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# Duckweed based wastewater stabilization ponds for wastewater treatment (a low cost technology for small urban areas in Zimbabwe)

J.M. Dalu, J. Ndamba *

*Institute of Water and Sanitation Development, Box MP 422, Mount Pleasant, Harare, Zimbabwe*

**Abstract**

A three-year investigation into the potential use of duckweed based wastewater stabilizations ponds for wastewater treatment was carried out at two small urban areas in Zimbabwe. The study hoped to contribute towards improved environmental management through improving the quality of effluent being discharged into natural waterways. This was to be achieved through the development and facilitation of the use of duckweed based wastewater stabilizations ponds. The study was carried out at Nemanwa and Gutu Growth Points both with a total population of 23 000. The two centers, like more than 70% of Zimbabwe's small urban areas, relied on algae based ponds for domestic wastewater treatment. The final effluent is used to irrigate gum plantations before finding its way into the nearest streams. Baseline wastewater quality information was collected on a monthly basis for three months after which duckweed (*Lemna minor*) was introduced into the maturation ponds to at least 50% pond surface cover. The influent and effluent was then monitored on a monthly basis for chemical, physical and bacteriological parameters as stipulated in the Zimbabwe Water (Waste and Effluent Disposal) regulations of 2000. After five months, the range of parameters tested for was narrowed to include only those that sometimes surpassed the limits. These included: phosphates, nitrates, pH, biological oxygen demand, iron, conductivity, chemical oxygen demand, turbidity, total dissolved solids and total suspended solids. Significant reductions to within permissible limits were obtained for most of the above-mentioned parameters except for phosphates, chemical and biological oxygen demand and turbidity. However, in these cases, more than 60% reductions were observed when the influent and effluent levels were compared. It is our belief that duckweed based waste stabilization ponds can now be used successfully for the treatment of domestic wastewater in small urban areas of Zimbabwe.


*Keywords:* Duckweed; Wastewater stabilization ponds wastewater treatment; Low cost technology; Urban areas

## 1. Introduction

Duckweeds are very small floating aquatic macrophytes belonging to the family *Lemnaceae*. The world over, they are found growing on surface of nutrient rich fresh and blackish waters. The family consists of four genera namely *Lemna*, *Spirodela*, *Wolffia* and *Wolffiella*. Duckweeds are ranked among the smallest flowering plants with an ovoid frond with a diameter of a few millimeters and a very short root usually less than 1 cm. The length of the root, to a large extent, depends on nutrient availability, being longer in nutrient deficient waters. Species of *Wolffia* are 2 mm or less in diameter, *Lemna* spp. has a frond of 5–8 mm, and *Spirodela* has the largest frond measuring 20 mm in diameter (Landolt, 1986; Landolt and Kandeler, 1987). In Zimbabwe, two species namely *Lemna* and *Spirodela* are found in municipal waters (see Fig. 1 for a photograph of a sample of duckweed, *Lemna* spp.).

However, among these aquatic macrophytes, *Lemnaceae* have the greatest capacity in absorbing the following macro-elements: nitrogen, phosphorus, potassium, calcium, sodium and magnesium among others (Landolt and Kandeler, 1987). High levels of N and P are known to cause the enrichment of our natural water bodies and causes (eutrophication) that in turn would promote the growth of blue green algae.

In Zimbabwe, algae based waste stabilization ponds are used for wastewater treatment in most small urban areas. This is mainly because they (small urban centers) lack the financial resources to put up the modern state of the art treatment systems and that they only produce low volumes of mainly domestic wastewater. The small urban centers also have the land on which to construct waste stabilization ponds that have low operation and maintenance costs. However, in a snap survey carried

* Corresponding author.
*E-mail address:* jndamba@iwsd.co.zw (J. Ndamba).

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Fig. 1. A sample of duckweed, *Lemna* spp.

out in Zimbabwe, a majority of WSP discharge directly into natural watercourses despite them producing effluent of inferior quality. By legislation, they are not supposed to discharge directly into rivers but onto agricultural land or gum plantations from where the wastewater would find its way through seepage into water bodies and courses. Improper waste disposal has health and environmental risks associated with it. However, duckweed based WSP are better than algae WSP mainly because of their high nutrient and BOD removal (Robson, 1991). This is mainly because of the ability of the duckweed to be harvested thus removing with it the trapped nutrients. Duckweed based WSP systems can produce effluent equaling tertiary treatment standards if properly managed.

It is against this background that the current study was carried out to investigate the potential use of duckweed based waste stabilization ponds for wastewater treatment in small urban areas in Zimbabwe. The overall goal of the study was to contribute towards improved environmental management through improving the quality of effluent being discharged into public waterways and water bodies. The project sought to:

- develop and facilitate the use of duckweed based wastewater stabilizations ponds.
- test the quality of wastewater discharged from duckweed based wastewater stabilization ponds.

## 2. Methodology

### *2.1. Establishment of duckweed based pond systems*

Algae based waste stabilization ponds can be converted to duckweed ponds without significant modifications. The same pond sequence applies and it is as follows: anaerobic, facultative and maturation ponds in that order.

Before the establishment of duckweed based ponds at Gutu and Nemanwa Growth Points, baseline information on wastewater quality was obtained. Duckweed was harvested from the Firle Sewage Works in Harare and introduced into the facultative and the first aerobic ponds at the two centers.

Since duckweeds are small floating aquatic plants, they can easily be blown by winds. This would then leave some of the pond areas uncovered with no nutrient removal. To minimize on such effects, PVC pipes were installed as wind barriers. However the PVC pipes are expensive and seem to crack under ultraviolet radiation. Dried bamboos were used instead. However, the bamboos did not provide a lasting solution as they also cracked and eventually sank.

Final effluent from both centers is discharged into nearby gum plantations before flowing into nearby rivers.

### *2.2. Wastewater quality monitoring results*

During the first three months of the study (March to June 1999), before the duckweed was introduced, wastewater (influent and effluent) samples were collected on a monthly basis and analysed for a range of parameters as stipulated in the Water (Waste and Effluent Disposal) regulations 1998. The basis for the wide selection of parameters was to enable us to choose those parameters that were a problem for each site. The following parameters were then identified as usually exceeding values as stipulated in the Water regulations of 1998 and later the new Water Act of 2000; pH, turbidity, conductivity, total suspended solids, dissolved solids, hardness, biological oxygen demand, chemical oxygen demand, phosphates, nitrates and iron. These then formed the basis for subsequent wastewater quality monitoring.

After the introduction of the duckweed, wastewater samples (influent and effluent) were initially collected on a fortnightly and later on monthly basis and sent to the National Water Quality Laboratory, Institute of Mining Research and the Department of Civil Engineering (University of Zimbabwe) for analysis of the above-mentioned parameters.

## 3. Results and discussion

The results of the analyses are as shown in Figs. 2–11. Figure indicates the new Water regulations of 2000 have set limits for most of the chemical, physical and bacteriological parameters based on a banding system. For BOD, the level is reported to be in the normal band when it ranges from 15 to 30 mg/l, sensitive band <15 mg/l, green band <50 mg/l, yellow band <100 mg/l and red band when levels are <120 mg/l (Fig. 2).

The BOD levels at Gutu were inconsistent and above the normal band limit except for the period Mar 99,

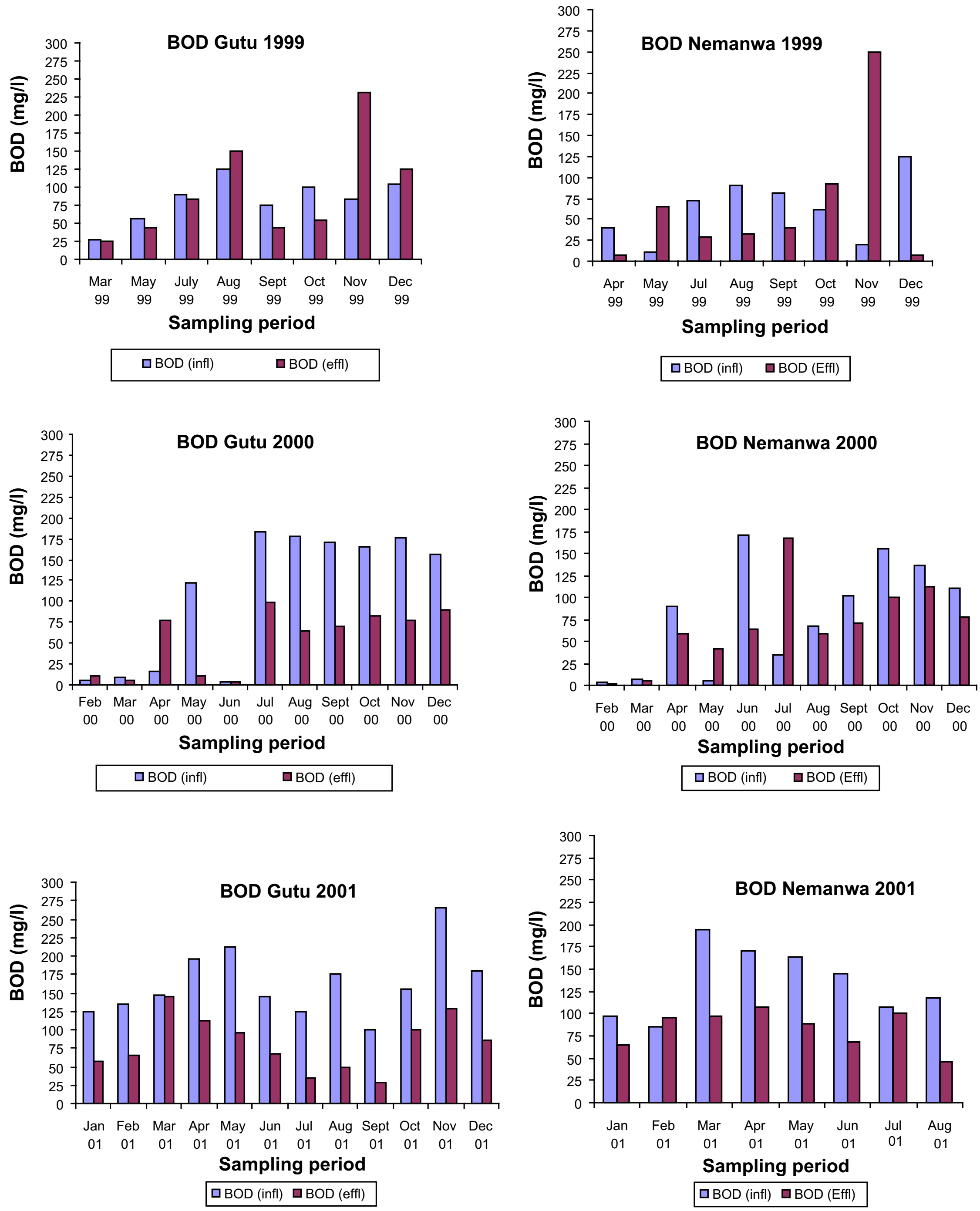


Fig. 2. Levels of BOD for wastewater (influent and effluent) from the duckweed based ponds at Gutu and Nemanwa Growth Points.

Feb 00, Mar 00, Jul 01 and Sept 01. However, from Jul 00 to Dec 01 except for Mar 01, there was on average a 50% reduction in BOD levels when influent and effluent levels were compared. On four occasions, the BOD effluent levels were reported to be higher than the influent levels (Aug 99, Nov 99, Dec 99 and Apr 00) that could be as a result of error of measurement. BOD levels were general lower during the winter than during the summer. This could be because the warmer temperatures increase the amounts of oxygen required to sustain biological activity in the aerobic pond. The period July to Dec 99 coincided with 100% duckweed cover resulting in algal death. To a lesser extent, the inconsistence could be due to under-harvesting of the duckweed resulting in weed die off in the ponds. Also, the anaerobic pond is not deep enough (1m rather than >2.5m) for the right conditions to prevail and as such, sometimes it does act as a facultative pond rather than an anaerobic pond.

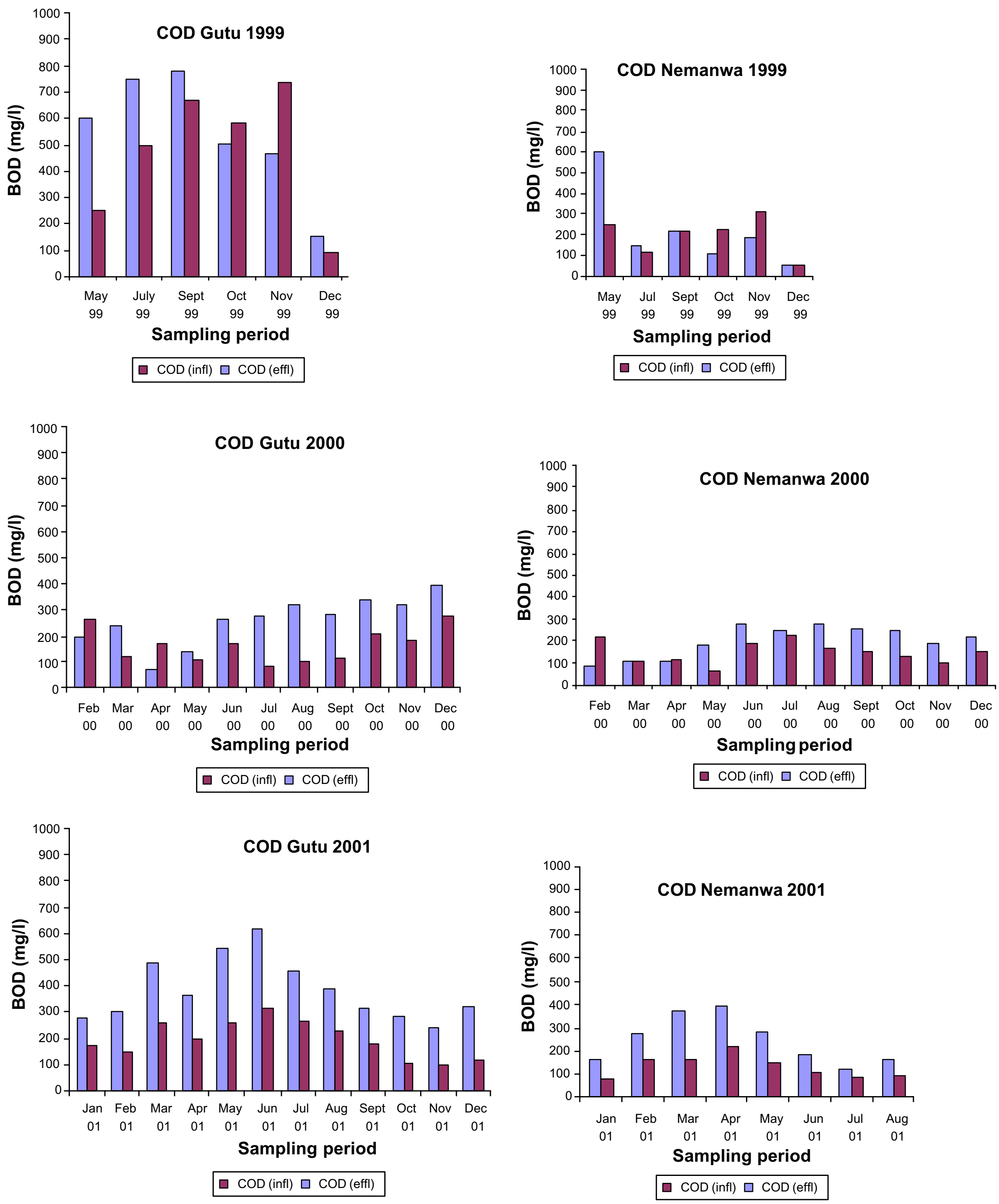


Fig. 3. Levels of COD for wastewater (influent and effluent) from the duckweed based ponds at Gutu and Nemanwa Growth Points.

The BOD levels at Nemanwa have also been inconsistent and above the normal band limit except for the months of Apr 99, Dec 99, Feb 00 and Mar 00. A majority of the levels are in the yellow band (100 mg/l). When influent and effluent levels are compared, the system managed to reduce the BOD levels on average by 30% that is lower than the 50% recorded at Gutu. Also on four occasions, effluent levels were higher than influent levels (May 99, Oct 99, Nov 99 and Jul 00) and this could also be due to error of measurement. The reasons for such a high BOD level are not very clear. However, BOD testing procedures require that the water samples be tested on site or be fixed on collection before transportation. This was not the case and an up to 5% BOD level could be ascribed to the non-fixing.

BOD is defined as the amount of oxygen required to oxidize the organic content of human waste and it is also the oxygen available to micro-organisms within the

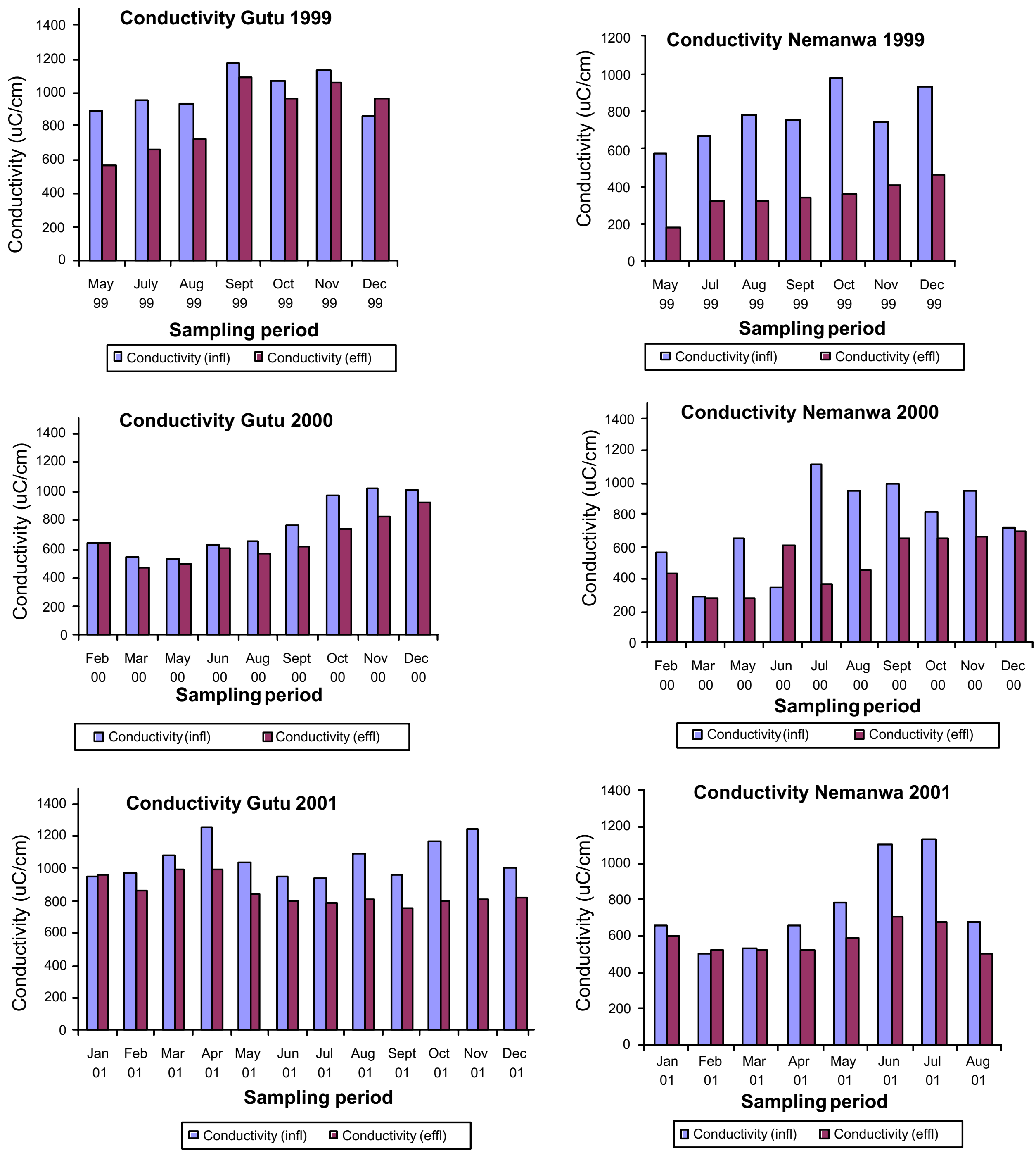


Fig. 4. Levels of conductivity for wastewater (influent and effluent) from the duckweed based ponds at Gutu and Nemanwa Growth Points.

system. BOD removal mainly occurs in the anaerobic pond and to a lesser extent in the facultative and maturation ponds of a duckweed system. A complete pond surface cover by duckweed may limit the free diffusion of oxygen from the air into the water. Another effect could be contributed by the adherence of a large bacterial population on the submerged duckweed surface that will consume most of the oxygen while mineralization of the organic matter occurs. It is also possible that duckweeds can supply oxygen to the wastewater via the transportation of atmospheric oxygen to the root zone.

The COD limits are classified as follows under the Water regulations of 2000: sensitive, <30 mg/l, normal band <60 mg/l, green band <90 mg/l, yellow band <150 mg/l and red band <200 mg/l (Fig. 3).

The Gutu COD levels have been above the normal band limit for a greater part of the sampling. The higher

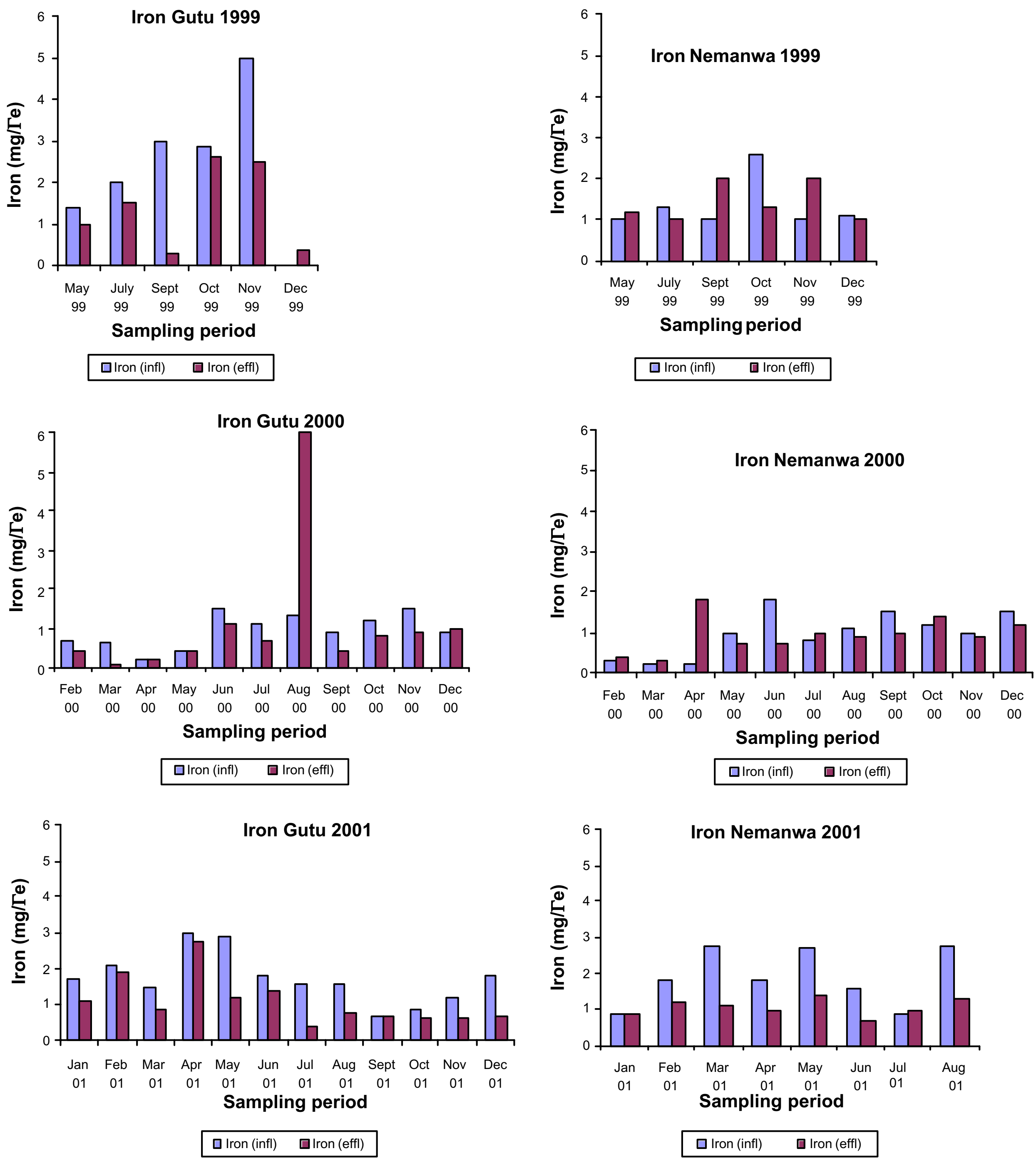


Fig. 5. Levels of iron for wastewater (influent and effluent) from the duckweed based ponds at Gutu and Nemanwa Growth Points.

levels during the first half of 1999 coincided with the introduction of duckweed in June. On four cases, the influent COD levels were higher than effluent levels (Oct 99, Nov 99, Feb 00 and Apr 00). On average a 50% reduction in COD levels was obtained when influent and effluent levels were compared.

The COD levels at Nemanwa have been higher than permissible limits for most of the time. Also, on four cases, the influent COD levels were higher than effluent levels (Oct 99, Nov 99, Feb 00 and Apr 00). The same pattern also prevailed at Gutu at the same period. The high COD levels could be due to duckweed die off experienced in Sept 99 in the ponds that in turn increased organic load. The chemical oxygen demand, that is the amount of oxygen available for chemical reactions (oxidation processes) within the system has been a problem parameter to address with the setting up of duckweed based waste stabilization ponds. The effluent

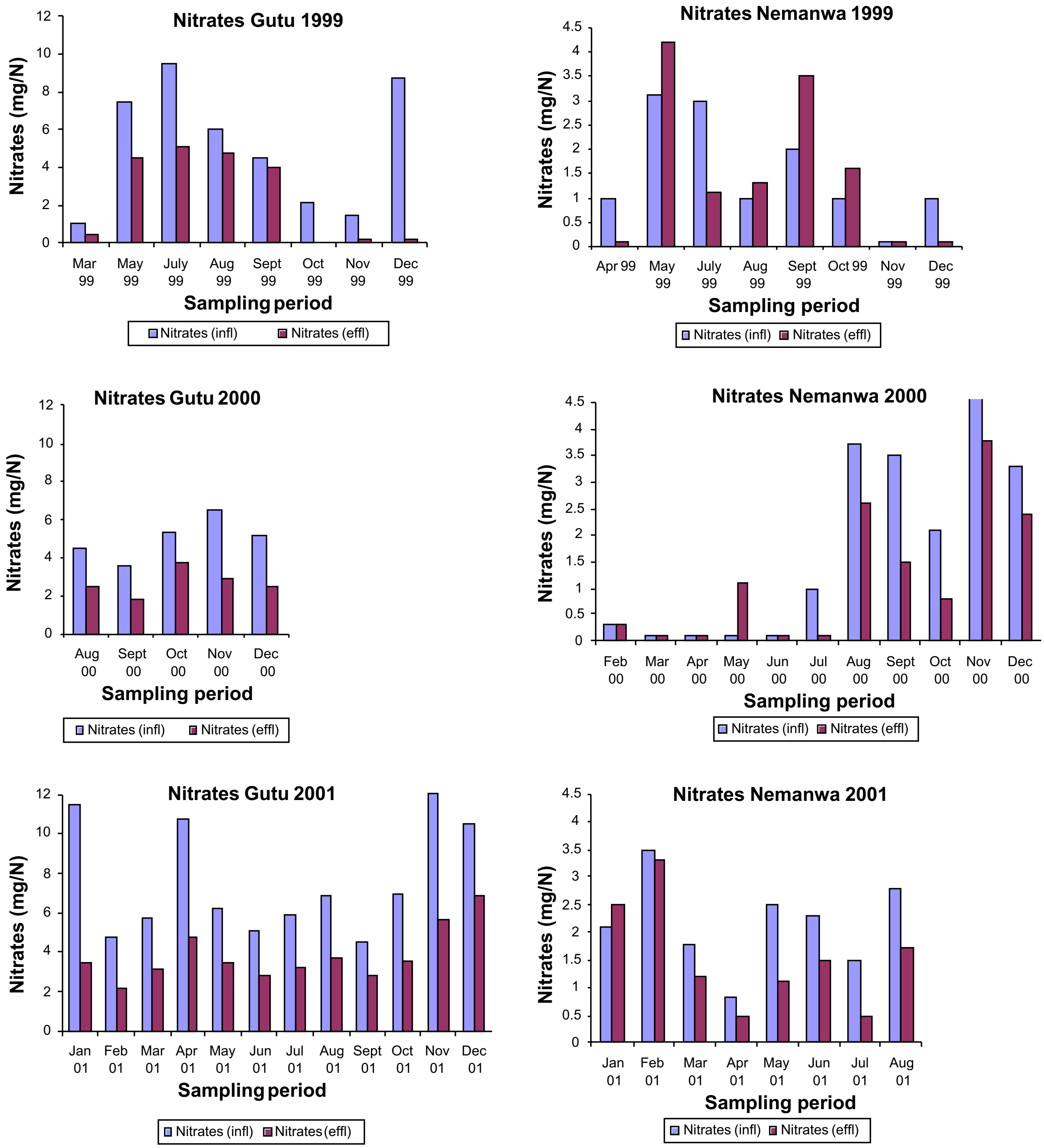


Fig. 6. Levels of nitrates for wastewater (influent and effluent) from the duckweed based ponds at Gutu and Nemanwa Growth Points.

levels have been above the normal band limit for the whole period.

The Water regulations of 2000 classify conductivity into the following bands: sensitive band <200 uS/cm, normal band <1000 uS/cm, green band <2000 uS/cm, yellow band <3000 uS/cm and the red band <3500 uS/cm (Fig. 4).

Conductivity levels at Gutu have largely been within the normal band limit (<1000 uS/cm) except for Sept 99 and Nov 99. The average effluent level was 800 uS/cm for the year 1999 and 2001 while for 2000 it was 600 uS/cm. When influent and effluent levels were compared, the percent reduction ranged from as low as 10% to as high as 30%.

At Nemanwa, effluent conductivity levels have also been within the normal band limit for the whole sampling period and the average has been 300 uS/cm during 1999, 450 uS/cm during 2000 and 575 uS/cm in 2001. Conductivity reductions of up to 60% were obtained.

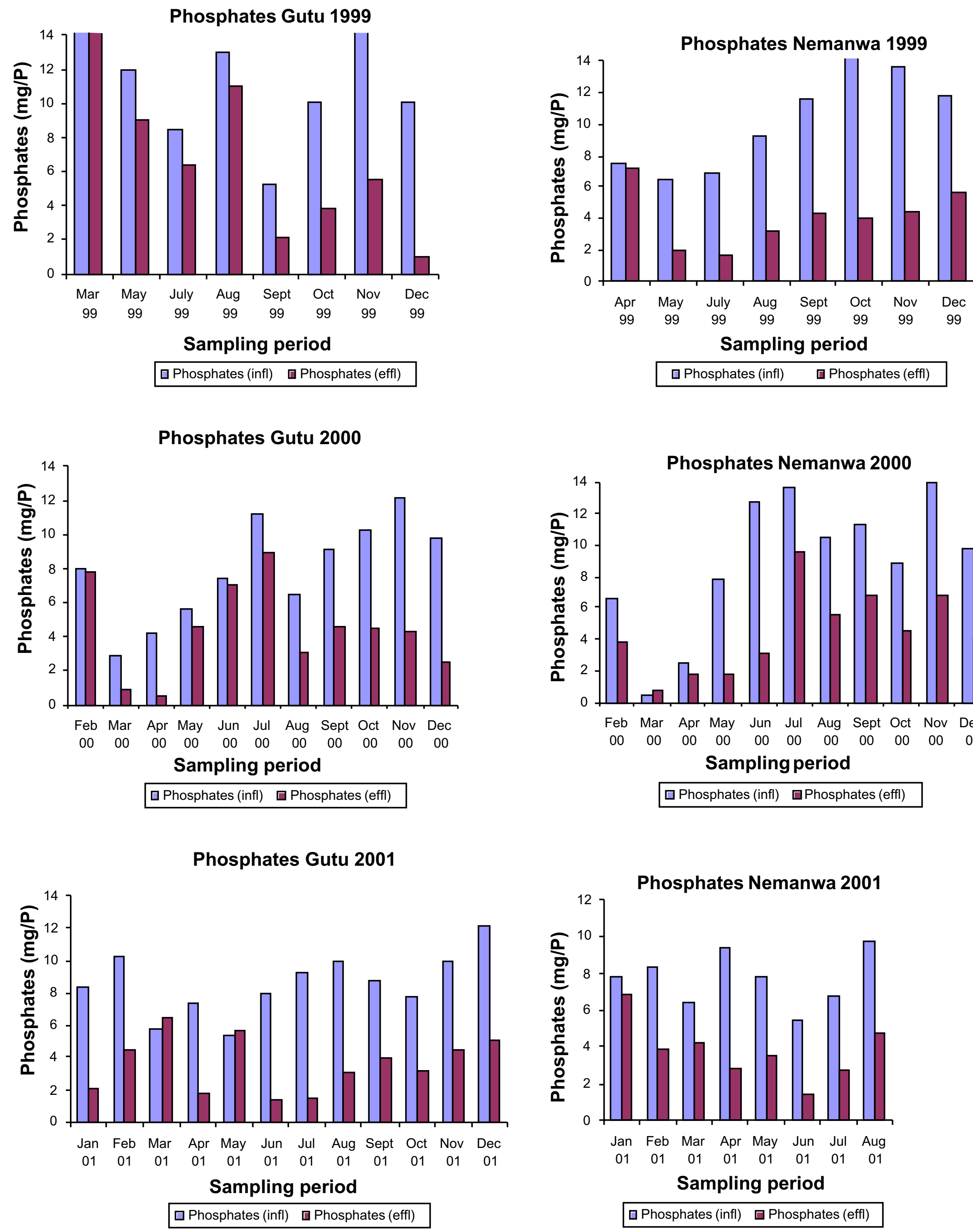


Fig. 7. Levels of phosphates for wastewater (influent and effluent) from the duckweed based ponds at Gutu and Nemanwa Growth Points.

Conductivity gives an indication of the mineral ion content of water. The parameter does not however give an indication as to which ions might be present. High levels of conductivity would indicate that there is a wide range of mineral ions in the wastewater that could be a problem to remove during treatment. The wastewater from the two Growth Points is expected to have a low mineral content as there is little industrial activity, with the bulk of the wastewater emanating from households (high organic load).

Water (Waste and Effluent Disposal) regulations, 2000 iron band limits: sensitive band <0.3 mg/l Fe, normal band <1 mg/l Fe, green band <2 mg/l Fe, yellow band <5 mg/l Fe and the red band <8 mg/l Fe (Fig. 5).

The Gutu iron levels have been within permissible limits for most of the period, although above limit levels

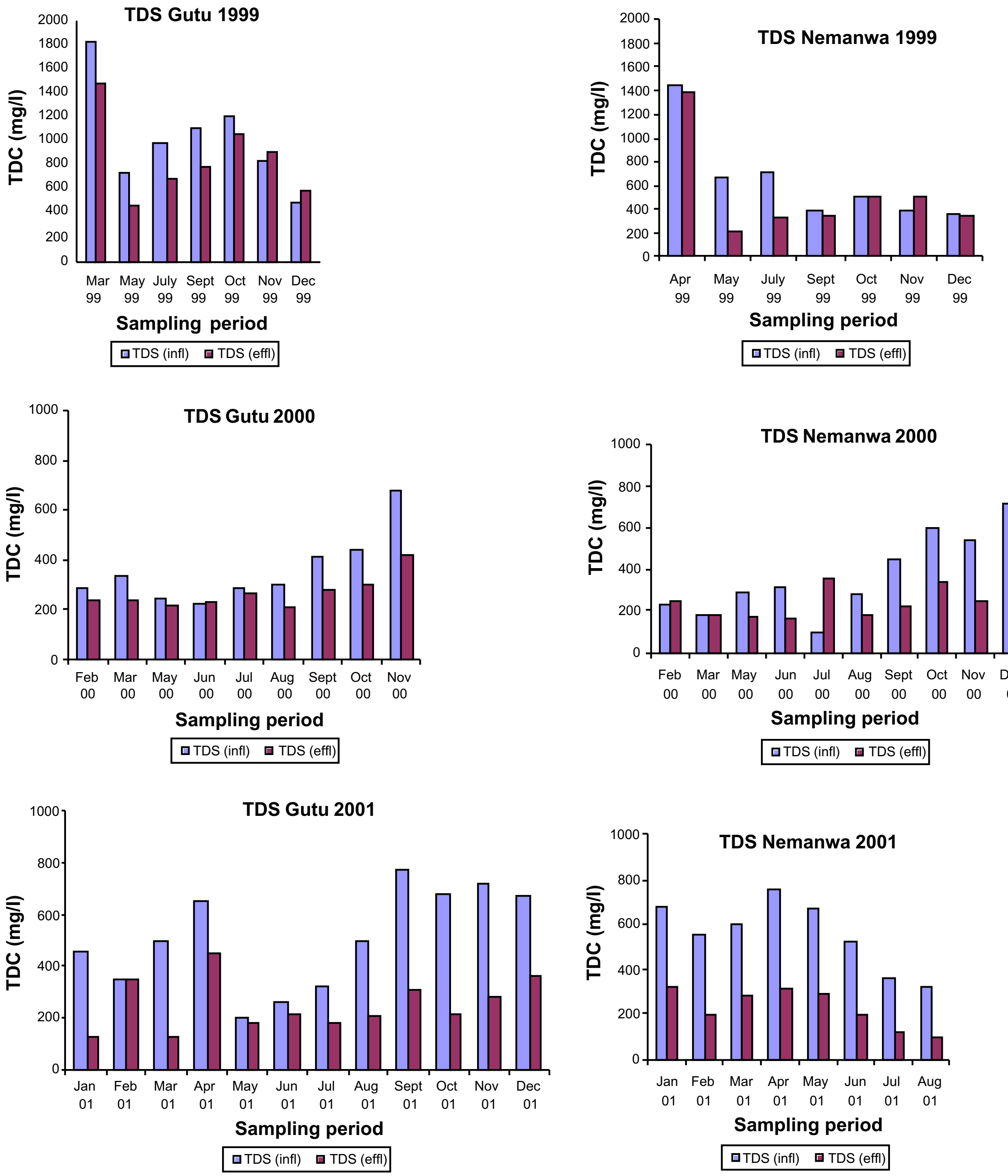


Fig. 8. Levels of TDS for wastewater (influent and effluent) from the duckweed based ponds at Gutu and Nemanwa Growth Points.

were obtained for the months of July 99, Oct 99, Nov 99, Jun 00, Aug 00, Feb 01, Apr 01 and Jun 01. However, all the effluent iron levels were below the green band limit (2 mg/l). In Aug 00, higher iron effluent levels were obtained than for influent. Even when the effluent iron levels were within limits for most of the time, iron uptake by duckweed has not been convincing when influent and effluent levels are compared. In some cases, there have been slight reductions and in others the iron effluent levels have remained the same as influent levels. The iron in the wastewater is likely to be coming from the water supplied to the growth point and some iron welding activities at the growth point. These include those from formal traders such as bus companies and informal traders such as scotch cart making and ordinary repair.

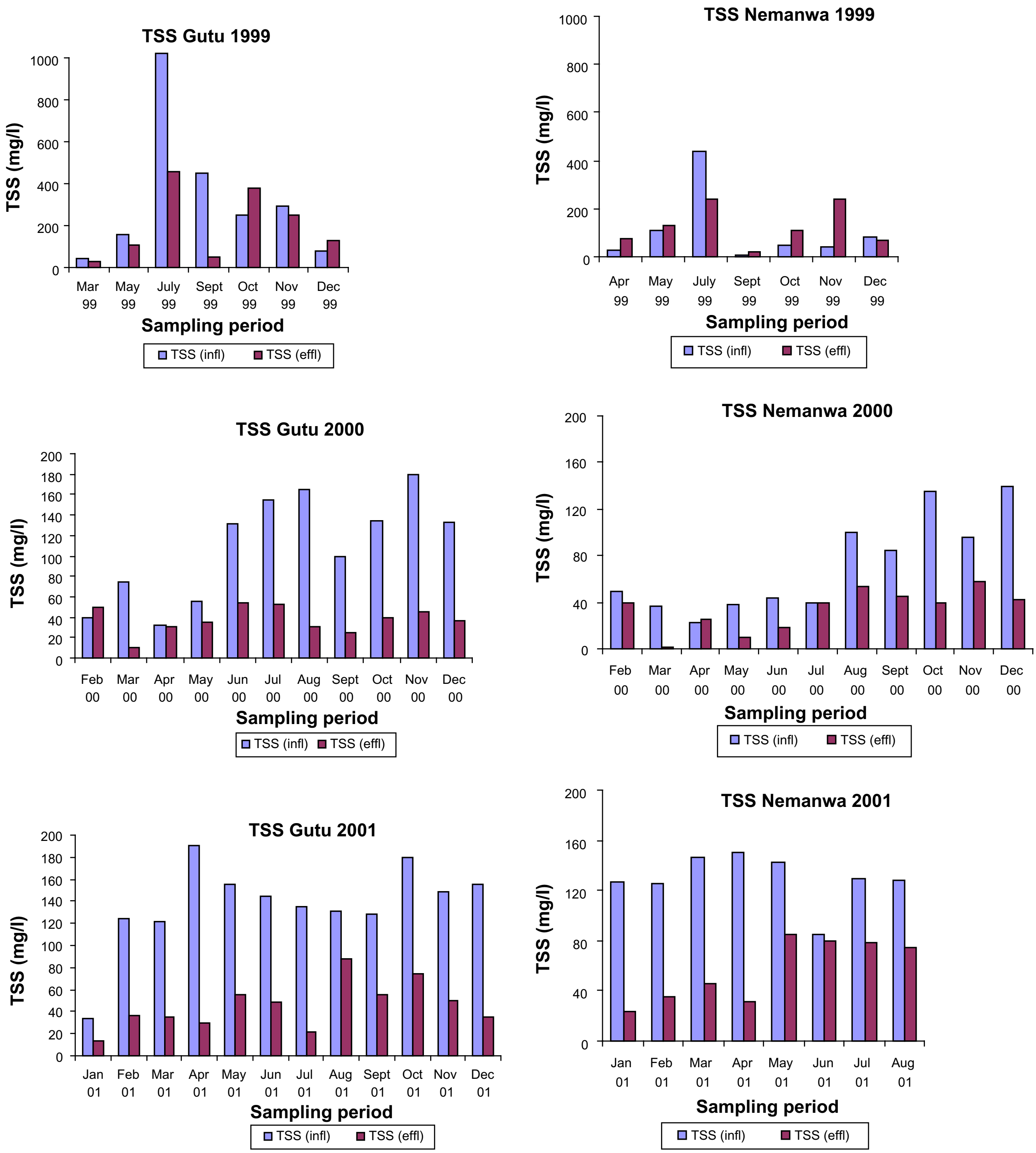


Fig. 9. Levels of TSS for wastewater (influent and effluent) from the duckweed based ponds at Gutu and Nemanwa Growth Points.

Iron levels at Nemanwa have been within limit for the greater part of the period except for Sept 99, Nov 99, April 00, Oct 00, Dec 00, Feb 01, May 01 and Aug 01. All the effluent levels were below the green band limit. The observed iron could probably be coming from the domestic water supply used in the growth point that comes from Lake Mutirikwi.

Water (Waste and Effluent Disposal) regulations, 2000 nitrate band limits: sensitive band <10 mg/l N, normal band <10 mg/l N, green band <20 mg/l N, yellow band 30 mg/l N and the red band <50 mg/l/ N (Fig. 6).

The nitrate levels at Gutu have been within permissible limits for the whole sampling period. The duckweed based waste stabilization ponds have performed well in relation to nitrogen uptake as the effluent levels are below the stipulated normal band limit of 10 mg/l N. When nitrate influent and effluent levels are compared,

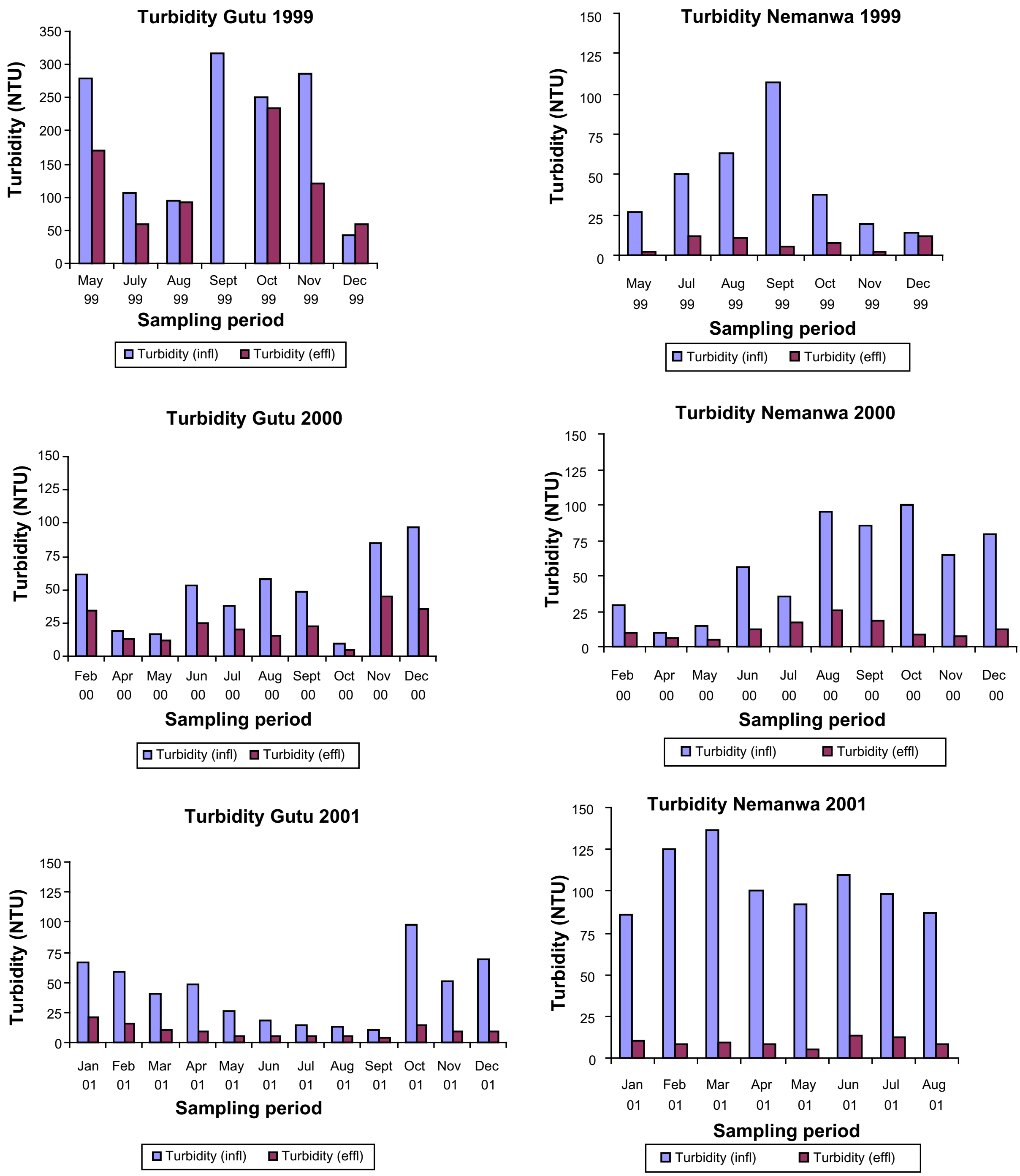


Fig. 10. Levels of turbidity for wastewater (influent and effluent) from the duckweed based ponds at Gutu and Nemanwa Growth Points.

reductions of up to 70% are observed. Slight increases in nitrate levels are observed during the rain season. This increment could be due to the storm water wash into the ponds that comes carries with it a lot of the organic wastes that would have accumulated during the dry season. The ponds at Gutu are situated on the northern side of the growth point and are in a low lying area making them receptive to most of the wash off from the growth point. A combination of too much nitrates and phosphorus is known to cause the enrichment of our natural water bodies and course resulting in the proliferation of blue algae that can cause 'blue babies disease'.

The nitrate levels at Nemanwa are within the normal band limit for the whole period. However, in May 99, Sept 99, Oct 99, May 00 and Jan 01, there were higher levels of nitrates in the effluent than in the influent. Such a situation normally arises when there is under harvesting of the duckweed resulting in duckweed die off in

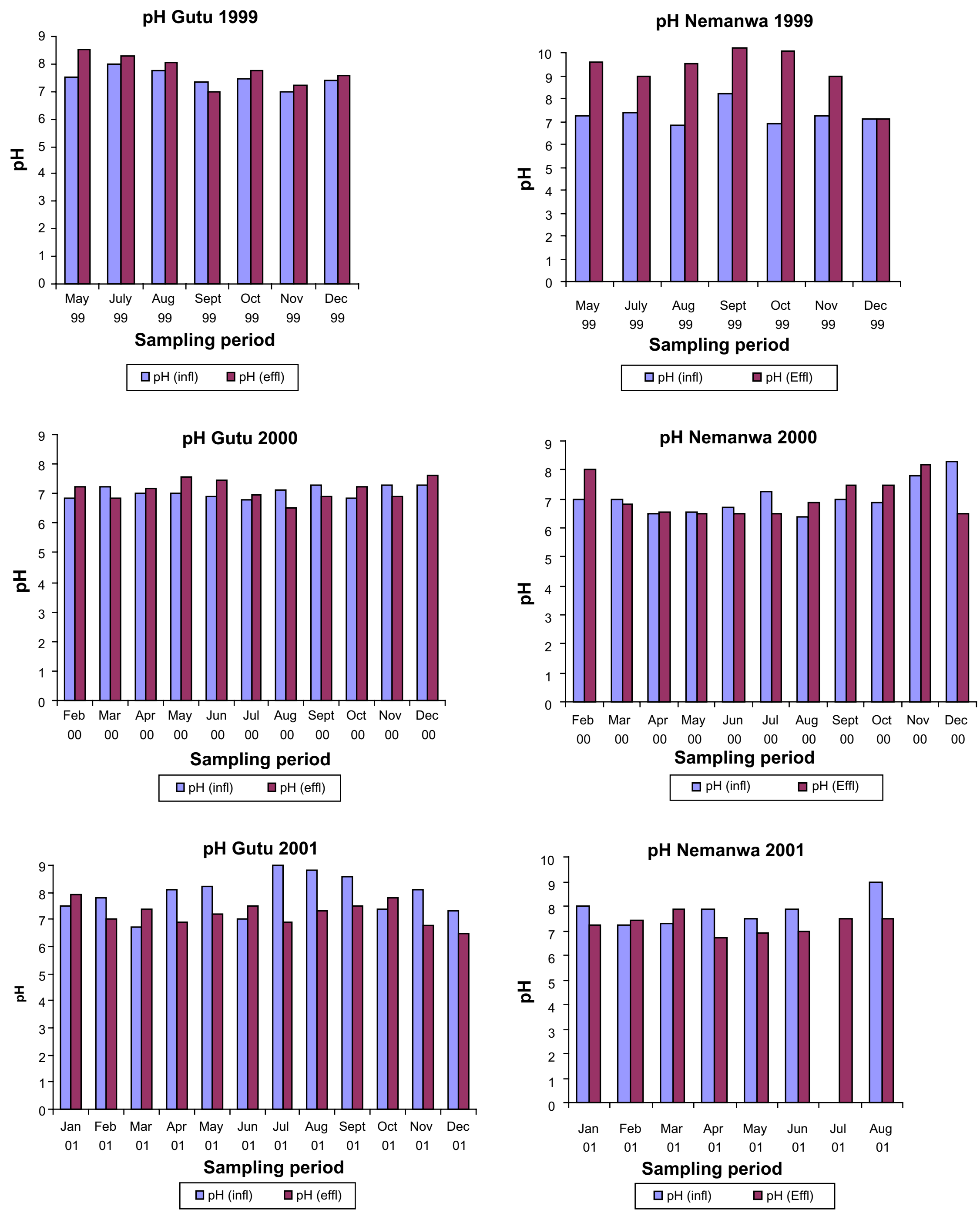


Fig. 11. Levels of pH for wastewater (influent and effluent) from the duckweed based ponds at Gutu and Nemanwa Growth Points.

the ponds. However, the duckweed based waste stabilizations ponds managed to reduce the nitrate levels by about 60% when the influent and effluent levels are compared. In Sept 2001, there was massive duckweed die off and as such no water quality monitoring was done for the remaining part of the year as efforts concentrated on establishing the cause and re-establishing the duckweed systems. The reasons for the massive death of duckweed could not be clearly established although indications are that there were limited wastewater inflows into the ponds due to water ratio at the growth point. As such, there were limited nutrients in the ponds against a high duckweed density resulting in nutrient starvation. The second reason could probably be due to ammonia toxicity due to high ammonia levels that were associated with a rise in pH to 10.

Water (Waste and Effluent Disposal) regulations, 2000 phosphate band limits: sensitive band <0.5 mg/l P, normal band <0.5 mg/l P, green band <1.5 mg/l P, yellow band <3 mg/l P and the red band <5 mg/l/ P (Fig. 7).

The phosphate levels at Gutu have remained above the normal band limit for the greater part of the period. However, considerable reductions occurred when the system was converted into a duckweed based one. Despite the high phosphate levels in the effluent, there were reductions of up to 80% when influent and effluent levels were compared. High phosphate levels are known to cause eutrophication of water resources.

At Nemanwa, like at Gutu, phosphate levels were consistently above the normal band limit for the reporting period. When influent and effluent levels were compared reductions of up to 65% were observed for example in April 2001. This is a positive sign that duckweed waste stabilization ponds can be used for phosphate removal in wastewater although in this particular case the levels did not drop to permissible limits.

Water (Waste and Effluent Disposal) regulations, 2000 TDS band limits: sensitive band <100 mg/l, normal band <500 mg/l, green band <1500 mg/l, yellow band <2000 mg/l and the red band <3000 mg/l/ (Fig. 8).

The Gutu TDS levels have been above limit for the period Mar 99, July 99 to Dec 99 that could be due to the products of the biodegradation of algae after the introduction of duckweed.

The TDS levels at Nemnwa were within normal band limit for the whole period except for Apr 99. The total dissolved solids have been constantly within the normal band with an average level of 250 mg/l. However, the situation is even made better by the long retention times that occur during the dry season when inflows into the ponds are low.

Water (Waste and Effluent Disposal) regulations, 2000 TSS band limits: sensitive band <10 mg/l, normal band <25 mg/l, green band <50 mg/l, yellow band <100 mg/l and the red band <150 mg/l (Fig. 9).

The TSS levels at Gutu have generally been above the normal band limit during 1999. In 2000 and 2001, the levels were on average in the green band. When influent and effluent levels were compared reductions of up to 90% were obtained. The total duckweed cover in the maturations ponds suppressed the growth of algae that normally results in a build up of TSS when the algae die.

Levels at Nemanwa also generally higher during the first year. In 2000 and 2001 the levels were slightly above the normal band but within the green band. Algae based ponds are normally associated with high TSS effluent levels as the algae are allowed to die in the wastewater unlike duckweed that has to be harvested. However if the duckweed is allowed to die in the wastewater, then TSS levels can also obtain. The removal of TSS in wastewater stabilization ponds in mainly affected by biodegradation of organic particles, settling of particles to sediment and production of algae within the pond system.

Water (Waste and Effluent Disposal) regulations, 2000 turbidity band limits: sensitive band <5 NTU, normal band <5 NTU, green band, yellow band red band are not specified (Fig. 10).

High levels of turbidity reported were reported at Gutu during the first year where the average was 125 NTU. For the second year the average was 15 NTU. Although the levels were above limit, considerable reductions occurred after converting the ponds into duckweed systems. Turbidity is a measure of the clarity of water. Under normal circumstances total duckweed cover would suppress the growth of algae thereby reducing debri due to algal death, producing a clear wastewater.

Lower turbidity levels prevailed at Nemanwa although the levels were slightly above the normal band limit. However reductions of up to 95% were obtained. At Nemanwa especially during the dry season, there is a water shortage resulting in reduced inflows into the ponds. As such, there is also reduced net movement of wastewater within the ponds resulting in increased retention times. This could then explain for the attainment of low turbidity levels.

Water (Waste and Effluent Disposal) regulations, 2000 pH band limits: sensitive band 6–7.5, normal band 6–9, green band 5–6, 9–10, yellow band 4–5, 10–12 and the red band 0–4, 12–14 (Fig. 11).

The wastewater pH results at Gutu were within the normal band limit for the whole sampling period. The average has been 7.5 which is the most ideal.

At Nemanwa, pH levels were within range following the introduction and the successful establishment of duckweed system. The pH levels have been within normal band with an average 7.5 which is the optimum operating pH for optimum pond performance.

The performance of the waste stabilizations ponds is affected by low or high pH levels. pH has effect on the living micro-organisms found in the ponds. The pH in the facultative and maturation ponds is expected to rise to around 9 for effective faecal bacterial removal. In our case, the last maturation pond was left without duckweed and as such, algae ended to colonise. The algae have the effect of absorbing carbon dioxide faster than it can be replaced by bacterial respiration. This has the effect of leaving excess hydroxyl ions causing a sudden rise in pH to around 9. pH also has an effect on chemical reactions that occur in the pond system resulting in the liberation of hydrogen sulphide, responsible for the rotten egg type of smell. At ideal pH of around 7.5, the sulphide is present as the odourless bisulphide ion.

## 4. Conclusions and recommendations

The three-year investigation has shown that duckweed based waste stabilization ponds can be used for effective wastewater treatment in small urban areas when properly managed with respect to seeding, maintenance and harvesting.

Duckweed based waste stabilization ponds have shown effectiveness in domestic wastewater treatment in small urban areas. It is therefore recommended that local authorities adopt duckweed based pond systems as low cost technologies for effective wastewater treatment.

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