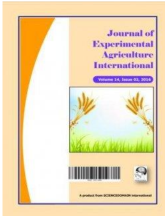

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Fish Yields in Relation to Water Quality and Plankton Production in Managed and Unmanaged Fresh Water Ponds

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Authors' contributions

This work was carried out in collaboration between all authors. Author GS designed the study, carried out the literature review, conducted the field experiments and laboratory work, performed data analysis and wrote the first draft of the manuscript. Author AB designed and reviewed the experimental design, managed literature review, carried out data analysis and managed the first drafts of the manuscript. Authors KA and SAA managed and reviewed the analyses techniques, performed data analysis and discussion, carried out further literature review and prepared the final drafts of the paper. All authors read and approved the final manuscript.

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ABSTRACT

Managed and unmanaged (unmanaged) extensive culture fisheries systems in small village ponds in the district of Kurukshetra, Haryana, India were explored and analyzed focusing on the relationship amongst water quality, production of fish food organisms, fish yields and management actions. In unmanaged ponds, fish growth/yield and dissolved oxygen were low and ammonia, chlorides, calcium, total hardness, magnesium, phosphates and biochemical oxygen demand were

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higher when compared against managed ponds. The differences are likely due to higher organic load in the unmanaged ponds arising from domestic sewage and cattle entry from non-point sources. Variations observed in the phytoplankton population for the unmanaged and managed ponds were insignificant, however, zooplankton were high in unmanaged ponds. The NPP was higher in the unmanaged ponds in contrast to managed ponds. From the finding it seems that Fish production does not tends to depend significantly on the extent of primary production. Significant direct relationship between fish production and primary productivity could not be determined in this study. However, multivariable relationships were detected through multivariate statistical analysis. Such relationships are not straightforward as a variety of factors including ammonia production, organic loading and the quantity and quality of fertilizers play important roles in influencing such relations.

Keywords: Ammonia pollution; net primary productivity; pond culture; water quality; organic pollution; biological oxygen demand.

1. INTRODUCTION

The aquaculture sector of the world has enhanced its technology and capacity building as well as the translation from experimental ideas of laboratories to its practical use by the common masses. Culture fisheries are practiced in small water bodies throughout the world [1] and are particularly common in Asia where the practices are found in communal lakes, reservoirs and village ponds as well as in private farm ponds [2-4]. The primary function of constructing village ponds or reservoirs is for the storage of water for domestic utilization and crop irrigation; however they are also used for fishing or fish culture. The productivity level of a water body is a characteristic feature by which the living substance is manufactured through interactions of the constituents of the natural environment. Ponds are essentially self-sustaining systems where the abiotic component like light energy, inorganic nutrients and biotic components like producers and consumers act together. This helps in production of aquatic biota, which serves directly or indirectly as food for fishes.

Different studies have carried out work on pond ecosystems [5-14]. It has been noted that although pond culturing has been intensifying, there have not been sufficient accounts of physicochemical and biological characteristics. Various temporary water bodies and artificial ponds of different sizes exists in Haryana, India which are used as extensively managed culture fisheries system and make an interesting biotype for physicochemical studies. Although the state of Haryana is the second largest in fish production in the entire nation, studies on the influence of water quality parameters on the pond fish culture are not available for the state. The farmers of the district Kurukshetra have been doing remarkable work by adopting fisheries in village ponds as well as in their own ponds.

The survey conducted by the district fisheries department reveal that total water area in the district is 400 hectare, out of which 173 hectare is the Seasonal and religious water area and remaining 227 hectare is used for fish culture (Data available at district fisheries department, Kurukshetra, India). Culture practices in such small fish culture ponds also generate income for the district villagers' socioeconomic livelihoods. The present study was focused on monitoring the fish food organism and water quality of the culture ponds in relation to the growth and productivity of fish in order to determine the relationships between fish yields, natural conditions and management actions in the district of Kurukshetra, Haryana, India.

2. METHODS

2.1 Study Area

A total of four culture ponds for fish were identified for the study in Kurukshetra district (Latitude, 29º-58'N; Longitude, 76º-52'E) of the state of Haryana in India (Fig. 1). Two were unmanaged ponds (K_1 and K_2) where there was no restriction placed on the entrance by cattle and incoming sewage effluents originating from non-point sources to the pond. The other two ponds were managed and constructed ponds (K_3 and K_4) where cattle visits were limited and where liming was regularly performed. The specific characteristics of the four selected ponds can be seen in Table 1. Both the managed and unmanaged pond types received direct sunlight and the bottom soil contained clay.

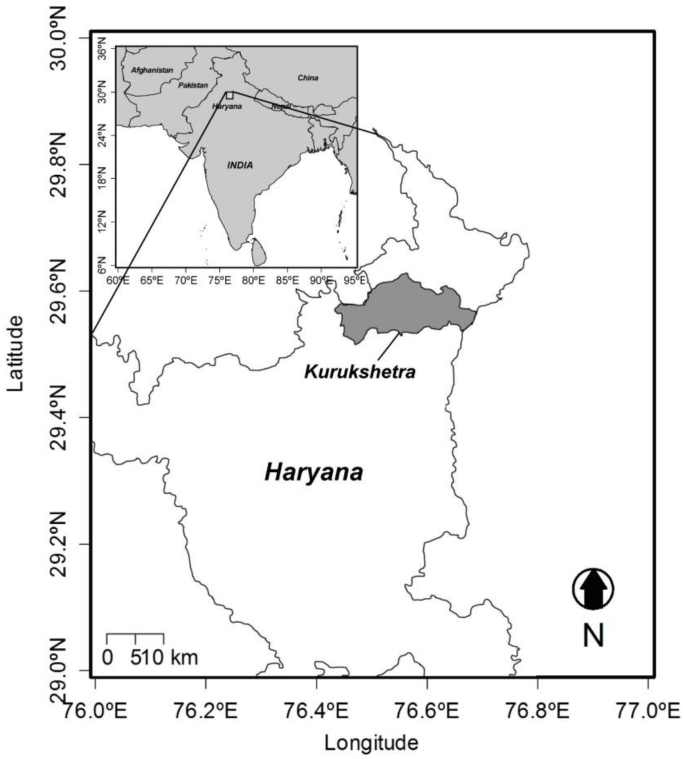

Fig. 1. Map showing the location of the district of Kurukshetra, in Haryana, India

Table 1. Basic descriptive characteristics of the pond sites

Characters	Unmanaged ponds		Managed ponds	
	K_1	K_2	K_3	K_4
Pond site	Barwa	Durala	Adhon	Boharsadan
Area (ha)	0.48	3.20	0.6	0.6
Source of water	Natural / Canal	Canal /Natural	Tubewell/ canal	Tubewell/ Canal
Species cultured	Four(CC,LR,CM,C)	Five(CC,LR, CM,CI,C)	Four(CC,LR,CM,C)	Four(CC,LR, CM,C)
Approximate mortality* if any (%)	23%, during weather change	18%,during weather change	2-4%, during harvesting	2-4%, during harvesting
Fertilizer utilized	No	No	Cow dung, urea, SP,MC	Cow dung,MC,Urea
Medicine utilized	Lime, $KMnO_4$	Lime, $KMnO_4$, Potash	Lime, $KMnO_4$, Turmeric	Lime, $KMnO_4$

CC–Catla catla (Catla), LR–Labeo rohita (Rohu), CM– Cirrhinus mrigala (Mrigal), C – Cyprinus carpio (Common carp), CI – Ctenopharynggodo nidella (Grass carp)
MC - Mustard oil cake, SP – Single Super Phosphate
**Mortality percentages were calculated based on the reports from farmers.*

2.2 Growth Studies

Bulk weighing of fish was conducted over a period of two years by recurrent netting on fortnightly basis at five random temporal replications for each pond. The specific growth rate (Equation 1) and the growth percentage increase in body weight (Equation 2) were calculated using the following equations. The recording of the fish yield was conducted at the harvesting time based on the actual harvests:

$$R = \ln(W_2) - \frac{\ln(W_1)}{t} \times 100 \quad (1)$$

$$G = \frac{W_2 - W_1}{W_1} \quad (2)$$

Where R is the specific growth rate, G is the growth per cent gain in body weight, W_1 is the initial weight of the fish, W_2 is the final weight of fish and t is the time lapse in the number of days of experiment.

2.3 Water Quality Monitoring

Two liter plastic bottles were used to collect water samples on bimonthly basis at five random temporal locations throughout the study period. The physicochemical characteristics such as temperature, free CO_2, DO, alkalinity and conductivity were analyzed onsite. Pond parameters such as calcium, hardness, chloride, total phosphate, magnesium and orthophosphate were investigated at the laboratory using the procedures as outlined in [15]. The samples were stored in cold storage and analyzed two to three days after sampling. The pH, salinity, DO and conductivity were determined using the Multiline F-set 3 (E-Merck, Germany). Seeding method was used for estimation of the Biological Oxygen Demand (BOD). Dilution of water samples was done using distilled water and these were incubated in a BOD incubator for a period of five days [15].

The overall water quality of the different ponds was estimated using the empirical equation [16] shown below:

$$WQI = k\frac{\sum_i C_i P_i}{\sum_i P_i} \quad (3)$$

Where k is a constant having a value of 1 for high quality water and a low value of 0.25 for poor quality or polluted water. C_i is the normalized parameter value and P_i is the assigned weight of the particular parameter. For P_i a maximum value of 4 was assigned for parameter considered highly important for aquatic life such as DO and a minimum value (unity) was assigned for parameters regarded as being of minimal importance such as pH.

2.4 Determination of Plankton Density and Net Primary Productivity

25L water samples were obtained from five different sites (5L from each site) of each pond. The total volume was passed through plankton net of 50 µm mesh size. This was performed at 60 day interludes over the two year study period. Following this the filtered samples were transferred into a measuring cylinder to make 50mL volume using distilled water. Finally, this was preserved in a solution of 5% buffered formalin using small plastic bottles. The Sedgwick Rafter cell was used for the estimation of plankton numbers. The keys as outlined in [17-19] were employed for the Identification of plankton up to genus level.

The Shannon and Weaver [20] plankton diversity index formula was used for determination of the species diversity of plankton (d) as shown below:

$$d = -\sum(n_i/N)\, log_2(n_i/N) \quad (4)$$

where, d is the species diversity, n_i is the plankton population of i^{th} species and N is the aggregate number of individuals. The Net Primary Productivity (NPP) was estimated by using the bottle technique outlined in [15].

2.5 Statistical Analysis

The SPSS packages was used for determination of the correlation coefficient "r" among the water quality parameters and students *t*-test [21] was used for comparison of group means.

3. RESULTS

The calculated fish yield revealed greater values in the managed ponds. The annual total fish production varied in the range of 4166 kg to 5625 kg ha^{-1}in unmanaged ponds and 6666 kg to 7666 kg ha^{-1} in managed ponds (Fig. 2). On the other hand, the NPP was significantly higher (p<0.05) in unmanaged ponds in contrast to managed ponds.

The water quality features of unmanaged (K_1 and K_2) and managed (K_3 and K_4) ponds are shown in Table 2. Pond water temperatures were lower during the winter period and higher during summer which following atmospheric temperature trend. Throughout the study period the pHs of the ponds was alkaline. The pH was higher in the unmanaged ponds in contrast to the managed ponds. Conductivity, calcium, alkalinity, hardness, BOD, chlorides, phosphates, ammonia, plankton population and BOD were significantly higher the unmanaged ponds compared to the managed ponds. In unmanaged ponds the DO was lower in comparison to the managed ponds.

The overall rating of the four ponds in terms of highest productivity and highest water quality was $K_3 > K_4 > K_2 > K_1$. Data on biological analysis showed that the total plankton population was higher in the unmanaged ponds (K_1 and K_1). In contrast, the species diversity was much higher in the managed ponds (K_3 and K_4) (Table 2, Fig. 3). Analysis of sediment chemistry showed that throughout the study period the pH of the four selected ponds (Table 3) remained alkaline. Conductivity and organic carbon accumulation was higher in unmanaged ponds in contrast to managed ponds. A similar trend was seen for Nitrate content (mg Kg^{-1} dry weight).

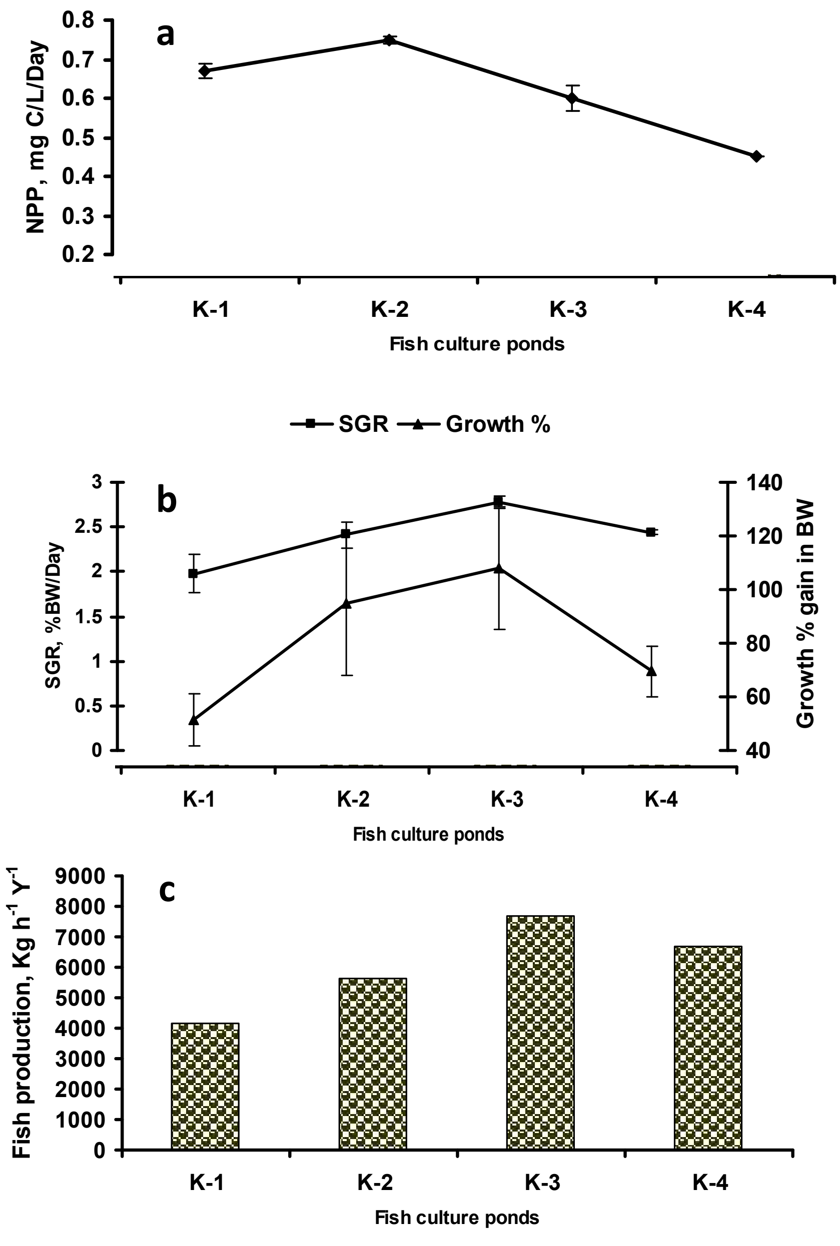

Fig. 2. Plots showing the net primary productivity (NPP) (mg C/L/Day), fish growth (Specific Growth Rate (SGR)), growth percentage gain in body weight (%BW/Day) and fish production (Kg/hectare/year) for the two unmanaged ponds (K_1 and K_2) and two managed ponds (K_3 and K_4) in the district of Kurukshetra, Haryana, India

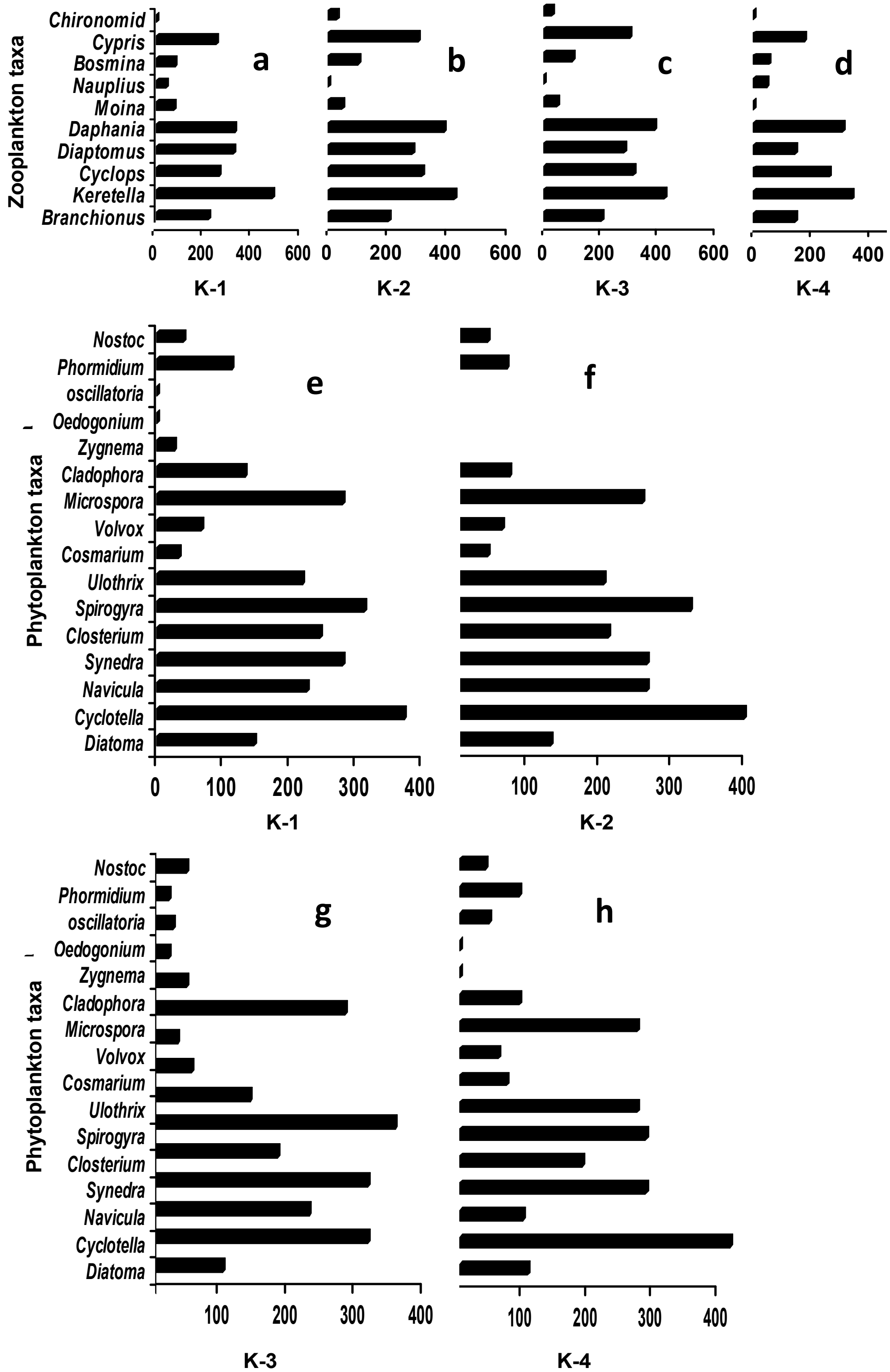

Fig. 3. Zooplankton (a, b, c, d) and phytoplankton (e, f, g, h) community and their abundance in ponds K_1, K_2, K_3 and K_4

Table 2. Physicochemical and biological characteristics of the two unmanaged ponds (K_1 and K_2) and two managed ponds (K_3 and K_4) in the district of Kurukshetra

Parameter	Unmanaged ponds		Managed ponds	
	K_1	K_2	K_3	K_4
Water Temp. °C	22.09±1.09	22.46±1.24	22.43±1.20	21.07±1.60
pH	9.22± 0.07	8.91± 0.17	8.51± 0.15	8.52± 0.10
Conductivity (µS cm^{-1})	838.88±9.01	1016.49±9.12	487.77±57.27	625.55±47.43
Salinity (ppt)	0.00	0.00	0.00	0.00
Dissolved oxygen (mg L^{-1})	5.92± 0.37	5.39± 0.20	7.58± 0.09	7.68± 0.19
Free CO_2 (mg L^{-1})	12.49±2.43	1.38±1.27	Absent	14.27±3.12
Carbonate Alkalinity (mg L^{-1})	20.66±3.14	17.60±1.89	23.05± 0.85	Nil
Bicarbonate Alkalinity (mg L^{-1})	274.94±18.67	461.05±14.68	295.05±5.89	268.99± 12.74
Total alkalinity (mg L^{-1})	295.60±19.05	478.66±20.09	318.10 ±6.12	268.99±12.74
Total Hardness (mg L^{-1})	237.35±4.60	276.27±17.72	198.71±5.39	217.89±3.09
Calcium (mg L^{-1})	44.60±2.86	40.61±4.97	17.72±1.19	41.49±1.60
Magnesium (mg L^{-1})	30.68±1.58	42.65±1.51	37.51±1.88	27.82±1.41
Chloride (mg L^{-1})	64.68±6.78	89.31±1.94	24.59±1.72	33.15±7.45
o-phosphate (mg L^{-1})	1.66± 0.28	1.41± 0.41	0.69± 0.14	0.60± 0.06
Total phosphate (mg L^{-1})	2.53± 0.26	2.81± 0.43	1.17± 0.22	1.01± 0.11
Total ammonia (mg L^{-1})	1.87± 0.29	1.50± 0.04	0.29± 0.02	0.39± 0.05
BOD (mg L^{-1})	3.05± 0.09	2.88± 0.13	2.05± 0.05	2.03± 0.06
Plankton Population (L^{-1})	4596.66±253.71	4470.00±158.78	3906.66±229.63	3926.66±174.88
Phytoplankton (L^{-1})	2506.66±156.57	2460.00±90.65	2320.00±167.71	2420.00±104.00
Zooplankton (L^{-1})	2090±138.76	2010±96.02	1586.66±85.00	1506.66±95.43

***All values are mean ± standard error (S.E) of the mean*

Table 3. Chemistry of the sediment for the four pond sites K_1, K_2, K_3 and K_4

Parameters	Unmanaged ponds		Managed ponds	
	K_1	K_2	K_3	K_4
Moisture (%)	29.6±1.16	28.33±1.36	25.33±2.11	24.66±0.09
pH	8.31±0.02	8.26±0.81	7.8± 0.02	7.76±0.02
Conductivity (µS cm^{-1})	720.0±4.36	970.7±2.99	491.66±1.99	642.4±2.48
Available phosphate (mg Kg^{-1} dry Wt.)	0.20±0.07	0.18±0.06	0.085±0.05	0.06±0.06
Nitrate (mg Kg^{-1} dry Weight)	0.076±0.01	0.068±0.04	0.066±0.06	0.035±0.05
Organic carbon %	0.836±0.06	0.793±0.03	0.67±0.02	0.76±0.01

***Values presented are the mean ± S.E.*

Significant relationship of BOD with DO was detected with r = -0.633 at p<0.05. The concentration of ammonia in the unmanaged ponds which was inversely and significantly correlated to fish yields and fish growth levels with r = -0.466 at p<0.05. Significant correlation between fish growth and BOD was determined with r = -0.465 at $p<0.05$ and between fish growth and ammonia with r = -0.466 at $p<0.05$.

4. DISCUSSION

The efficiency of fish production varied in quite a wide range in both the unmanaged and managed ponds in the district. Conversely, the average conversion rate was higher in the managed ponds. The highest production was observed in pond K_3. The relation between primary productivity (NPP) and fish production for these pond ecosystems under this study agrees with the findings of [22]. Thus there are tangible key differences between the type of fish rearing ecosystems (managed and unmanaged). Based on this argument it can be stated that identical equations cannot be applied to all water body types.

This study also suggests that there are a number of factors describing the reasons for high or low fish yields. The phytoplankton population did not exhibit any significant variation in the unmanaged and managed ponds. The zooplankton numbers were significantly ($p<0.05$) greater in unmanaged ponds. Despite this fish production was higher in managed ponds (Fig. 3). The grazing pressure applied by the fish can explain the lower zooplankton population and the elevated fish growth in the managed ponds as documented in [5,6]. Plankton production is dependent on variables such as the carrying capacity of the environment, available nutrients and oxygen supply. These variable scan have direct influence on the production levels of fish food organisms. The interface of the phytoplankton-zooplankton is the vital zone where alterations in the type and number of predators on top of the food web changes based on deviations in the ecosystem properties including primary productivity and recycling of nutrients [23]. The findings of this study show the NPP to be higher in unmanaged ponds in contrast to managed ponds. As such, higher fish growth or yield was not directly associated with primary productivity. Fish discharge several waste materials such as carbon dioxide, ammonium, nutrients and organic material and remove oxygen from the water and particulate, organic material which includes plankton from the pond system. While correlating fish yield with the quality characteristics of water, it was observed that the pH and alkalinity levels were high revealing that both unmanaged and managed ponds were found to be in good trophic status. On the other hand, organic pollution indicators of chlorides, BOD, ammonia and phosphates were considerably ($p<0.05$) higher in unmanaged ponds in contrast to the managed ponds despite no fertilizers being added to the unmanaged ponds. Similarly, magnesium, calcium and total hardness were higher in the unmanaged ponds. The pond sediments also revealed higher load of organic pollution portraying high buildup of nitrate and organic carbon in the sediments. Such levels of these variables in the unmanaged ponds could be resulting from an controlled access of cattle as well as waste products of domestic origin coming from non-point sources which are usually taken as pollution indicators [12,24,25]. On the other hand DO was invariably lower in unmanaged ponds compared to managed ponds again depicting higher organic load in unmanaged ponds. The significant relationship of BOD with DO further supports the view.

The concentration of ammonia was higher in the unmanaged ponds which were inversely and significantly correlated to fish yields and fish growth levels. The findings of Meade [26] show that the acceptable maximum concentration of ammonia is 0.1 mg L^{-1} and higher value of ammonia toxicity can causes kidney failure, osmoregulatory imbalance and damages to the gill epithelium which causes fish to suffocate. In this study, the values of ammonia toxicity were moderately high in unmanaged ponds. Fish growth displayed significant correlations with BOD and ammonia. This shows that NH_4-N and BOD levels are two key factors affecting the productivity of the pond ecosystems. As per the findings of Harrison [27], elevated concentrations of, phosphate, calcium and magnesium ions pose positive influences on the ammonification process. Ammonification is executed by heterotrophic group of bacteria whose density is heavily reliant upon the accessibility of organic substrate [28].

The positive influence of the growth of fish on ecology and the quality of water is that they help stabilize the structure of the food web structure and sustain a stable production. The undesirable influence is that the rise in biomass leads to decline of the net production factor [29]. In this study, the decline in the quality of water as shown by the elevated BOD and ammonia content in the unmanaged ponds probably have reduced the growth of fish. Conversely, the decline of the NPP in the managed ponds might be attributed to the grazing pressure but it might have also resulted in the high biomass.

Our findings regarding the use of organic fertilization for management agrees with the findings of Noriega-Curtis [30], where it was concluded that the primary productivity on its own does not sufficiently justify the elevated yields achieved within systems with organic fertilization. The bacterial food chain and the levels of organic load are the important factors governing the production in such village fish ponds. The Insignificant relationship between the levels of primary production and production of fish in this study is thus explained.

5. CONCLUSION

From the findings of this study it can be stated that fish production appears to be dependent to a lesser magnitude on the scale of primary productivity. The universal relationship among the primary productivity levels and fish productivity was not supported as a range of variables such as ammonia production, organic load and quantity and quality of fertilizers affect such relationships. For aquaculture at small levels in village ponds, the fish production can be effectively enhanced through controlling the quality of water quality by managing the waste input at optimized levels.

There is a need to carry out such studies in village ponds for different agro-climatic conditions. Studies should also be carried out by optimizing the waste input in village ponds to manage the water quality. Evaluation of the successive limiting factors is also necessary as this may impede the increase of fish production.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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