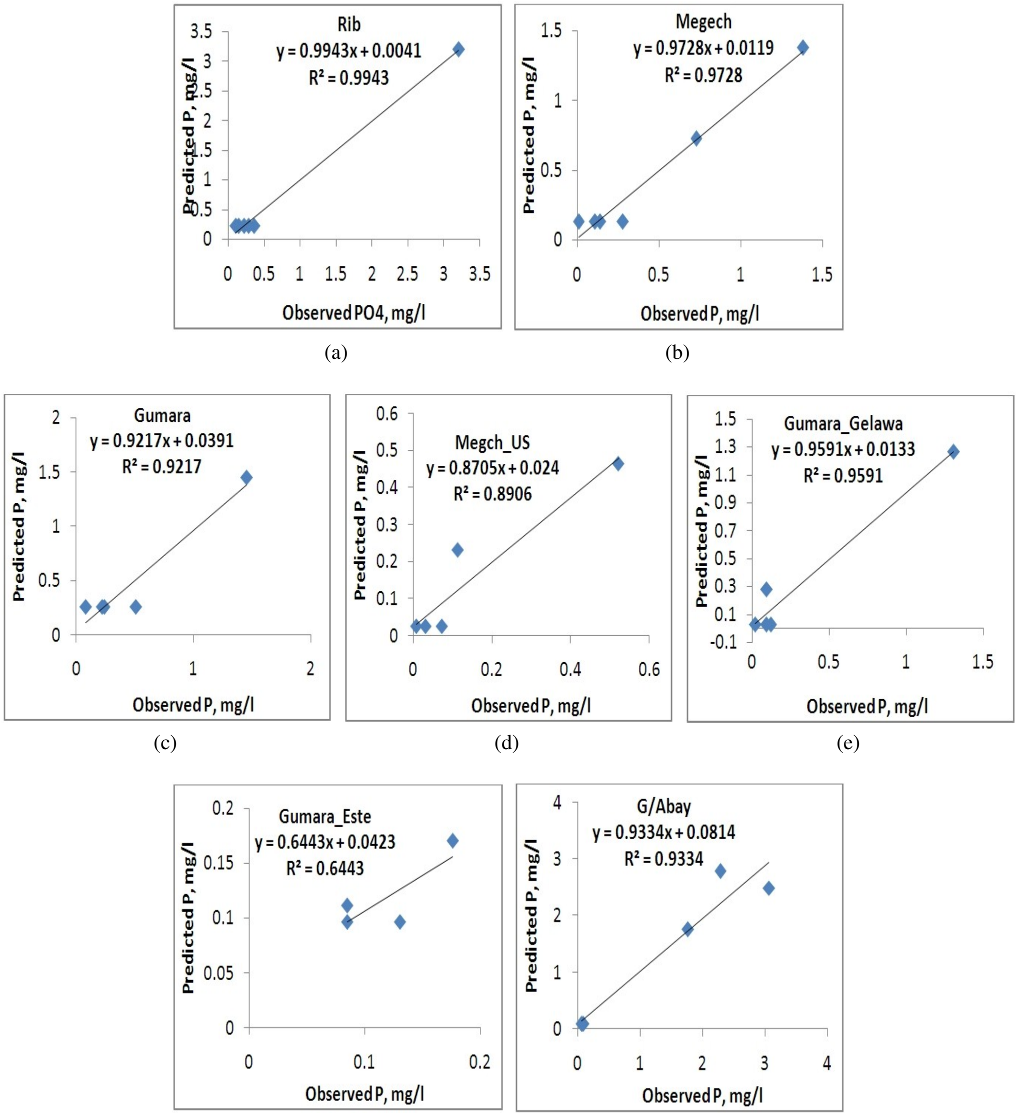
Daily total dissolved phosphorus was predicted at the outlet of the watershed using semi-distributed hydrological model as the sum of base flow, inter flow and overland flow contribution. Modeling was performed at 7 watersheds in Lake Tana Basin, with variety of catchment area, ranging from 37.7 km^2 to 1665 km^2. Regional homogeneity principle from the major watershed were used to predict stream flow for the case of Gumara (Gelaw), Gumara (Este) and Megech (US) in which no stream flow records were available. Predicted vales were subsequently compared to the daily observed load that were recorded at the watershed outlet and parameter calibration was performed. Different efficiency criteria were used to evaluate the model efficiency was used to evaluate the efficiency of the model: Nash Sutcliffe efficiency criterion [3] and determination coefficient R^2. The efficiency of the model is presented in the **Table 2** for different catchments. Amazingly, the model predict phosphorus load resulting in excellent efficiency, with limited data and many constraints. Hence, the model can be applied to predict phosphorus load from the same catchment.

Table 3. **Model parameter values for the 7 watershed in Lake Tana Basin.**

Parameters Values (g/m^3)	Catchments						
	Gumara	Gumara Gelaw	Gumara Este	G/Abay	Megech US	Megech	Rib
Cb	0.261	0.080	0.297	0.294	0.078	0.132	0.223
Ci	0	14.054	14.047	14.047	0	0.103	0.103
Co	8.842	5.669	0.629	20.12	3.485	3.283	9.062

3.2 Model parameters

Parameter values after model calibration is presented in **Table 3** . Analysis of parameter values indication is performed for the region. The contribution of overland flow to total dissolved phosphorus is higher for the major watersheds in Lake Tana Basin Gumara, Gilgel Abay, Rib, Megech and Megech (US). Base flow contribution stands second for the mentioned major watersheds where as the interflow



(a) (b)

(c) (d) (e)

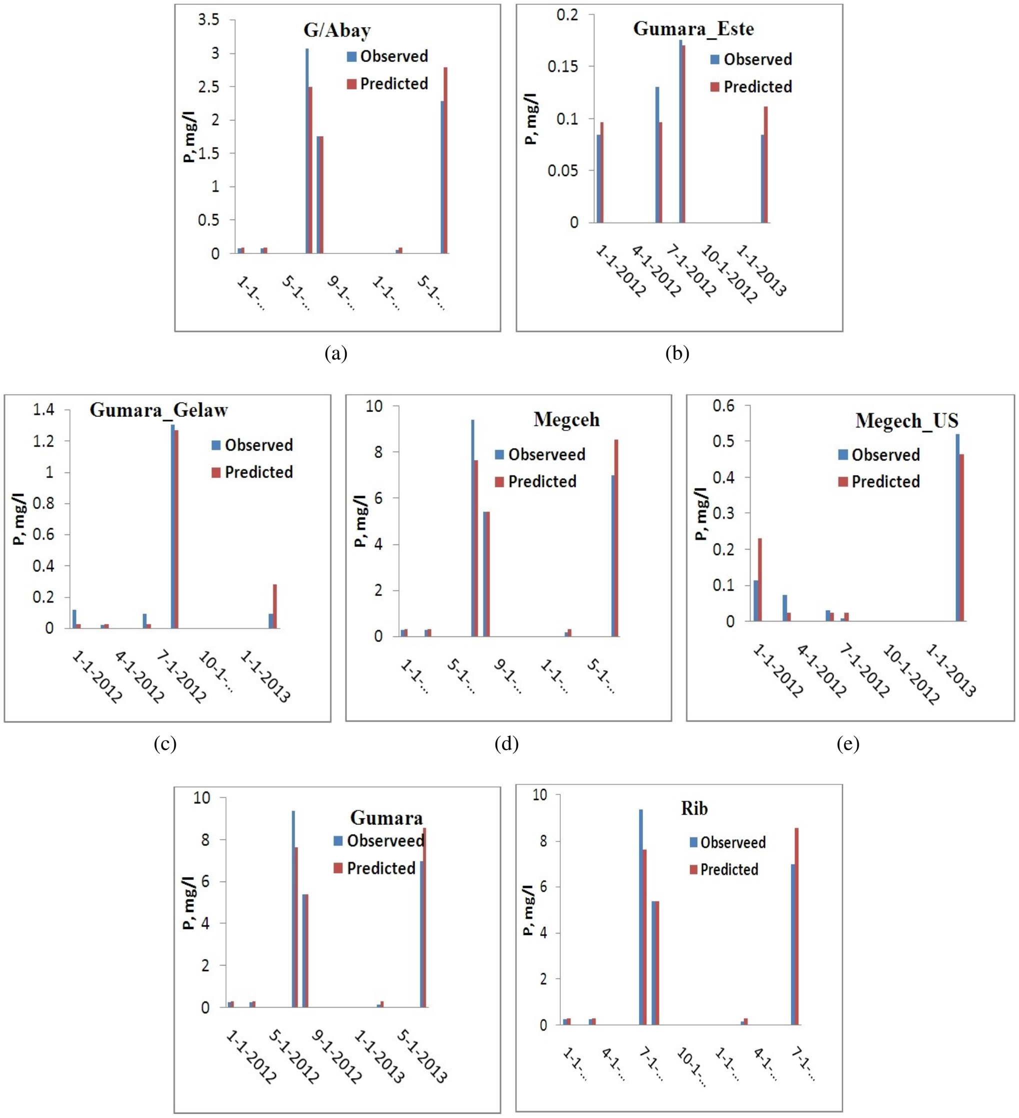
(f) (g)

Figure 3. **Predicted vs observed P concentration for 7 catchments in Lake Tana Basin**

contributed to a small amount for the dissolved phosphorous. However, the reverse is true for the case of Gumara (Gelaw) and Gumara (Este), the inter flow contributed more followed by overland flow with small contribution of base flow to the dissolve phosphorus.

As we can see from **Table 3** , overland flow contributed large amount of phosphorus. Agricultural landcould be considered to be a major source of P in streams [4]. The fertilized areas would also have great contribution to surface runoff phosphorus concentration. P loss from fertilized areas can be separated into two components, P contributed directly by fertilizer, and indirectly by the higher P concentration in the soil due to past fertilizer application [5–8].

The baseflow can act as the source of P [7] and contribute substantially to the cumulative p load [9] as indicated in **Table 3** as the second major contributor to p laod. Additionally, soils exhibiting macro pore flow can contribute significant P loads to the subsoil, or directly to groundwater [10], thus increasing the base flow P contribution, especially in tile drained watersheds. For Gumara (Gelaw) and Gumara (Esete)



(a) (b)

(c) (d) (e)

(f) (g)

Figure 4. **Predicted Vs Observed P Concentration chart for 7 catchments**

interflow is the major contributor to river phosphorus load. This could be from land cover conditions, letting the surface runoff to infiltrate, however further research is needed to understand the condition better.

3.3 Recommended better management practices from literature

Reducing P levels that can be efficiently used by agricultural system would be one solution for management. This needs a good understanding of the path ways NPS P follows to reach surface water (terrestrial process) and the way P behaves (aquatic process) once it reaches those waters.Land use practices like cultivation and grazing would alter the pathway and process taken by P in natural setting and generally increased the amount of NPS P reaching surface water.

Better management practices like conservation tillage, terracing, intensive management grazing, and establishment of riparian buffer may reduce overland flow (the major P terrestrial pathway) and stream bank erosion (the major P aquatic input) that current land use practices have enhanced. Best management practices for a specific watershed should consider watershed characteristics such as degree and length of slopes, land-use practices (raw-crop fields, pastures, and forests), precipitation amounts, soil types, and land drainage among other factors.However, solving agricultural NPS P pollution is difficult because of measurement and regulation of NPS P and this may take long time. Many soils have soil P levels that are so high that even when P fertilizer or manure is not applied, P losses still remain high [11]. In surface water, even after terrestrial P loads have been reduced eutrophication levels may not decrease substantially because of the steady source of P in the sediments in the bed of the stream or lake that have accumulated P and continue to release it [12].

As long as soil erosion is controlled and phosphate fertilizers, plant residues, manure and wastewater from farming operations are not directly applied to surface waters, there will be no point source phosphorus pollution. Control of non-point phosphorus pollution can be achieved by controlling the quantity and type of runoff from agricultural fields. Sites with steep slopes and highly erodible soils adjacent to surface waters will always be at greater potential risk to phosphorus pollution than sites with less steep slopes and less erodible soils. Management practices can greatly influence whether high- or low-risk sites become potential polluters. The use of cover crops and buffer strips can greatly reduce the amount of sediment leaving a field. Similarly, a lack of soil cover or barriers between the field and water can increase the risk of pollution.

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